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Water-Level Changes in Aquifers of the Atlantic Coastal Plain, Predevelopment to 2000

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By Vincent T. dePaul, Donald E. Rice, and Otto S. Zapecza

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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

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

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

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Water-Level Changes in Aquifers of the Atlantic Coastal Plain, Predevelopment to 2000

By Vincent T. dePaul, Donald E. Rice, and Otto. S. Zapecza

Abstract

The Atlantic Coastal Plain aquifer system, which underlies a large part of the east coast of the United States, is an important source of water for more than 20 million people. As the population of the region increases, further demand is being placed on those ground-water resources. To define areas of past and current declines in ground-water levels, as well as to document changes in those levels, historical water-level data from more than 4,000 wells completed in 13 regional aquifers in the Atlantic Coastal Plain were examined.

From predevelopment to 1980, substantial water-level declines occurred in many areas of the Atlantic Coastal Plain. Regional variability in water-level change in the confined aquifers of the Atlantic Coastal Plain resulted from regional differences in aquifer properties and patterns of ground-water withdrawals. Within the Northern Atlantic Coastal Plain, declines of more than 100 ft were observed in New Jersey, Delaware, Maryland, Virginia, and North Carolina. Regional declines in water levels were most widespread in the deeper aquifers that were most effectively confined—the Upper, Middle, and Lower Potomac aquifers. Within these aquifers, water levels had declined up to 200 ft in southern Virginia and to more than 100 ft in New Jersey, Delaware, Maryland, and North Carolina. Substantial water-level declines were also evident in the regional Lower Chesapeake aquifer in southeastern New Jersey; in the Castle Hayne-Piney Point aquifer in Delaware, Maryland, southern Virginia and east-central North Carolina; in the Peedee-Severn aquifer in east-central New Jersey and southeastern North Carolina; and in the Black Creek-Matawan aquifer in east-central New Jersey and east-central North Carolina. Conversely, declines were least severe in the regional Upper Chesapeake aquifer during this period.

In the Southeastern Coastal Plain, declines of more than 100 ft in the Chattahoochee River aquifer occurred in eastern South Carolina and in southwestern Georgia, where water levels had declined approximately 140 and 200 ft from prepumping conditions, respectively. Within the Upper Floridan aquifer, decline was most pronounced in the coastal areas of Georgia and northern Florida where ground-water withdrawals were at their highest. These areas included Savannah, Jesup, and Brunswick, Ga., as well as the St. Marys, Ga. and Fernandina Beach, Fla., area. Regional water levels had declined by 80 ft near Brunswick and Fernandina Beach to as much as 160 ft near Savannah.

Since 1980, water levels in many areas have continued to fall; however, in some places the rate at which levels declined has slowed. Conservation measures have served to limit withdrawals in affected areas, moderating or stabilizing water-level decline, and in some cases, resulting in substantial recovery. In other cases, increases in ground-water pumpage have resulted in continued rapid decline in water levels.

From 1980 to 2000, water levels across the regional Upper, Middle, and Lower Potomac aquifers continued to decline across large parts of Delaware, Maryland, Virginia, and North Carolina, and water levels had stabilized or recovered throughout much of Long Island and New Jersey. Substantial water-level recovery had also occurred in east-central New Jersey in the Peedee-Severn and Black Creek-Matawan aquifers and in east-central North Carolina in the Castle Hayne-Piney Point aquifer. Substantial declines from about 1980 to about 2000 occurred in the Peedee-Severn aquifer in southern New Jersey, the Beaufort-Aquia aquifer in southern Maryland, and the Black Creek-Matawan and Upper Potomac aquifers in central and southern parts of the coastal plain in North Carolina.

From 1980 to about 2000, water levels within the regional Upper Floridan aquifer had generally stabilized in response to shifting withdrawal patterns and reductions in pumpage at many places within the coastal region. Groundwater levels had stabilized and recovered at the major cones of depression at Savannah, Brunswick, and Jesup, Ga.; had remained about the same in the St. Marys, Ga. and Fernandina Beach, Fla., area; and were stable to slightly declining in the Jacksonville, Fla., area. In the Southeastern Coastal Plain, water levels in the Chattahoochee River aquifer continued to decline in eastern South Carolina, particularly in and around Charleston and Georgetown Counties; water levels recovered in Myrtle Beach.

Introduction

The Atlantic Coastal Plain aquifer system underlies a large part of the eastern United States from Florida to New York (pl. 1) and supplies water for more than 20 million people. This aquifer system has been extensively developed throughout the region, and withdrawals from these aquifers have resulted in water-level declines of over 200 ft in several locations. As the population of the region increases, further demand is being placed on these water resources.

In the past two decades, substantial water-level declines and instances of salt-water intrusion have raised concerns over the sustainability of this important water supply, and ground-water monitoring and management programs have been instituted in all the Atlantic Coastal Plain states. Water levels currently are measured in over 3,000 wells from New York to Florida as a part of U.S. Geological Survey (USGS) and state long-term monitoring programs. Long-term, systematic measurements of water levels provide essential data needed to evaluate changes in the resource over time. Data from these monitoring networks are assessed to varying degrees in each state. However, no regional assessment of water levels has been conducted since the USGS Regional Aquifer System Analysis (RASA) Programs studied the Atlantic Coastal Plain aquifer systems in the early 1980s.

Atlantic Coastal Plain Aquifer System Study Area

The Atlantic Coastal Plain, located in the eastern and southeastern United States, extends from Long Island, N.Y., southward to Florida (pl. 1). The study area includes the Coastal Plain from Long Island southward into northeastern Florida and southwestward to the Georgia-Alabama border. The study area is bounded on the west by the Fall Line and on the east by the Atlantic Ocean. Though the Atlantic Coastal Plain extends offshore and beneath the Continental Shelf, the primary focus of this study was the emergent part of the Coastal Plain, an area of approximately 104,000 mi^2. Topography within the study area is relatively flat; altitudes range from 0 ft NGVD 29 along estuaries, bays, and the Atlantic coastline to more than 700 ft near the Fall Line in parts of North Carolina and Georgia.

The Atlantic Coastal Plain is underlain by a seaward-dipping wedge of clay, silt, sand, gravel, and carbonate rocks that range in age from Jurassic to Holocene. Atlantic Coastal Plain sediments thicken seaward from a featheredge at the Fall Line, which marks the boundary between the Coastal Plain and the Piedmont Physiographic Province, to approximately 10,000 ft at Cape Hatteras, N.C. This sedimentary wedge forms a complex ground-water system in which the unconsolidated sands and gravels and the openings in consolidated carbonate rocks function as aquifers, and the silts and clays function as confining units. Water derived from the aquifers of the Atlantic Coastal Plain constitutes a major source for public and domestic supply, as well as an important source for industrial and agricultural purposes. To provide a unified assessment, water-level data were aggregated into 13 regional aquifers characterized in hydrogeologic and ground-water-flow simulation studies from the USGS RASA Program for the Northern and Southeastern Atlantic Coastal Plain and the Floridan aquifer system. A brief definition of each of the regional aquifers addressed in this report and the source of aquifer nomenclature as defined for each of the Atlantic Coastal Plain RASA study units are described in each section.

Purpose and Scope

This report presents the results of a compilation and assessment of long-term and synoptic ground-water-level data of the Atlantic Coastal Plain states from New York (Long Island) to Florida. Regional assessments of water-level data provide a broad view of the effects of ground-water development and are essential to managing and sustaining the region’s water supply. This information is useful to (1) identify areas with greater or lesser water-level declines, (2) identify cumulative areal declines that may cross state boundaries, (3) evaluate the effectiveness of ground-water management strategies practiced in different states, and (4) identify areas with significant data gaps that may preclude effective management of ground-water resources.

Regional water-level-change maps are presented for selected time intervals (predevelopment to circa 1980 and circa 1980 to circa 2000) for 13 regional aquifers characterized as part of the USGS RASA Program for the Northern Atlantic Coastal Plain, Southeastern Coastal Plain, and the Floridan aquifer system. Where substantial cones of depression or changes in water levels are identified, long-term hydrographs are provided. The assessment evaluates the nature of regional water-level declines or rises within each aquifer system on the basis of available water use and population data.

Sources of Data

Basic hydrologic data used in this study included ground-water-level measurements and ground-water-withdrawal data. Ground-water-level measurements throughout the Atlantic Coastal Plain were obtained through an extensive network of observation wells administered by the USGS as well as by state and local governmental agencies. In addition, water-level measurements from public, domestic, and industrial supply as well as irrigation wells were used to augment the network in order to more completely characterize changes in an aquifer.

Water-level changes in the Atlantic Coastal Plain aquifer system from predevelopment to 2000 were based on measurements from more than 4,000 wells. Much of this data was obtained from unpublished sources, in particular, the local National Water Information System (NWIS) databases of each USGS Water Science Center (WSC) within the study area. Selected ground-water-level data also were included from the

Delaware Geological Survey and the North Carolina Division of Water Resources. Additional water-level data were compiled from various studies and reports published by both the USGS and state agencies. Prepumping water-level data used in this study were from digital representations of simulated or estimated prepumping water-level surfaces developed as part of the USGS RASA Program studies (Leahy and Martin, 1993; Barker and Pernik, 1994; Krause and Randolph, 1989). Additional prepumping data for the Northern Atlantic Coastal Plain were obtained from Martin (1998), and for the Southeastern Coastal Plain, Aucott and Speiran, (1985a), Faye and Mayer (1996), and Clarke and West (1997). In this report, prepumping or predevelopment refers to time prior to 1900 for the Northern Atlantic and Southeastern Coastal Plains and prior to 1880 for the Upper Floridan aquifer.

Donaldson and Kosalka (1983a, 1983b) provide data on the potentiometric surface as well as water-level data for Long Island, N.Y., for March 1979. Walker (1983) and Eckel and Walker (1986) documented water-level data and published potentiometric maps estimating circa-1980 conditions within Coastal Plain aquifers of New Jersey. Measurements included in these reports span the period 1978-83. Simulated 1980 potentiometric contours from Martin (1998) also were used for comparisons with later data.

In the Southeastern Coastal Plain, Aucott and Speiran (1985b) estimated 1982 potentiometric surfaces of the Floridan and Tertiary Sand aquifer, and the Black Creek and Middendorf aquifers. Faye and Mayer (1996) provide observed as well as simulated water-level data for 1980 for aquifers of the Southeastern Coastal Plain in Georgia.

Recent measurements of ground-water levels in Coastal Plain aquifers of South Carolina were listed by Hockensmith (2003a, 2003b). Water-level measurements were included for the Floridan and Tertiary Sand aquifer and the Black Creek and Middendorf aquifers and span 1998-2001.

Site-specific ground-water-withdrawal data for 1980 and 2000 were obtained from the USGS, New Jersey, Maryland, and Virginia WSCs water-use databases. County aggregate water-use data were obtained from the National Water Use Information Program (Solley and others, 1988; Hutson and others, 2004). Additional tabular as well as anecdotal withdrawal information was obtained from the following USGS and state publications. Leahy and Martin (1993) provide estimates of simulated 1980 withdrawals for aquifers and locations within the Northern Atlantic Coastal Plain. Buxton and Shernoff (1999) discuss historical and 1980 withdrawal data for western Long Island, N.Y., and Busciolano (2002) provides 1999 pumpage data throughout Long Island. Martin (1998) also provides withdrawal estimates from 1978 to 1980 for New Jersey Coastal Plain aquifers. Similarly, Lacombe and Rosman (2001) document water-withdrawal trends for New Jersey and Delaware from 1978 to 1998 and map individual pumping centers throughout their study area. Additional 1980-era data for Maryland and Delaware are included in Fleck and Vroblesky (1996). Harsh and Laczniak (1990) discuss historical and circa-1980 pumpage and provide locations of major withdrawals within the Virginia Coastal Plain. Giese and others (1997) present the same for the North Carolina Coastal Plain. In addition, the North Carolina Department of Environment and Natural Resources (2004a, 2004b) provide maps locating recent withdrawals in the Central and Southern Coastal Plain of North Carolina.

In the Southeastern Coastal Plain, Newcome (2000) lists pumpage data from South Carolina's largest public suppliers of 2000. Earlier withdrawal information was provided in Aucott and Speiran (1985), Barker and Pernik (1994), Aucott (1996), and Campbell and van Heeswijk (1996).

Maps of simulated pumpage in the Floridan aquifer system (Krause and Randolph, 1989) were useful in determining the location and amounts of major withdrawals during 1980. County-aggregate and withdrawal trends throughout Georgia from 1980 to 2000 were included in Fanning (2003). Additional tabular data for the Floridan aquifer system in coastal Georgia, South Carolina, and Florida were compiled by Payne and others (2005), and are provided by county for 5-yr intervals from 1980 to 2000.

Aquifer boundaries for the northern Atlantic Coastal Plain were modified from Leahy and Martin (1993). Modifications included the omission of the Castle Hayne-Piney Point and Beaufort-Aquia aquifers in Long Island because these hydrogeologic units are absent there. Furthermore, the extension of the Peedee-Severn and Black Creek Matawan aquifers into Long Island was eliminated, and water-level data were grouped with the Upper Potomac and Magothy aquifers. Aquifer boundaries for the Southeastern Coastal Plain are from the Ground-Water Atlas of the United States (Miller, 1990). The boundary of the Upper Floridan aquifer as used in this report was modified from Krause and Randolph (1989).

Methods and Data Representation

Water-level data used in the analysis of the Northern Atlantic Coastal Plain aquifers were initially selected to coincide with the periods of major data collection efforts for New Jersey's focused synoptic water-level studies, generally the fourth quarters (October through December) of 1978 and 1998.
In many cases, the data from other states do not match the amount and distribution of New Jersey data; therefore, these time periods were expanded to include the fourth quarters of previous and subsequent years. For data and maps classified as "circa 1980," data may, in fact, range from late 1978 through early 1983. For data and maps classified as "circa 2000," data range from late 1997 through late 2002. Southeastern Coastal Plain aquifer water-level data used in the 1980 analysis were generally collected in the fall of 1980, 1981, and 1982 from South Carolina, and from Georgia, the fall of 1978 and 1982. For the circa-2000 period, most of the data from South Carolina were collected in 1998 and 2001, and from Georgia, 1998 and 2002. A minority of data from South Carolina and Georgia for the circa-2000 period were from 1996. For states that include the Upper Floridan aquifer as defined in this

study, the majority of the synoptic data for the 1980 and 2000 periods was collected during April and May of 1980 and 1998, respectively. In limited cases however, water-level data from additional periods were included.

Values of water-level decline for predevelopment to circa 1980 were calculated as the difference between the measured 1980 water level and the simulated regional or subregional RASA water level at the same position. Reliability of these estimated declines range ±50 ft on the basis of estimated residuals between observed and simulated heads within the regional models. For the Northern Atlantic Coastal Plain and the Southeastern Coastal Plain, the calculated water-level-change values for circa 1980 to circa 2000 have three levels of reliability. The most reliable values were those calculated from measured water levels. The next level of reliability was that for values calculated as the difference between a measured circa-2000 water level and a 1980 water level that was based on either published potentiometric surfaces or surrounding observed head values at an equivalent location. Use of such values was necessary in order to increase the density of data points and to better define lines of equal head decline. Least reliable values of water-level decline were those values calculated as the difference between measured circa-2000 water levels and 1980 or 1985 simulated water levels. Calculations of this type were necessary in areas where 1980 data were sparse and the resulting interpreted potentiometric surface would have been otherwise uncertain. Where water levels appeared to rise in 1980 relative to prepumping levels, change was assumed to be negligible, and the resulting values were mapped as such. The assumption was that recharge to the aquifer remained relatively unchanged and that the consequences of development were considered to be, at best, unchanged water levels or, more likely, declining water levels.

Water-level-change values were plotted on digital base maps and initially contoured using mapping software in order to provide an unbiased interpolation of the data. Contours then were manually adjusted to reflect the understanding of the ground-water system. Thiessen polygons have been used to represent areas of equal ground-water decline in other regional studies (Dugan and Cox, 1994). Thiessen polygons define the area around each well that is closest to that well relative to all other points; the size of each polygon is governed by its proximity to neighboring wells. However, in this study, the irregular distribution and low density of data points resulted in places in polygons of considerable size containing only a single value of change. Furthermore, the use of this method results in abrupt differences in water-level-change values in adjacent polygons, whereas actual changes are likely gradational. For that reason, a gridded representation created from the water-level-difference contours was used to illustrate water-level change.

Limitations of the Analysis

Water-level data are best interpreted when collected synoptically, that is, within a relatively short period of time and under similar climatic and hydrologic conditions. Water-level data from the Upper Floridan aquifer for 1980 and 1998 were collected in this manner, as were data from several subregions of the Northern Atlantic Coastal Plain. Such data, however, were not available for the entire study area, thus it was necessary to combine data from several time periods in order to estimate water-level change throughout the entire region. Therefore, fluctuations in water levels over the range of time periods introduces inaccuracies into the water-level-change maps.

Another limitation of the analysis was the spatial distribution of water-level data points. Data used in the analysis were a conglomeration of water levels collected from administered statewide networks as well as for geographically focused studies, resulting in an irregular distribution of data in some regions. Wells with water-level data in several areas, particularly in the Southeastern Coastal Plain, were clustered in small areas, while in other areas, data were sparse or nonexistent. As a result, some large expanses within the extent of the regional aquifers were omitted from the analysis because of the lack of data. Moreover, in some areas, water-level changes have been analyzed on the basis of sparsely distributed data, creating a large uncertainty as to the accuracy of estimated potentiometric surfaces and water-level changes over these areas.

Measured head data used to estimate prepumping conditions in the Atlantic Coastal Plain were sparse in many locations and were inadequate to define a comprehensive representation of the flow system. Therefore, regional RASA-simulated potentiometric surfaces were used as the best estimates of the regional prepumping water levels. However, model resolution was coarse; grid-cell sizes used in the regional models were 49 mi^2 and 64 mi^2 for the Northern Atlantic Coastal Plain and the Southeastern Coastal Plain, respectively. Hydraulic properties and simulated water levels are averaged at each cell and do not represent local hydrologic features and heterogeneities. In other cases, model layers of regional extent may encompass several aquifers that were composited for simulation. Therefore, there is a measure of error in the simulated water levels and, ultimately, the interpreted water-level changes.

Errors associated with poor representation of local hydrologic features are greatest in unconfined parts of aquifers. In the updip areas, the simulated prepumping water levels are influenced by an average stream head that overlies an aquifer model cell at or near an outcrop. Grid-cell size is large, and areas near the Fall Line, especially in the southern part of the Coastal Plain, are characterized by considerable topographic relief. Therefore, an average simulated head at an aquifer cell in these areas commonly results in simulated heads that are lower than measured water levels. Subsequent comparisons with measured post-development data in these areas can show false increases in the water levels.

Many wells used in this study did not have measured data for both the circa-1980 and circa-2000 periods; therefore, water-level-change values are calculated differences between an actual measurement and an interpreted value that was based on either published potentiometric surfaces or surrounding observed head values. Depending on the accuracy of the interpreted or simulated head value, error is introduced into the resulting water-level-change value.

Changes in water levels in the confined aquifers of the Atlantic Coastal Plain were caused predominantly by changes in ground-water withdrawals. Ground-water-withdrawal data, however, are not uniformly compiled and maintained by each state within the study area. Data characterized by location, aquifer, withdrawal amount, and type of use were available for some areas, but much of the available withdrawal data were aggregated by county and type of use. Within many areas of the Atlantic Coastal Plain, a single county may utilize several aquifers; where the apportionment among aquifers was not known, only general interpretations regarding withdrawal and water-level decline could be made.

Water-Level Changes in Aquifers of the Northern Atlantic Coastal Plain

Analysis of water-level data and changing water-level conditions is provided for nine regional aquifers of the Northern Atlantic Coastal Plain as mapped by Trapp (1992). Aquifer nomenclature is based on regional aquifer names used by Leahy and Martin (1993) in their analysis of geohydrology and simulation of ground-water flow in the aquifer system. The Northern Atlantic Coastal Plain aquifer system extends from Long Island, N.Y., through New Jersey, Delaware, Maryland, Virginia, and North Carolina, encompassing an area of approximately 44,000 mi^2. The regional hydrogeologic framework of Trapp (1992) is based on detailed hydrogeologic-framework studies produced for the individual States including New York (Getzen, 1977; Garber, 1986), New Jersey (Zapecza, 1989), Maryland and Delaware (Vroblesky and Fleck, 1991), Virginia (Meng and Harsh, 1988), and North Carolina (Winner and Coble, 1996). The relation of the nine regional aquifer units to subregional aquifer units named in these detailed state framework studies is provided in table 1. A brief definition of each of the regional aquifers based on Trapp (1992) is included in each section below.

Upper Chesapeake Aquifer

The Upper Chesapeake aquifer consists of permeable beds in the upper part of the Chesapeake Group of Miocene-Pliocene age in the Delmarva Peninsula and their approximate stratigraphic equivalents including the upper part of the unconfined Kirkwood-Cohansey aquifer system in New Jersey, the Yorktown-Eastover aquifer in Virginia, and the Yorktown aquifer in North Carolina.

Before pumping began, the simulated potentiometric surface for the Upper Chesapeake aquifer (fig. 1) indicated that ground-water flow was from topographic highs near the Fall Line southeastward toward the Atlantic Ocean (Leahy and Martin, 1993). On the central Delmarva Peninsula, ground water flowed from higher altitudes toward both the Atlantic Ocean and the Chesapeake Bay. Upstream-trending contours in New Jersey, Virginia, and North Carolina reflect the local discharge to streams and estuaries (Leahy and Martin, 1993). The simulated potentiometric surface from 1980 (Leahy and Martin, 1993) closely resembles that from predevelopment, with the exception of a small cone of depression in the southern part of peninsular Cape May in New Jersey, where water levels were observed at depths to 26 ft below the NGVD 29.

Water levels in the Upper Chesapeake aquifer changed little from prepumping flow conditions to 1980. Ground-water withdrawals have caused scattered areas of slight to modest decline throughout the aquifer's extent at this time; however, cones of depression generally were limited in their extent and influence (fig. 2). Estimated withdrawals from the Upper Chesapeake in 1980 were approximately 68 Mgal/d (Leahy and Martin, 1993). The largest declines were observed in New Jersey, where more than 48 Mgal/d of water was withdrawn from the aquifer, and in particular, Cape May County. Most of the aquifer in New Jersey is unconfined and can readily accept recharge from precipitation; therefore, water-level changes resulting from climatic variability and withdrawals typically were localized. In lower Cape May County, however, the aquifer is well confined and less transmissive than elsewhere in New Jersey, and ground-water declines were most pronounced in this area. In 1980, ground-water withdrawals from the confined Cohansey aquifer (the local equivalent of the Upper Chesapeake aquifer in Cape May County) were estimated at nearly 6.5 Mgal/d and were made primarily from production and industrial supply wells in the southern part of the county (unpublished data on file at the USGS New Jersey WSC). Water levels also declined in coastal Ocean County, N.J., near the northernmost landward extent of the aquifer as well as in small, isolated areas of Somerset and Worcester Counties in Maryland. Withdrawals from the aquifer in Maryland were substantially less than those in New Jersey during 1980, totaling approximately 6.5 Mgal/d. Much of the ground-water pumping was in coastal Worcester County, Md., on or near the barrier islands that include major tourist communities. The transmissivity of the aquifer is at its highest near here (Trapp and Meisler, 1992; Leahy and Martin, 1993) and as a result, ground-water decline was barely perceptible.

By 2000, water levels in the Upper Chesapeake aquifer had stabilized, and between 1980 and 2000, virtually no net change was observed. Water levels across the aquifer in New Jersey had risen slightly; scattered areas of gentle rise were observed in the northern and western parts of the aquifer extent in the state. Previously declining water levels in peninsular Cape May County had stabilized (fig. 3) because of a

Table 1. Northern Atlantic Coastal Plain, relation of regional aquifer names and subregional aquifer names used in this study. [Modified from Leahy and Martin (1993)]

Regional aquifer	Subregional aquifer[1]				
	North Carolina	Virginia	Maryland Delaware	New Jersey	New York (Long Island)
Upper Chesapeake	Yorktown	Yorktown-Eastover	Upper Chesapeake[2]	Upper Kirkwood-Cohansey	
Lower Chesapeake	Pungo River	St. Mary's-Choptank	Lower Chesapeake[3]	Lower Kirkwood-Cohansey and Confined Kirkwood[4]	
Castle Hayne-Piney Point	Castle Hayne	Chickahominy-Piney Point	Piney Point-Nanjemoy	Piney Point	
Beaufort-Aquia	Beaufort	Aquia	Aquia-Rancocas	Vincentown	
Peedee-Severn	Peedee		Severn	Wenonah-Mount Laurel	
Black Creek-Matawan	Black Creek		Matawan	Englishtown	
Upper Potomac and Magothy	Upper Cape Fear	Brightseat-upper Potomac	Brightseat and Magothy	Upper Potomac-Raritan-Magothy	Magothy
Middle Potomac	Lower Cape Fear	Middle Potomac	Patapsco	Middle Potomac-Raritan-Magothy	Lloyd
Lower Potomac	Lower Cretaceous	Lower Potomac	Patuxent	Lower Potomac-Raritan-Magothy	

[1]The subregional aquifer names in the six states were derived from the following geologic units, which are generally listed in descending order: Tertiary units—Yorktown, Eastover, St. Mary's, and Choptank Formations, Chesapeake Group, Kirkwood Formation and Cohansey Sand, Pungo River, Castle Hayne, Chickahominy, Piney Point, Nanjemoy, Beaufort, Aquia, Vincentown, and Brightseat Formations, and Rancocas Group; Cretaceous units—Peedee, Severn, and Wenonah Formations, Mount Laurel Sand, Black Creek, Matawan, Englishtown, Cape Fear, Magothy and Raritan Formations, Patapsco and Patuxent Formations of the Potomac Group, and Lloyd Sand Member of the Raritan Formation. The regional aquifer names were derived from subregional aquifer names and combinations of the names.

[2]Contains the Pocomoke, Ocean City, and Manokin aquifers on the Delmarva Peninsula.

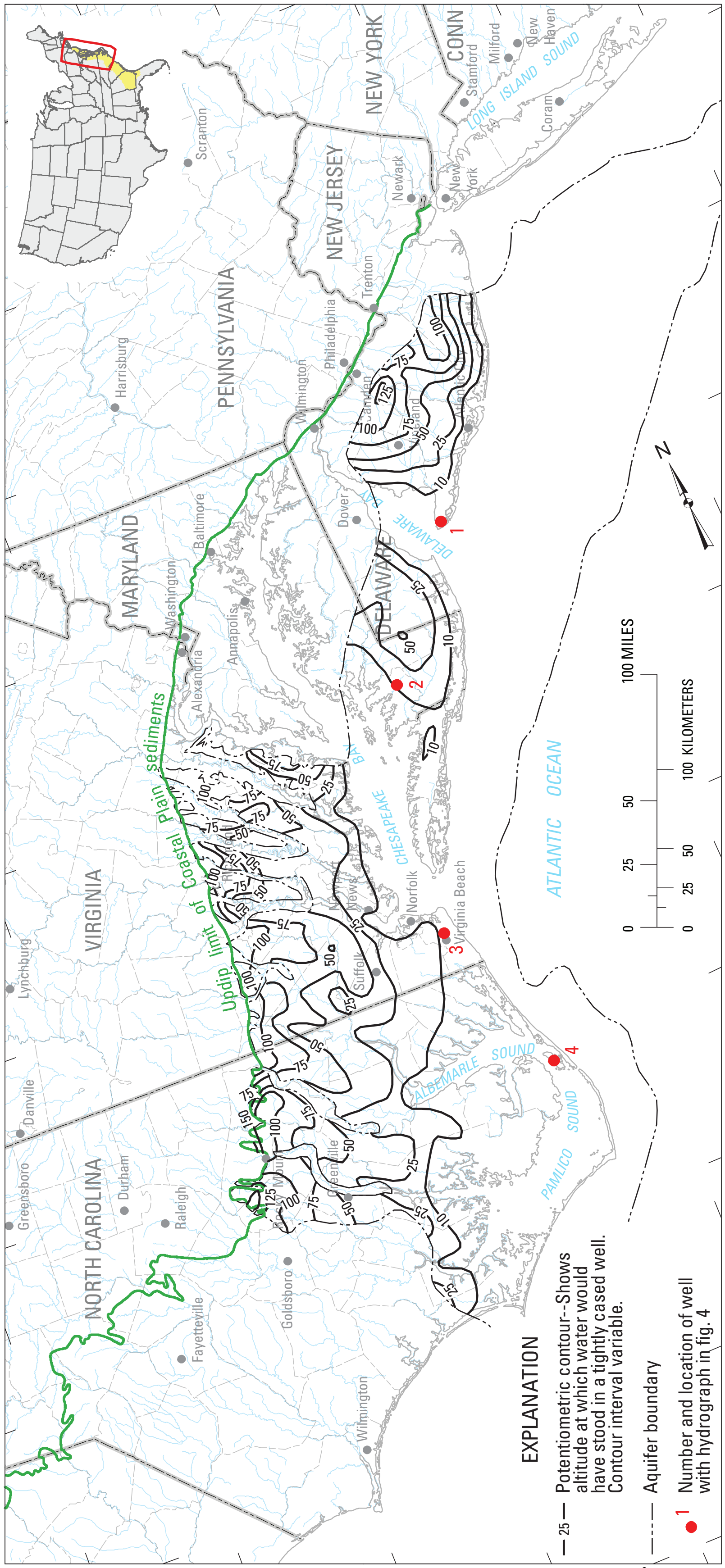
[3]Contains the Frederica, Federalsburg, and Cheswold aquifers on the Delmarva Peninsula.

[4]Contains the Rio Grande water-bearing zone and the Atlantic City 800-foot sand in New Jersey.

reduction in ground-water withdrawals from the Upper Chesapeake aquifer, which, in the Cape May area, decreased to less than 5 Mgal/d in 2000. Although the population dependent on ground water within the county increased by 15 percent from 1985 to 2000 (Solley and others, 1988; Hutson and others, 2004), withdrawals from the aquifer were reduced because of saltwater migration into the aquifer. In early 1998, a desalination plant in lower Cape May County began operation, and withdrawals of saline water were increased from the Lower Chesapeake aquifer to augment the supply.

Water levels declined up to 25 ft in a small area in north-central Somerset County, Md., from 1980 to 2000, although ground-water withdrawals increased only slightly during this period.

Representative hydrographs for wells screened in the Upper Chesapeake aquifer showing long-term trends in water levels are shown in figure 4; locations are indicated in figure 1. The hydrograph for the Canal 5 observation well shows that water levels have been below NGVD 29 since the late-1950s in lower Cape May County, N.J. Water levels fluctuated annually in response to nearby pumping by as much as 20 ft but steadily declined from 1958 to 1975, stabilized, then recovered slightly from 1996 to 2000. The observed rise in water-level altitude in this well resulted from decreased



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30′N and 45°30′N, central meridian 96°00′W

Contours modified from Leahy and Martin, 1993

Figure 1. Simulated potentiometric surface of the Upper Chesapeake aquifer, prior to development.

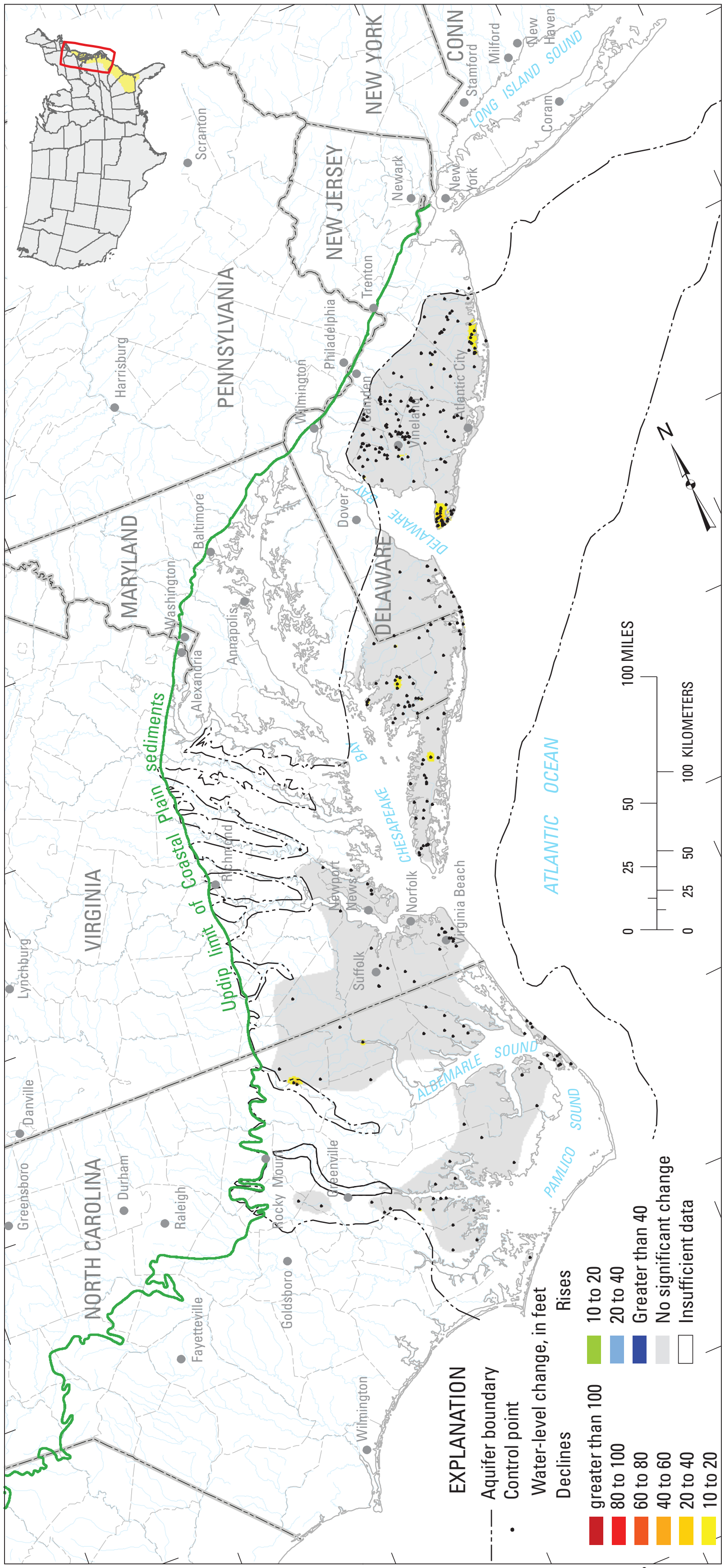
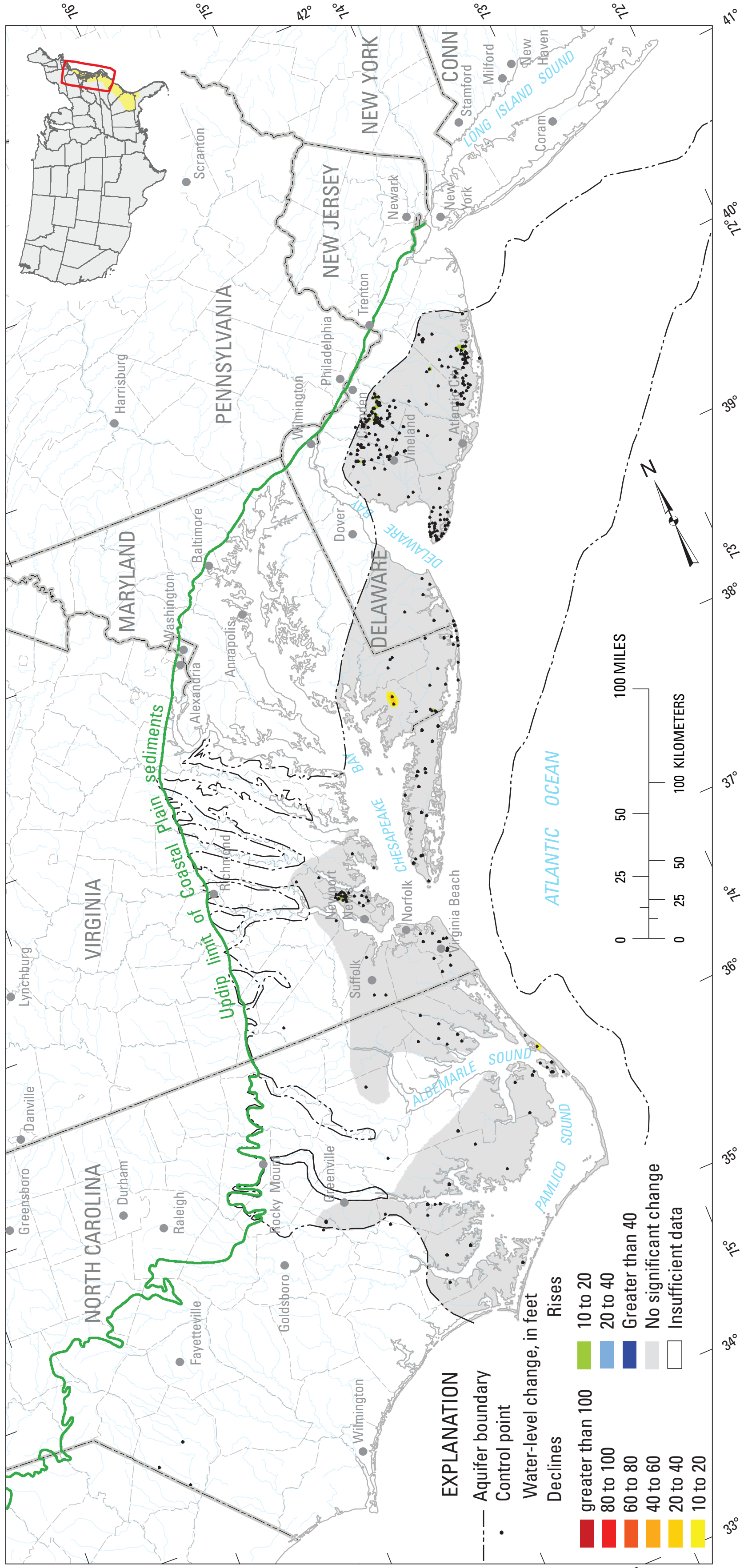


Figure 2. Estimated water-level changes in the Upper Chesapeake aquifer, predevelopment to circa 1980.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 3. Estimated water-level changes in the Upper Chesapeake aquifer, circa 1980 to 2000.

production in nearby supply wells in response to salt-water intrusion into the aquifer.

Water levels in well SO Be 42, located along the eastern shore of the Chesapeake Bay in Maryland's Somerset County, were above NGVD 29 in the early 1950s; by 1955, water levels had declined 20 ft to 10 ft below NGVD 29. Levels continued to fall through 1976, stabilized through the late 1980s, and then declined again to lows of near 50 ft below NGVD 29 around 1991. Water levels have since stabilized to about 40 ft below NGVD 29.

The hydrograph from well 62C 2 SOW 092A in Virginia Beach, Va., shows generally declining levels throughout the period of record. Although water levels vary seasonally in any given year, recent seasonal highs are about 5 ft lower than in 1980.

Water levels from observation well J 303, hydrograph 4, in Dare County, N.C., indicate static levels from the beginning of record to about 1980. Thereafter, water-level fluctuations reflect nearby seasonal pumping to meet increased demand during the summer months. Subsequent seasonal highs were lower than water levels prior to 1980, indicating a slight downward trend.

Lower Chesapeake Aquifer

The Lower Chesapeake aquifer consists of permeable beds in the lower part of the Chesapeake Group and their approximate stratigraphic equivalents including the lower part of the unconfined Kirkwood-Cohansey aquifer system, the confined Rio Grande water-bearing zone and the Atlantic City 800-ft sand aquifer in New Jersey, the St. Marys and Choptank aquifers in Virginia, and the Pungo River aquifer of North Carolina (table 1).

The simulated predevelopment potentiometric surface of the Lower Chesapeake aquifer indicates ground-water flowpaths from south-central and east-central New Jersey trending southeastward towards Atlantic City and to the south through the Cape May peninsula (fig. 5). Lateral regional ground-water movement is generally downdip toward low-lying areas where flow discharges upward through sediments to the Atlantic Ocean in the east and southeast. Farther to the south, on the central Delmarva Penisula, ground water flowed from areas of higher head toward areas of low head along the Delaware and Chesapeake Bays. In North Carolina, flow was from potentiometric highs along the updip boundary of the aquifer eastward toward the Pamlico and Albemarle Sounds. Regional recharge to the aquifer occurs by infiltration in topographically high outcrop areas of the unconfined units comprising the Chesapeake Group and by leakage through overlying strata (Leahy and Martin, 1993).

By 1980, a well-developed cone of depression had formed in coastal New Jersey, centered on pumping wells of the barrier islands near Atlantic City and extending from Cape May to southern Ocean County (fig.6) (Walker, 1983; Leahy and Martin, 1993). Water levels were measured at altitudes of 82 ft below NGVD 29 at the center of this cone. A second, smaller cone of depression was present in Kent County, Del., as a result of long-term development of the local Cheswold aquifer (Leahy, 1979). Water levels of -66 ft NGVD 29 were measured nearby in a single observation well, though it is likely that water levels were lower than that nearer the pumping center to the east. In Maryland, aquifer water levels were slightly below 0 ft NGVD 29 in wells nearest the Chesapeake Bay. Lack of data in the North Carolina part of the Lower Chesapeake aquifer precluded interpretation in this area, and therefore, analysis is limited to the aquifer's northern extent.

Declines in water levels in the Lower Chesapeake aquifer were greatest along the southeastern coast of New Jersey. Prepumping water-level altitudes near the center of the cone of depression were estimated to be approximately 23 ft NGVD 29. By 1980, water levels declined to -82 ft NGVD 29, indicating a maximum decline of 105 ft, or about 1.3 ft/yr (fig. 6). Leahy and Martin (1993) estimate withdrawals from the Lower Chesapeake aquifer circa 1980 at 45.3 Mgal/d (Leahy and Martin, 1993); pumpage from the aquifer in New Jersey was substantial at approximately 38 Mgal/d, and about half of that amount was from the subregional confined Kirkwood aquifer, the primary source of water for coastal communities. The aquifer is generally well confined in this area; however, the transmissivity of the aquifer is high relative to other areas at approximately 5,000 to 10,000 ft^2/d (Trapp and Meisler, 1992).

In Delaware, the aquifer is less transmissive, and withdrawals were more modest at 4.8 Mgal/d, mostly from in and around the city of Dover in Kent County. Water-level altitudes in the Lower Chesapeake aquifer prior to development were estimated at 25 ft NGVD 29 in this area. A single measurement near Dover indicated that the water level declined more than 90 ft from prepumping levels. Leahy (1982) estimated about 95 ft of drawdown in the local Cheswold aquifer in the vicinity of Dover. A comparison of simulated prepumping and 1980 potentiometric surfaces (Leahy and Martin, 1993) indicates a decline in this area, though somewhat less at 30 ft. Because this was an area where the aquifer was utilized for supply, declines in heads were plausible, though the magnitude cannot be determined with certainty. To the west, along the border with Maryland, water levels declined 10 ft or less from prepumping levels. In eastern Maryland, withdrawals from the aquifer were less than 2 Mgal/d (Leahy and Martin, 1993; unpublished data on file at the USGS Maryland WSC) and widely scattered throughout the counties bounding the eastern shore of the Chesapeake Bay; consequently, no substantial change in water levels was observed for this time period.

By 2000, the areally extensive cone along the New Jersey coast had deepened, and water levels continued to decline in this area (Lacombe and Rosman, 2001) (fig. 7). Total ground-water withdrawals in the confined part of the aquifer increased by nearly 18 percent to about 22 Mgal/d during this time period (unpublished data on file at the USGS New Jersey WSC). Although withdrawals near the center of the cone of depression had remained constant, additional

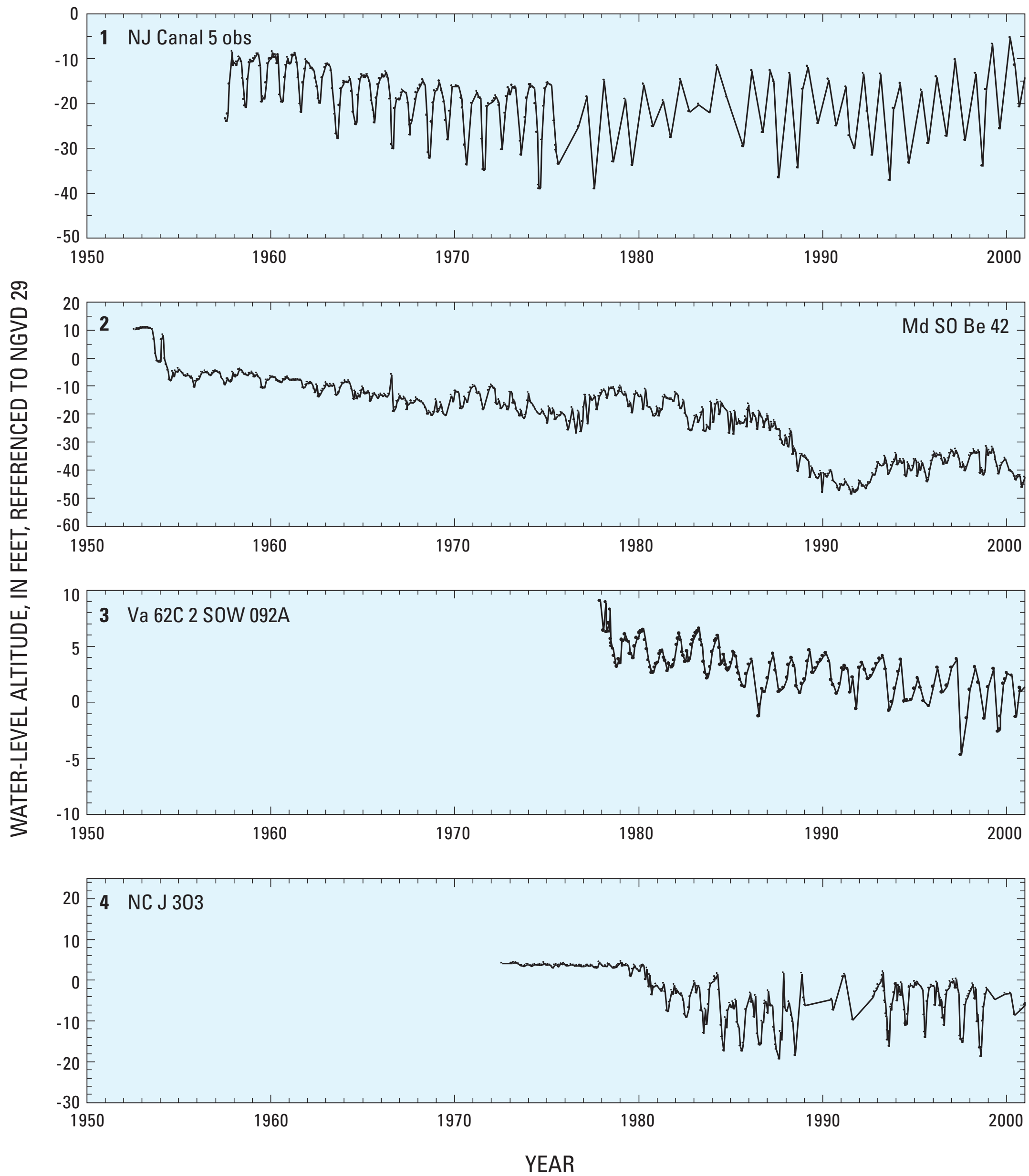
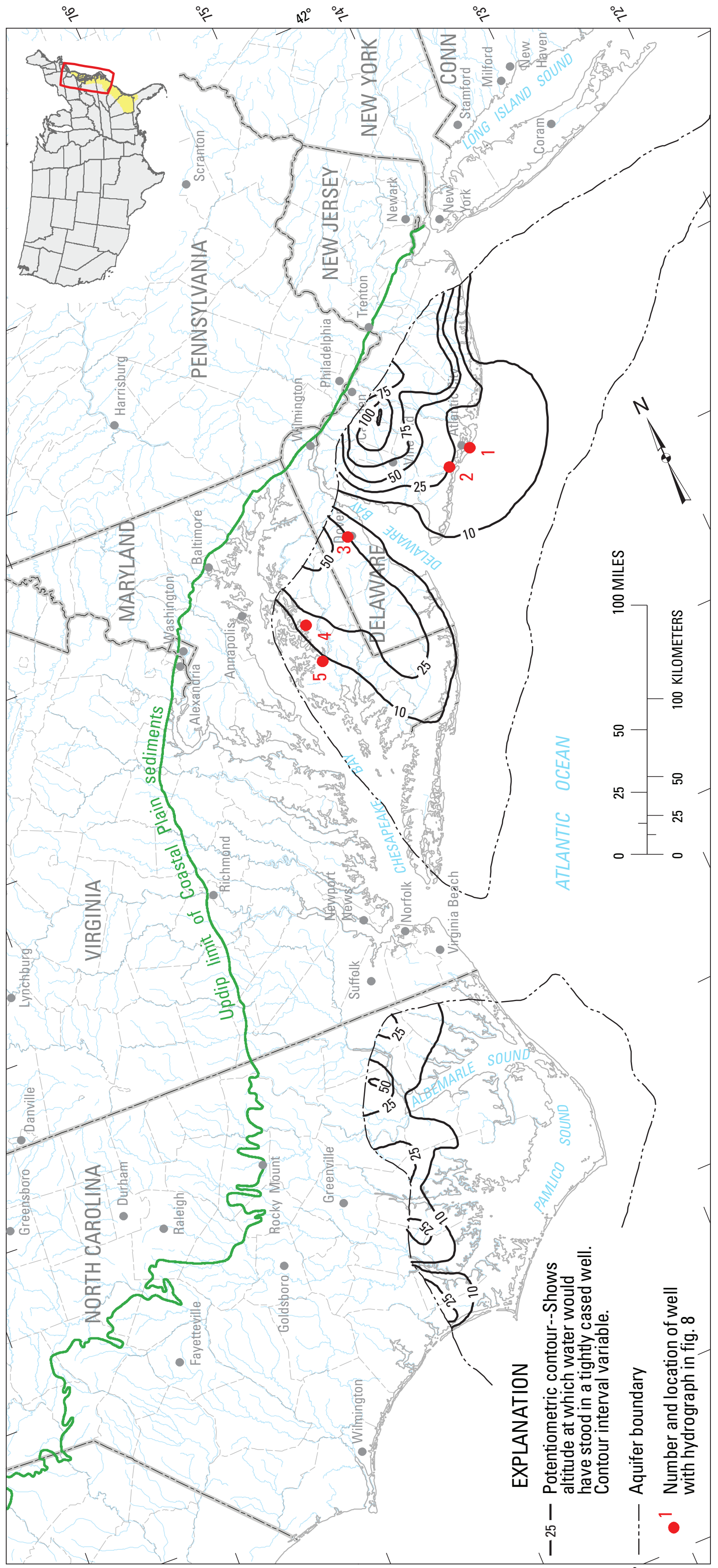


Figure 4. Selected hydrographs from wells screened in the Upper Chesapeake aquifer. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 1.)

water-level decline of 20 to 25 ft occurred along the barrier islands of coastal Atlantic County, bringing the total since pumping began to nearly 125 ft. Along the northeastern and southwestern edges of this regional cone of depression, water levels declined by approximately 10 to 15 ft during the same period. The maximum decline in New Jersey of 45 ft occurred in interior Atlantic County, slightly to the north and west of the cone's center, where withdrawals began in the mid-1990s. Although water levels in the aquifer remain below 0 ft NGVD 29 at the cone of depression near Dover, Del., water levels have generally stabilized and have begun to recover. In western Kent County, water-level change for this period was negligible. Withdrawals from the aquifer in Delaware in 2000 were approximately 4.5 Mgal/d, similar to amounts in 1980, and again were concentrated in a relatively small area near the city of Dover. Ground-water withdrawals during 2000 again were minor in Maryland, at approximately 2 Mgal/d, and water levels generally remained stable.

Selected hydrographs for wells open to the Lower Chesapeake aquifer are shown in figure 8; locations are indicated in figure 5. Water levels in the Galen Hall observation well, on the northern end of the barrier island near the center of the large cone of depression at Atlantic City, N.J., were already depressed to more than 60 ft below NGVD 29 by 1950. Fluc-



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection
Standard parallels 29°30′N and 45°30′N, central meridian 96°00′W

Contours modified from Leahy and Martin, 1993

Figure 5. Simulated potentiometric surface of the Lower Chesapeake aquifer, prior to development.

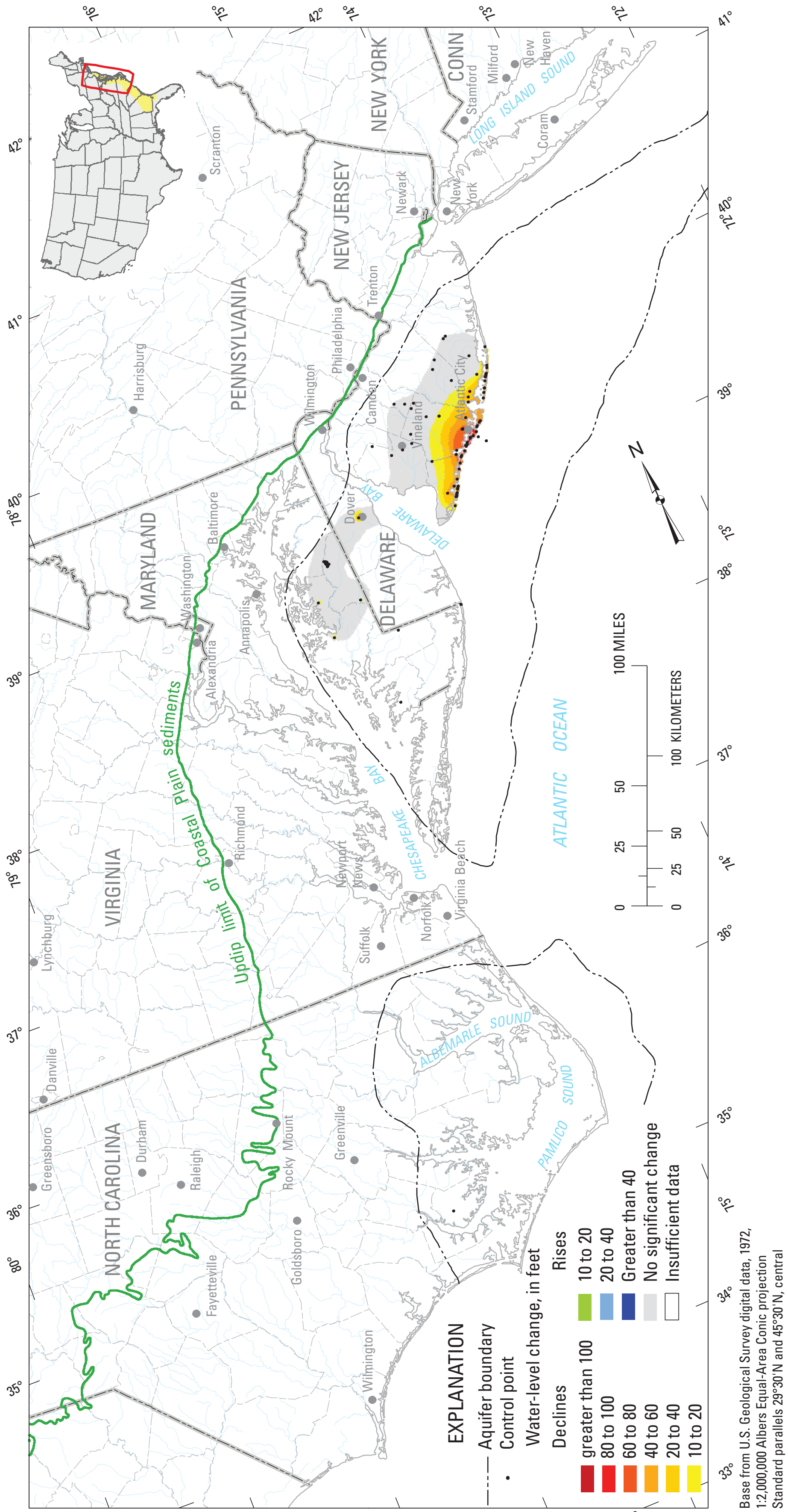


Figure 6. Estimated water-level changes in the Lower Chesapeake aquifer, predevelopment to circa 1980.

tuations in heads by as much as 25 ft reflect seasonal changes in local pumping schemes; however, the general trend was a gradual decline to more than 90 ft below NGVD 29 by 2000, two periods of mild recovery notwithstanding.

The Jobs Point observation well, to the southwest of the Galen Hall well and on the mainland, is within the influence of the Atlantic City cone of depression. Water levels exhibit similar seasonal fluctuations as well as an overall downward trend through 2000.

Near Dover, Del., water levels in well Jd14-01 rose 25 ft during the mid 1970s. In the late 1990s, water levels generally were higher than in the mid-1970s, indicating subtle recovery despite the extended period of missing record.

Water levels in well TA CE 7 in Talbot County, Md., near the Chesapeake Bay show annual fluctuations in excess of 50 ft to about 1973; levels from the late 1950s to the early 1970s were, on average, at about 30 ft below NGVD 29. In the mid-1970s to 1980, water levels rose approximately 20 ft and have remained relatively stable to 2000. Long-term data from well DO Ce 85 show little change from 1974 through 2000.

Castle Hayne-Piney Point Aquifer

The Castle Hayne-Piney Point aquifer is a limestone and lime sand aquifer in North Carolina and a sand aquifer in Virginia, Maryland, Delaware, and New Jersey, predominantly of Eocene age. The use of the name “Castle Hayne aquifer” is established in North Carolina, whereas the use of the “Piney Point aquifer” is established in Virginia, Maryland, Delaware, and New Jersey. Both are based on names of corresponding geologic formations.

The simulated predevelopment potentiometric surface for the Castle Hayne-Piney Point aquifer indicates that ground-water flow was from updip potentiometric highs in Ocean and Burlington Counties in New Jersey toward the Atlantic Ocean and the Delaware Bay (fig. 9). On the Delmarva Peninsula, simulated water levels suggest a ground-water divide near the center of the peninsula, with flow toward both the Delaware and Chesapeake Bays. In Virginia, steep gradients along the updip boundary of the aquifer indicate ground-water flow to the major streams that bisect the area (Leahy and Martin, 1993). In North Carolina, flow was generally to the east-south-east toward the Atlantic Ocean.

By 1980, substantial cones of depression had developed in the areas of Beaufort County, N.C., the eastern shore of the Chesapeake Bay in Maryland, and central Delaware, with smaller cones underlying coastal Ocean County, N.J., and the West Point area of Virginia (Leahy, 1979; Winner and Coble, 1996; Leahy and Martin, 1993; Martin, 1998). At the centers of the major cones of depression near Kent County, Del., Cambridge, Md., and Beaufort County, N.C., water-level altitudes were 110, 84, and 75 ft below NGVD 29, respectively.

By 1980, water levels in the regional Castle Hayne-Piney Point aquifer had declined substantially from those prior to pumping. Areas of greatest decline were centered in areas of high pumpage: Dover (Kent County), Del., Cambridge (Dorchester County), Md., and the James City and West Point areas of Virginia. Decline during this time period was greatest in Delaware, where a maximum decline of 129 ft was observed in Kent County (fig. 10).

Pumpage from the aquifer in Delaware began in the late 1950s (Leahy, 1979); by 1980 approximately 3.4 Mgal/d of water was withdrawn from the aquifer here (Leahy and Martin, 1993; unpublished data on file at the Delaware Department of Natural Resources and Environmental Control (DNREC)), primarily from areas near the cone of depression at Dover in Kent County. The aquifer has a lower transmissivity in this area relative to that in other locales; Leahy (1979) and Trapp and Meisler (1992) reported values ranging from 2,000 to 5,000 ft^2/d; thus, the larger magnitude of decline was reasonable. More than 4 Mgal/d were withdrawn from the Maryland part of the aquifer in 1980 (unpublished data on file at the USGS Maryland WSC); most withdrawals (75 percent) were from pumping centers in Dorchester County though smaller centers were scattered throughout St. Mary’s and Calvert Counties to the west. Decline in Maryland was greatest near the pumping center in Cambridge; water levels had declined nearly 100 ft from prepumping levels. In St. Mary’s and Calvert Counties, water levels generally declined from 10 to 30 ft relative to prepumping levels; however, declines of up to 40 ft were observed. Estimated withdrawals in both counties were less than 1 Mgal/d during 1980 (unpublished data on file at the USGS Maryland WSC); however the low transmissivity of the aquifer here (< 1,000 ft^2/d) contributed to declining heads.

In North Carolina, the aquifer is very productive; estimated withdrawals in 1980 were in excess of 130 Mgal/d (Leahy and Martin, 1993; Giese and others, 1997) and far surpass those of any state at this time. Pumping centers withdrawing at least 100,000 gal/d were primarily in the counties to the south and west of the Pamlico Sound, although large withdrawals also were made in proximity to the Albemarle Sound to the north. The largest single withdrawal in the state was associated with an open-pit phosphate mine in Beaufort County near the town of Aurora. By 1980, withdrawals here were approximately 64 Mgal/d (Giese and others, 1997); consequently, this area experienced the greatest water-level decline. Water levels had declined more than 20 ft from prepumping levels over a large part of the county; near the center of the cone of depression, decline was as great as 80 ft. Giese and others (1997) reported similar declines for this area. In eastern Onslow County, N.C., ground-water withdrawals caused water levels to decline approximately 20 ft from prepumping levels. Though the aquifer was utilized throughout its extent, the transmissivity of the aquifer in areas where porous limestone is the predominant lithology ranges from 20,000 to more than 40,000 ft^2/d, serving to constrain horizontal expansion of head decline.

Water-level declines in Virginia were greatest in and around the major pumping centers in West Point and in eastern James City County. By 1980, water levels had declined by as

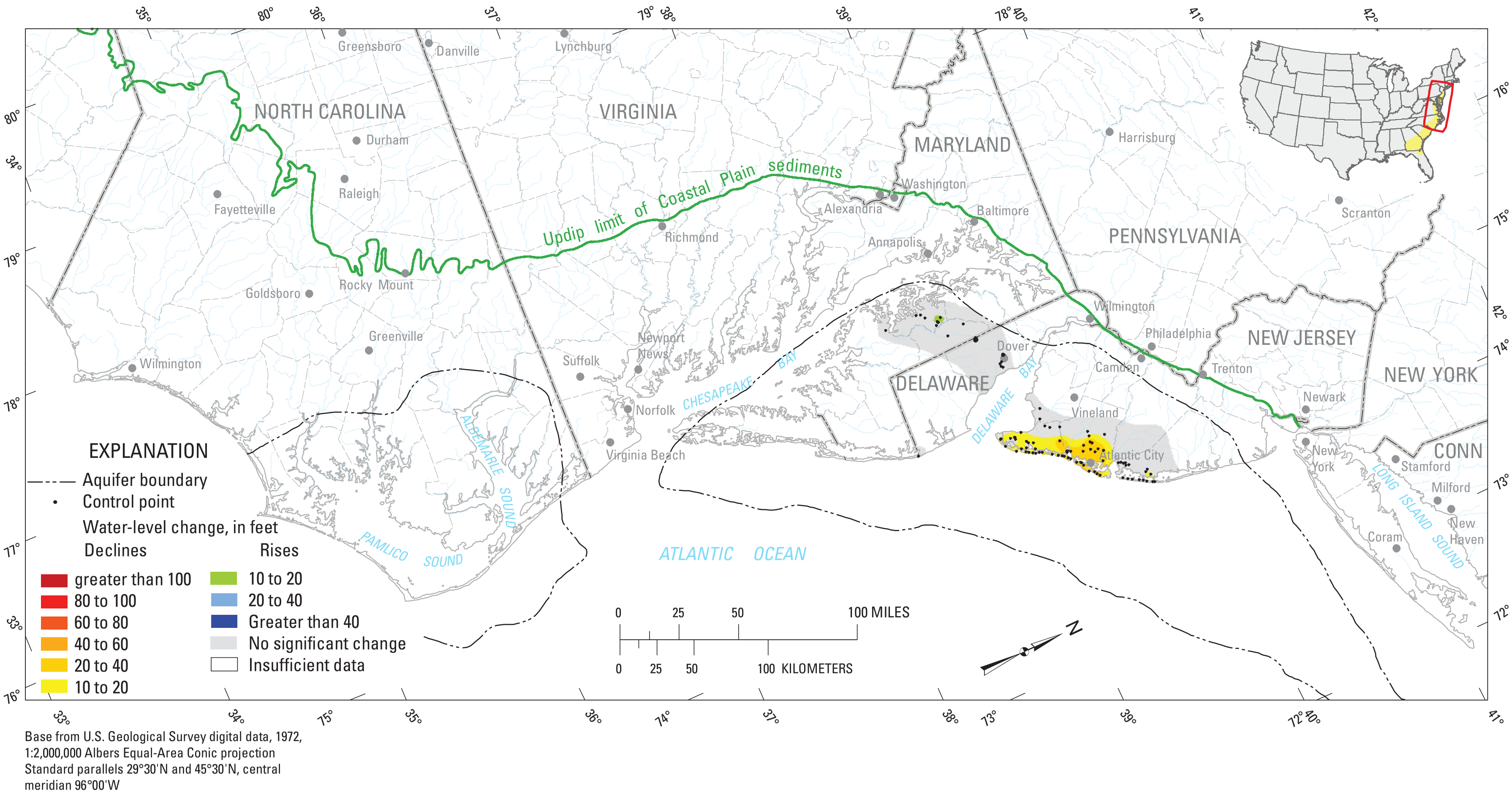


Figure 7. Estimated water-level changes in the Lower Chesapeake aquifer, circa 1980 to 2000.

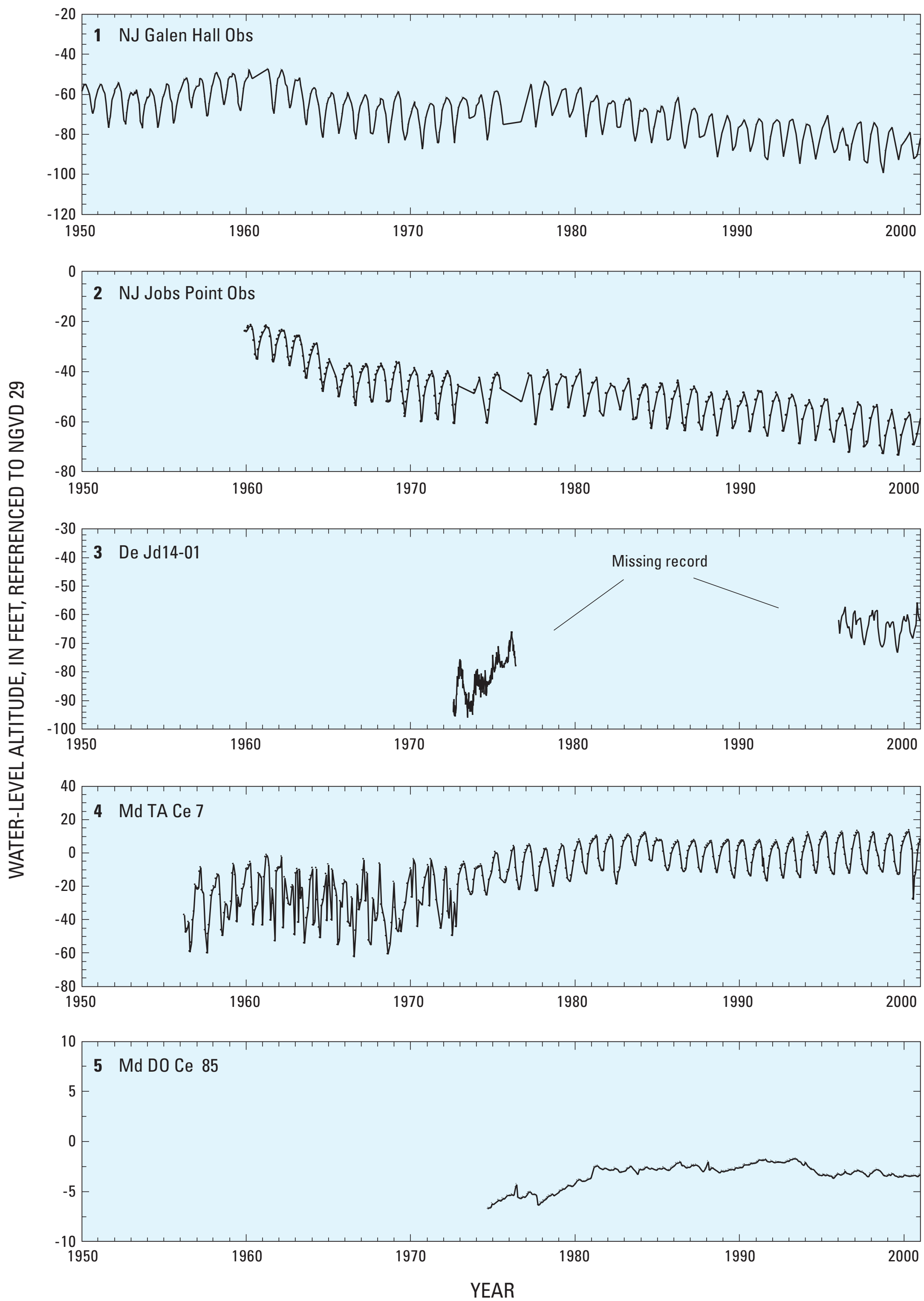
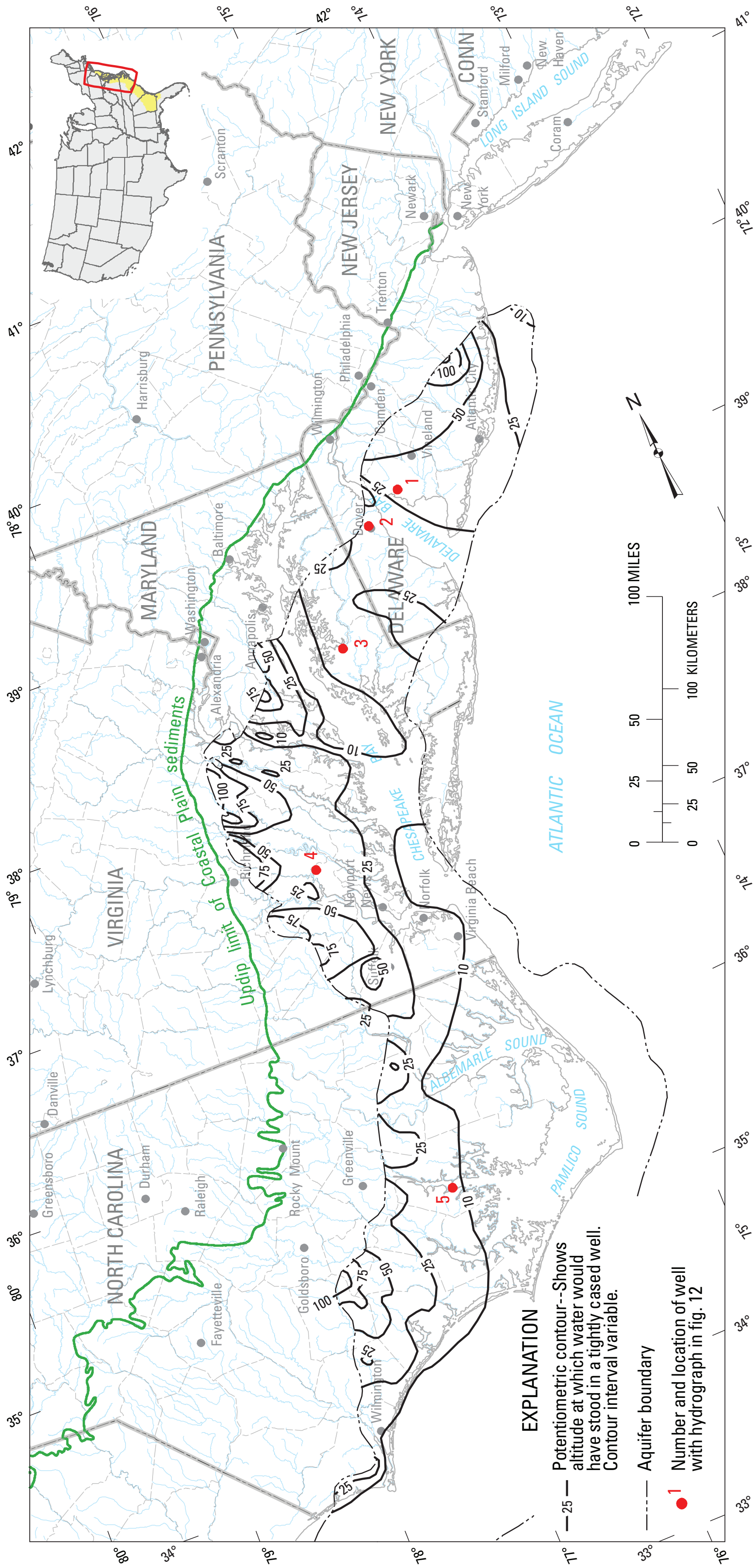


Figure 8. Selected hydrographs from wells screened in the Lower Chesapeake aquifer. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 5.)



Contours modified from Leahy and Martin, 1993

Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30′N and 45°30′N, central meridian 96°00′W

Figure 9. Simulated potentiometric surface of the Castle Hayne-Piney Point aquifer, prior to development.

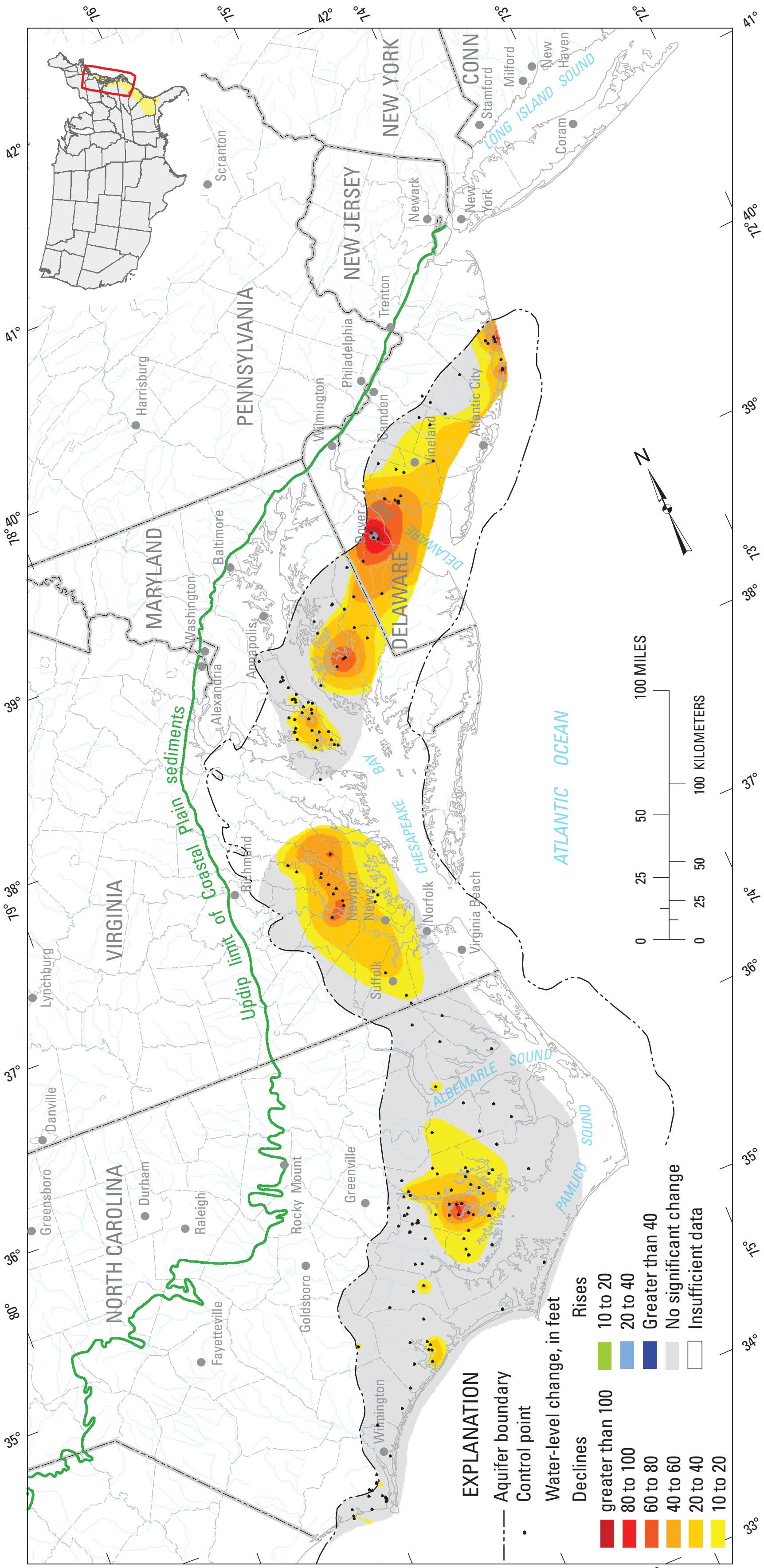


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Figure 10. Estimated water-level changes in the Castle Hayne-Piney Point aquifer, predevelopment to circa 1980.

much as 63 ft from prepumping levels at West Point; Laczniak and Meng (1988) reported a maximum simulated decline of 100 ft here from prepumping levels to 1983. In southeastern James City County, water levels declined by as much as 75 ft from predevelopment levels. The area encompassed by 20 ft of decline or greater extended east to Newport News and west to eastern Charles City County; declines of similar magnitude were observed as far south as northern Suffolk County. Withdrawals from the aquifer in Virginia circa 1980 were estimated at nearly 3 Mgal/d (unpublished data on file at the USGS Virginia WSC), mostly from pumping wells in the West Point area. The transmissivity of the aquifer ranges from 1,000 to 5,000 ft^2/d; thus, much lower withdrawal volumes produced a water-level decline comparable to that observed in North Carolina. Well data points were absent in parts of central Virginia, and therefore, these areas were not mapped.

Pumping from the aquifer in New Jersey circa 1980 was limited; usage throughout the state was approximately 2 Mgal/d, most of which was near the northernmost boundary of the aquifer. By 1980, water levels had declined by as much as 80 ft from prepumping levels at individual wells or in small pumping centers on the barrier islands; declines had propagated beneath the bays and about 2 to 4 mi inland, though the average decline here was 10 to 20 ft. Water-level declines of up to 50 ft in the southern part of the aquifer extent in New Jersey were largely a result of the relatively low aquifer transmissivities and withdrawals in Kent County, Del.

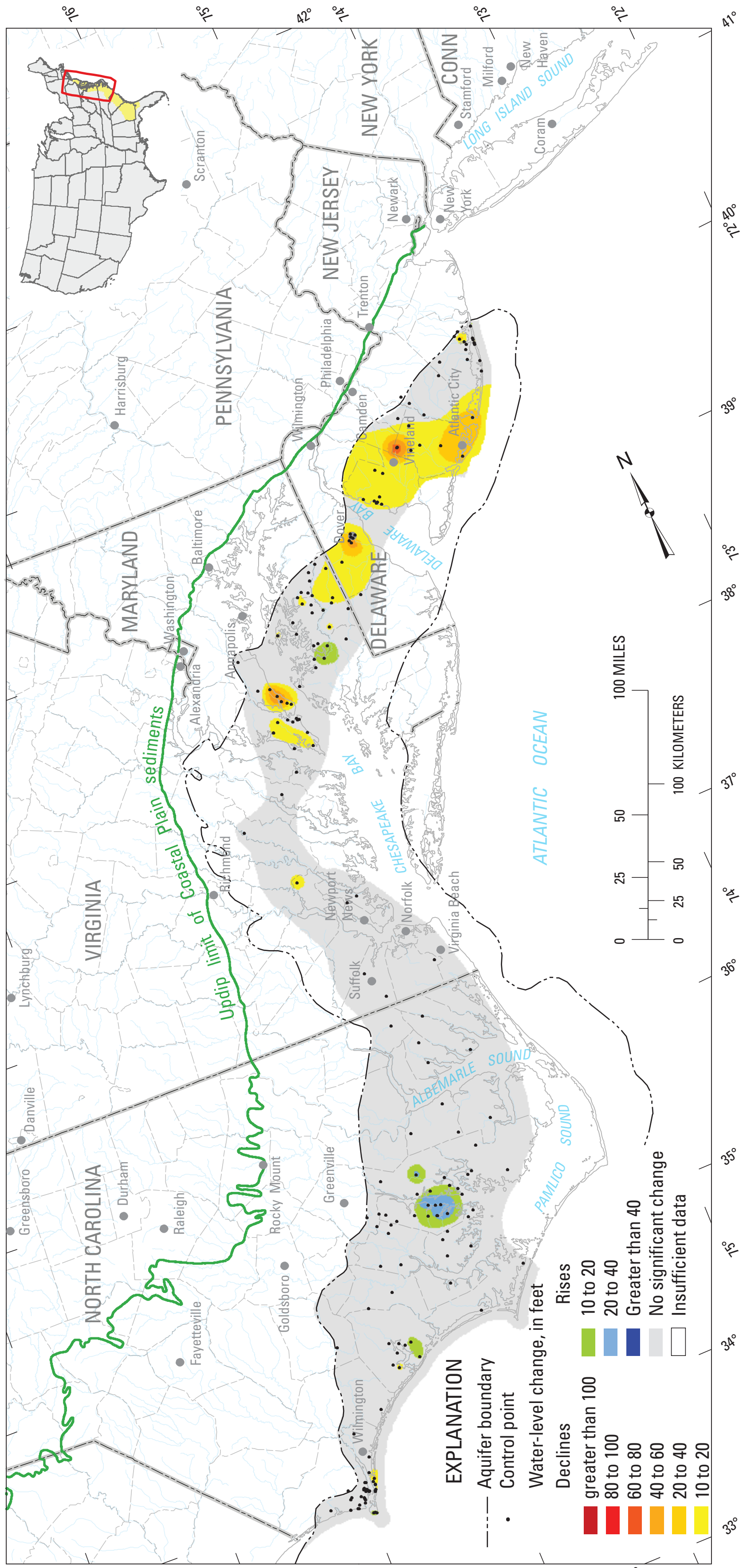
From 1980 and 2000, water levels continued to decline around the pumping centers in Delaware and the western shore of the Chesapeake Bay in Maryland, while water levels increased at the cone of depression in Beaufort County, N.C., and near Cambridge, Md. By 2000, two additional smaller cones of depression had developed in western and coastal Atlantic County, N.J. (Lacombe and Rosman, 2001), and ground-water levels had further depressed in southern New Jersey and in Kent County, Del. Elsewhere, there was little change regionally in the water levels during this time period (fig. 11).

In Kent County, Del., water levels declined approximately 40 ft from 1980 levels near the center of the cone of depression, although during the latter part of the 1990s water levels began to recover. The decrease in aquifer heads was more moderate only a short distance from the cone's center, where decline was generally 10 to 20 ft. Reported water use for Delaware in 2000 from the Castle Hayne-Piney Point was approximately 3 Mgal/d (unpublished data on file at DNREC), similar to withdrawal volumes reported for 1980. Significant changes also were noted in Atlantic County, N.J., where water levels had, on average, declined nearly 20 ft but as great as 60 ft in the western part of the county. Withdrawals from the aquifer in New Jersey remained nearly constant from 1980 through the early 1990s at about 2 Mgal/d; thereafter, withdrawals steadily increased through 2000 to more than 4 Mgal/d (unpublished data on file at the USGS New Jersey WSC). Much of the increased pumpage occurred in northern Ocean County, although the largest withdrawals had shifted inland and to the west. Consequently, water levels in this area declined up to 20 ft, while water levels on the barrier islands had generally stabilized. Withdrawals near the area of decline in western Atlantic County were minor in 2000 at less than 1 Mgal/d; however, usage here more than tripled during this time period. The aquifer was lightly utilized in coastal Atlantic County at this time; observed declines here were likely the result of withdrawals and continued declining heads in the overlying Lower Chesapeake Aquifer (Lacombe and Rosman, 2001). The greatest rise in water levels within the aquifer, nearly 40 ft, was in Beaufort County, N.C., near the center of the cone of depression. Estimated withdrawals from the aquifer for 2000 of 94 Mgal/d (U.S. Geological Survey, 2003) represent a 28 percent decrease from those reported in 1980. Similar percentage reductions in withdrawals also occurred in Beaufort County, prompting the rise in water levels. Recovering water levels also were evident in coastal Onslow County; throughout the remainder of the state, water levels had generally stabilized. In Dorchester County, Md., water levels remained static to slightly recovering. Ground-water withdrawals from the aquifer in Maryland decreased from 1980 volumes; the largest reductions occurred in Dorchester County.

Selected hydrographs showing long-term trends in water levels in wells completed in the Castle Hayne-Piney Point aquifer are shown in figure 12; locations of the wells are indicated in figure 9. The Jones Island 2 observation well, near Delaware Bay in southern New Jersey, shows a steady decline from the beginning of record in 1972 through 1996. Thereafter, water levels stabilized to 35 ft below NGVD 29. The lack of seasonal variability in the data indicates that this well was not directly affected by nearby pumping.

The water level in well Id55-01, in central Delaware, declined 60 ft from 1970 to 1980 and, by 1990, declined an additional 20 ft. Reductions in ground-water withdrawals in and near the city of Dover since the early 1990s prompted water levels to recover by about 10 ft through 2000. Well DO Ce 21, located near the center of the cone of depression underlying Dorchester County on Maryland's eastern shore, shows that water levels declined approximately 20 ft from 1960 to 1972. From 1972 to 1980, water levels recovered about 32 ft and have generally stabilized at 60 ft below NGVD 29 through 2000. The hydrograph for well 56H 29 SOW 177E, in the western part of the York-James peninsula, shows water levels at 30 ft below NGVD 29 by 2000. Water levels had declined at an annual rate in excess of 1 ft, or a total of about 20 ft, for the duration of record.

Well BO-363 is located in Beaufort County, N.C., near the center of the large cone of depression. Heads in the well, measured at 90 ft below NGVD 29 in the late 1960s, had risen approximately 40 ft subsequent to 1984. This rise in water level was attributed to significant reductions in withdrawals from the Castle Hayne aquifer during this period.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30′N and 45°30′N, central meridian 96°00′W

Figure 11. Estimated water-level changes in the Castle Hayne-Piney Point aquifer, circa 1980 to 2000.

Beaufort-Aquia Aquifer

The Beaufort-Aquia aquifer includes the local Beaufort aquifer in North Carolina, the Aquia aquifer in Virginia and Maryland, the Rancocas aquifer in Delaware, and the Vincentown aquifer in New Jersey. All are composed of Paleocene sands and are named for the corresponding geologic units in the individual states.

The potentiometric surface for the Beaufort-Aquia aquifer (fig. 13) shows simulated ground-water-flow conditions circa 1900 (Leahy and Martin, 1993). In New Jersey, prepumping flow was from a ground-water divide beneath Ocean and Burlington Counties northeast towards the Atlantic Ocean and southward to the Delaware Bay. Along the Maryland-Delaware border, flow was from a ground-water divide northeast towards the Delaware Bay and southwest to the Chesapeake Bay. In Maryland and Virginia, most horizontal ground-water flow in the aquifer was towards the bay. In North Carolina, ground-water flow was from the western limit of the aquifer eastward to coastal back bays and the Atlantic Ocean.

By 1980, substantial cones of depression were centered in St. Mary's County, Md., York and Gloucester Counties, Va., and Beaufort County, N.C. (Leahy and Martin, 1993; Laczniak and Meng, 1988; Mack and others, 1983; Giese and others, 1997). Water-level altitudes as low as 57 ft below NGVD 29 in York County, Va., and 51 ft below NGVD 29 in St. Mary's County, Md., were observed at the centers of the cones of depression. These cones captured ground-water flow that had previously discharged to the Chesapeake Bay and the Atlantic Ocean.

Areas with more than 20 ft of water-level decline extended across large parts of the aquifer from Maryland to Virginia, as well as in the central part of the Coastal Plain in North Carolina (fig.14). Water-level decline from prepumping conditions was greatest in Virginia; declines of 20 ft or more were present throughout much of the aquifer in the central and southern parts of the Coastal Plain in the state. The local Aquia aquifer was not heavily pumped in Virginia at this time; statewide withdrawals from the aquifer were estimated at approximately 1.9 Mgal/d in 1980 (Leahy and Martin, 1993). Decline was most pronounced in the aquifer underlying the York-James Peninsula; in this area, the aquifer is thin and has a transmissivity of less than 1,000 ft^2/d (Trapp and Meisler, 1992). Leahy and Martin (1993) and Harsh and Laczniak (1990) depict simulated potentiometric lows here. Moderate withdrawals from the Piney Point and Aquia aquifers were documented at West Point and James City County; however, the largest withdrawals in this region in 1980 were from the underlying Upper Potomac aquifer (Harsh and Laczniak, 1990). The maximum decline within Virginia of nearly 95 ft occurred in York County, or about 1.2 ft/yr from the time prior to pumping. The hydrograph for well 57G 2 SOW 003, in York County, Va., shows that water levels declined 31 ft from 1968 to 1980. Estimated prepumping heads near here ranged from 25 to 28 ft NGVD 29 (Harsh and Laczniak, 1990), marking a decline of approximately 80 ft by 1980 (fig. 16).

In Maryland, water-level decline was greatest in Calvert and St. Mary's Counties, just north of the Virginia border and proximate to the Chesapeake Bay. Water levels had generally declined about 40 ft from prepumping levels throughout this area, with declines of more than 60 ft in places in eastern St. Mary's County. During 1980, approximately 5 Mgal/d was withdrawn from the Aquia aquifer statewide (unpublished data on file at the USGS Maryland WSC); half that was from St. Mary's County.

Water levels throughout the aquifer in Delaware and New Jersey changed little during this period. The hydrograph for the Colliers Mills 2 observation well, in Ocean County, N.J., shows that the water level was virtually unchanged from 1964 to 1980 (fig. 16). Although well data were not available throughout most of the narrow northeast extent of the aquifer both in Delaware and New Jersey, water-level change was considered negligible because of little to no pumpage at this time. Ground-water withdrawals during 1980 from the Beaufort-Aquia aquifer in New Jersey were approximately 1.2 Mgal/d, most of which was from Monmouth County. Withdrawals from the Delaware part of the aquifer were insignificant at less than 0.5 Mgal/d.

In North Carolina, water-level decline in Beaufort County was typically 20 to 30 ft from prepumping levels. Water-level decline in this area coincided with the cone of depression in the overlying Castle Hayne-Piney Point aquifer. Although withdrawals from the Beaufort-Aquia aquifer were not reported in this area, substantial pumpage from the overlying Castle Hayne aquifer had caused the upward movement of water such that the potentiometric surface of the aquifer was lowered (Giese and others, 1997). Elsewhere in North Carolina, water levels changed very little because of negligible pumpage. Approximately 0.1 Mgal/d of ground water was withdrawn from the aquifer throughout the state during 1980 (Giese and others, 1997).

Between 1980 and 2000, water levels changed little in the Beaufort-Aquia aquifer in North Carolina, Delaware, and New Jersey; however, heads continued to decline along the Chesapeake Bay in Maryland and in the area of James City County, Va. (fig. 15). Water-level decline during this period was greatest in Maryland; levels across much of the aquifer in the southern part of the state had declined by at least 20 ft. In St. Mary's and Calvert Counties, water levels declined from 40 to 60 ft; in the eastern parts of both counties and along the Chesapeake Bay, declines from 1980 levels of greater than 90 ft were observed at the major pumping centers. Similar results were reported by Curtin and others (2002b). From 1980 to 2000, ground-water withdrawals from the Beaufort-Aquia aquifer in Maryland increased from about 6 to 11 Mgal/d (unpublished data on file at the USGS Maryland WSC); at the major pumping centers in eastern St. Mary's and Calvert Counties, withdrawal amounts doubled to more than 4 Mgal/d. Declines of more than 50 ft occurred in western St. Mary's County at other withdrawal centers. Water-level declines of 20 to 40 ft had further propagated into the eastern part of Charles County. Along the eastern shore of the Chesapeake Bay near

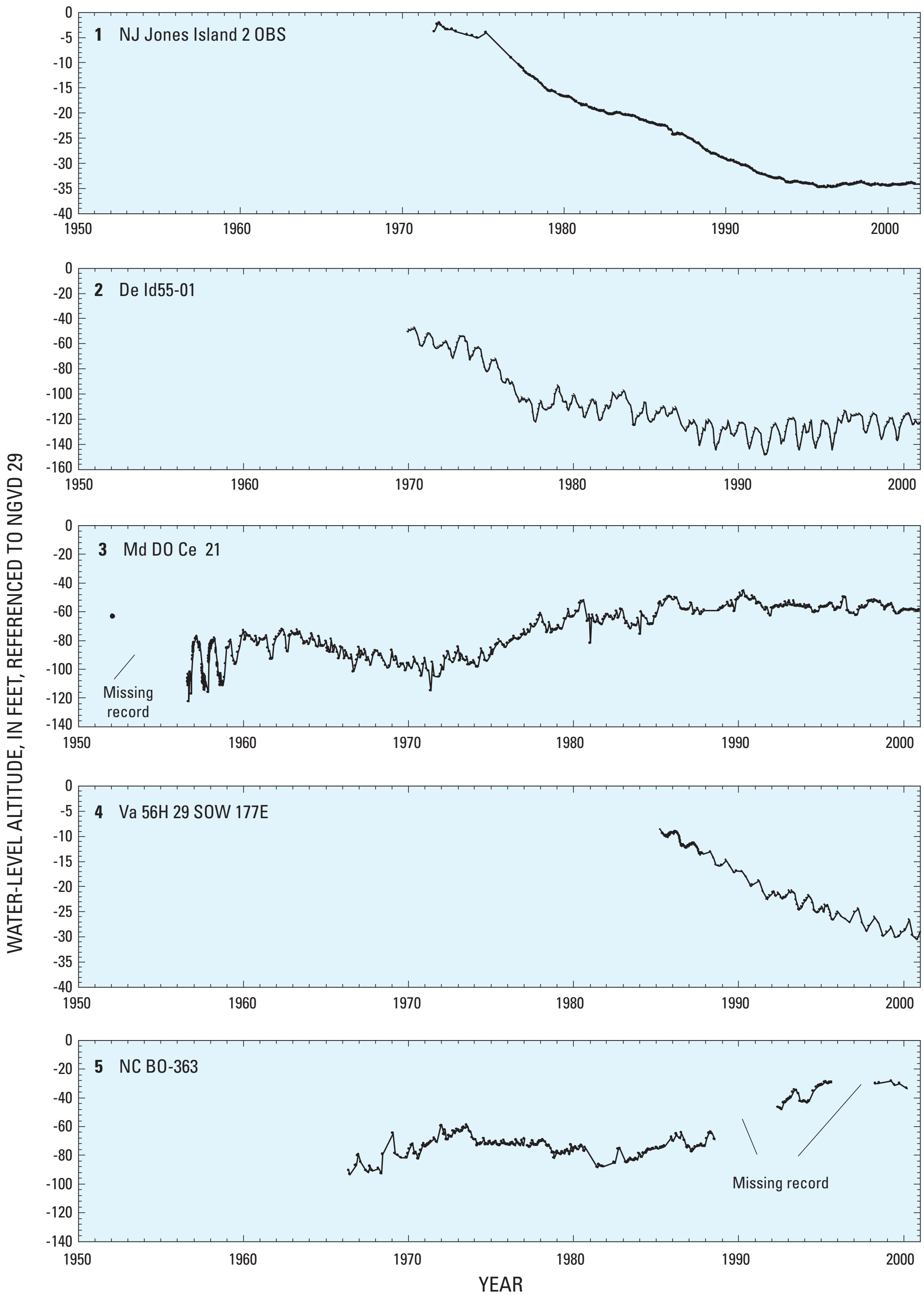
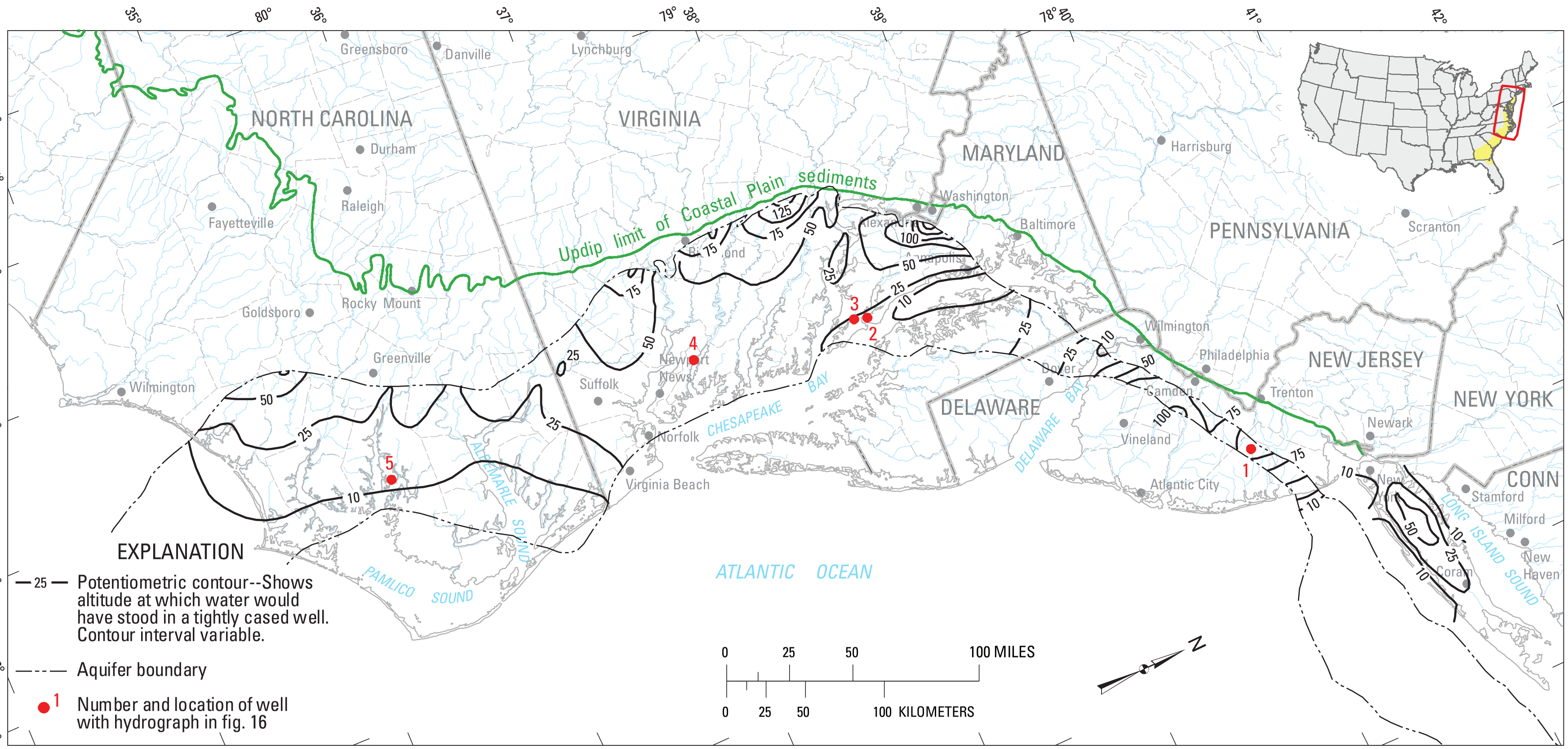


Figure 12. Selected hydrographs from wells screened in the Castle Hayne-Piney Point aquifer. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 9.)



Base from U.S. Geological Survey digital data, 1972,
1:2,000,000 Albers Equal-Area Conic projection
Standard parallels 29°30'N and 45°30'N, central
meridian 96°00'W

Contours modified from Leahy and Martin, 1993

Figure 13. Simulated potentiometric surface of the Beaufort-Aquia aquifer, prior to development.

the downdip limit of the aquifer in Talbot County, water-level declines of as much as 60 ft were observed. Hydrographs of wells CA Gd 6 and SM Df 71 illustrate the magnitude of the decline in water levels in Calvert and St. Mary's Counties (fig. 16). The hydrograph for well SM Df 71, located in St. Mary's County, shows a water-level decline of about 80 ft between 1980 and 2000; while water levels in well CA Gd 6, located in Calvert County, declined about 94 ft during this same period.

Between 1980 and 2000, small local changes in water levels in the Beaufort-Aquia aquifer in New Jersey occurred along the border of northern Ocean and southern Monmouth Counties. Water levels declined from 10 to 20 ft along the downdip limit of the aquifer because of an increase in pumpage. In central New Jersey, water levels remained virtually unchanged between 1980 and 2000. The aquifer in this area is confined across a narrow band, is less than 40 ft thick, and is used very little (Zapecza, 1989). In New Jersey, estimated withdrawals from the aquifer were approximately 1.2 Mgal/d in both 1980 and 2000. There was virtually no pumpage in either 1980 or 2000 from the aquifer in Camden County, and in Ocean County, withdrawals decreased from 0.6 Mgal/d in 1980 to 0.3 Mgal/d in 2000. The hydrograph for Colliers Mills 2 observation well, in Ocean County, showed little change in water level from 1980 to 2000 (fig 16).

In North Carolina, little change was observed in water levels between 1980 and 2000, except for a small area in Beaufort County where water levels recovered 10 ft. The hydrograph for well BO-392 (5), located near here, substantiates this recovery; water levels rose about 12 ft between 1980 and 2000. Although pumpage during 2000 from the local Beaufort aquifer in North Carolina was not known, it was assumed that the change in withdrawals from the aquifer was negligible. Because the Beaufort aquifer is hydraulically connected to the overlying Castle Hayne aquifer in many places because of the discontinuous nature of the overlying confining unit (Lautier, 2001), stabilization and recovery of water levels within the aquifer were probably the result of reduced withdrawals in the local Castle Hayne aquifer.

In Virginia, limited water-level data indicate declines of up to 50 ft in the Beaufort-Aquia aquifer in the area of the York-James Peninsula. Water levels in well 57G 2 SOW 003 declined about 20 ft between 1980 and 1995 (fig. 16).

Peedee-Severn Aquifer

The Peedee-Severn aquifer is the uppermost regional aquifer of Cretaceous age in the Northern Atlantic Coastal Plain. This aquifer includes the local Peedee aquifer in North Carolina, the Severn aquifer in Maryland and Delaware, and the Wenonah-Mount Laurel aquifer in New Jersey, all consisting of Upper Cretaceous sands (table 1). The regional Peedee-Severn aquifer is not laterally continuous through Virginia, where equivalent formations function as confining units.

In New Jersey, predevelopment flow was from a potentiometric high in the northern part of the Coastal Plain to the north and east toward the Atlantic Ocean. In the southern part of the state, flow emanated from a second potentiometric high to the southeast toward the Atlantic Ocean and to the southwest toward the Delaware Bay (fig. 17).

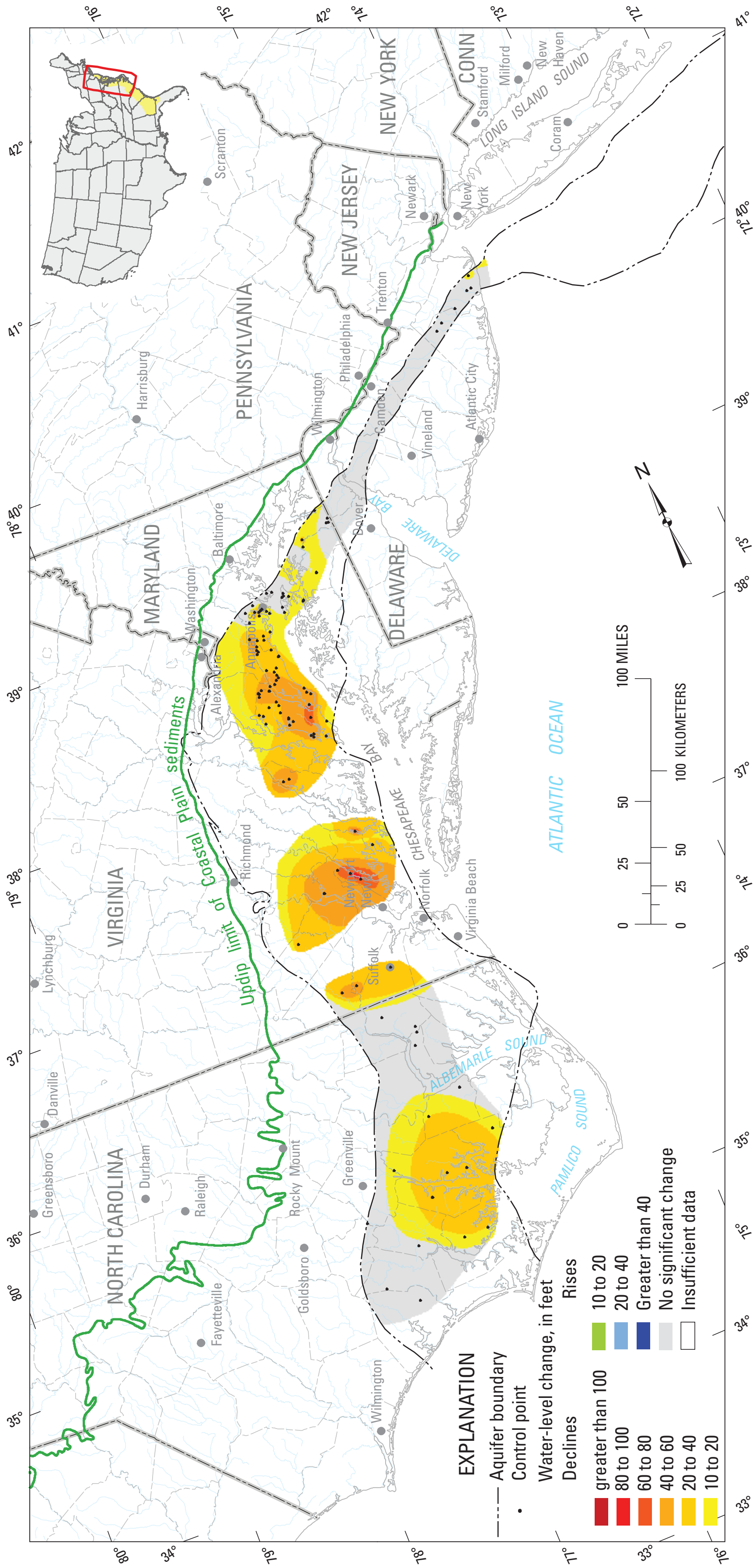
Flow in the aquifer underlying the Delmarva Peninsula was to both the Chesapeake Bay and the Atlantic Ocean. In North Carolina, ground-water flow was primarily from the potentiometric highs at the updip margins of the aquifer southeastward toward the Atlantic Ocean. Prepumping groundwater levels were highest in North Carolina and New Jersey along the updip limit of the aquifer coincident with topographic highs in these areas.

By 1980, a steep cone of depression had formed along the coast of New Jersey in southeastern Monmouth County (Walker, 1983; Leahy and Martin, 1993). Lowest observed heads in the aquifer at this time were 190 ft below NGVD 29 near the center of this cone. Two lesser cones of depression also had formed in New Jersey in Burlington and Salem Counties where small municipal suppliers were withdrawing from the local Wenonah-Mount Laurel aquifer. A second, regionally extensive area of depressed potentiometric head also had developed in the aquifer in east-central North Carolina (Leahy and Martin, 1993).

Water-level declines from prepumping flow conditions were greatest in New Jersey, those of 20 ft or greater extended throughout a large part (nearly 60 percent) of the aquifer's extent (fig.18). Near the major cone of depression in coastal Monmouth County, average decline across the aquifer was in excess of 125 ft, with a maximum decline at the center of 240 ft. The Peedee-Severn was the least utilized aquifer in 1980 among those that comprise the Northern Atlantic Coastal Plain; total withdrawals were estimated at only 8.7 Mgal/d for the entire aquifer (Leahy and Martin, 1993). Greater than one-half of all pumpage occurred in New Jersey, but less than 1 Mgal/d was withdrawn from coastal Monmouth County, within the area encompassed by the regional cone of depression. This amount of pumpage alone was not enough to cause such declines. The relatively low transmissivity of the aquifer in this area coupled with large withdrawals from the underlying Black Creek-Matawan aquifer contributed to the large declines. Most of the aquifer extent elsewhere in New Jersey, except for the extreme updip part, experienced declines in excess of 10 ft (fig. 18).

In Maryland and Delaware, 1980 data for comparison with prepumping levels were scarce; data were limited to wells near the updip limit of the aquifer where change in water levels was minor. Leahy and Martin (1993) estimate that less than 1 Mgal/d was withdrawn from Maryland and Delaware combined. Because withdrawals were primarily from the updip part of the aquifer, major changes in water levels within the downdip areas were unlikely.

In North Carolina, the maximum water-level declines from prepumping levels to 1980 were in Onslow County. Declines of at least 20 ft encompassed an area of approxi-



Base from U.S. Geological Survey digital data, 1972,
1:2,000,000 Albers Equal-Area Conic projection
Standard parallels 29°30'N and 45°30'N, central
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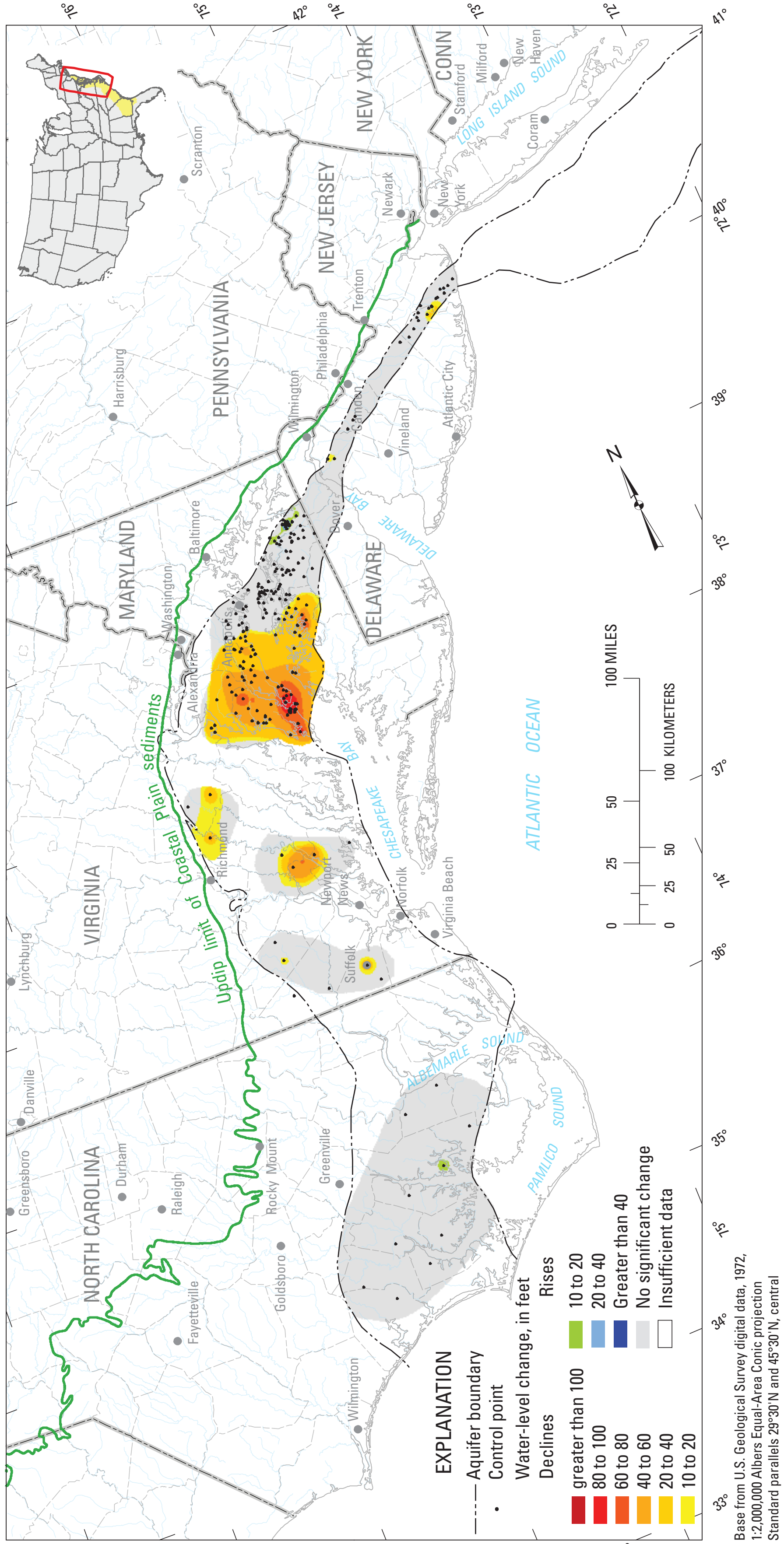
Figure 14. Estimated water-level changes in the Beaufort-Aquia aquifer, predevelopment to circa 1980.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection
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Figure 15. Estimated water-level changes in the Beaufort Aquia aquifer, circa 1980 to 2000.

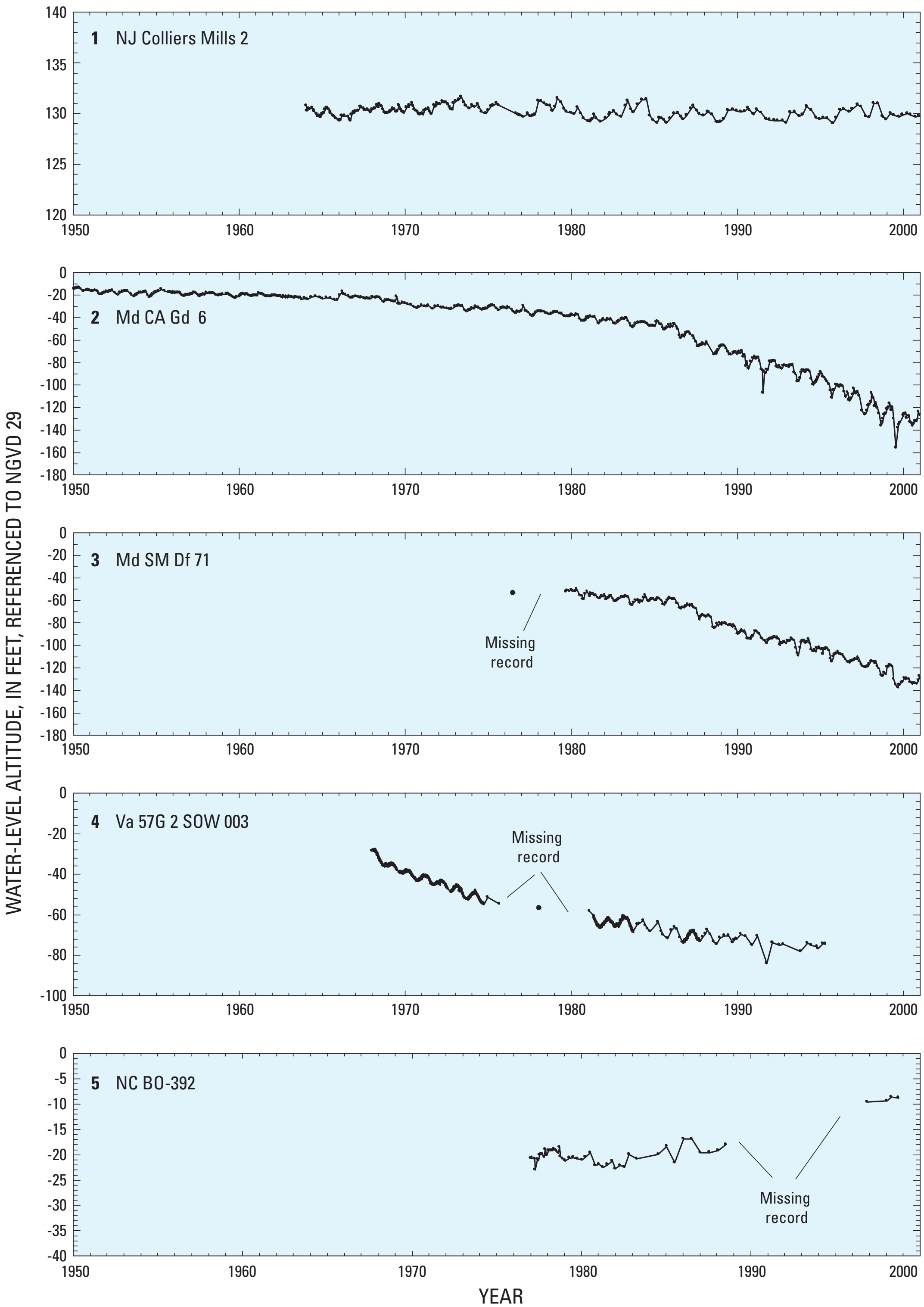
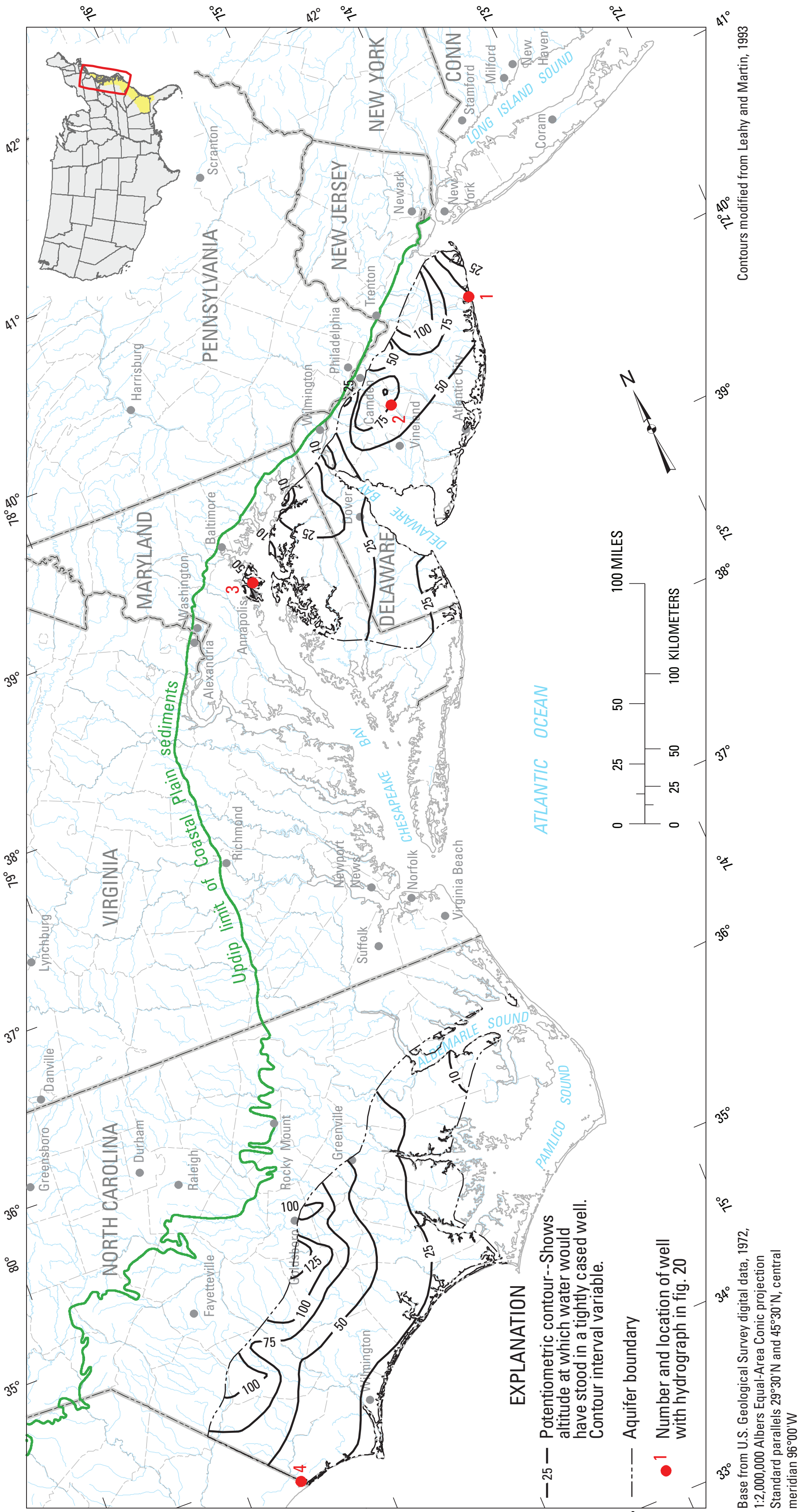


Figure 16. Selected hydrographs from wells screened in the Beaufort-Aquia aquifer. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 13.)



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Contours modified from Leahy and Martin, 1993

Figure 17. Simulated potentiometric surface of the Peedee-Severn aquifer, prior to development.

mately 140 mi^2, extending from the west-central part of the county north to the border with Jones County. Maximum observed decline near the center of this area was in excess of 100 ft. Declines in excess of 80 ft in the Peedee-Severn aquifer from prepumping levels to 1986 for this area were reported by Lyke and Brockman (1990). The minor difference in the magnitude of decline was probably the result of comparison of post-development water levels with slightly differing prepumping potentiometric surfaces. Elsewhere in North Carolina, moderately depressed heads were observed in Lenoir County as well as in northern Brunswick County, where water levels in both areas generally declined from 10 to 20 ft. Withdrawals from the Peedee-Severn aquifer in North Carolina at this time were estimated at approximately 3.4 Mgal/d (Leahy and Martin, 1993; Giese and others, 1997). Greater than one-half of water withdrawn from the aquifer was attributable to a large pumping center in northwestern Onslow County; however, decline was tempered by the relatively high transmissivity in this area. Unlike the northern extent of the aquifer where the transmissivity is typically less than 1,000 ft^2/d, transmissivity values in coastal North Carolina range from 5,000 to 10,000 ft^2/d.

By 2000, there were notable differences in the configuration of the water-level-change surface, particularly in New Jersey (fig. 19). Estimated withdrawals from the Peedee-Severn aquifer in New Jersey had increased from 4.5 to more than 7 Mgal/d (unpublished data on file at the USGS New Jersey WSC). Yet, within the area encompassed by the large cone of depression in 1980, water levels were observed to rise, on average, 45 ft and near the center of the cone, up to 107 ft. These changes were brought about by a shift in water-use patterns in this area. In 1989, the New Jersey Department of Environmental Protection (NJDEP) mandated reductions in withdrawals from the Peedee-Severn and deeper aquifers in this area in response to the large-scale withdrawals of ground water and steeply declining heads. Upon completion of the Manasquan Reservoir in 1991, ground-water withdrawals from confined Coastal Plain aquifers in this area were reduced and replaced with surface-water withdrawals and, to a lesser extent, with withdrawals from shallower, unconfined aquifers (Watt, 2000). Although this area experienced a large increase in population from 1980 to 2000, ground-water withdrawals from the confined Cretaceous-age aquifers in this area decreased from 32 to 14 Mgal/d or 53 percent. Consequently, fresh surface-water withdrawals increased by nearly 11 Mgal/d, or 34 percent. Additionally, ground-water withdrawals from the Peedee-Severn aquifer in this region decreased from 1.3 to 0.3 Mgal/d.

While withdrawals in the Peedee-Severn decreased in the aquifer's northern New Jersey extent, ground-water withdrawals in the southern counties (Burlington, Camden, Gloucester) increased from 2.8 Mgal/d in 1980 to 7 Mgal/d by 2000. As a result, an elongated cone of depression underlying the counties of Burlington, Camden, and Gloucester had formed (Rosman and others, 1996; Lacombe and Rosman, 2001). At the northern and southern limbs of this cone, ground-water levels had generally declined from 10 to 20 ft. At the cone's center, water levels stood at -81 ft NGVD 29 in 1998; 1980 water levels in this area were at least 40 ft NGVD 29 and indicate total decline in excess of 120 ft. Data were limited in Delaware and Maryland, however, and no substantial changes were observed.

In North Carolina, changes in water levels were much more subdued than those in the north. An area of decline of moderate size not previously identified was evident in southern Columbus and Brunswick Counties near the border with South Carolina. A recent estimate indicates that nearly 1 Mgal/d of water for municipal use is withdrawn from the aquifer in Columbus County (North Carolina Department of Water Resources, 2004a). No large withdrawals of ground water were reported for Brunswick County, and declining heads here were indicative of large-scale pumping from the Black Creek-Matawan aquifer in South Carolina (Harden and others, 2003). In both Onslow and Lenoir Counties, ground-water declines had moderated, although declines of 20 ft were still observed in Onslow. In addition, water level declines of approximately 1.4 ft/yr since 1980 were recorded near the Jones/Onslow County border (Lautier, 2001). However, these areas were not contiguous and did not represent a broader, regional trend.

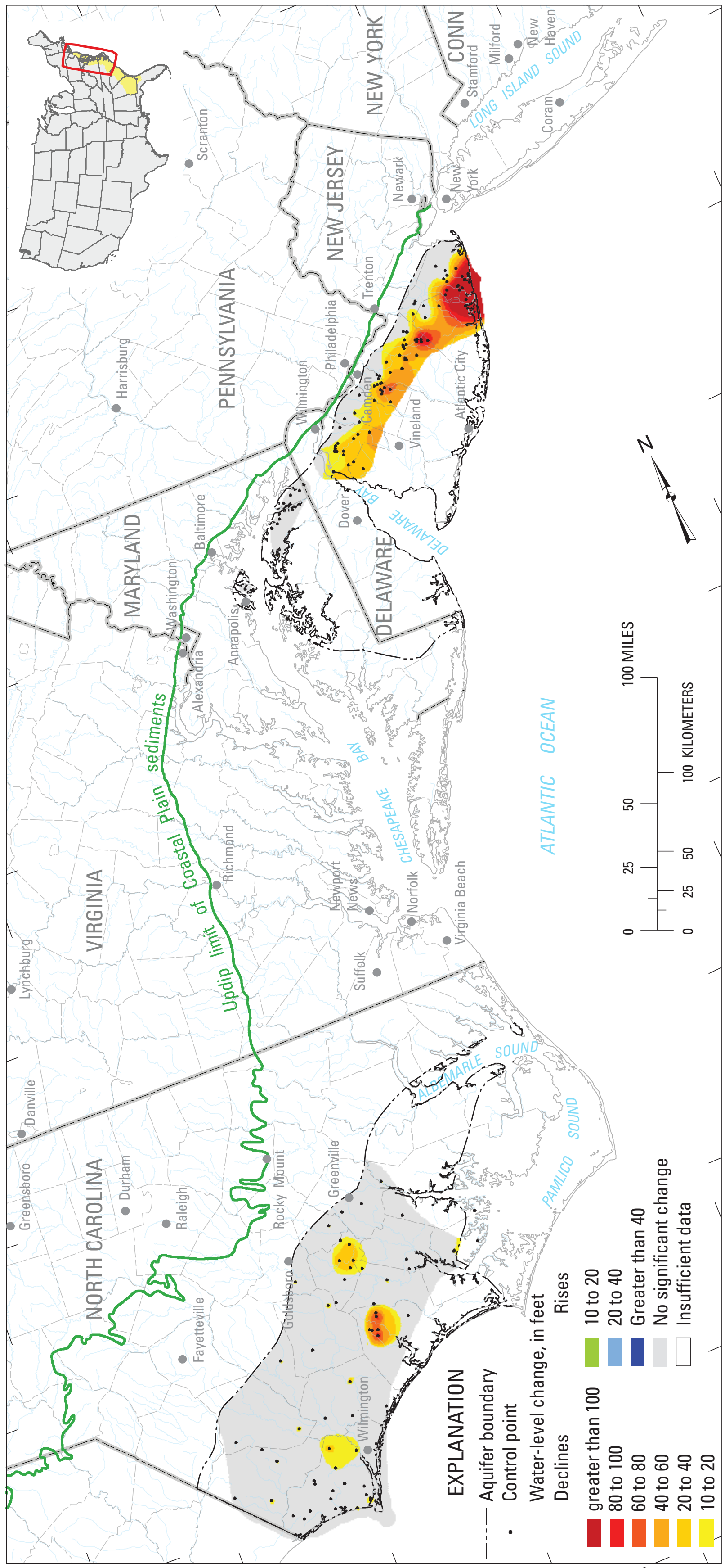
Selected hydrographs for wells open to the Peedee-Severn aquifer are shown in figure 20, locations are indicated in figure 17. The hydrograph of the Sea Girt observation well (1), located on the Atlantic Coast of New Jersey near the center of the major cone of depression (fig. 20), shows that water levels in this vicinity were well below 0 ft NGVD 29, at -180 ft, during the mid 1980s. Owing to imposed restrictions of ground-water allocations, water levels began to recover at a rapid rate. From 1990 to 1994, the water level in the Sea Girt observation well recovered 90 ft, to approximately 90 ft below NGVD 29. Levels rose an additional 30 ft through 2000.

Water levels in the New Brooklyn 3 observation well, located near the center of the cone of depression in southern New Jersey (fig. 20), were stable to slightly falling from 1960 through 1984. Steadily diminishing heads since 1985 resulted from the increased pumping of the aquifer in this area. Total decline subsequent to 1985 was in excess of 70 ft.

The hydrograph of well AA Cf 98 near Annapolis, Md., indicates that, although water levels fluctuated slightly, they were virtually unchanged from 1969 to 2000. The hydrograph of Calabash well Br-118 in North Carolina indicates a steady decline in water levels from 1973 to 1986. Thereafter, water levels varied considerably, suggesting nearby pumping had caused fluctuations as great as 25 ft annually. The water-level altitude through 2000 was at 20 ft below NGVD 29, and total cumulative decline was 45 ft.

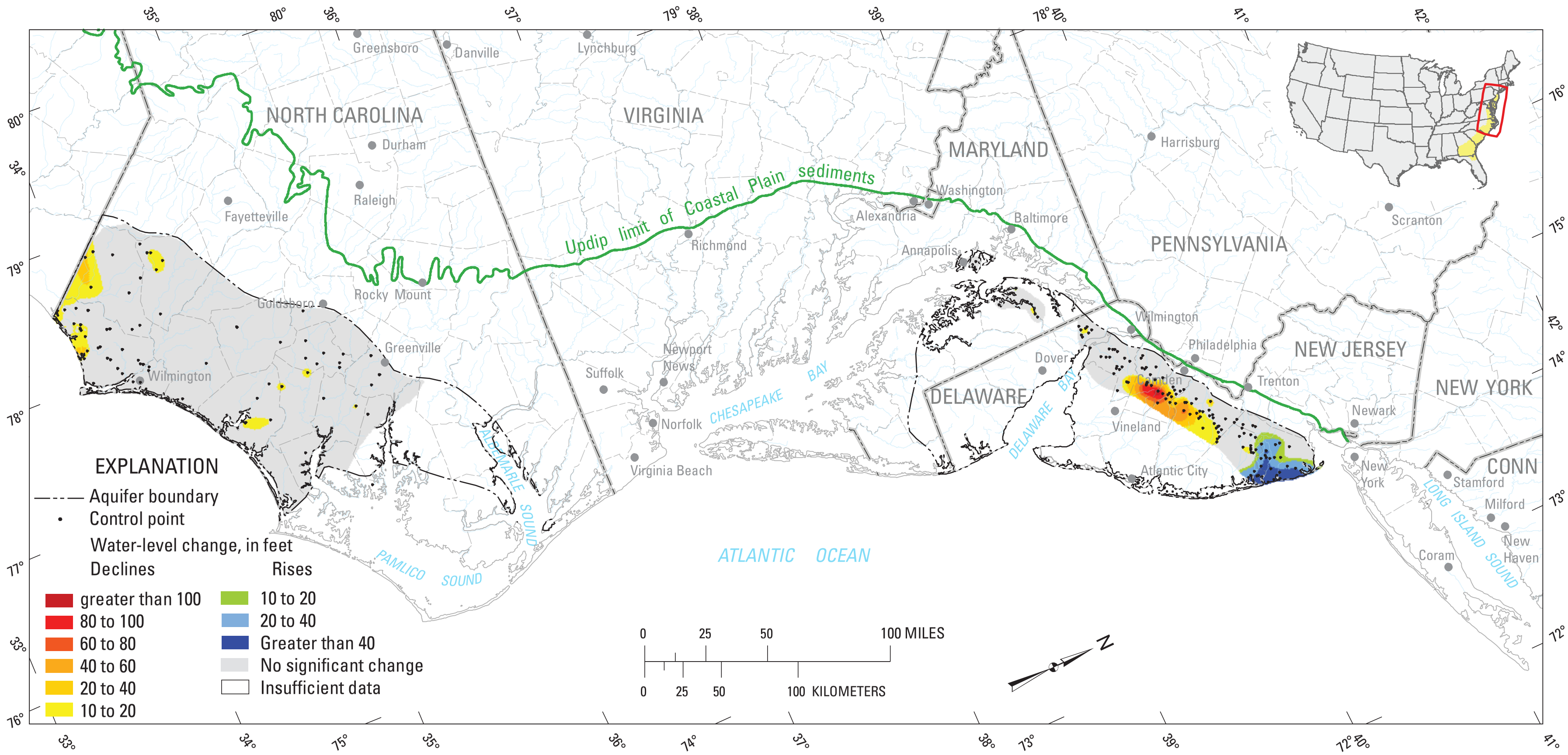
Black Creek-Matawan Aquifer

The Black Creek-Matawan aquifer includes the local Black Creek aquifer of North Carolina, the Matawan aquifer



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30′N and 45°30′N, central meridian 96°00′W

Figure 18. Estimated water-level changes in the Peedee-Severn aquifer, predevelopment to circa 1980.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 19. Estimated water-level changes in the Peedee-Severn aquifer, circa 1980 to 2000.

of Maryland and Delaware, and the Englishtown aquifer system in New Jersey, all consisting of Upper Cretaceous sands (table 1). The regional Black Creek-Matawan aquifer is not laterally continuous through Virginia where equivalent formations function as confining units. This unit is mainly present in New Jersey and North Carolina; although the aquifer also is recognized in part of the northern Delmarva Peninsula, it is thin or missing in most places. In addition, water-level data were not available for this part of the aquifer for any time period.

The prepumping potentiometric-surface map for the Black Creek-Matawan aquifer indicates that, in New Jersey, flow originated from potentiometric highs near the updip boundary of the aquifer (fig. 21). Ground water flowed to the north and east toward the Atlantic Ocean, to the southeast toward the Atlantic, and to the southwest toward the Delaware Bay. In North Carolina, flow was predominantly eastward from potentiometric highs in the south-central part of the state toward the Cape Fear area and the Pamlico and Albemarle Sounds.

By 1980, the potentiometric surface of the Black Creek-Matawan aquifer was dominated by large regional cones of depression in east-central New Jersey and North Carolina (Walker, 1983; Leahy and Martin, 1993; Winner and Coble, 1996; Giese and others, 1997). The prominent cone of depression underlying the coastal region of New Jersey in Monmouth and northern Ocean Counties in the subregional Englishtown aquifer system had previously been well documented; a 1959 piezometric map by Jablonski (1968) showed heads in this area in excess of 80 ft below NGVD 29. By 1980, this cone had expanded and deepened, and water levels had declined to 249 ft below NGVD 29 near its center. The natural hydraulic gradients in the aquifer were now reversed such that water, formerly discharging upward through the top of the aquifer in the nearshore and offshore areas, now flowed from an offshore direction toward the center of the cone of depression (Martin, 1998). Withdrawals from the aquifer had induced leakage from the overlying units, and although heads were substantially lower in the Black Creek-Matawan, the location and configuration of this cone was similar to that in the overlying Peedee-Severn aquifer.

In the central part of the Coastal Plain in North Carolina, another extensive cone of depression had formed near the border of Craven and Lenoir Counties; water-level altitudes here had declined to 62 ft below NGVD 29.

From 1900 to 1980, water levels across the aquifer had fallen but declines were greatest in New Jersey. Declines in the coastal region within the cone of depression averaged 165 ft; the maximum decline was 289 ft (fig. 22). Declines in the aquifer in this area have been well documented. Nichols (1977) reports declines from 1900 to 1959 in excess of 100 ft near the border of Monmouth and Ocean Counties; from 1959 to 1970, ground-water levels in this vicinity fell by an additional 120 ft.

As of 1980, the Black Creek-Matawan aquifer was an important source of water in North Carolina but was considered a minor source of supply in New Jersey. Ground-water withdrawals were estimated at 10 Mgal/d in New Jersey during 1980 (Martin, 1998), but nearly 75 percent of all pumpage occurred in a narrow band straddling the border of Monmouth and Ocean Counties from the coast and extending to about 10 mi inland. The relatively low transmissivity of the aquifer, ranging from 500 to 1,000 ft^2/d, contributed to the low heads and steep declines in this area. Away from this area and to the south, scattered pumping centers with minor withdrawals resulted in more modest water-level declines in the aquifer. Water levels in southern New Jersey declined from 10 to 20 ft across much of the downdip part of the aquifer; the maximum decline in this region was approximately 50 ft near a pumping center in Burlington County.

By contrast, the estimated transmissivity values were much higher in North Carolina, ranging from 1,000 to 10,000 ft^2/d, and as a result, the magnitude of decline near pumping centers in North Carolina was less than that in New Jersey. In the central Coastal Plain section of the North Carolina, a large area of decline had encompassed most of Craven, Jones, Lenoir and Pitt Counties; water levels in the aquifer had declined, on average, approximately 40 ft. Near Kinston, in Lenoir County, water-level decline was generally 100 ft from prepumping levels; the maximum water-level decline, 115 ft, was observed near the center of the cone of depression. Winner and Lyke (1986) also compared prepumping levels in the Black Creek-Matawan and Upper Potomac aquifers with 1979-81 water-level measurements in this area. Similarly, they reported declines of 100 ft near major pumping centers in the central Coastal Plain; however, the maximum observed decline near Kinston was greater, at nearly 150 ft. This area has historically relied on the local Black Creek aquifer for supply because of the high quality of water and low cost of treatment (Lautier, 2001); withdrawals in this area from the local Black Creek aquifer were approximately 17 Mgal/d, nearly one half of all pumpage from the aquifer within the state. Farther south, water levels declined from 20 to 25 ft near pumping centers in Duplin and Pender Counties. Declines of up to 25 ft in southern Brunswick and Columbus Counties were likely associated with declines in the local Black Creek aquifer in northern Horry County, S.C. Estimated ground-water withdrawals from the Black Creek-Matawan aquifer throughout its extent in North Carolina at this time were approximately 35 Mgal/d (Leahy and Martin, 1993; Giese and others, 1997).

From 1980 to 2000, substantial recovery in water levels of the Black Creek-Matawan aquifer was observed in the northern extent of the aquifer in coastal New Jersey, similar to that observed for the overlying Peedee-Severn aquifer (fig. 23). Ground-water levels throughout this coastal region had, on average, recovered at a rate of about 3 ft/yr or 60 ft for this period. Near the center of the cone of depression in southeastern Monmouth County, water levels had risen by a maximum of 140 ft. State-mandated restrictions introduced in 1989 reduced withdrawals in the Black Creek-Matawan aquifer in this area by 55 percent.

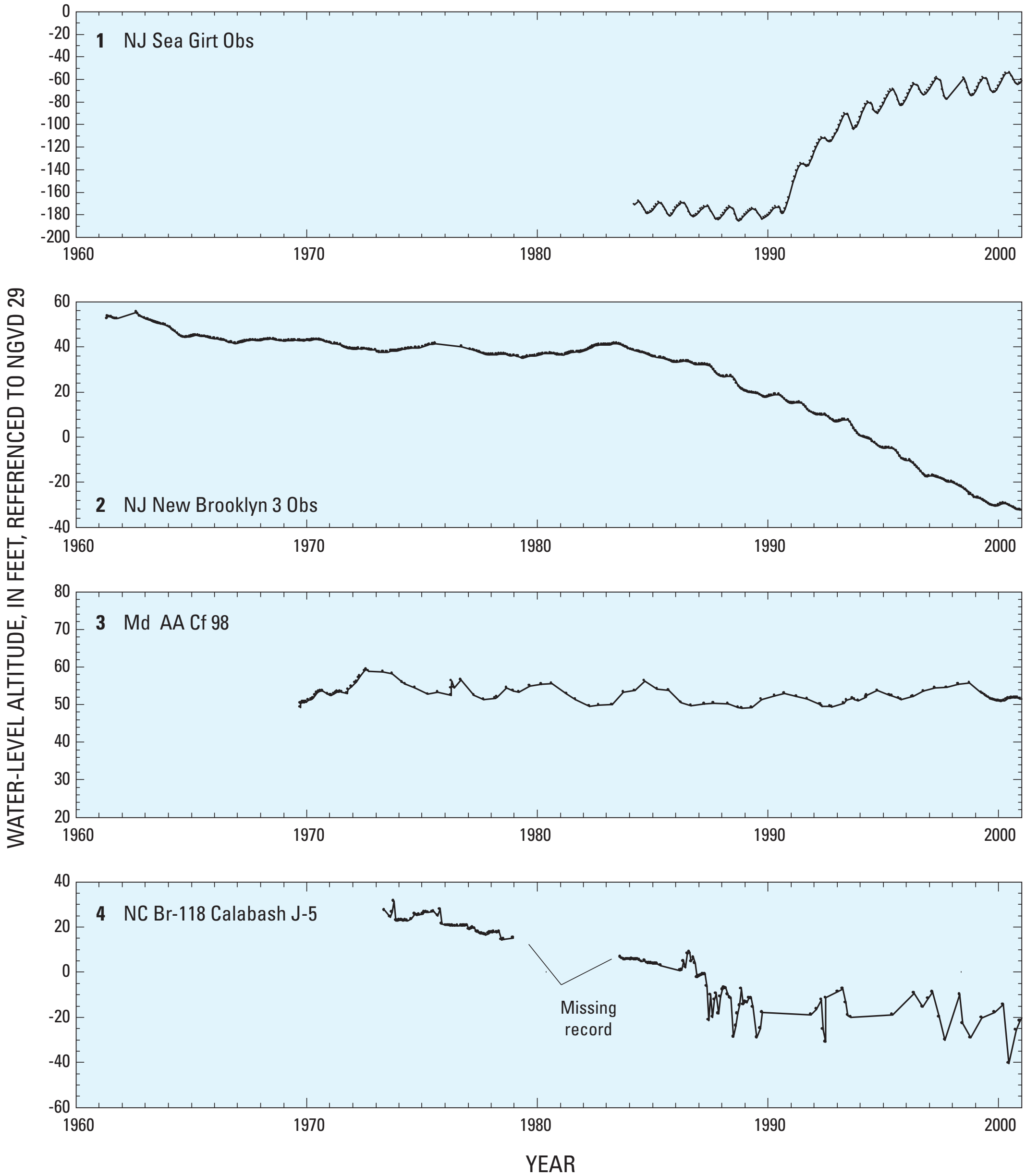


Figure 20. Selected hydrographs from wells screened in the Peedee-Severn aquifer. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 17.)

The major area of decline present in the central part of the Coastal Plain of North Carolina had shifted to the south and was now centered beneath Onslow County. An area characterized by water-level decline of at least 20 ft extended northward from Onslow and had encompassed Jones as well as large parts of Lenoir, Craven, Pitt, Duplin, and Beaufort Counties. A maximum water-level decline of nearly 165 ft from estimated 1980 water levels occurred in central Onslow County. Lautier (2001) estimates an average of nearly 37 ft of decline within the Black-Creek Matawan aquifer in this area from 1980 to 2000; the largest decline of 120 ft occurred in Jones County. Winner and Lyke (1986) noted large increases in pumpage from the Black Creek-Matawan aquifer from 1980 to 1986 in Jones and Onslow Counties; withdrawals tripled to nearly 7 Mgal/d. Previous estimates by Winner and Lyke (1986) and Lyke and Brockman (1990) determined total withdrawals from the Cretaceous aquifers in 1980 to be about 24.5 Mgal/d. Significant increases in withdrawals are evident by the late 1990s; recent estimates by the North Carolina Department of Water Resources (Lautier, 2001) approximate withdrawals from the Cretaceous aquifers in the central Coastal Plain to be 116 Mgal/d.

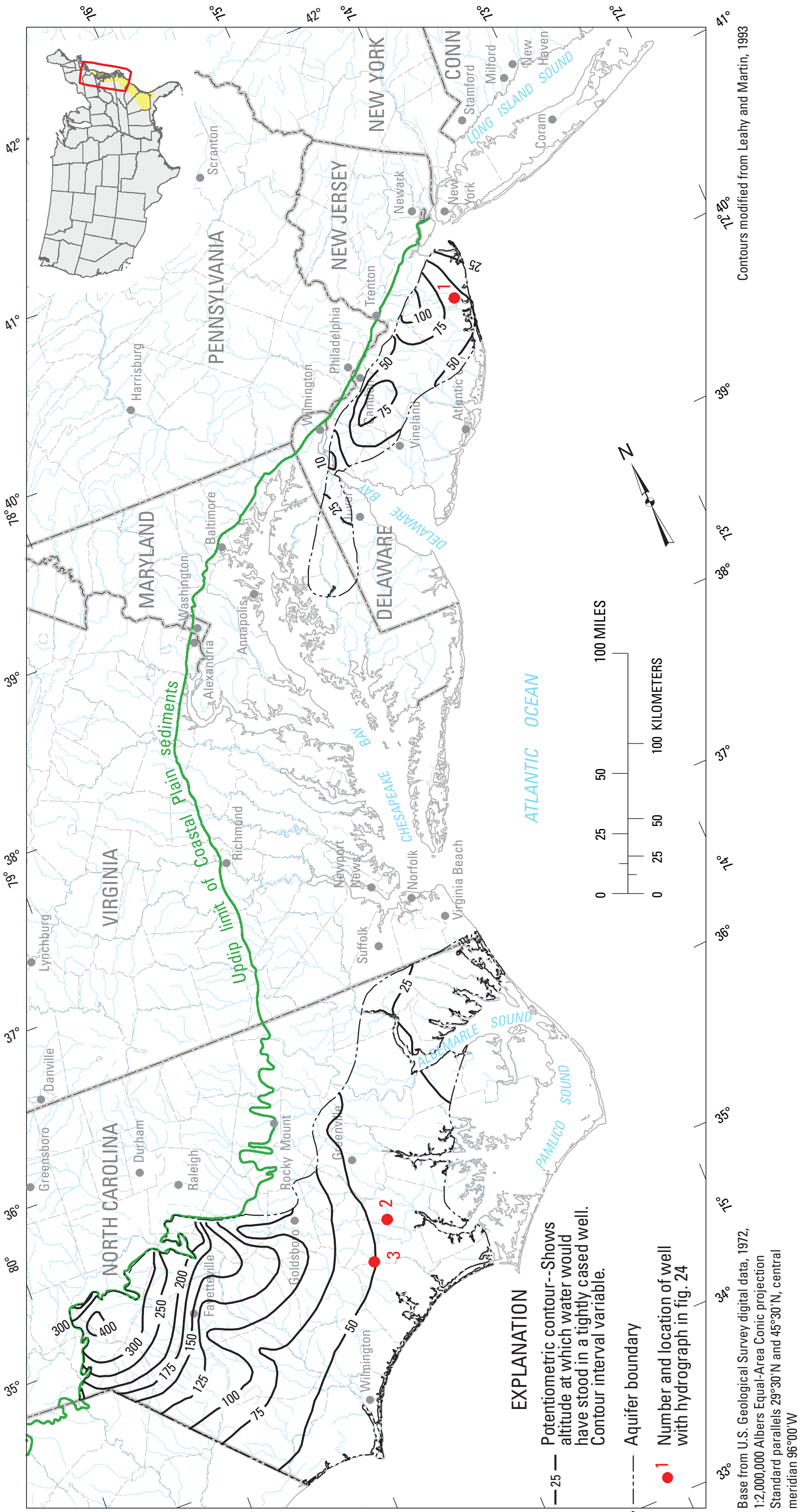


Figure 21. Simulated potentiometric surface of the Black Creek-Matawan aquifer, prior to development

Additional, smaller pockets of declining water levels in North Carolina also were observed in Bladen, Robeson, Hoke, and Scotland Counties, to the southwest. Within this area, the maximum observed decline of 106 ft occurred in central Bladen County. Ground-water withdrawals had increased significantly from 1985 to 2000 in both Bladen and Robeson Counties. The local Black Creek aquifer is the primary source of water for Robeson County; although ground-water use of the aquifer is greater here than in Bladen County, the lower transmissivity and recharge in Bladen County increase the aquifer's sensitivity to lesser withdrawals; therefore causing greater declines. Strickland (2000) also noted areas of declines from 1992 to 1998 in Scotland, Robeson, and Bladen Counties because of increases in pumping from the local Black Creek aquifer. In northwestern Bladen County, water-level data also show a substantial decline from 1980. Strickland (2000) does not represent this area as a cone of depression; rather, this is an area with a steep hydraulic gradient indicating discharge to the Cape Fear River. While Strickland reports a decrease in potentiometric head because of increased withdrawals in the mid-to-late 1990s, declines shown here may be overestimated. Lack of 1980 measurements at wells measured in the late 1990s preclude an exact comparison, and interpreted or simulated heads for 1980 do not capture this feature.

Selected hydrographs for wells open to the Black Creek-Matawan aquifer are shown in figure 24; locations are indicated in figure 21. The hydrograph for the Allaire State Park C observation well, located in east-central New Jersey 6 mi to the north and west of the center of the regional cone of depression in Monmouth and Ocean Counties, shows that water levels in this vicinity were -40 ft NGVD 29 by the mid 1960s (fig. 24). Water levels in this well steadily declined to -140 ft through 1980 where, despite seasonal fluctuations by as much as 20 ft, they exhibited only a slight downward trend during the following decade. Owing to conservation measures introduced in the late 1980s, long-term declines began to reverse, and from 1990 to 1996, the water level in this well rose approximately 100 ft. Subsequent to 1996, water levels in this well had stabilized at -40 ft through 2000.

The continued rapid growth of the cone in the central Coastal Plain of North Carolina is illustrated by the hydrographs from wells CR-615 and JO-033. Wells CR-615, located in Craven County, and JO-033, located to the south in Jones County, lie within the influence of the extensive cone of depression. Water levels declined continually for the duration of record at both sites; periods of prolonged stabilizing levels evident at other sites within the Black Creek-Matawan aquifer in North Carolina were absent here. Water levels in well JO-033, located nearer the major pumping center in Onslow County, declined at an annual rate of nearly 5.5 ft from 1979 to 2000. The net decline observed at this site was approximately 120 ft.

Upper Potomac and Magothy Aquifers

The Upper Potomac and Magothy aquifers include the Magothy aquifer of Maryland, Delaware, and New York and the upper aquifer of the Potomac-Raritan-Magothy aquifer system in New Jersey (table 1). It is essentially identical to the Magothy Formation of Late Cretaceous age, except that on Long Island, N.Y., the aquifer includes beds equivalent to the Matawan and Monmouth Groups and hydraulically connected surficial deposits of Pleistocene sand and gravel. The regional aquifer also includes the upper Cape Fear aquifer of North Carolina and the Upper Potomac aquifer in Virginia. This regional aquifer also includes the local Brightseat aquifer in northern Virginia and southern Maryland.

Simulated prepumping ground-water-flow conditions in the Upper Potomac and Magothy aquifers (Leahy and Martin, 1993) show heads ranging from 300 ft above NGVD 29 at the extreme updip part of aquifer in Moore County, N.C., to less than 10 ft above NGVD 29 near the Raritan Bay (fig. 25). The simulated contours indicate that beneath Long Island ground water flowed from an area of high water-level altitude near the center of the island toward both the north and south shores, discharging to the Long Island Sound and the Atlantic Ocean. In New Jersey, ground water flowed from the outcrop area northeast to the Raritan Bay, east to the Atlantic Ocean, and southwest toward the Delaware River estuary. Ground water from updip areas of Maryland's western shore generally flowed east toward the Chesapeake Bay. In the northern Delmarva Peninsula, flow was from a ground-water divide westward toward the Chesapeake Bay and east toward the Atlantic Ocean. In Virginia, ground-water flow was east toward and beneath the Chesapeake Bay, and in North Carolina, regional flow was generally east and southeast toward the Pamlico Sound and the Atlantic Ocean.

By 1980, prominent cones of depression in the potentiometric surface of the Upper Potomac and Magothy aquifers were centered in New Jersey, Virginia, and North Carolina (Leahy and Martin, 1993). In New Jersey, water levels at or below 0 ft NGVD 29 were observed throughout much of the aquifer extent within the state. Water levels had declined to more than 80 ft below NGVD 29 in the Camden area and to more than 40 ft below NGVD 29 in Monmouth County. Water levels in the Magothy aquifer also had declined significantly in southern Maryland; in parts of Prince Georges and Charles County, heads had declined to more than 30 ft below NGVD 29.

In Virginia, a steep cone of depression had formed in the Franklin area, and shallower cones had appeared in the West Point and Newport News areas. These cones had merged to form an areally extensive cone of depression of greater than 5,000 mi^2 within the Upper Potomac aquifer. Water levels had declined to 143 ft below NGVD 29 at Franklin and to more than 80 ft below NGVD 29 at West Point and Newport News and were below 0 ft NGVD 29 in much of the aquifer extent in Virginia.

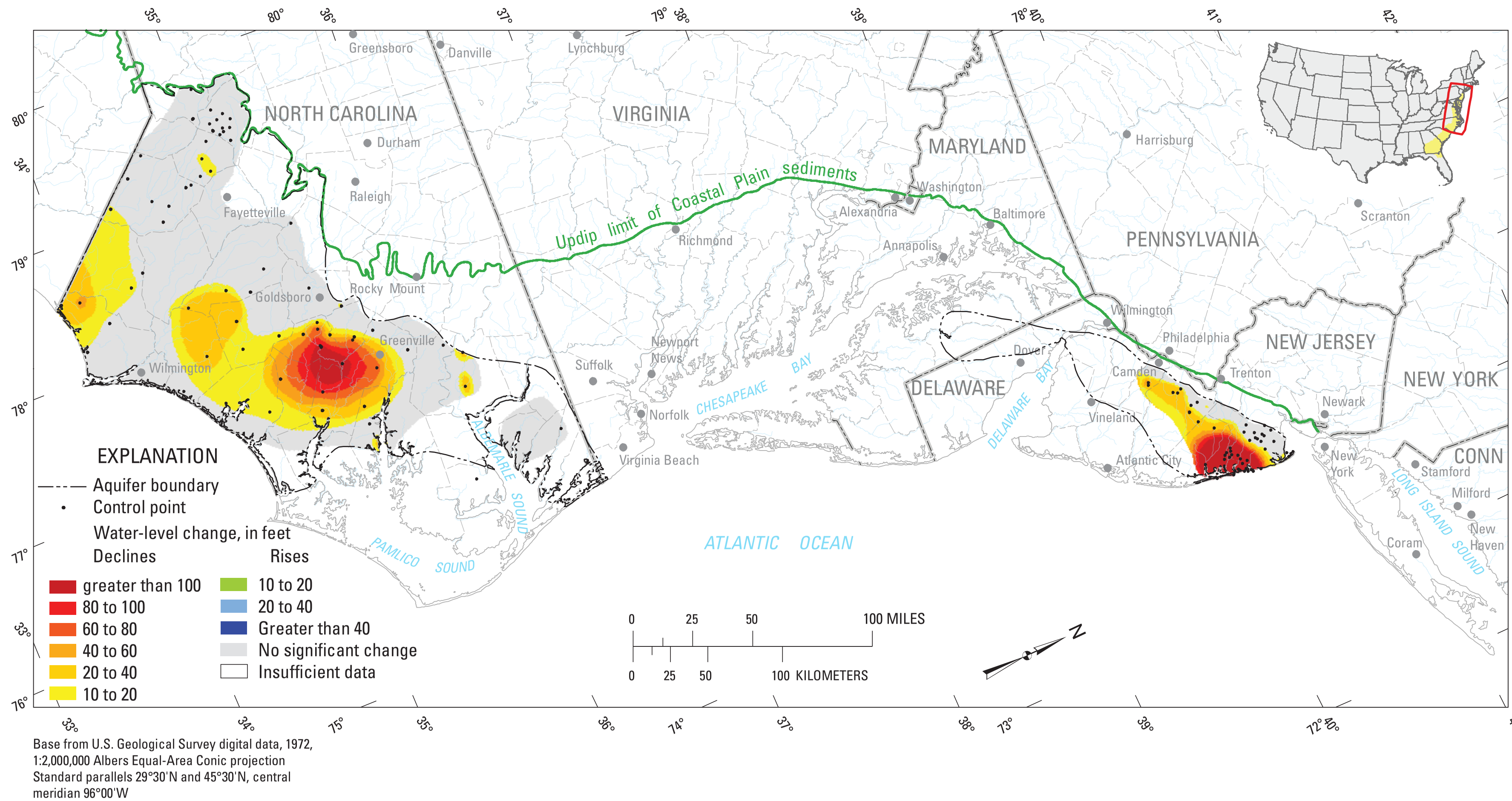
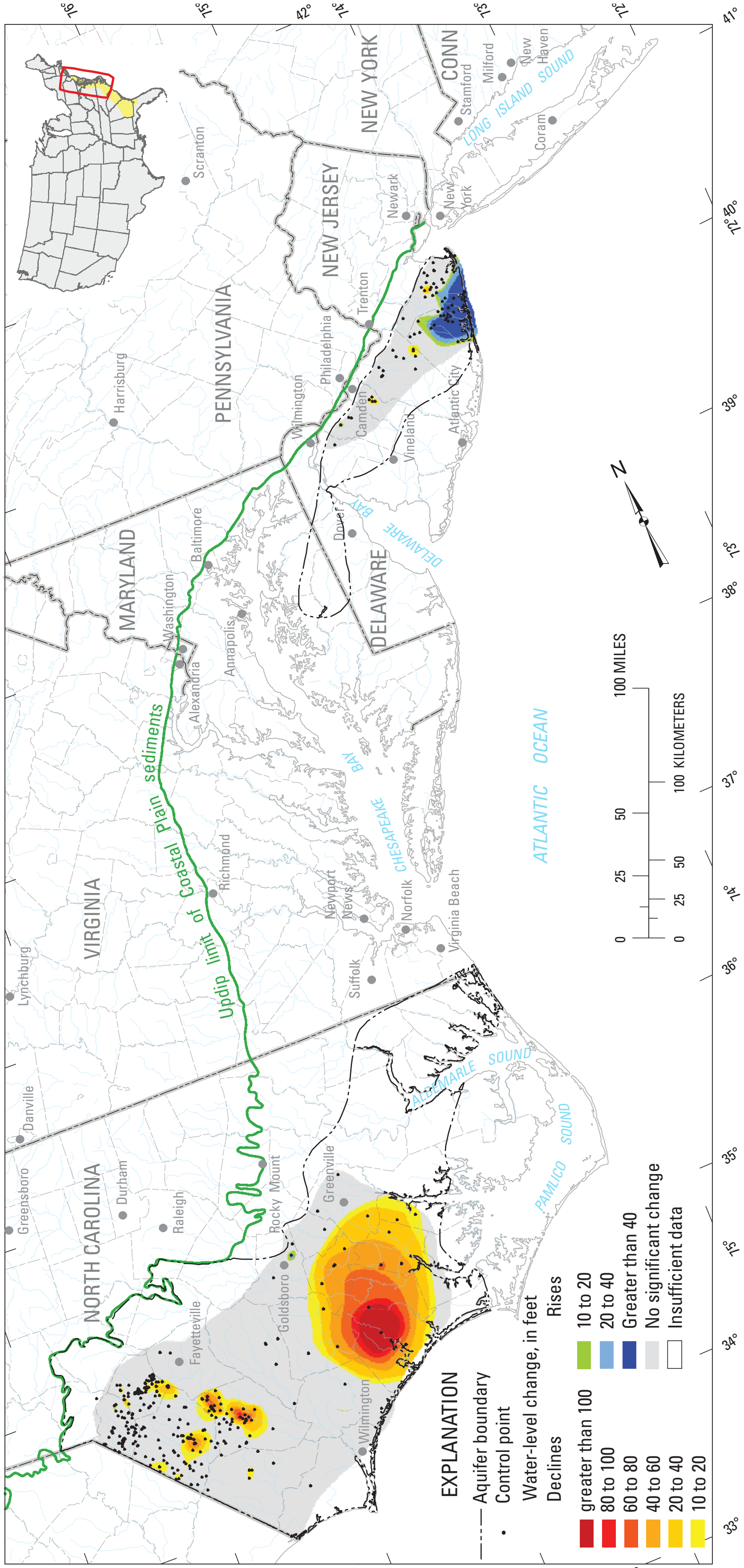


Figure 22. Estimated water-level changes in the Black Creek-Matawan aquifer, predevelopment to circa 1980.



Base from U.S. Geological Survey digital data, 1972,
1:2,000,000 Albers Equal-Area Conic projection
Standard parallels 29°30'N and 45°30'N, central
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Figure 23. Estimated water-level changes in the Black Creek-Matawan aquifer, circa 1980 to 2000.

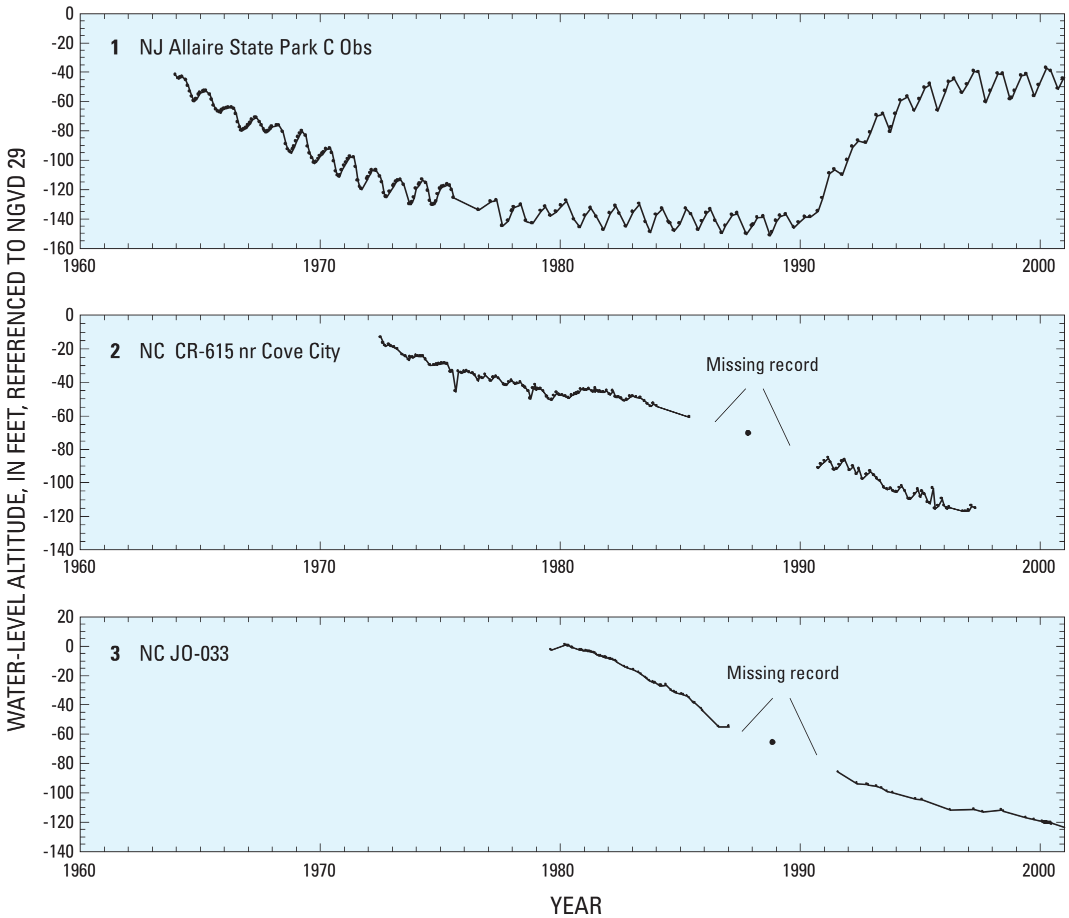
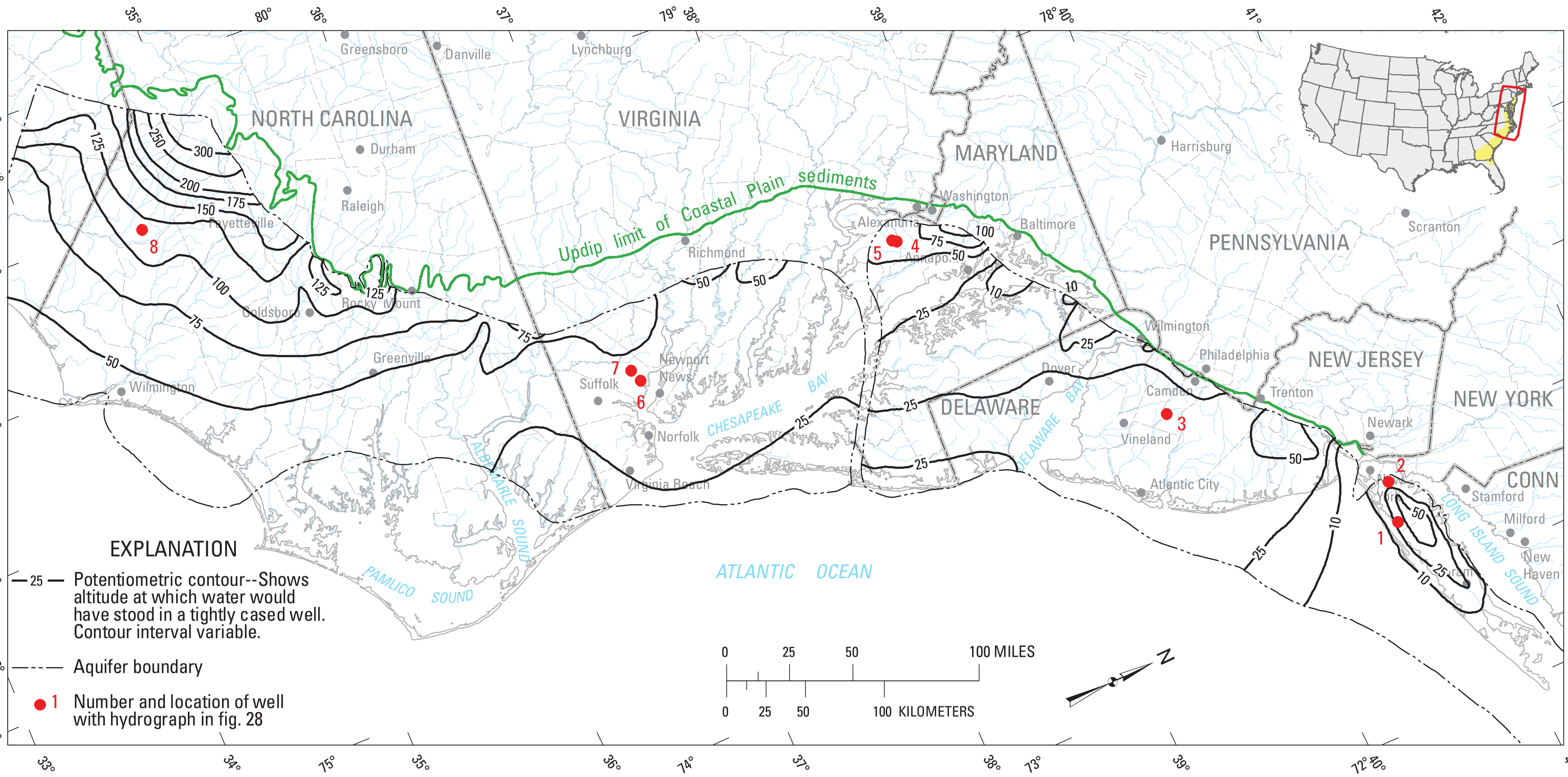


Figure 24. Selected hydrographs from wells screened in the Black Creek-Matawan aquifer. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 21.)

In North Carolina, the dominant feature of the potentiometric surface was a cone of depression centered beneath the city of Kinston in Lenoir County but extending throughout parts of Pitt, Craven, Jones, and eastern Greene Counties (Leahy and Martin, 1993; Giese and others, 1997). By 1980, water-level altitudes had declined to 60 and 42 ft below NGVD 29 in Pitt and Lenoir Counties, respectively. In the southeastern part of the state, declining water levels were evident by the updip shifting of potentiometric contours in Brunswick, Columbus, western Bladen, and eastern Robeson Counties (Giese and others, 1997).

Increasing reliance on the Upper Potomac aquifer as a source of water caused substantial water-level declines over a large percentage of the aquifer's extent by 1980 (fig. 26). Approximately 45 percent of the aquifer extent had undergone declines in excess of 20 ft; and declines of 50 ft or greater occurred across nearly 30 percent of the aquifer. Water-level decline in the Upper Potomac generally was greatest in Virginia and least on Long Island, N.Y. Declining water levels were also widespread in New Jersey, North Carolina, and, to a lesser extent, southern Maryland.

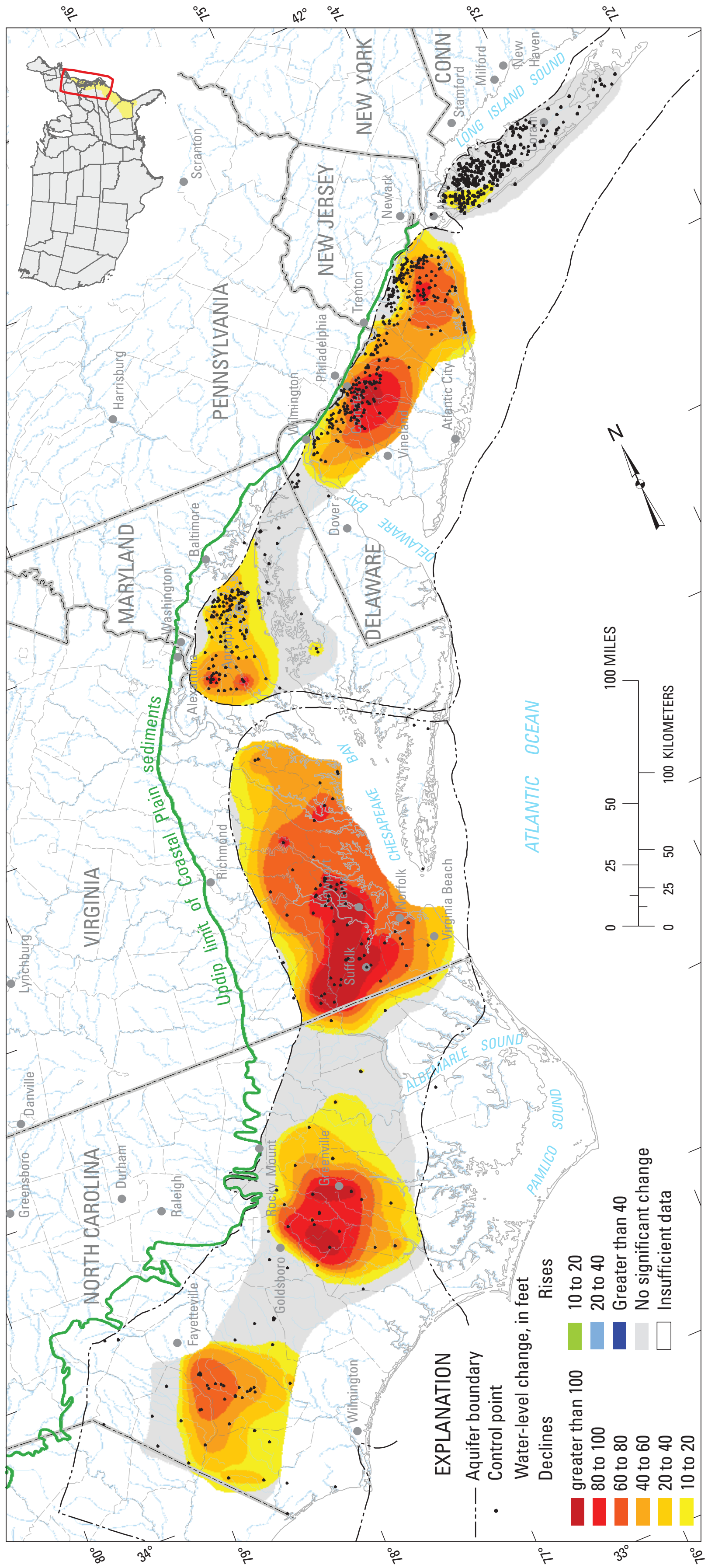
In Virginia, ground-water levels declined at least 40 ft from prepumping levels throughout much of the aquifer's extent. The largest changes occurred in the south-central part of the Coastal Plain from Williamsburg south to the city of Franklin, where water levels typically declined more than 100 ft from prepumping flow conditions. Ground-water withdrawals from the Upper Potomac aquifer in Virginia during 1980 were estimated at 17 Mgal/d (Leahy and Martin, 1993). The largest withdrawals were concentrated in a narrow band from Middlesex County south to Suffolk County and accounted for more than 90 percent of all usage from this aquifer in the state. In and around the city of Franklin, withdrawals from the Upper Potomac aquifer were minor; however, water levels declined, on average, approximately 160 ft. The maximum decline from prepumping levels, 185 ft, at any single well within the aquifer was observed near here. Pumping from the underlying Middle Potomac aquifer had induced downward leakage from the Upper Potomac aquifer and likely



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection
Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Contours modified from Leahy and Martin, 1993

Figure 25. Simulated potentiometric surface of the Upper Potomac and Magothy aquifer, prior to development.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 26. Estimated water-level changes in the Upper Potomac and Magothy aquifers, predevelopment to circa 1980.

contributed to the large declines in southern Virginia. During 1980, combined ground-water withdrawals from both the middle and Lower Potomac aquifers near Franklin were approximately 40 Mgal/d, with the middle aquifer accounting for 30 Mgal/d. (Harsh and Laczniak, 1990). Heads in the underlying Middle Potomac aquifer were generally 20 ft lower than those in the Upper Potomac aquifer near Franklin, indicating a downward vertical gradient and flow from the Upper Potomac aquifer to the Middle Potomac aquifer. Near the town of West Point, ground-water withdrawals from the Potomac aquifers caused water levels in the Upper Potomac to decline more than 130 ft from prepumping conditions. Laczniak and Meng (1988) reported nearly 157 ft of decline in the same area through 1983.

In New Jersey, as a result of pumping, water levels declined throughout much of the aquifer. Two major areas of ground-water decline were present at this time; one area was centered in Camden County in the southern part of the state and another in central Monmouth County. Throughout the state, withdrawals from the aquifer averaged 69 Mgal/d during 1980 (unpublished data on file at the USGS New Jersey WSC). Withdrawals in and around Camden and Monmouth Counties accounted for more than 80 percent of all pumpage from the aquifer in New Jersey; approximately 33 Mgal/d was withdrawn in Monmouth and Middlesex Counties, and an additional 24 Mgal/d was withdrawn in Camden and Gloucester Counties. Declines in southern New Jersey generally were greater, however, than those in the northern extent because of considerable withdrawals from the underlying aquifers and the discontinuous nature of the confining units here. Water levels in the cone of depression underlying Camden County and adjacent counties declined, on average, 84 ft from prepumping levels; the maximum decline was observed at 115 ft. Declines in Monmouth County, which were the largest in the aquifer in east-central New Jersey, averaged nearly 65 ft from prepumping levels. The maximum decline here of approximately 100 ft occurred near pumping wells in the western part of the county.

In Maryland, ground-water declines were greatest to the southeast of Washington, D.C., where the Counties of Prince Georges, Charles, and Calvert converge. Declines extended to and affected much of Anne Arundel County to the north and parts of northern St. Mary’s County to the south. Water levels generally declined about 40 to 60 ft throughout this area; the maximum decline of nearly 95 ft from prepumping levels was observed in Charles County. Ground-water withdrawals in Maryland from the Magothy aquifer at this time were estimated at about 10 Mgal/d (Leahy and Martin, 1993; Fleck and Vroblesky, 1996). About 30 percent of the pumpage occurred in northern Charles County, and although withdrawals southeast of Baltimore in northern Prince Georges and Anne Arundel Counties were greater than in Charles County, the higher transmissivity of the aquifer tempered the water-level decline in this area (Fleck and Vroblesky, 1996). Estimated water-level decline from prepumping levels averaged 30 ft, with a maximum of nearly 60 ft. Ground-water-level data circa 1980 along the Eastern Shore of the Chesapeake Bay were limited, but water-level data from an observation well near Cambridge indicate declines of nearly 30 ft. Fleck and Vroblesky (1996), however, reported simulated declines along the Eastern Shore of up to 50 ft.

By 1980, the Magothy aquifer was the most important source of supply for Long Island. Estimated withdrawals for Long Island during 1978-80 averaged 306 Mgal/d (Leahy and Martin, 1993). Modest declines of 10 to 20 ft were observed along the south shore of the island in Queens and Nassau Counties. In eastern Queens County, however, water levels in the Magothy aquifer had declined up to 35 ft in places. Declining water levels were a result of large increases in pumpage since the mid 1950s and subsequent large-scale installation of sanitary and storm sewers and resulting loss of recharge (Busciolano, 2005). Although withdrawals from the aquifer were substantial, declines were moderate because the aquifer on Long Island is highly transmissive; values range from less than 6,000 ft^2/d in eastern Queens County to more than 16,000 ft^2/d along the southern shore in Suffolk County (Trapp and Meisler, 1992). In addition, in parts of northern Queens, Nassau, and Suffolk Counties, the overlying confining unit is absent and the Magothy aquifer is in direct hydraulic connection with the water-table aquifer, effectively increasing recharge.

In North Carolina, two distinct depressions mark the water-level-change surface (fig. 26). The steeper area of decline in the Upper Potomac aquifer was centered in the central Coastal Plain section of North Carolina near the cities of Kinston and Greenville. Water-level declines of at least 30 ft had encompassed the counties of Pitt, Lenoir, Greene, and Craven. Water levels declined, on average, about 64 ft from prepumping levels; the maximum decline of 113 ft was observed near Kinston. Ground-water withdrawals in North Carolina from the Upper Potomac aquifer at this time were estimated at 12 to 13 Mgal/d (Leahy and Martin, 1993; Giese and others, 1997), 60 percent of which was from pumping centers in the central Coastal Plain. A second area, characterized by less severe water-level declines, was centered near the Bladen/Robeson County border in an area where the aquifer was utilized. Water levels had declined, on average, about 35 ft in the affected area of the southern Coastal Plain, although, in places, as great as 70 ft.

From 1980 to 2000, water levels in the Upper Potomac and Magothy aquifers had generally stabilized on Long Island and in New Jersey but had continued to decline from Maryland through North Carolina (fig. 27). The Magothy aquifer continued to be the most important source of water on Long Island. Estimated withdrawals in 1999 were 328 Mgal/d (Busciolano, 2002); however, water levels generally showed little change during this period, except in east-central Queens County, where rises of approximately 20 ft occurred. The volume of ground water withdrawn throughout Long Island was not substantially higher than that in 1980; however, withdrawals from the aquifer in central and eastern Queens County had shifted away from here and by 1999 were reduced by approximately 50 percent.

In east-central New Jersey, water levels generally rose from 6 to 10 ft; the maximum recovery in this area during this period was about 30 ft. Water levels also had stabilized in the major cone of depression underlying New Jersey's southern counties. Withdrawals from the Magothy aquifer had decreased by 27 percent from 1980 to 2000; the largest reductions occurred in Monmouth and Camden Counties (unpublished data on file at the USGS New Jersey WSC). Mandated restrictions on withdrawals in aquifers of the Potomac group that began in 1989 in the northern Coastal Plain counties and in 1996 for counties in southern New Jersey caused the cessation of water-level decline and subsequent rise in these areas. Several areas of moderate recovery also were observed in Monmouth and western Camden Counties, where water levels in both counties had risen by as much 30 ft. Conversely, water levels in small areas of eastern Camden and northern Ocean County declined by as much as 20 ft as result of shifting pumping patterns.

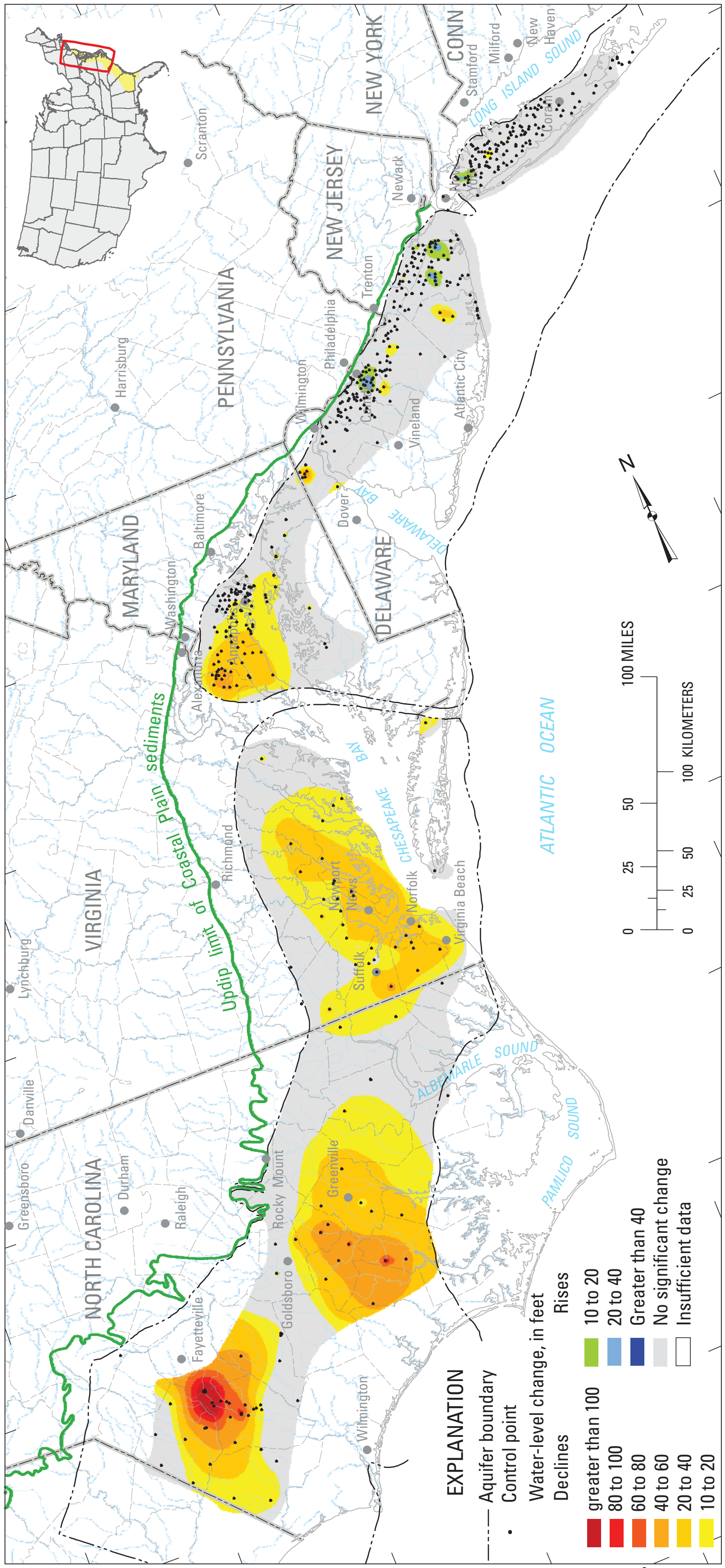
In Delaware, water levels indicated apparent declines from 1980 to 2000 in central New Castle County. Because few data were available for 1980, simulated or estimated water levels in this area may not be representative and may introduce error into subsequent comparisons. Although withdrawals from the aquifer had increased through 2000, pumpage from the aquifer was minor, and declines represented may be overestimated.

From 1980 to 2000, water-level declines were greatest in southern Maryland near the southwestern boundary of the Magothy aquifer, an area that had experienced significant growth in population during this period. Limited potential for surface water as a source of supply incurred further use of the confined aquifers in this area, and as a result, ground-water withdrawals nearly doubled during this time period to about 80 Mgal/d (Maryland Department of Environment, 2004). Although pumpage in the Magothy increased, increases were greater in the two adjacent aquifers, the overlying local Aquia and the deeper Patapsco aquifer. In northern Charles County, the water levels generally declined at about 1.5 ft/yr during this period, or approximately 30 ft. The maximum declines in Maryland were nearly 60 ft during this period. Water-level-difference maps compiled by Curtin and others (2002c) show declines in this vicinity in excess of 70 ft from 1975 to 2001.

Water levels continued to decline in Virginia during this period. From the Middle Peninsula, south through the York-James Peninsula, and through parts of Suffolk and Chesapeake Counties, water levels declined, on average, about 25 ft. Near the town of West Point, increases in withdrawals from the Potomac aquifers resulted in further decline of the potentiometric surface of about 30 ft; water levels were measured as low as -123 ft NGVD 29 in late 2000. Simulated prepumping water levels of approximately 30 to 40 ft NGVD 29 (Harsh and Laczniak, 1990) in this area indicated a total decline of about 160 ft. In and around Franklin, water levels declined by as much as 20 ft, although the rate of decline appears to have moderated. Water-level data in the Upper Potomac aquifer away from the center of the cone of depression show declines of 6 to 21 ft from 1980 to 2000. Data nearer the pumping center were not available circa 2000; however, it was likely that levels near the center of the cone had declined by at least as much, to below -160 ft NGVD 29, indicating total decline from prepumping flow conditions of about 200 ft. Estimated ground-water withdrawals for 2000 near Franklin were about 38 Mgal/d (unpublished data on file at the USGS Virginia WSC) for the Potomac aquifers, an amount similar to 1980 totals. On the York-James Peninsula, along the border of Newport News and James City County, heads had declined by an additional 25 ft. Total decline from prepumping conditions here was approximately 130 ft.

In North Carolina, water levels in the Upper Potomac aquifer declined more than in any other state during this period. In the central Coastal Plain section of North Carolina, withdrawals from the Cretaceous aquifers (primarily the local Black Creek and Upper Cape Fear aquifers) increased dramatically from 1980 to 1999 (Lautier, 2001); recent estimates indicate withdrawals from these aquifers to be approximately 116 Mgal/d. As such, the area has experienced a continued downtrend in heads in the Upper Potomac aquifer. From eastern Greene County and southeast to Craven and Jones Counties, water levels declined more than 40 ft. Additionally, apparent decline at individual sites within this area was as great as 100 ft from 1980 to 2000. Lack of 1980 data near these sites, however, necessitated comparison to estimated or simulated potentiometric contours. Because the estimated 1980 levels may have been high, the larger decline values may also be overestimated and therefore were mapped showing minimal influence. Lautier (2001) calculated 19.41 ft as the average decline observed at several monitoring stations in the local Upper Cape Fear aquifer in the central Coastal Plain from 1980 to 2000. Average decline observed here was greater than the decline calculated by Lautier (2001) at nearly 40 ft or 2 ft/yr. Southwest from here, in northern Bladen County adjacent to the Cape Fear River, water levels had declined 139 ft to altitudes of -103 ft NGVD 29. Strickland (2000) notes that substantial pumping from the Upper Cape Fear aquifer in and around this area began in late 1992. The hydrograph from well RB-183 (fig. 28), located in eastern Robeson County, shows that water levels declined about 10 ft from 1980 through 1993 after which, through 2000, the water level declined an additional 40 ft. Another regional pumping center downstream and to the southeast in Bladen County contributed to the overall declines in this area.

Hydrographs representative of water-level change in the regional Upper Potomac and Magothy aquifers are shown in figure 28, locations are indicated in figure 25. Water levels in observation well N 180.2, located in Nassau County along the southern shore of Long Island, show seasonal variations of approximately 5 ft but little change overall from 1960 through 2000. Water levels in Q 1812.1, located to the west in eastern Queens County, Long Island, recovered nearly 20 ft from the mid 1980s to 1992, stabilized, then rose an additional 4 ft from 1996 to 1998. From 1998 to 2000, water levels again declined slightly. The New Brooklyn number 2 observation well,



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30′N and 45°30′N, central meridian 96°00′W

Figure 27. Estimated water-level changes in the Upper Potomac and Magothy aquifers, circa 1980 to 2000.

located in southern New Jersey near the center of the regionally extensive cone of depression, shows water levels initially measured at nearly 20 ft below NGVD 29. Levels declined steadily from 1961 to 1995; total decline for this period was nearly 70 ft. From 1995 to 2000, the water level had recovered by approximately 20 ft. The water-level rise in this well resulted from a state-issued mandate in 1996 to restrict withdrawals from all Potomac Group aquifers in southern New Jersey in order to stabilize or replenish water levels (Watt, 2000).

Hydrographs for wells CH Bf 101 and CH Bf 128, two adjacent wells located in Charles County, Md., illustrate considerable decline that has occurred in the local Magothy aquifer in southern Maryland. Nearby withdrawals caused water levels to decline approximately 105 ft from 1963 to 1985. Thereafter, water levels stabilized or declined only slightly through 2000. The water level in well 57D 1 SOW 005, located in Isle of Wight County in southern Virginia, shows fluctuations in the early part of the record that reflect local pumping cycles. By the early 1980s, water levels had declined to 85 ft below NGVD 29. Another well, 57D 22 SOW 143B, located about 5.5 mi to the southwest and away from the pumping center, indicates water levels that were 25 ft higher in altitude. From 1980 to 2000, although the downtrend in water levels had moderated during the latter part of the period of record, water levels in this well had declined more than 20 ft.

Middle Potomac Aquifer

The Middle Potomac aquifer consists predominantly of nonmarine sands and gravels of Early Cretaceous age in Virginia, Maryland, and Delaware and those of Late Cretaceous age in North Carolina, New Jersey, and Long Island. The regional aquifer includes the Lower Cape Fear aquifer of North Carolina, the Patapsco aquifer of Maryland and Delaware, the middle aquifer of the Potomac-Raritan-Magothy aquifer system of New Jersey, and the Lloyd aquifer of Long Island, N.Y. (table 1).

The prepumping potentiometric surface for the Middle Potomac aquifer was simulated by Leahy and Martin (1993) (fig. 29). On Long Island, ground-water flow was from east-west trending potentiometric highs toward the Long Island Sound and the Atlantic Ocean. In New Jersey, ground water in the aquifer flowed from areas near the Fall Line toward potentiometric lows along the Raritan Bay and the Atlantic Ocean, and in the south, toward the Delaware River (Martin, 1998). Ground water that originated in updip areas of the Delmarva Peninsula flowed toward and discharged upward to both the Chesapeake and Delaware Bays. Elsewhere in Maryland and Virginia, ground water in the aquifer generally flowed toward and beneath the Chesapeake Bay. In North Carolina, ground-water flow in updip areas was generally from potentiometric highs along the western extent toward discharge to streams and rivers within local flow systems, and in downdip areas, flow was generally coastward in a south-southeast direction (Giese and others, 1997).

By 1980, substantial cones of depression had formed in the potentiometric surface of the Middle Potomac aquifer in Virginia and New Jersey (Leahy and Martin, 1993). In western Long Island, N.Y., a smaller cone of depression also was present in the aquifer (Leahy and Martin, 1993; Donaldson and Koszalka, 1983b). Smaller cones also had appeared in northern Delaware and near the western boundary of the aquifer in Maryland. Water-level altitudes as low as -166 ft near Franklin, Va., and -89 ft NGVD 29 in Camden County, N.J., were observed at the centers of the cones of depression. Leahy and Martin (1993) noted that the deep cone near Franklin and an adjacent one near West Point, Va., had coalesced, forming a large area of extensive declines that had encompassed both the Middle and Lower Potomac aquifers.

Water levels in the Middle Potomac aquifer declined across much of the aquifer from prepumping flow conditions from western Long Island through northern North Carolina. Declines exceeded 100 ft in Middlesex and Camden Counties in New Jersey as well as in large areas around West Point and Franklin in Virginia (fig. 30).

Water-level decline within the Middle Potomac aquifer was most pronounced in Virginia, particularly in and around the city of Franklin. Within a 13-mi radius surrounding the regional pumping center near Franklin, water levels declined, on average, 141 ft. The single largest water-level decline, 210 ft, was observed near here in Isle of Wight County. At this time, the Middle Potomac aquifer was the most utilized of the Coastal Plain aquifers in Virginia. Leahy and Martin (1993) reported Virginia withdrawals from the Middle Potomac aquifer averaged nearly 53 Mgal/d from 1978 to 1980, more than 30 Mgal/d was withdrawn in the vicinity of Franklin (Harsh and Laczniak, 1990; Leahy and Martin, 1993). Withdrawals at another major pumping center, located to the northeast near Suffolk, caused water levels to decline to -96 ft NGVD 29, or nearly 132 ft from prepumping conditions. Large-scale declines also had occurred within the aquifer in and around West Point, where withdrawals were estimated at about 7 Mgal/d. Water levels declined to -117 ft NGVD 29 near the center of the cone of depression, or about 160 ft from prepumping levels. Subregional cones of depression centered underneath pumping centers at Suffolk and West Point had coalesced with the cone near Franklin to form the largest continuous area of water-level decline within the aquifer. Declines of at least 60 ft extended east from this area toward the Chesapeake Bay and Atlantic Ocean and to North Carolina to the south. To the west, water-level change in the aquifer was negligible nearing the updip boundary.

In North Carolina, the steepest decline, nearly 120 ft, was along the border of Virginia and North Carolina at the outer edge of the large cone of depression centered near Franklin, Va.

In Maryland, water levels declined near pumping centers to the southeast of Baltimore and to the south and east of Washington, D.C. In Charles County, south of Washington, D.C., water levels declined from 45 to 83 ft from prepumping conditions. Declines of more than 40 ft extended as far

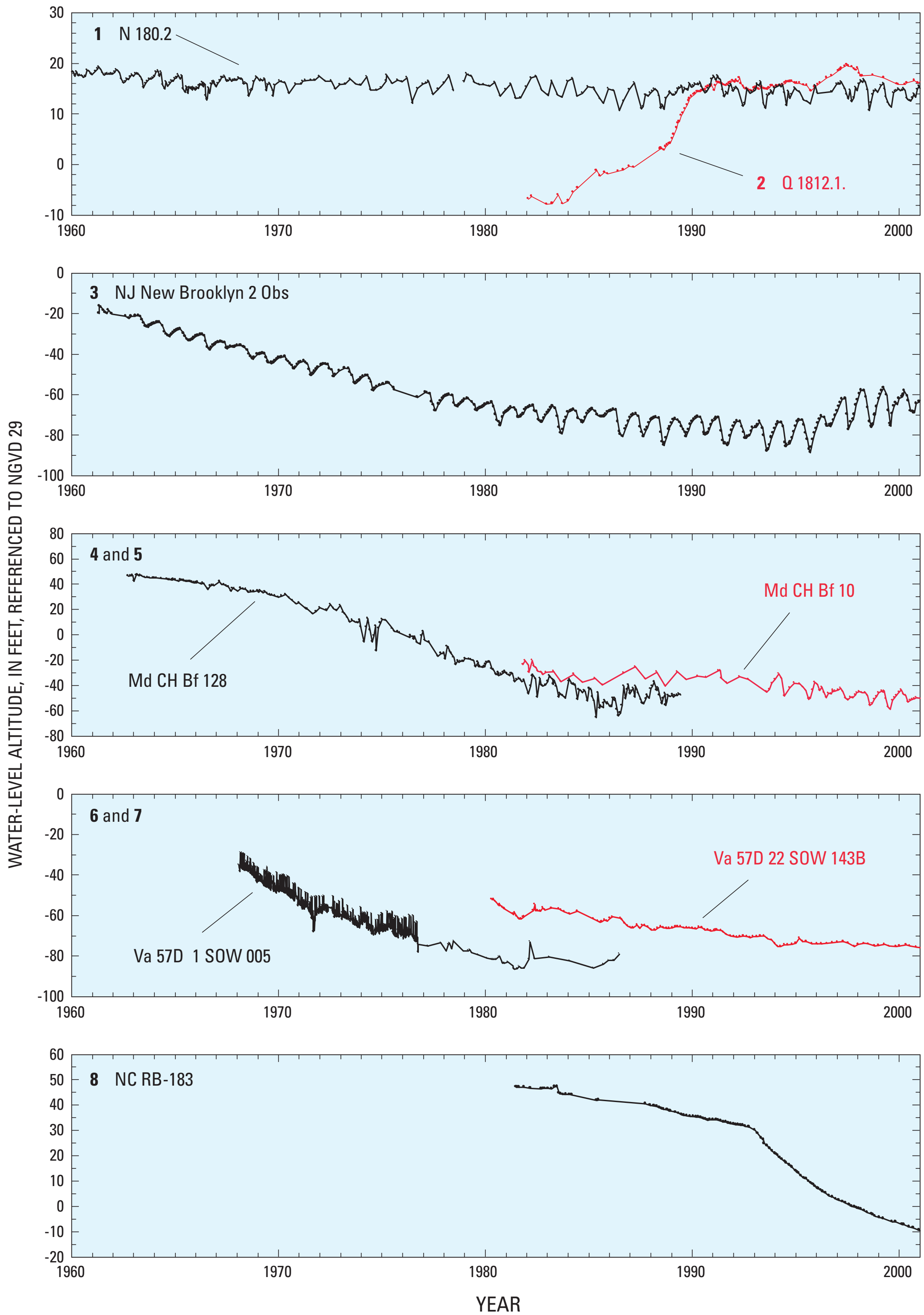
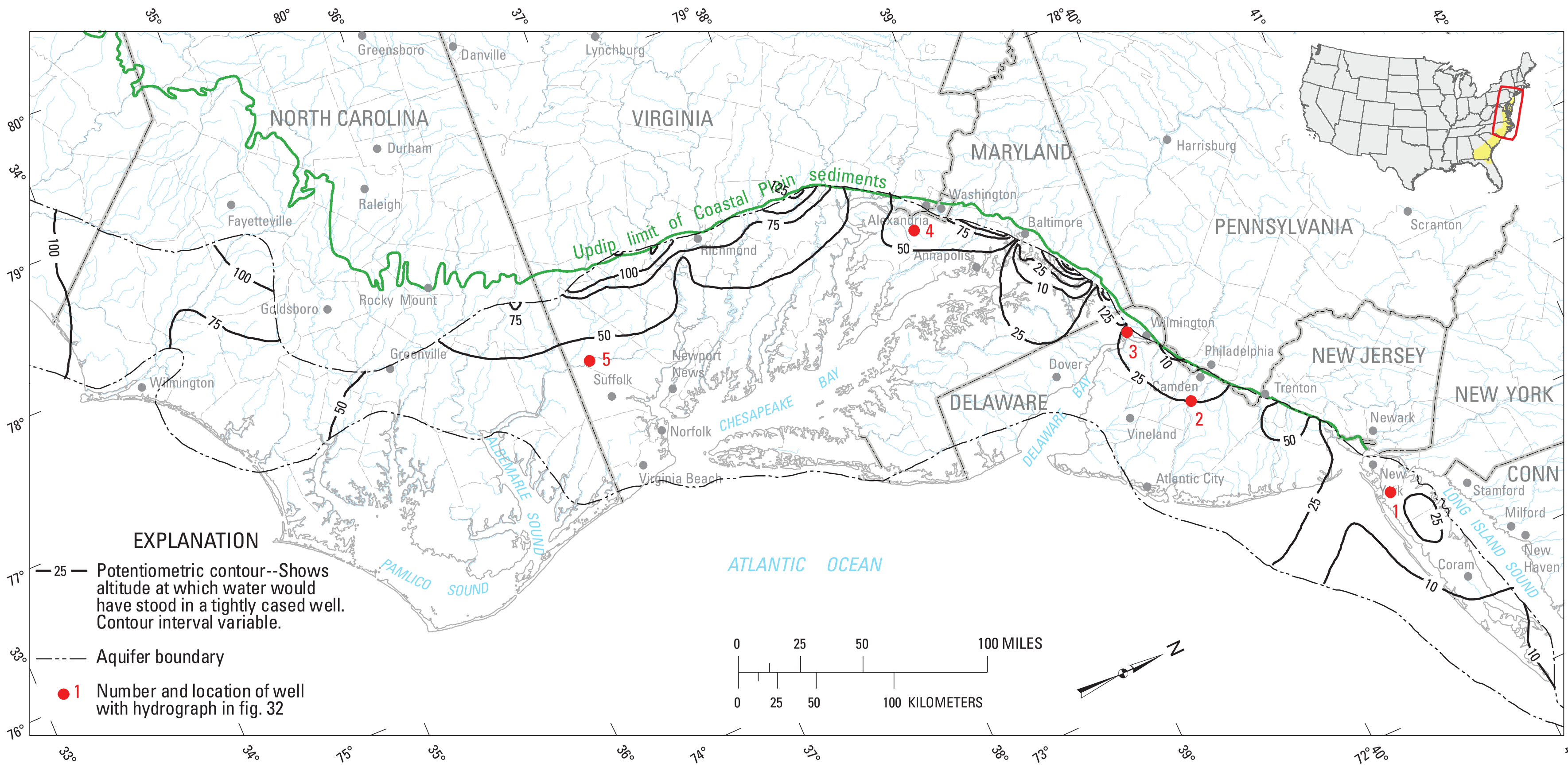


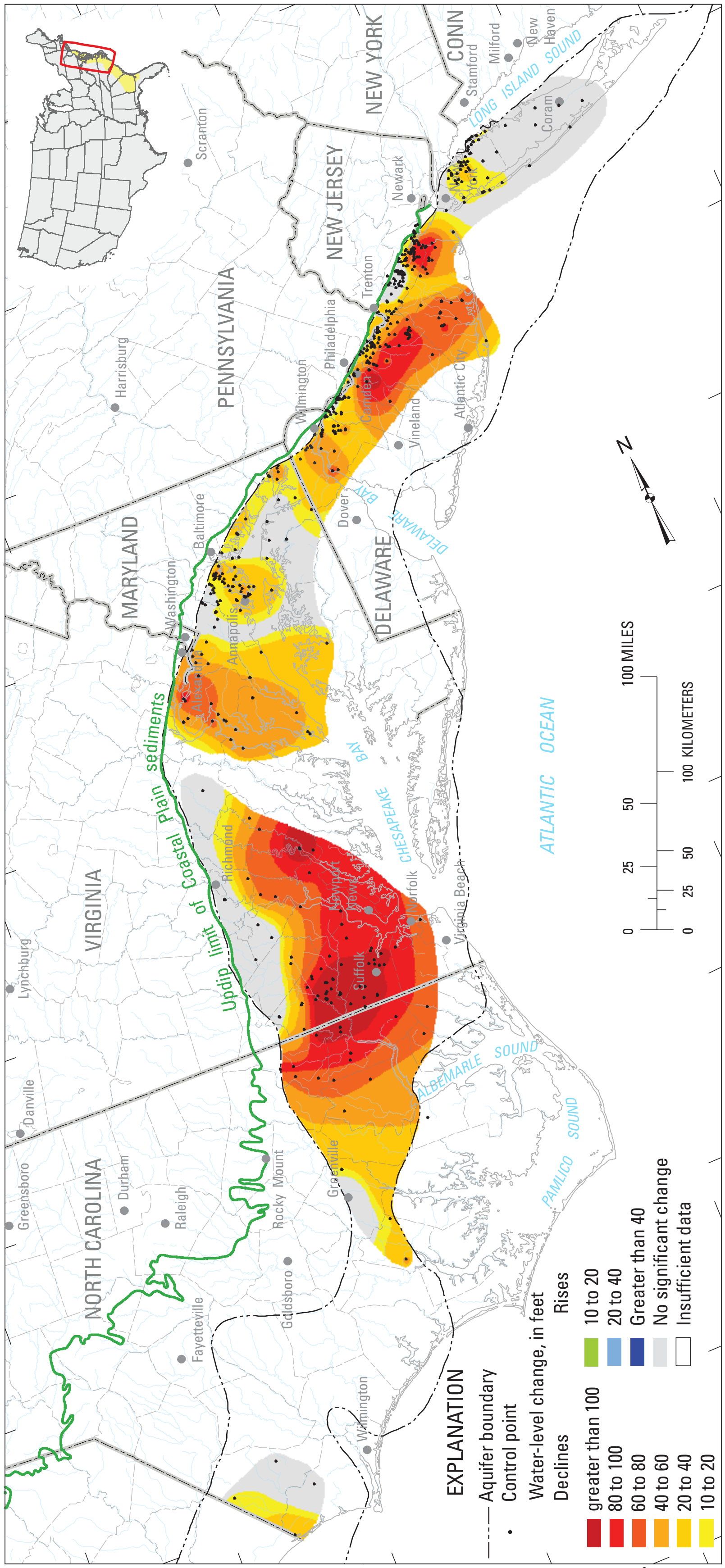
Figure 28. Selected hydrographs from wells screened in the Upper Potomac and Magothy aquifers. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 25.)



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Contours modified from Leahy and Martin, 1993

Figure 29. Simulated potentiometric surface of the Middle Potomac aquifer, prior to development.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection
Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 30. Estimated water-level changes in the Middle Potomac aquifer, predevelopment to circa 1980.

eastward as Dorchester County, along Maryland's Eastern Shore. South of Baltimore, in Anne Arundel County, water levels typically declined from 40 to 60 ft. In the eastern part of the county, water-level altitudes ranged from 10 to -25 ft NGVD 29. Simulated prepumping water levels in this area typically ranged from 25 to nearly 50 ft, indicating total declines ranging from 20 to nearly 60 ft. Total ground-water withdrawals from the Middle Potomac aquifer in Maryland were approximately 28 Mgal/d in 1978 (Leahy and Martin, 1993). The transmissivity of the aquifer is generally lower in Maryland than in Virginia; in Charles County, values range between about 2,000 and 5,000 ft^2/d; in Anne Arundel County, transmissivities are much more variable, ranging from about 2,000 to 20,000 ft^2/d (Trapp and Meisler, 1992). Withdrawals in Anne Arundel County approached 19 Mgal/d in 1980 and were more than four times as much as those in Charles County; the heads in areas of low transmissivity, such as in Charles County, are sensitive to even modest ground-water withdrawals.

In northern Delaware, ground-water decline throughout New Castle County ranged from 33 to 61 ft; the greatest decline was near pumping centers proximate to the updip limit of the aquifer and the Delaware River. The water-level decline from 1956 to 1980, simulated by Martin (1984), was as much as 70 ft in the same area. Estimated ground-water withdrawals in 1980 were nearly 10 Mgal/d (Leahy and Martin, 1993; Lacombe and Rosman, 2001). Given the relatively low transmissivity of the aquifer here, ranging from 2,000 to 4,000 ft^2/d, and the amount of water withdrawn, the decline depicted on the map in figure 30 seems plausible.

From 1900 to 1980, water levels in the Middle Potomac aquifer declined substantially throughout New Jersey, except in limited areas along its western boundary. Declines were greatest in central Camden and Burlington Counties and in the east-central part of the state, along the boundary of Monmouth and Middlesex Counties. Water-level declines in Camden County generally were coincident with those in the Upper Potomac aquifer; in east-central New Jersey, however, steepest declines occurred to the north and west of those observed in the upper aquifer, reflecting a preference for withdrawals in the shallower part of the system. The Middle Potomac aquifer was heavily utilized throughout New Jersey; estimated withdrawals during 1980 were approximately 84 Mgal/d (unpublished data on file at the USGS New Jersey WSC). Although pumping centers were located throughout the state, withdrawals typically were greatest in northern Burlington and western Middlesex Counties. Water levels in the Burlington-Camden area declined, on average, about 56 ft from prepumping levels. Maximum declines of 116 and 109 ft occurred in the downdip areas of Burlington and Camden Counties, respectively, where the aquifer is more effectively confined. Water levels declined least near the outcrop area. In Middlesex County, the magnitude of decline was similar, ranging from 20 to 112 ft; maximum declines occurred in the east-central part of the county and along the Raritan Bay front. Declines again were tempered approaching the outcrop area where the aquifer is more easily recharged.

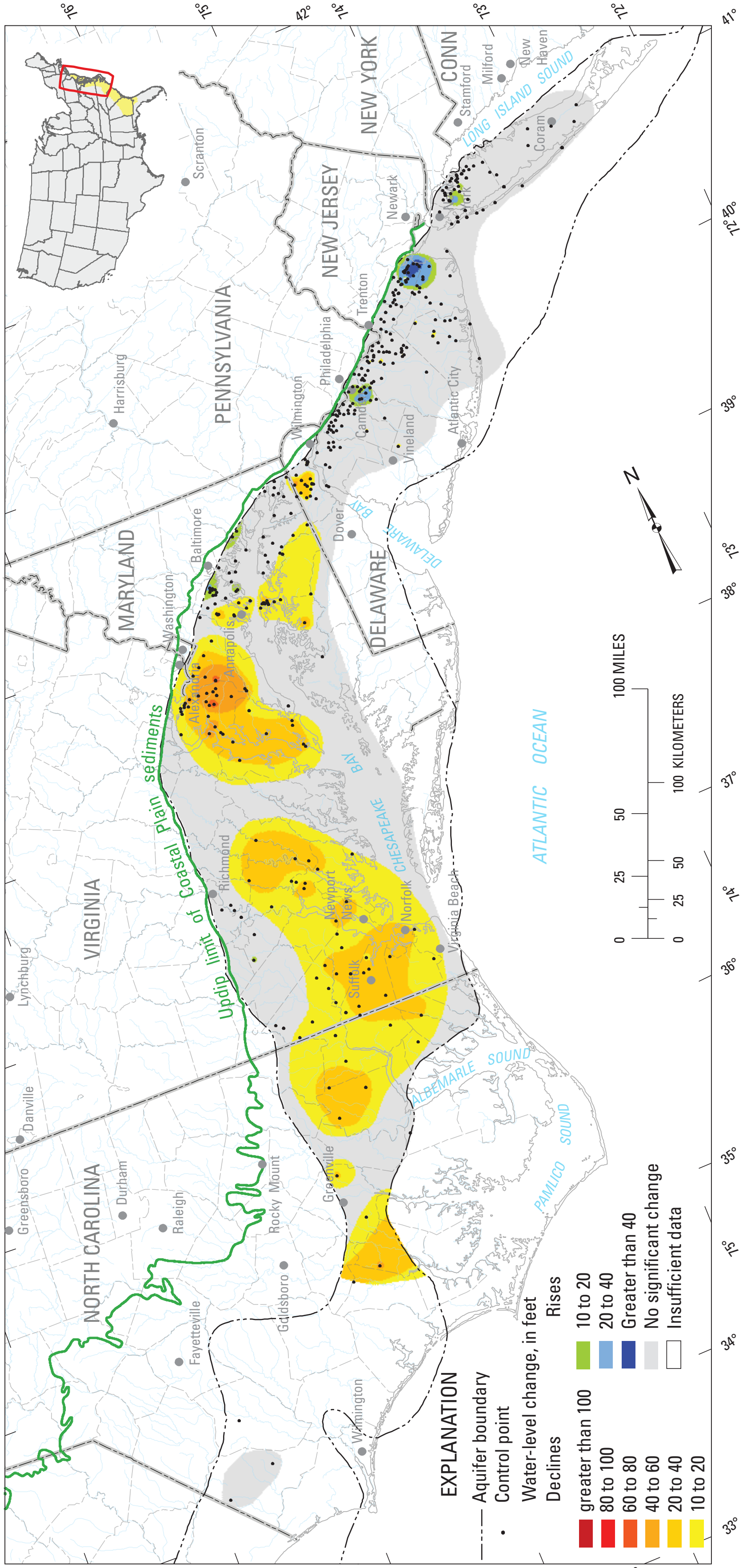
On Long Island, water levels declined 10 to 25 ft from prepumping flow conditions along the border of eastern Queens and western Nassau Counties and to the southern shore. In eastern Nassau and Suffolk Counties, there was no discernible change in water levels, because the aquifer here was little used. Average daily ground-water withdrawals during 1978-80 from the aquifer on Long Island were estimated at 19 Mgal, most of which were from the western part of the island in Queens and Nassau Counties.

Between 1980 and 2000, water levels continued to decline throughout the aquifer in Delaware, Maryland, Virginia, and parts of North Carolina. In New Jersey and on Long Island, water levels were generally stable or had recovered at the major cones of depression (fig. 31)

In North Carolina, water levels declined from 34 to 45 ft in western Bertie County. Nearing the border with Virginia, water levels generally declined 10 to 15 ft, likely as a result of continued pumpage near Franklin. A decline of 50 ft, observed in Craven County, was likely caused by induced leakage from pumping in the overlying local Upper Cape Fear and Black Creek aquifers because the aquifer is minimally pumped here (Lautier, 2001). Data were lacking in the local Lower Cape Fear aquifer in much of the central Coastal Plain area, probably because of the salty nature of the ground water.

Between 1980 and 2000, water levels continued to decline in Virginia around Suffolk and West Point and, to a lesser extent, Franklin. Water levels in and around these municipalities had continued to drop, although the annual rate of decline had moderated. Near Franklin, water levels declined, on average about 13 ft, or about 0.6 ft/yr; prior to 1980, the annual rate of decline in the same area was nearly three times as great. Withdrawals from all Potomac aquifers had decreased in this area to about 37 Mgal/d (unpublished data on file at the USGS Virginia, WSC). To the northeast in Suffolk County, water levels generally declined about 20 ft, although reported withdrawals from the Potomac aquifers had decreased. Near the pumping center at West Point, water-level decline ranged from 20 to 30 ft at the center of the cone of depression; withdrawals from the Potomac aquifers had increased from 14 Mgal/d during the early 1980s to about 18 Mgal/d in 2000 (unpublished data on file at the USGS Virginia WSC).

In Maryland, the most pronounced water-level declines were observed to the south and east of Washington, D.C., where declines of more than 20 ft encompassed parts of St. Mary's, Charles, Prince Georges, and Calvert Counties. Near larger pumping centers in northern Charles County, water levels declined more than 40 ft; maximum declines of nearly 90 ft occurred at pumping centers near La Plata and Waldorf, Md. Curtin and others (2002d) document as much as 50 ft of decline in this area during an 11-yr period from 1990 to 2001. Water-level altitudes circa 2000 ranged from -31 to -138 ft NGVD 29 near here. Similarly, Curtin and others (2002a) reported water-level altitudes below -150 ft NGVD 29 during



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection
Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 31. Estimated water-level changes in the Middle Potomac aquifer, circa 1980 to 2000.

September 2000. Estimated ground-water withdrawals of more than 6 Mgal/d from the Middle Potomac aquifer were more than double those from 1978 (unpublished data on file at the USGS Maryland WSC); increased withdrawals coupled with low aquifer transmissivity resulted in the steep declines in Charles County. Reported withdrawals from the Middle Potomac aquifer increased from about 25 Mgal/d in 1980 to 36 Mgal/d in 2000; most of the pumpage (22 Mgal/d) was used in Anne Arundel County for public supply (Maryland Department of the Environment, 2004). Water levels had also declined in Anne Arundel County, though not as steeply, from about 10 ft to nearly 40 ft in close proximity to the pumping wells. The aquifer was much more heavily utilized here than to the south; transmissivities in the aquifer of more than 16,000 ft^2/d served to mitigate the overall decline.

From 1980 to 2000, the cone of depression in central New Castle County, Del. deepened, and water levels declined from 15 to 30 ft and, in places, as much as 40 ft. The large declines shown in figure 31 were estimated from comparisons to 1980 simulated values because of the lack of measured data and thus may be overestimated. The Potomac aquifers are heavily pumped in this area of Delaware, and by 2001, withdrawals from both the middle and lower aquifers were approximately 25 Mgal/d (Data available on file at DNREC). County-aggregate estimates indicate an increase in ground-water withdrawals in New Castle County of 10 Mgal/d from 1985 to 2000 (Solley and others, 1988; Hutson and others, 2004), most of which can be attributed to aquifers of the Potomac Group.

In New Jersey, water levels across the Middle Potomac aquifer generally had stabilized except near regional cones of depression in Camden and Middlesex Counties, where water levels had recovered. Water-level recovery was greatest near the cone of depression in Middlesex County. Water levels generally rose from 20 to 40 ft near pumping centers in the east-central part of the county and constituted the largest recovery within the aquifer at this time. Rises of up to 61 ft were observed near the center of the cone of depression. In western Camden County, water levels also had risen substantially; recoveries were from 10 to as much as 35 ft near the center of the cone of depression. Water-level rises in both central and southern New Jersey are a result of the New Jersey Department of Environmental Protection’s mandate to restrict withdrawals from all the Potomac aquifers in order to stabilize or cause aquifer water levels to recover (Lacombe and Rosman, 2001). Estimated withdrawals from the Middle Potomac aquifer in New Jersey decreased from 84 Mgal/d in 1980 to 63 Mgal/d in 2000; the largest reductions occurred in Middlesex, Burlington, and Camden Counties (unpublished data on file at the USGS New Jersey WSC). Reductions began in New Jersey’s northern Coastal Plain counties starting about 1988, and in the southern Coastal Plain counties in about 1996 (Lacombe and Rosman, 2001).

Water levels throughout the Middle Potomac changed little on Long Island, N.Y., except in eastern Queens County, where water levels have risen by as much as 20 ft. Generally, water from the aquifer was moderately used on Long Island; a recent estimate indicates that approximately 12.9 Mgal/d was withdrawn during 1999 (Busciolano, 2002). Pumpage from the aquifer had shifted from Queens County, and by 1999, nearly all withdrawals were made in Nassau County.

Selected hydrographs for wells open to the regional Middle Potomac aquifer are shown in figure 32, locations are indicated in figure 29. The hydrograph of well N7.1 (1), located in western Nassau County, Long Island, near the area of recovering water levels, shows seasonal water-level variations of as much as 10 ft, with less than a 10 ft decline between 1941 and 1980. From 1980 to 2000, water levels recovered from 6 to 7 ft.

The water level in the Elm Tree 3 observation well, located in Camden County, N.J., near the center of the cone of depression, was approximately 20 ft below NGVD 29 when data collection began. From the early 1960s to 1980, water levels declined approximately 45 ft. Thereafter, the annual fluctuations in water level increased in response to seasonal withdrawals but generally indicated a steady decline of an additional 12 ft until about 1996, followed by a sharp rise during 1996-97. From 1996 to 2000, water levels in this well recovered about 25 ft. Dramatic rises were the result of imposed restrictions of withdrawals from aquifers of the Potomac-Raritan-Magothy system that commenced in 1996 in order to encourage recovery of aquifer water levels.

Well Dc34-06 (3) is in New Castle County, Del., near the aquifer outcrop and adjacent to the Delaware River and several large capacity pumping wells. The hydrograph shows highly variable seasonal fluctuations in water levels with both significant declines and rises over the 1980 to 2000 period. Since the early 1990s water levels have shown a general downward trend. The hydrograph of well PG Fc 17 (4), located in Prince Georges County, Md., shows water levels at 30 ft NGVD 29 when data collection began. From 1956 to 1980, the water level declined approximately 20 ft. From 1980 to 2000, the water level steadily declined more than 40 ft to an altitude of -36 ft NGVD 29, indicating a total decline of 66 ft. Water levels in well 55B 16 (fig. 32), located in Isle of Wight County, Va., had declined more than 70 ft during the period from 1960 to 1970. Subsequent to 1970, the annual rate of decline had moderated; from 1970 to 2000, water levels had declined an additional 15 ft.

Lower Potomac Aquifer

The Lower Potomac aquifer consists predominantly of nonmarine sands of Early Cretaceous age and includes the Lower Cretaceous aquifer of North Carolina, the Lower Potomac aquifer of Virginia, the Patuxent aquifer of Maryland and Delaware, and the lower aquifer of the Potomac-Raritan-Magothy aquifer system in New Jersey (table 1).

The simulated predevelopment potentiometric surface for the Lower Potomac aquifer is shown in figure 33. Prepumping conditions in the lowermost unit were the most poorly defined

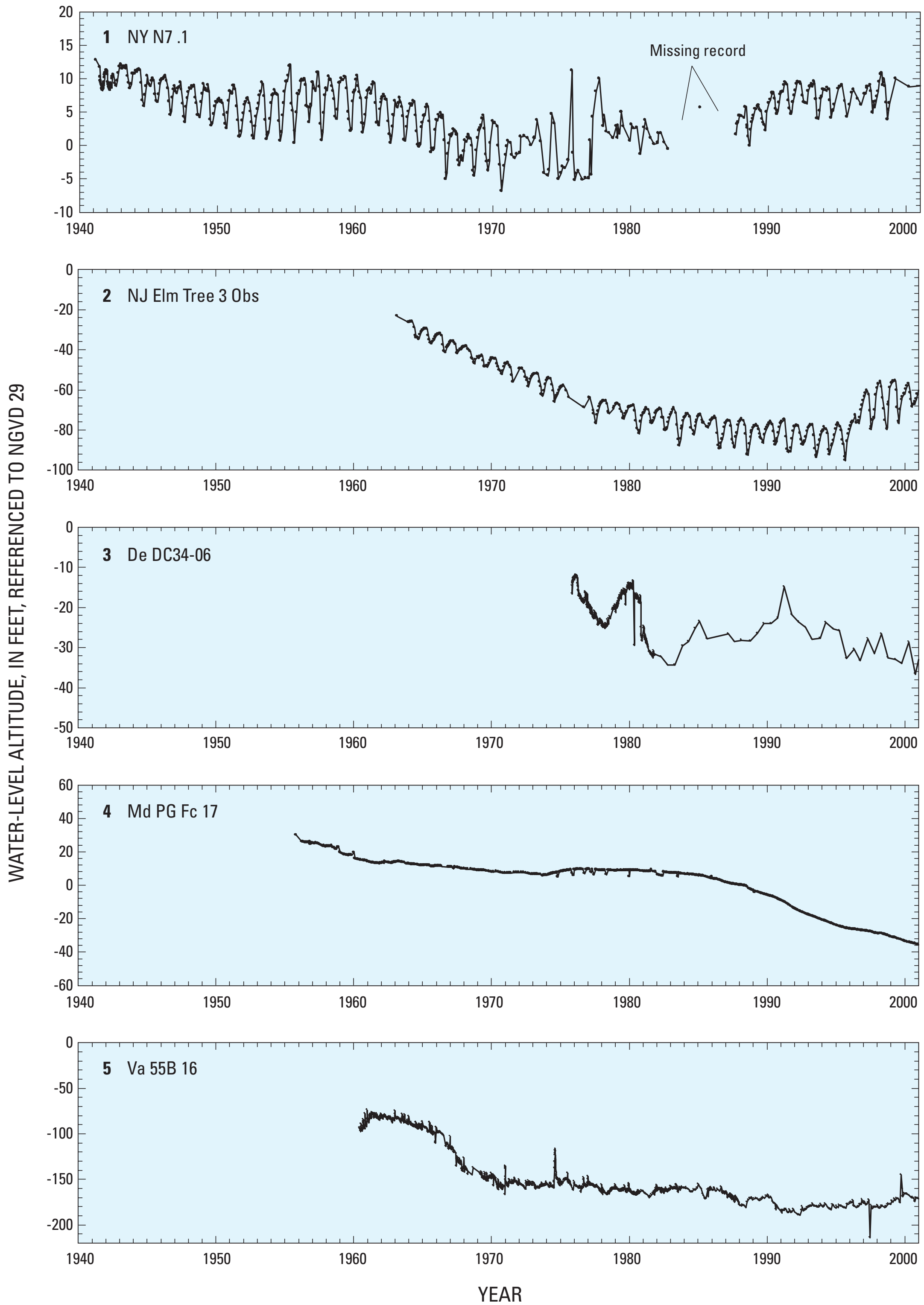


Figure 32. Selected hydrographs from wells screened in the Middle Potomac aquifer. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 29.)

among aquifers of the Northern Atlantic Coastal Plain (Leahy and Martin, 1993). Simulated contours indicate a ground-water divide in east-central New Jersey; north of this divide flow was to the northeast and to the Atlantic Ocean. South of the divide, ground water flowed toward and discharged to the Delaware River. Flow originating on the Delmarva Peninsula was to discharge areas along the Delaware River and to the Chesapeake Bay and its tributaries. In southern Maryland and Virginia, ground-water flow was from updip areas to the Chesapeake Bay and its tributaries.

By 1980, water levels had declined throughout much of the aquifer to below 0 ft NGVD 29, and substantial cones of depression had formed in the potentiometric surface in southern New Jersey, New Castle County, Del., near Baltimore, Md., and in and around Franklin, Va. Substantially lowered aquifer water levels altered ground-water-flow paths and discharge from the aquifer. Pumping wells had captured much of the ground-water flow that otherwise would have discharged to major estuaries and bays.

By 1980, water levels in the Lower Potomac aquifer had declined 100 ft or more from North Carolina to New Jersey (fig. 34). In North Carolina, the aquifer extends about 25 mi into and underlies parts of Hertford and Gates Counties; wells open to the Lower Potomac aquifer were absent there. Declines of more than 120 ft near the Virginia border were an extension of the expansive cone underlying nearby Franklin, Va. Giese and others (1997) similarly reported drawdowns of more than 135 ft from prepumping flow conditions due largely to withdrawals at Franklin.

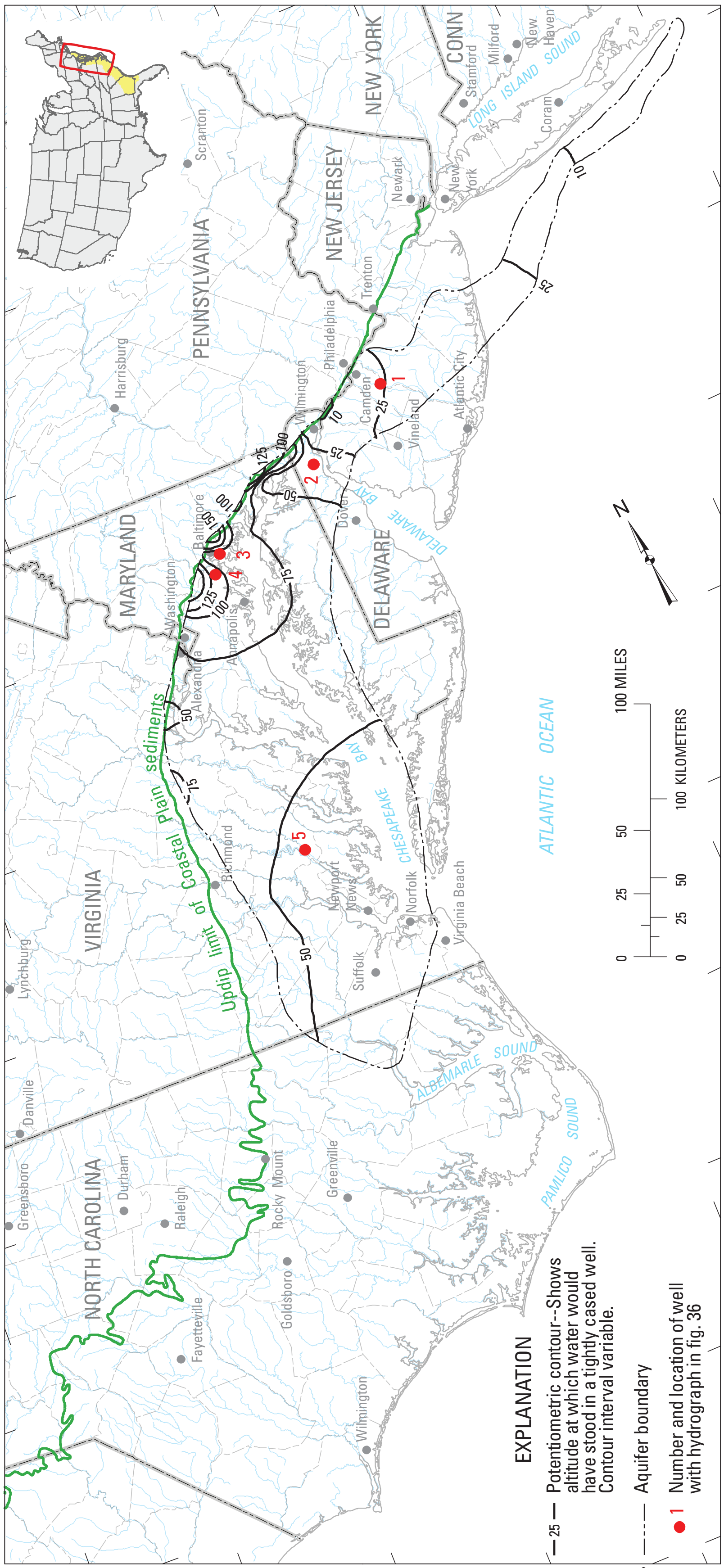
In Virginia, large-scale pumping of the Potomac aquifers had caused substantial declines in water levels throughout the extent of the lower aquifer. In southern Virginia, water-level altitudes ranged from -64 to -150 ft NGVD 29 near the large pumping center at Franklin. Estimated water-level declines of up to 200 ft at the center of the cone of depression were the largest observed within the Lower Potomac aquifer during this period. Ground-water withdrawals from the aquifer in Virginia were estimated at approximately 13.6 Mgal/d by 1980 (Leahy and Martin, 1993); the majority of this pumpage occurred near Franklin. Near the town of West Point, withdrawals averaging more than 3 Mgal/d caused water levels to decline approximately 110 ft from prepumping levels.

Lack of 1980 water-level data precluded analyses north of West Point, Va., and south of the Maryland border. The large depths to the top of the aquifer in coastal areas and the quality of water have limited the use of the aquifer so that few wells are open to the Lower Potomac for water-level-change mapping. Withdrawals and significant declines in these areas were considered unlikely.

In Maryland, areas of most pronounced decline were to the south and east of Washington, D.C., and Baltimore, near areas of heavy withdrawals. Estimated pumpage from the aquifer in Maryland during 1978 was approximately 17 Mgal/d (unpublished data on file at the USGS Maryland WSC; Leahy and Martin, 1993), most of which was from pumping centers in Baltimore and Anne Arundel Counties and, to a lesser extent, Prince Georges County. The largest declines in the overlying Middle Potomac aquifer generally coincided with these areas, though declines were more pronounced within the Lower aquifer. Withdrawals from the aquifer of 11 Mgal/d in and around the city of Baltimore caused ground-water levels to decline from 80 to more than 150 ft from prepumping levels. To the south, in Anne Arundel County, water levels declined, on average, about 90 ft from prepumping levels. The largest declines of about 130 ft occurred near a pumping center in the northern part of the county. Southeast of Washington, D.C., in neighboring Prince Georges County, Md., water levels had declined to -75 ft NGVD 29 more than 120 ft from prepumping conditions. Although pumpage here was substantially lower than in areas to the north, declines of at least 60 ft had propagated as far as northern Charles County. The least decline was observed in northeastern Maryland near the downdip limit of the aquifer, where apparent decline was less than 10 ft.

By 1980, water levels within the Lower Potomac aquifer in northern Delaware had declined substantially from prepumping flow conditions. The steepest declines occurred near industrial areas along the Delaware River in New Castle County, where the maximum decline, 166 ft, was observed at the center of the cone of depression (fig. 34). Pumpage from the Lower Potomac aquifer was estimated at approximately 4 Mgal/d in 1980 (Lacombe and Rosman, 2001), although withdrawals from all aquifers of the Potomac Group were substantially greater at nearly 20 Mgal/d (Martin and Denver, 1982). Pumpage was concentrated in New Castle County north of the Chesapeake and Delaware Canal and primarily along the Delaware River, although substantial withdrawals were also made near the city of Newark. Martin (1984) simulated declines of more than 160 ft in this area from 1956 to 1980; the magnitude and location of the declines were similar to that observed in this study.

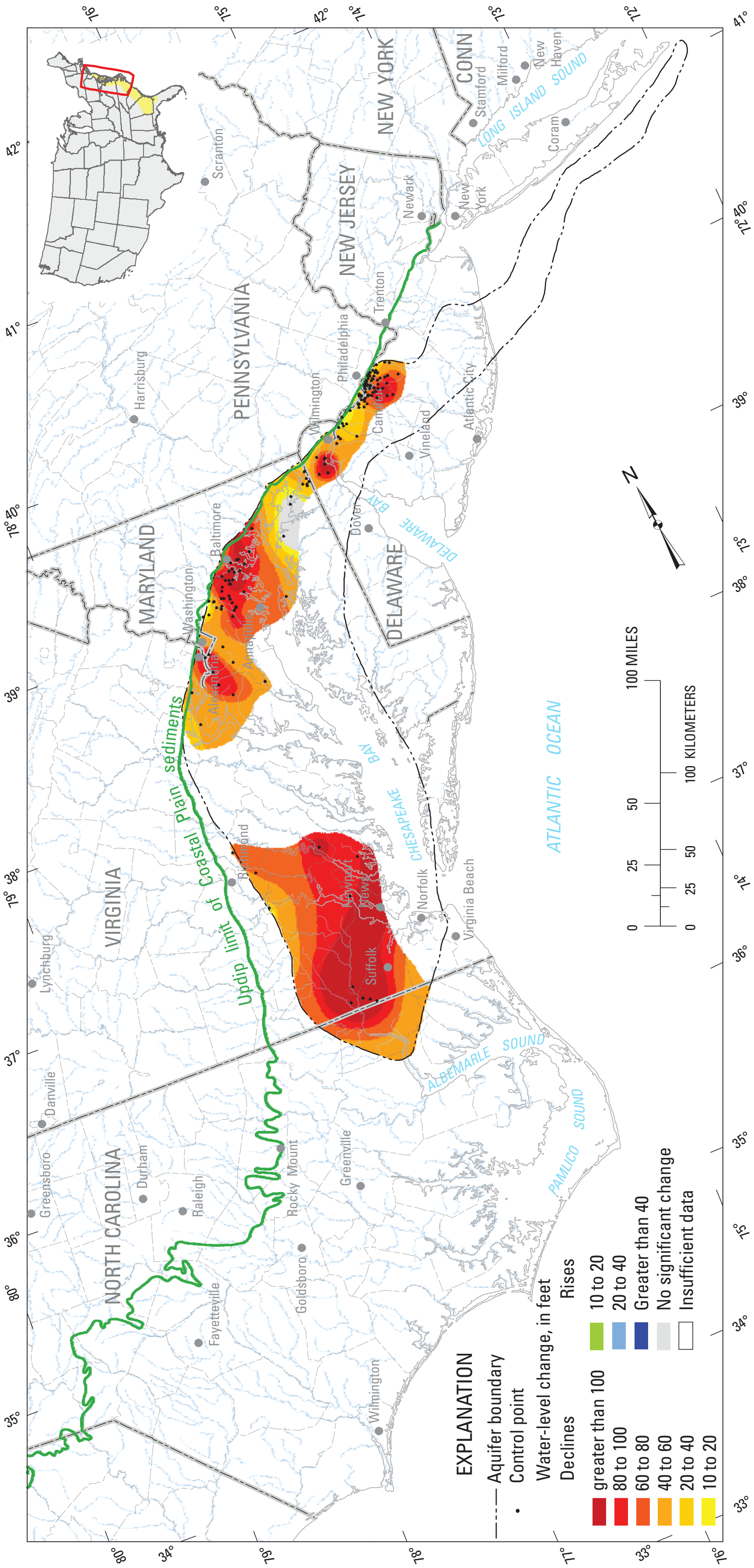
By 1980, water levels in the Lower Potomac aquifer also had declined substantially throughout the extent in New Jersey (fig. 34). Changing water-level conditions were not interpreted beyond Burlington County in southern New Jersey because the aquifer cannot be differentiated from overlying sediments of the Middle Potomac aquifer; changes here were included in the section detailing the Middle Potomac aquifer. In New Jersey, water-level altitudes circa 1980 ranged from 3 to -85 ft NGVD 29; the lowest altitudes were observed near pumping wells in central Camden County. Water-level decline was greatest in central Camden County where the maximum decline from prepumping levels, 106 ft, was observed at the center of the cone of depression. Water-level changes here were similar to those observed in the Upper and Middle Potomac aquifers, both in magnitude and lateral extent. The transmissivity of the Lower Potomac aquifer in Camden County ranges between 5,000 and 10,000 ft^2/d (Trapp and Meisler, 1992) within close proximity to its updip extent, enabling the installation of large capacity wells at relatively shallow depths. As a result, the aquifer in this area is very productive and heavily utilized; ground-water withdrawals in Camden County



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Contours modified from Leahy and Martin, 1993

Figure 33. Simulated potentiometric surface of the Lower Potomac aquifer, prior to development.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30′N and 45°30′N, central meridian 96°00′W

Figure 34. Estimated water-level changes in the Lower Potomac aquifer, predevelopment to circa 1980.

for 1980 totaled about 51 Mgal/d (unpublished data on file at the USGS New Jersey WSC). An additional 16 Mgal/d was withdrawn from neighboring counties, and declines within the aquifer in these areas generally were less severe, ranging from 10 to 60 ft relative to prepumping conditions. Decline was least in updip areas of Gloucester County where the aquifer was not heavily pumped; however, in southern Salem County, water levels declined nearly 50 ft, largely as a result of pumping in New Castle County, Del.

By 2000, water levels had stabilized throughout much of the extent of the Lower Potomac aquifer, although some areas of substantial change were observed in Virginia, Delaware, and New Jersey (fig. 35). Data from the aquifer in Virginia were sparse at this time; however, water levels in observation wells indicated continued decline in and around Franklin, Va. Water levels in this area declined from 10 to 20 ft during this period, despite withdrawal amounts from the Potomac aquifers remaining about the same as in prior years. Declining water levels resulting from pumpage at Franklin extended several miles into North Carolina, though further decline in the northern counties was likely minor. The largest water-level declines within Virginia were observed in the aquifer underlying the York-James Peninsula, extending from the town of West Point southeast to Newport News. Water levels declined about 10 to 20 ft from 1980 levels near the edge of the cone of depression here, and by nearly 40 ft near pumping wells at West Point. Ground-water withdrawals from the Potomac aquifers had increased slightly from pumping centers throughout the Peninsula from the early 1980s to 2000; however, those in the immediate vicinity of West Point had increased by 4 to 5 Mgal/d, or about 30 percent (unpublished data on file at USGS Virginia WSC).

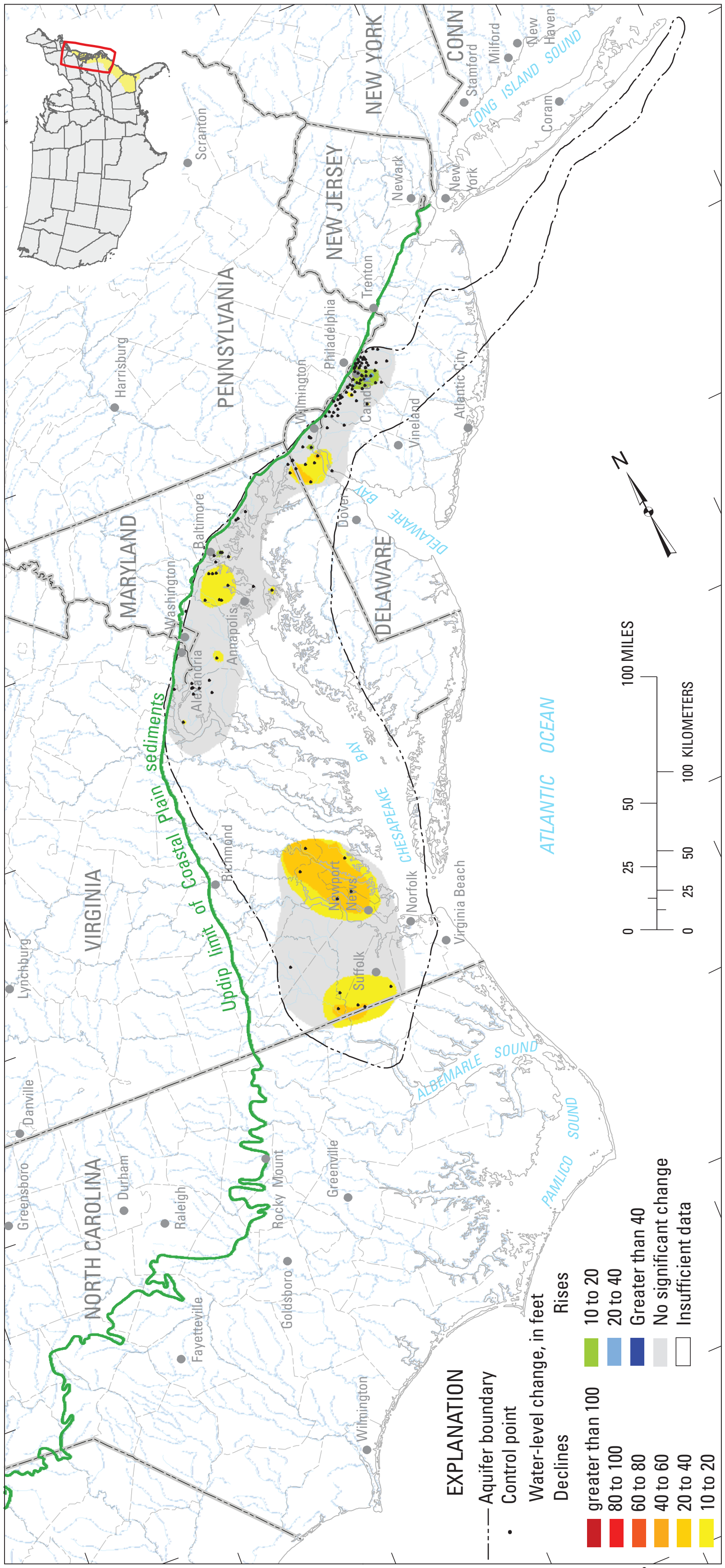
In Maryland, declining heads were evident in Anne Arundel County, while water levels rose in and around the city of Baltimore. Ground-water withdrawals from the Lower Potomac aquifer throughout Maryland generally decreased. Water levels rose as much as 30 ft locally near the Baltimore Harbor; most of this recovery occurred over a short period in late 1997, presumably when a nearby pumping well was turned off. Reported withdrawals nearby were nearly 4 Mgal/d in 1978; by 2000, withdrawals from the Lower Potomac aquifer here were about 0.15 Mgal/d (unpublished data on file at the USGS Maryland WSC). To the south, in Anne Arundel County, water levels declined from 10 to 15 ft although withdrawals from the aquifer had not significantly increased from circa 1980 amounts.

In Delaware, two areas of decline were noted during this period; one area had spanned the Maryland-Delaware border and another was about 10 mi to the east in Delaware City. In Delaware City, near the center of a steep cone of depression (Lacombe and Rosman, 2001), the water-level altitude was approximately -175 ft NGVD 29 in both 1998 and when measured again in 2003. Martin (1984) reported water levels in this area at approximately -130 ft in 1980, though simulated water levels were lower at -160 ft. The simulated 1980 water levels of Leahy and Martin (1993), however, do not capture the depth of this cone; subsequent comparisons with 2000 data yield decline values that are probably overestimated. While water levels in the cone of depression remain at altitudes far below 0 ft NGVD 29, actual decline during this period was probably less than 40 ft. Total decline in this area from prepumping conditions to 2000 was approximately 200 ft. To the west, along the border with Maryland, apparent declines of 20 to 40 ft near pumping centers were observed. Measured water-level data in the Lower Potomac for 1980 in this area were absent. Simulated 1980 water levels in this area by Martin (1984) and Leahy and Martin (1993) differ substantially; contours from Martin (1984), which were nearly 20 ft lower at 0 to -20 ft NGVD 29, were used for comparison, and resulting change values were more subtle. In northern New Castle County along the Delaware River, scattered areas of limited lateral extent show water-level rises. Wells in this area exhibit seasonal fluctuations of 10 to 15 ft as a result of nearby pumping, and though water levels generally stabilized or have risen slightly, larger rises may be an artifact of when measurements were taken. Elsewhere, water levels generally changed little within the state between 1980 and 2000. Lacombe and Rosman (2001) estimate that daily ground-water withdrawals were 5 to 6 Mgal from the Lower Potomac aquifer in Delaware from 1978 to 1997 and noted little change in the potentiometric surface of the aquifer in Delaware during this time.

From 1980 to 2000, water levels in the regional cone of depression at Camden County, N.J., had recovered from 13 to 30 ft. Beginning in 1988, the New Jersey Department of Environmental Protection declared the Lower Potomac aquifer in the Camden area a critical area, and withdrawals from the aquifer were limited to stabilize or reduce the cone of depression in the potentiometric surface (Lacombe and Rosman, 2001). Withdrawals from the Lower Potomac aquifer during 1980 totaled approximately 68 Mgal/d, but by 2000, because of conservation measures, withdrawals had decreased to 38 Mgal/d (unpublished data on file at the USGS New Jersey WSC), resulting in substantial water-level rises in Camden County. Elsewhere in New Jersey, water levels generally did not change.

Selected hydrographs for wells open to the Lower Potomac aquifer are shown in figure 36; locations are indicated in figure 33. The hydrograph for well 7-412 Elm Tree 2, located at the center of the cone of depression in Camden County, N.J., shows a water-level altitude of 6 ft NGVD 29 when data collection began in 1964. Steadily increasing withdrawals from nearby pumping centers had caused water levels to fall to -63 ft by 1980, a decline of nearly 70 ft. The water level in this well declined through 1988, after which withdrawals from the aquifer began to decrease, and heads stabilized from 1988 to 1996. Further reductions in withdrawals subsequent to 1996 resulted in a sharp rise of more than 20 ft from 1996 to 1998; thereafter, levels generally were stable. The estimated prepumping water level at this well was about 25 ft, indicating a total decline of about 80 ft.

Well EC3207, located in New Castle County, Del., on the southwest side of the steep cone of depression, shows a water-



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 35. Estimated water-level changes in the Lower Potomac aquifer, circa 1980 to 2000.

level decline of about 40 ft between 1968 and 1980. From 1980 to 2000, the hydrograph indicates a prevailing downward trend, during which water levels declined an additional 15 ft. The net deficit in water-level altitude for the period of record was approximately 55 ft; total decline from estimated pre-pumping levels was about 120 ft.

The hydrograph of 2S5E-1 (3), located in the city of Baltimore near the updip extent of the aquifer, shows a water-level altitude of -53 ft NGVD 29 in 1943. By 1958, the water level in this well declined nearly 20 ft, after which, from 1958 to 1964, water levels rose. In 1983-84, water levels again declined. During the latter part of 1997, water levels rose sharply when nearby pumpage was reduced.

Well AA Ad 29 (4), located in Anne Arundel County, Md., was flowing when first measured in 1948; between 1948 and 1958, water levels remained nearly constant at 48 ft NGVD 29. Seasonal fluctuations in water levels after 1959 indicate effects of nearby pumping, and by 1980, the water level in this well had declined more than 60 ft. Between 1980 and 2000, although sharp rises were apparent in 1989 and 1994, water levels declined an additional 15 ft.

The hydrograph for well 56J 11 (5), located at the center of the cone of depression at West Point, Va., shows that between 1962 and 1980, the water level declined about 60 ft, and the estimated deficit from predevelopment conditions to 1980 was about 110 ft. From 1980 to 2000, nearby increases in pumpage caused water levels to decline an additional 40 ft, indicating a total decline from prepumping levels of about 150 ft.

Water-Level Changes in Aquifers of the Southeastern Atlantic Coastal Plain

Analysis of water-level data and changing water-level conditions are provided for four regional aquifers of the southeastern Atlantic Coastal Plain. These include the Upper Floridan aquifer in southeastern South Carolina, Georgia, and northeastern Florida and the Pearl River, Chattahoochee River, and Black Warrior River aquifers in South Carolina and Georgia.

The carbonate rocks of the Upper Floridan aquifer system and its stratigraphic and hydrologic relation to lateral and underlying clastic sediments comprising the Pearl, Chattahoochee, and Black Warrior River aquifers in South Carolina and Georgia are described in detail by Miller (1992), Renken (1996) and Barker and Pernik (1994) as part of the USGS RASA Program for the Floridan and southeastern Coastal Plain aquifer systems. These regional aquifers range in age from Cretaceous to Tertiary, encompass numerous local aquifers and geologic formations, and have been defined on the basis of overall hydraulic and stratigraphic continuity. A brief description of the geologic and local hydrogeologic units comprising each regional aquifer based on Miller (1986) and Renken (1996) is included in each section below. The stratigraphic relation of the regional and subregional aquifers of the Southeastern Atlantic Coastal Plain is shown in table 2**.** A generalized time stratigraphic relation between regional aquifers of the Northern Atlantic Coastal Plain and Southeastern Coastal Plain study areas is shown in table 3.

Upper Floridan Aquifer

The Floridan aquifer system which was mapped and described in detail by Miller (1986) includes highly permeable carbonate rocks of Oligocene, Eocene, and Paleocene age. The major geologic units that constitute the Upper Floridan aquifer are from youngest to oldest, the Suwannee Formation, the Ocala limestone, and the Avon Park Formation.

The boundary for the Upper Floridan as used in this report was modified from Krause and Randolph (1989) and encompasses approximately 27,750 mi^2 in Georgia, southern South Carolina, and northeastern Florida. The southwestern limit of the study area was slightly contracted to bound both prepumping and 1980 potentiometric contours in this area. In southern South Carolina, the area north of Beaufort and Hampton Counties was omitted where the Upper Floridan aquifer is thin or absent.

The areas of highest recharge within the Upper Floridan occur near the updip part of the aquifer, where it is either exposed or near land surface (Krause and Randolph, 1989). Ground-water flow in the Upper Floridan prior to pumping was generally from these updip areas southeastward toward major streams and rivers, where ground water was discharged (fig. 37). As ground water flows coastward, low permeability sediments near the Gulf Trough inhibit flow and steepen the hydraulic gradient, as indicated by closely spaced contours ranging from 80 to 120 ft on the potentiometric surface map (Krause and Randolph, 1989; Payne and others, 2005). Ground water also flowed from potentiometric highs in the southwest near Valdosta (Lowndes County), Ga., where the aquifer is unconfined or semiconfined, toward the Atlantic Ocean. Ground water also flowed from a potentiometric high at the southern end of the study area in Clay County, Fla., where ground water discharged as springs along the St. Johns River. The widely spaced contours on the potentiometric-surface map in the southeastern part of the study area indicate lower velocities and primarily lateral flow, where recharge and discharge were minimal and the aquifer is highly transmissive (Krause and Randolph, 1989).

By 1980, the coastal region stretching from northeastern Florida to the South Carolina border was the most heavily pumped area of the aquifer (Johnston and Bush, 1988). In 1980, total estimated withdrawals from the Floridan aquifer system within the study area were 625 Mgal/d (Krause and Randolph, 1989); nearly three-fourths of this pumpage was concentrated in coastal regions. As a result, substantial cones of depression had formed by 1980 in the coastal areas of Georgia, near Savannah and Brunswick, and near St. Marys, Ga., and Fernandina Beach, Fla., (fig. 38). Shallower cones of

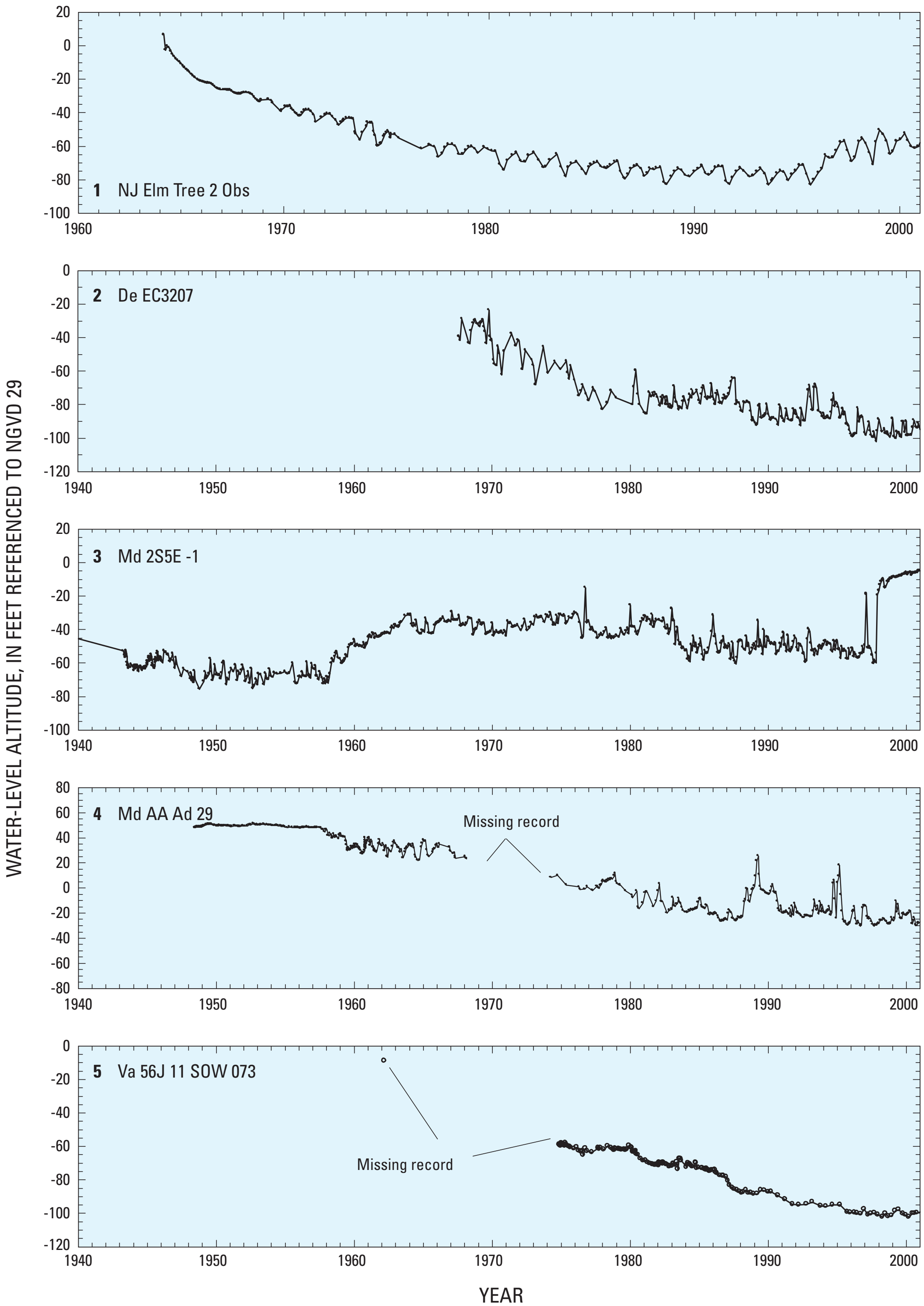


Figure 36. Selected hydrographs from wells screened in the Lower Potomac aquifer. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 33.)

Table 2. Southeastern Atlantic Coastal Plain, relation of regional aquifer names and subregional aquifer names used in this study.

[Modified from Miller and Renken (1988), Clarke and West (1997) and Harrelson and Fine (2006).]

Regional aquifer	Subregional aquifer		
	Florida	**Georgia**	**South Carolina**
Upper Floridan	Upper Floridan	Upper Floridan	Upper Floridan
Pearl River		Upper Three Runs Gordon Claiborne	Upper Three Runs Gordon
Chattahoochee River		Clayton Providence Millers Pond Dublin Middendorf Midville	Black Creek Middendorf
Black Warrior River		Tuscaloosa	Cape Fear

Table 3. Generalized time-stratigraphic correlation of Northern Atlantic and Southeastern Coastal Plain regional aquifers.

<table>
<tr><th>Southeastern Coastal Plain Regional aquifer</th><th colspan="2">Series Time Stratigraphic Relationship</th><th>Northern Atlantic Coastal Plain Regional aquifer</th></tr>
<tr><td rowspan="2"></td><td colspan="2" rowspan="2">Miocene</td><td>Upper Chesapeake</td></tr>
<tr><td>Lower Chesapeake</td></tr>
<tr><td>Upper Floridan</td><td colspan="2">Oligocene</td><td rowspan="2">Castle Hayne-Piney Point</td></tr>
<tr><td>Pearl River</td><td colspan="2">Eocene</td></tr>
<tr><td rowspan="4">Chattahoochee River</td><td colspan="2">Paleocene</td><td>Beaufort-Aquia</td></tr>
<tr><td rowspan="5">Cretaceous</td><td>upper</td><td>Peedee-Severn</td></tr>
<tr><td></td><td>Black Creek-Matawan</td></tr>
<tr><td></td><td>Upper Potomac and Magothy</td></tr>
<tr><td rowspan="2">Black Warrior River</td><td></td><td>Middle Potomac</td></tr>
<tr><td>lower</td><td>Lower Potomac</td></tr>
</table>

depression also were evident in the vicinity of Jacksonville, Fla., and inland near Jesup, Ga., along the border of Long and Wayne Counties.

Estimated total pumpage in the aquifer in 1980 at Brunswick, Ga., was approximately 95 Mgal/d (Payne and others, 2005); total withdrawals from the aquifer in the vicinity of Savannah were approximately 75 Mgal/d. The cone of depression at Savannah was steep and laterally extensive; its influence propagated more than 15 mi in all directions and more than 20 mi in the seaward direction. Water-level altitudes as low as -129 ft NGVD 29 were measured near the center of the cone in 1980. In contrast, the cone of depression at Brunswick extended radially for only a few miles; the lowest observed water levels were about -15 ft NGVD 29. Although withdrawals were greater in the Brunswick area than at Savannah, the cone of depression was shallower, and decline was less because the high transmissivity of the aquifer and leakage from adjacent units increased water availability (Krause and Randolph, 1989). Similar conditions prevailed near Jacksonville, Fla.; substantial withdrawals have caused water levels to decline to 31 ft NGVD 29, but the cone of depression was limited in depth and breadth by high interaquifer leakage rates. North of Jacksonville, near the Fernandina Beach, Fla.,-St. Marys, Ga., area, a cone of depression, extending from southeastern Camden County, Ga., to northeastern Nassau County, Fla., had formed as a result of substantial industrial and municipal withdrawals. Water-level altitudes near the center of the cone had declined to -23 ft NGVD 29.

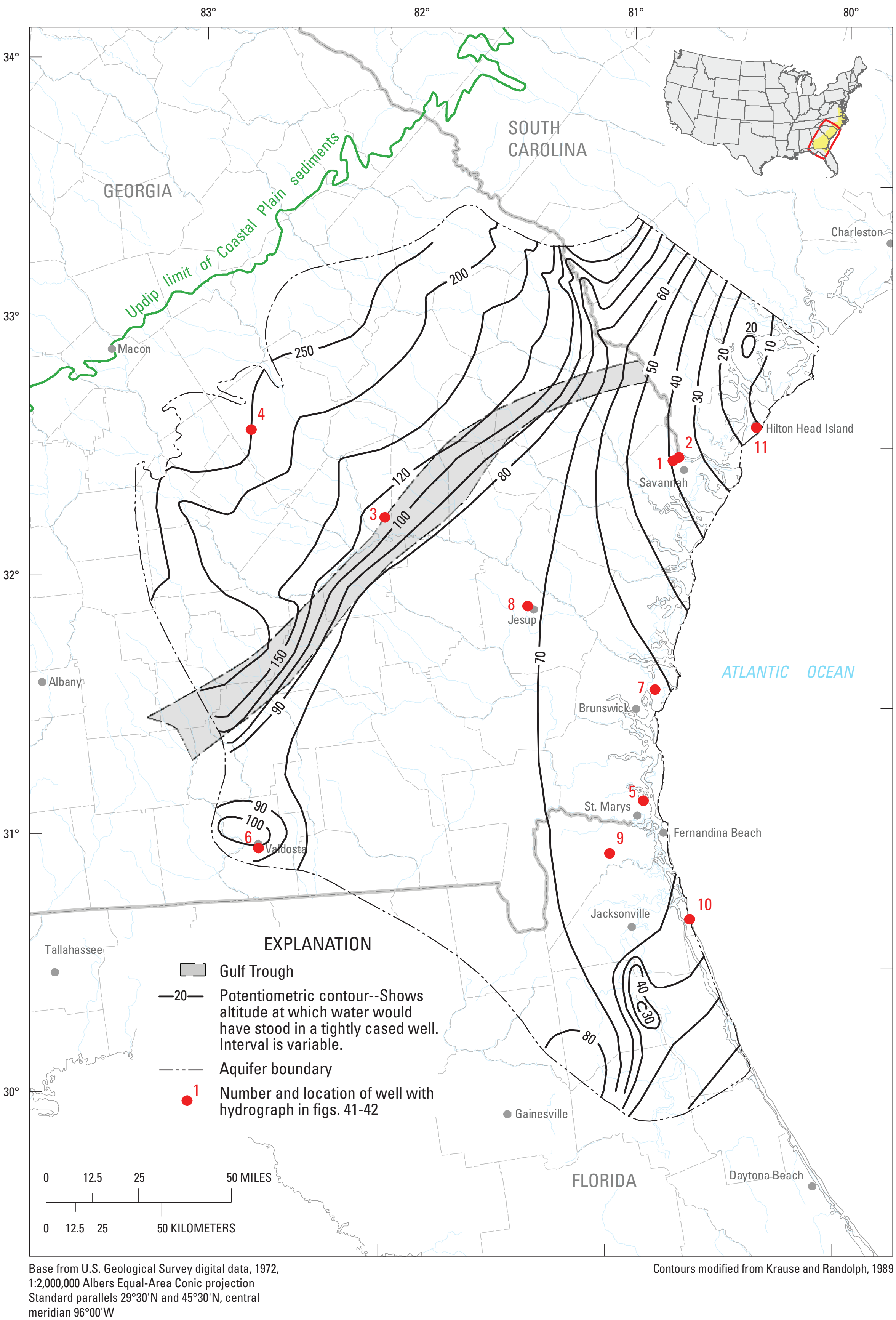
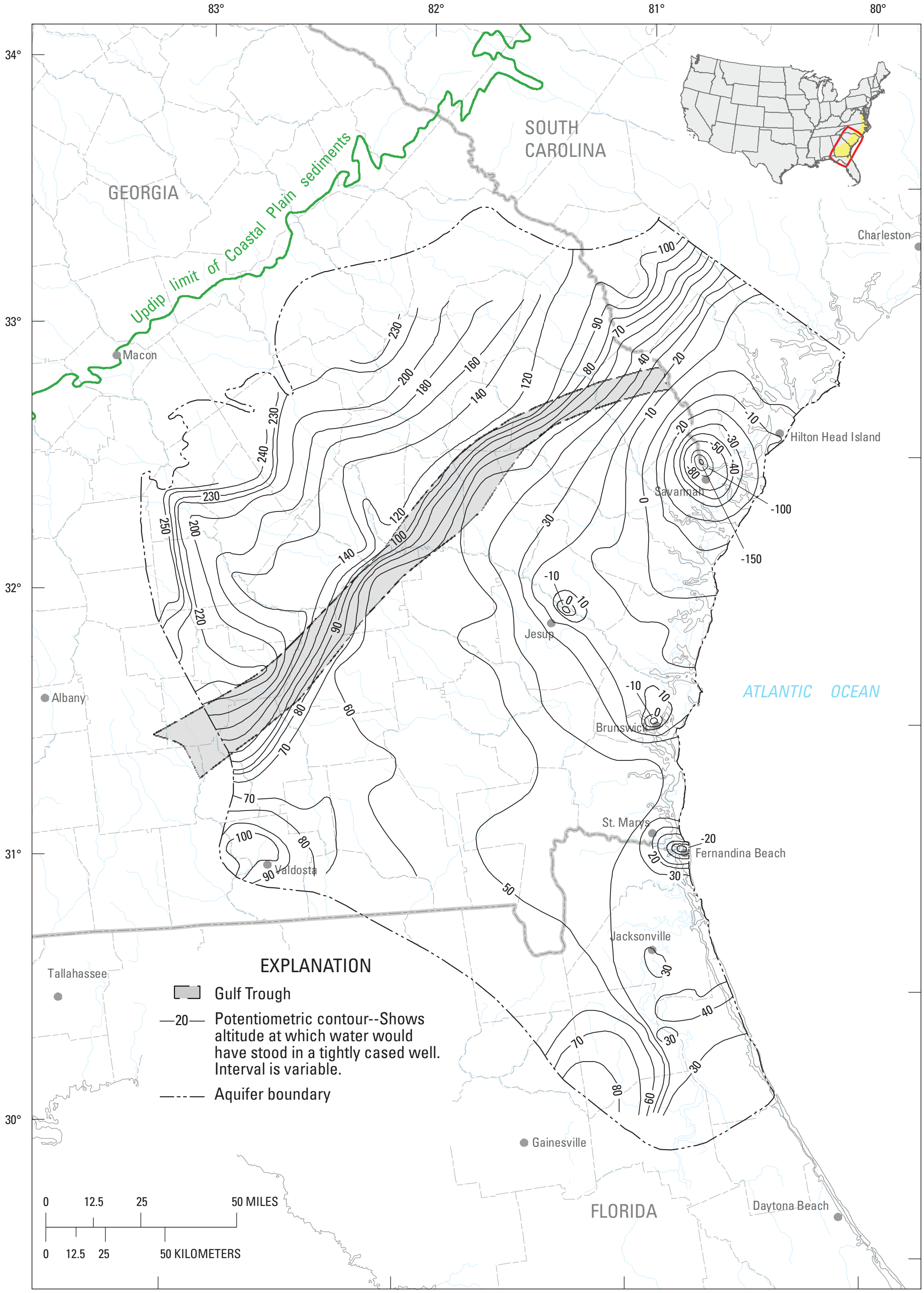


Figure 37. Estimated potentiometric surface of the Upper Floridan aquifer, prior to development.



Base from U.S. Geological Survey digital data, 1972,
1:2,000,000 Albers Equal-Area Conic projection
Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Contours modified from Krause and Randolph, 1989

Figure 38. Estimated potentiometric surface of the Upper Floridan aquifer, 1980.

By 1980, water levels declined 10 ft or greater across much of the eastern part of the Upper Floridan aquifer within the study area. (fig. 39). Hydraulic head in the aquifer was such that wells flowed at land surface throughout much of coastal Georgia prior to large-scale pumping; by 1980, this area of artesian flow was reduced substantially (Krause and Randolph, 1989). Decline in aquifer water levels was greatest at the regional cones of depression in Georgia; the area influenced by the three major pumping centers at Savannah, Jesup, and Brunswick had merged to produce a contiguous area characterized by a minimum of 40 ft of decline. A similar pattern was recognized by Krause and Randolph (1989). Declines exceeded 50 ft in a large area that includes the Savannah cone of depression along with pumping centers in neighboring Bryan, Liberty, Long, and Wayne Counties in Georgia and extending north into Jasper and Beaufort Counties in South Carolina. In Chatham County, Ga., water-level declines ranged from 45 ft near the coast to 161 ft at Savannah, or at rates of approximately 0.5 ft/yr to 1.6 ft/yr. Near the city of Brunswick, Ga., water levels declined, on average, nearly 70 ft, but up to more than 80 ft in places. In the Jesup-Doctortown, Ga., area, at the cone of depression straddling the border of Wayne and Long Counties, water levels had declined at pumping wells to altitudes ranging from 10 to -30 ft NGVD 29. Prepumping water levels were estimated at approximately 70 ft NGVD 29, indicating that, by 1980, total decline ranged from 60 to 100 ft. Estimated withdrawals in 1980 from the aquifer in Wayne County of 75 Mgal/d (Fanning, 2003; Payne and others, 2005) were largely attributed to industrial pumping along the Altamaha River. Withdrawals from the aquifer in neighboring Long County were minor at less than 300,000 gal/d.

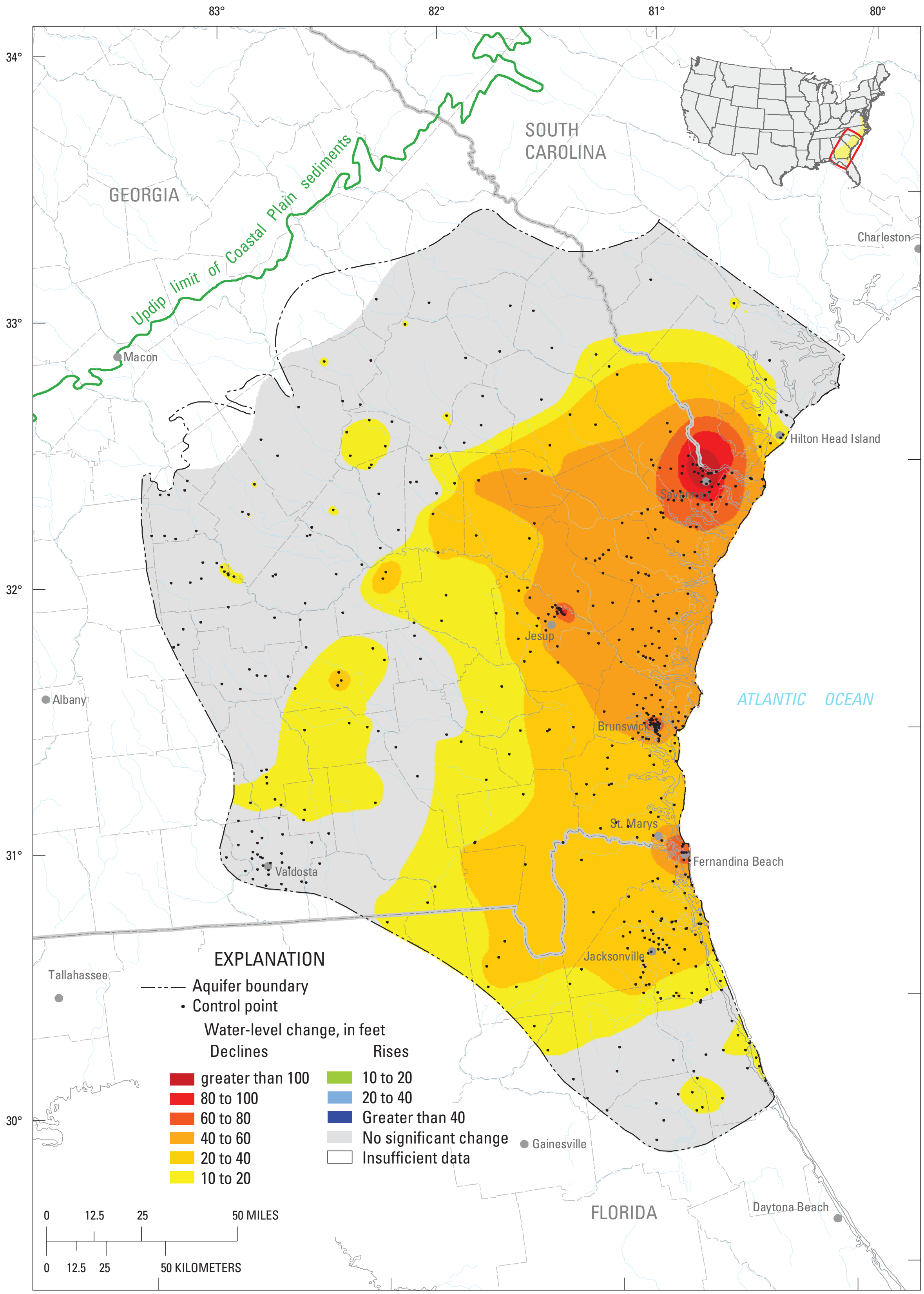
In the St. Marys, Ga.,-Fernandina Beach, Fla., area, water-level decline from prepumping conditions ranged from 25 to 80 ft; declines were greatest in Fernandina Beach and decreased toward south-central Camden County, Ga., where 4 mi west of St. Marys, declines were generally about 25 ft. Combined 1980 withdrawals from the Upper Floridan aquifer from both Camden and Nassau Counties were approximately 81 Mgal/d (Payne and others, 2005).

Throughout Duval County, Fla., water levels declined from 5 to 40 ft relative to prepumping levels; the smallest declines occurred in the southern and southwestern parts of the county and the largest in and around the city of Jacksonville. Near Jacksonville, water levels had declined, on average, about 28 ft, though, nearer the center of the cone of depression, declines typically were in excess of 30 ft. Withdrawals from the Floridan aquifer system in Duval County during 1980 of 146 Mgal/d, with approximately 64 percent from the lower Floridan, represented the largest concentrated pumpage from the aquifer system. Effects of these large withdrawals from the Upper and Lower Floridan were tempered by the high transmissivity of the aquifer here, and declines were less severe than those observed at other large pumping centers.

Water-level declines of 20 to 40 ft extended from the coastal, developed area of Georgia as far updip as Evans, Tattnall, and Bulloch Counties, where the Gulf Trough limited the expansion of head decline (Krause and Randolph, 1989). Moderate ground-water-level declines also were observed in central Coffee and northern Jeff Davis Counties and near the northwestern limit of the study area. Decline from prepumping levels in these areas was typically 10 to 15 ft, although declines of more than 20 ft occurred in limited areas near public-supply wells. Estimated withdrawals during 1980 from Coffee and Jeff Davis Counties were approximately 12.5 and 5.1 Mgal/d, respectively, and areas of declining heads generally were coincident with lower permeability sediments of the Gulf Trough. Near the northwestern limit of the aquifer, scattered areas of limited extent and apparent water-level declines of 10 to 15 ft were observed. Withdrawals from the aquifer in these areas typically were minor, and declines in these areas may be an artifact of overestimated prepumping levels.

In 1998, substantial cones of depression were still persistent near Savannah, Brunswick, and Jesup, Ga., and in the St. Marys, Ga.,-Fernandina Beach, Fla., area (Peck and others, 1999), although water levels generally had stabilized. The distribution of ground-water withdrawals had shifted inland from Georgia's coastal region resulting in a combination of stable to recovering water levels along the coast and moderate declines to the west (Payne and others, 2005). Water levels at the ground-water highs at Valdosta and Keystone Heights in Clay County and those along most of the updip limit of the aquifer showed little to no change from 1980 to 1998.

At the center of the major cone of depression near Savannah, Ga., ground-water levels recovered from 10 to 20 ft in response to a decrease in pumping (fig. 40). Away from the center of the cone, water levels generally were stable; however, both declines and rises of up to 9 ft were observed. Although the population dependent on ground water increased by more than 12 percent from 1985 to 2000, total ground-water pumpage in Chatham County decreased by 10 percent during this period. Moreover, the amount of ground water withdrawn from the Upper Floridan aquifer decreased by about 14 percent during 1980 to 2000 (Payne and others, 2005). Less-pronounced rises occurred at the cones of depression in Brunswick and Jesup, Ga. At Brunswick, Ga., water levels in the area influenced by the cone of depression rose on average 8 ft and by as much as 17 ft near the center, in response to substantial reductions in ground-water withdrawals. During 1980 to 2000, ground-water withdrawals from the Upper Floridan aquifer in Glynn County were reduced by 34 Mgal/d, or 36 percent (Payne and others, 2005). Withdrawals also were reduced near the Jesup-Doctortown cone of depression, and as a result, water levels recovered at magnitudes similar to those observed at Brunswick, though more limited in extent. Away from the center of the cone, change was subtler, where both slight declines and rises were observed. Near St. Marys, Ga.-Fernandina Beach, Fla., area, withdrawals increased from 1980 levels; however, water levels did not substantially change between 1980-98. In the Jacksonville area of Duval County, Fla., ground-water withdrawals from the Upper Floridan decreased slightly from 1980 to 2000, though pumpage from the Lower Floridan had increased (Payne and



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 39. Estimated water-level changes in the Upper Floridan aquifer, predevelopment to 1980.

others, 2005). Stable to slightly declining water levels were observed near the city of Jacksonville, but to the east, water levels declined from 10 to 15 ft relative to 1980 levels.

In Beaufort County, S.C., water levels circa 2000 generally were lower than those measured in 1980. Near the coast, water levels were typically 6 to 8 ft lower than in 1980, but in the north-central part of the county, water levels had declined from 10 to 12 ft. The Upper Floridan in Beaufort County supplied 21 Mgal/d during 2000, and although withdrawals were substantial since the mid 1980s, reported withdrawals during 1980 were less than 1 Mga1/d (Payne and others, 2005).

Water-level declines of more than 10 ft were observed in scattered areas from the southwestern boundary of the study area toward the northeast, approximately trending along the Gulf Trough. Declines of 10 to 15 ft centered around pumping wells typically were limited in areal extent. Withdrawals from the aquifer in these counties were generally low, although in some areas, pumpage had substantially increased from 1980 to 2000. In central Bulloch County, Ga., in the north-central part of the study area, water levels declined up to 30 ft. Withdrawals had increased from 1980 to 2000 but were relatively low at approximately 6 Mgal/d; however, some of the least transmissive strata of the Upper Floridan in the study area, ranging from 2,900 to 6,600 ft^2/d (Clarke and others, 2004), are present here and probably contributed to declining heads. Near the northwestern limit of the aquifer, in Washington County, water levels declined more than 30 ft in an area where the aquifer thins and transmissivity is low.

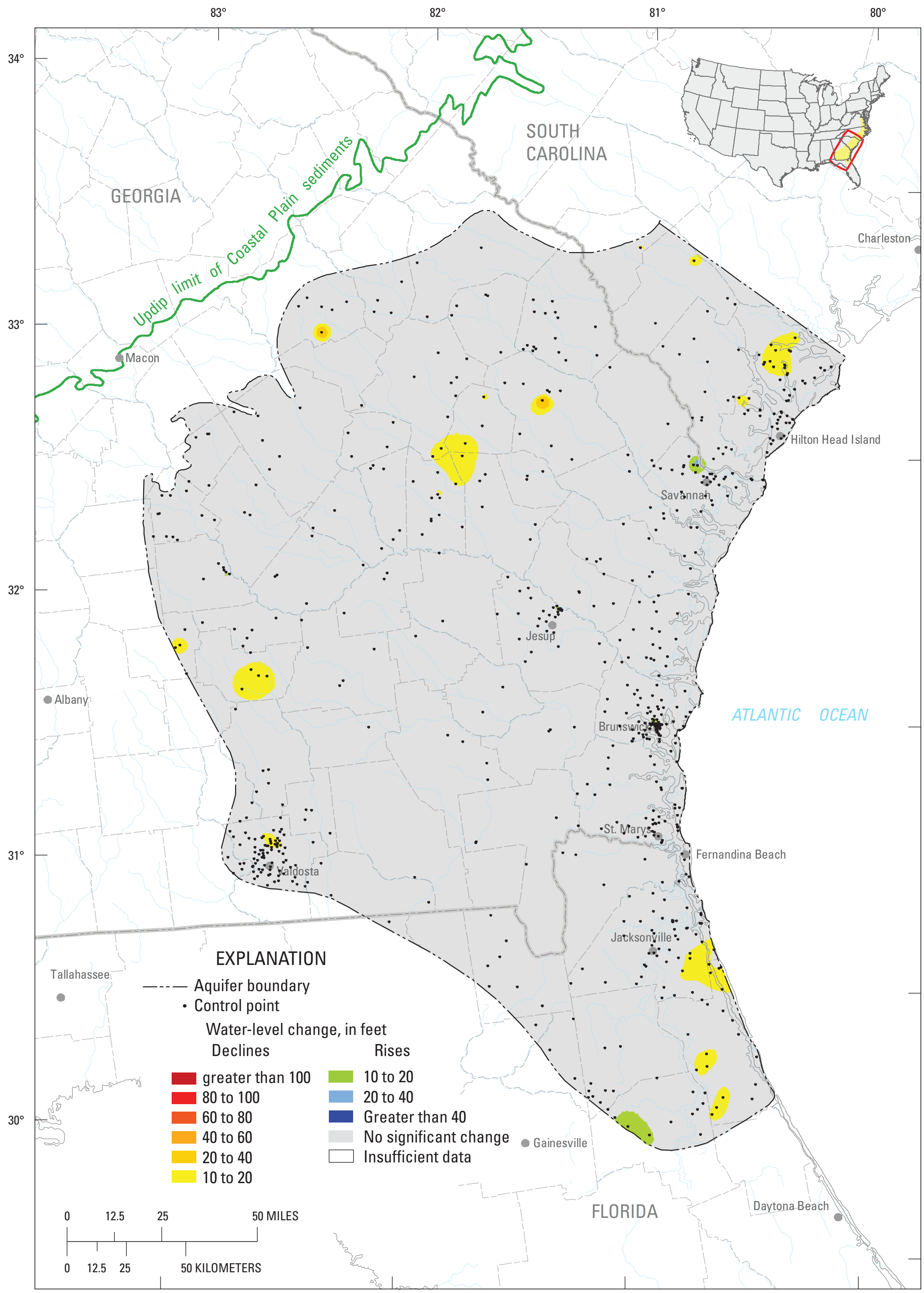
In northeastern Florida, near the southern boundary of the study area, water levels rose 10 to 15 ft in parts of Putnam County, but toward the east, heads typically declined 5 to 15 ft from 1980 levels.

Payne and others (2005) indicated a similar pattern of head decline in the Upper Floridan aquifer from 1980 to 2000. Declines of 10 to 20 ft were simulated for most of the western part of the study area; total decline exceeded 20 ft along parts of the western and northern boundaries and in small areas of Screven and Toombs Counties in Georgia. Simulated changes throughout most of the study area typically were greater than observed changes represented here. Simulated rises in water level at the major cone of depression at Savannah were greater than those observed. In Screven County, Ga., simulated declines of more than 20 ft were likely based on large increases in withdrawals that occurred between 1997 and 2000. Effects of increased withdrawals were not yet evident in 1998 water-level data, which yielded measurements that were generally 5 ft greater than 1980 levels. Simulated declines near the northwestern limit in Washington County, Ga., encompass much of the county and may result from low transmissivity and proximity of significant pumpage to a no flow boundary (Payne and others, 2005); observed data suggest that the area of declining head is less extensive.

From predevelopment to 1998, water-level declines of at least 20 ft occurred over 50 percent of the study area, and declines of 40 ft or greater occurred over 33 percent of the extent. Decline was greatest along the heavily developed coastal region and, in particular, in Chatham County, near Savannah, Ga. Within the area influenced by the cone of depression centered near here, declines averaged nearly 90 ft from prepumping levels. The maximum decline near Savannah, 145 ft, was also the largest observed within the aquifer. Inland, near Jesup, Ga., decline from prepumping levels to 1998 ranged from 45 to nearly 90 ft, and in the Brunswick area, declines averaged 51 ft, ranging from 40 to 75 ft. Of the five major areas of heavy withdrawals identified within the coastal region, water levels were least affected in the Jacksonville, Fla., area, where the average decline was less than 30 ft and did not exceed 40 ft.

Selected hydrographs from wells open to the Upper Floridan aquifer are shown in figure 41 (Georgia) and figure 42 (South Carolina and Florida), locations are indicated in figure 37. The hydrographs indicate varying responses in water levels because of local differences in the patterns and magnitude of ground-water pumping as well as local variations in aquifer properties. The hydrographs from wells 37Q006 and 36Q008, near the center of the cone of depression at Savannah, Ga., indicate a long-term pattern of decline to 1980. The water level in well 37Q006 was at -59 ft NGVD 29 in early 1940; by late 1980, the water level had declined to its low of 146 ft below NGVD 29. The hydrograph for well 36Q008, located approximately 1.8 mi to the southwest, shows a similar pattern at the early part of the record, but after 1980, water levels within the well indicate that the cone of depression had generally stabilized and recovered slightly through 2000. Well 25Q001, located in the north-central part of the study area in southern Montgomery County, Ga., shows a general downward trend from 1966 through 2000. Water levels had declined nearly 10 ft by 1980. Seasonal fluctuations in this well increased after 1980, and water levels declined an additional 15 ft through 2000. Well 21T001, located near the outcrop of the aquifer in western Laurens County, shows marked seasonal water-level fluctuations but little overall trend for the period of record because of high rates of recharge and low pumpage in the area (Krause and Randolph, 1989). Water levels in the St. Marys–Fernandina Beach area also show little change from 1980 to 1998. The hydrograph for 33E027, located near the cone of depression at St. Marys, Ga., shows periods of declining and rising water levels but little overall trend from 1980 to 1998. Subsequent to 1998, increasing withdrawals in Camden County between 1997-2000 (Payne and others, 2005) have again caused ground-water levels to decline.

Water levels in observation well 19E009, near the city of Valdosta in Lowndes County, show pronounced seasonal fluctuations in response to recharge from precipitation and surface-water infiltration. The hydrograph shows periods of decline and recovery throughout the record but indicates no significant long-term changes through 2000. Water levels in well 34H328, located near the northeastern edge of the cone of depression at Brunswick, Ga., declined more than 30 ft from 1940 through 1980. Water levels rose in 1982, responding to reductions in withdrawals, but declined again through 1990;



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 40. Water-level changes in the Upper Floridan aquifer, 1980 to 1998.

thereafter, limited measurements indicate that heads have probably stabilized. Nearer the center of the cone of depression, water levels were generally 20 ft lower in altitude (well 33H133) and exhibit greater seasonal fluctuations but follow a similar trend. Substantial decreases in pumpage in the Brunswick area during the 1990s resulted in a rise in water levels from 1990 to 1998 (Peck and others, 1999).

Water levels near Jesup, Ga., (well 30L003) declined nearly 15 ft from the mid 1960s to 1980, and although water levels declined and recovered after 1980, the water-level altitude in 1998 was similar to that in 1980. Nearer the pumping centers, water levels generally rose from 1980 to 1998.

Well N-50, located in east-central Nassau County, Fla., shows long-term water-level trends near the western edge of the St. Marys, Ga.,–Fernandina Beach, Fla., cone of depression. Water levels declined approximately 20 ft from 1940 to 1980; from 1980 to 1998 water levels declined an additional 5 ft. Water levels in D-0160, located in eastern Duval County, Fla., declined about 15 ft from the 1940 to 1980. From 1980 to 2000, water levels have declined approximately 10 ft. In Beaufort County, S.C., water levels in well BFT-101 show a slight downward trend from 1978 to 2000.

Pearl River Aquifer

The Pearl River aquifer contains mostly sand but also minor amounts of sandstone, gravel, and transitional carbonate rocks that range in age from Paleocene to late Eocene. Geologic and hydrogeologic units that constitute the Pearl River aquifer in South Carolina and Georgia include the Barnwell Formation and members of the Barnwell Group, locally referred to as the Upper Three Runs aquifer, the McBean Formation and the Gordon aquifer, which consists of the Huber, Congaree, and Fishburne Formations in South Carolina and the Lisbon and Tallahatta Formations of the Claiborne Group in Georgia. The Gordon and Upper Three Runs aquifers are clastic aquifers of middle and late Eocene sediments, respectively, and are the updip age-correlatives of the carbonate Floridan aquifer. The Black Mingo Formation is the lowermost geologic unit included in the regional Pearl River aquifer. In southern Georgia and southwest South Carolina, the rocks of the Pearl River aquifer undergo a facies change into carbonate rocks of the Floridan aquifer system locally including the Santee limestone in South Carolina and the Ocala limestone in Georgia within the regional Pearl River aquifer.

Simulated predevelopment flow in the Pearl River aquifer was generally from the northwest to the southeast in the study area, paralleling the dip of the formation bedding (fig. 43). Recharge to the aquifer occurred in the updip outcrop areas under largely unconfined conditions; ground-water flow in this area was predominantly along relatively short flowpaths, discharging to the major streams and rivers in the area, and only a small percentage of the flow migrated into the deeper part of the system. Base flow to major streams and rivers is illustrated by the concave upstream potentiometric contours crossing deeply entrenched streams such as the Savannah River along the border between Georgia and South Carolina and the Chattahoochee River along Georgia's border with Alabama (Barker and Pernik, 1994). Downdip from recharge areas, inflow to the aquifer occurs as diffuse downward leakage from the overlying carbonates of the Floridan aquifer system (Barker and Pernik, 1994). Farther downdip, deep ground-water flow in the Pearl River discharges primarily as diffuse upward flow into the Upper Floridan aquifer and, to a lesser extent, seaward as lateral flow into the Lower Floridan aquifer.

By 1980, ground-water development in the Pearl River aquifer resulted in substantial water-level declines in eastern South Carolina, southwestern Georgia, and near the updip limit of the aquifer in east-central Georgia (fig. 44). In Dougherty County, Ga., water-level altitudes circa 1980 ranged from 116 to 172 ft NGVD 29 in wells screened within aquifers of the local Claiborne group. Simulated prepumping water-level altitudes in this area were greater than 200 ft (Barker and Pernik, 1994; Faye and Mayer, 1996); in addition, observed predevelopment levels reported by Faye and Mayer (1996) ranged from 200 to 240 ft NGVD 29. Comparison of 1980 levels to estimates prior to development, therefore, suggests apparent declines of 30 to more than 80 ft. Dougherty County, in particular Albany, was one of the more populous areas in southwestern Georgia in 1980, and accordingly, ground-water withdrawals were relatively high at approximately 40 Mgal/d (Fanning, 2003). Much of the pumpage here was a combination of withdrawals from the Floridan, the local Tallahatta (Pearl River aquifer) and the Clayton and the Providence Sand aquifers (Chattahoochee River aquifer), but apportionment among aquifers was unknown. Because long-term data prior to 1980 were unavailable and simulations by Faye and Mayer (1996) and Barker and Pernik (1994) yielded more modest drawdown in this area, the declines depicted in figure 44 may be overestimated.

In Washington County, east-central Georgia, near the updip boundary of the Pearl River aquifer, water levels declined more than 40 ft from prepumping levels. Payne and others (2005) simulated substantial declines here in the Upper Floridan aquifer. Ground-water withdrawals in 1980 averaged about 16 Mgal/d (Fanning, 2003). Ground-water pumping also produced moderate declines in Laurens County, Ga. Water levels typically declined 15 to 20 ft from prepumping levels; however, declines in excess of 20 ft were observed near individual supply wells. Data were not available in the downdip part of the aquifer in Georgia, and therefore, interpretations for this area could not be made.

In eastern South Carolina, water levels declined from predevelopment throughout the coastal region, but the greatest declines were in coastal regions of central Charleston and southern Beaufort Counties as well as in southern Berkeley County. In southern Beaufort County, S.C., water-level altitudes ranging from 1 ft to -14 ft NGVD 29 were observed approaching the Savannah River, indicating declines of up to 40 ft from prepumping levels. Faye and Mayer (1996) simulated a decline in the Savannah, Ga., region of 25 to more

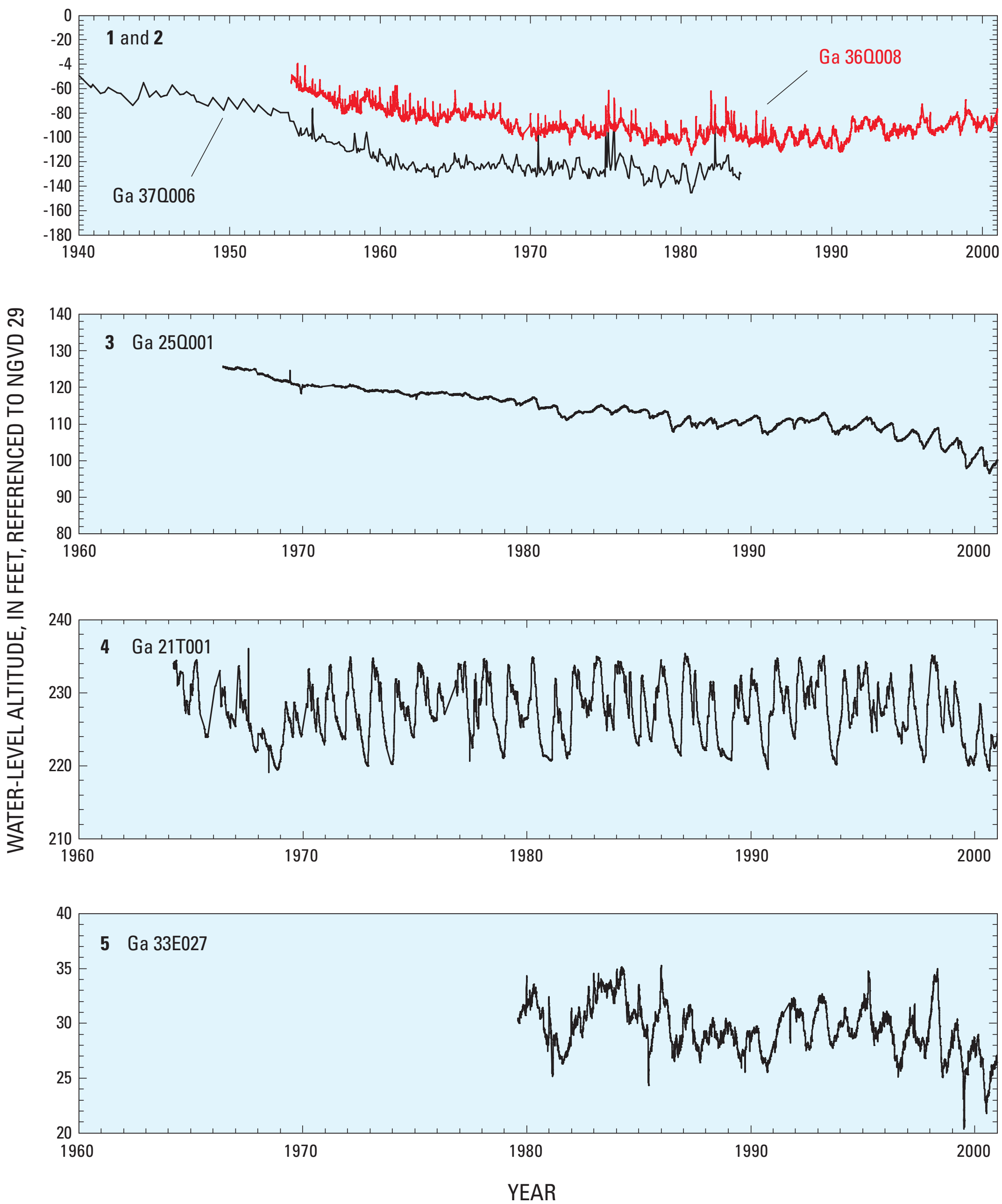


Figure 41. Selected hydrographs from wells open to the Upper Floridan aquifer, Georgia. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 37.)

than 100 ft from predevelopment conditions to 1980, probably a result of increased upward vertical leakage into the heavily utilized Upper Floridan aquifer in this area. In Charleston and Berkeley Counties, water levels declined more than 40 and 60 ft, respectively. The primary aquifer for municipal supply in this area was the Chattahoochee River aquifer, although domestic and smaller community supplies also withdrew from the surficial and the local Santee-Black Mingo aquifer (Pearl River aquifer).

In updip areas of the aquifer in proximity to the Savannah River, water levels generally showed little change from prepumping levels.

From 1980 to 2000, isolated areas of minor to moderate water-level declines were evident throughout South Carolina (fig. 45). In southwestern Georgia, along the border of Dougherty and Lee Counties, water levels declined about 10 to 15 ft. In the southern part of Dougherty County, decline was typically less than 10 ft. Withdrawals increased substantially in

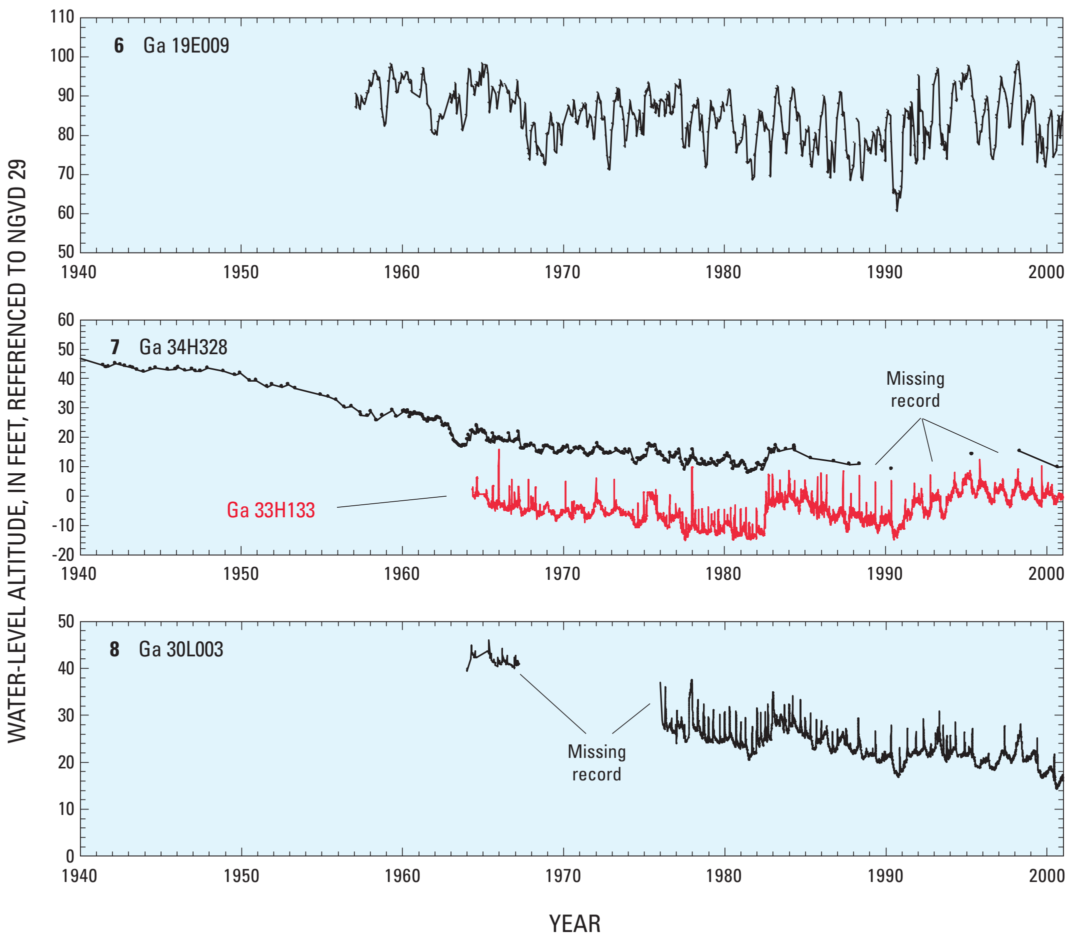


Figure 41. Selected hydrographs from wells open to the Upper Floridan aquifer, Georgia.—Continued (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 37.)

Dougherty County from 1980 to 2000; the estimated increase during this period was approximately 15 Mgal/d or 38 percent (Fanning, 2003) The population in the county, all served by publicly supplied ground water, had decreased slightly during this period; increases in withdrawals here were probably because of substantial increases in irrigated acreage.

Available data for this period throughout much of Georgia were sparse and poorly distributed. Loss of observation points throughout the southwestern and central parts inhibit mapping of regional water-level change; however, single observation wells in Dooly, Crisp, Early, Randolph, and Dodge Counties showed little to no change from 1980 to 2000. In addition, data were not available in other areas that showed decline from prepumping to 1980. Isolated areas of apparent decline in southern Jefferson, Burke, and central Jenkins Counties were probably a result of time of measurement; heads were likely at seasonal lows circa 2000 and therefore are not shown on the map.

In updip areas near the Savannah River, Clarke and West (1997) reported periodic water-level rises and declines that were the result of changes in precipitation and pumpage, although no long-term declines were observed for the period of record to 1993. In the shallower part of the system, declines of more than 15 ft occurred in places in Aiken and Barnwell Counties, S.C., and in northern Jefferson, northern Burke, and southern Screven Counties in Georgia. From 1992 to 2002, Cherry (2003) reported average head decline of nearly 11 and 13 ft within the shallow and deeper parts of the system, respectively.

From 1980 to 2000, isolated areas of minor to moderate water-level declines were evident throughout eastern South Carolina. In the Charleston County area, water levels declined an additional 10 to 20 ft from 1980 levels. Water levels had also declined more than 20 ft proximate to pumping wells in Colleton, Orangeburg, and Dorchester Counties. Minor declines of approximately 10 ft also occurred in areas of western Beaufort, Jasper, and eastern Hampton Counties. Elsewhere throughout South Carolina, water levels were generally stable.

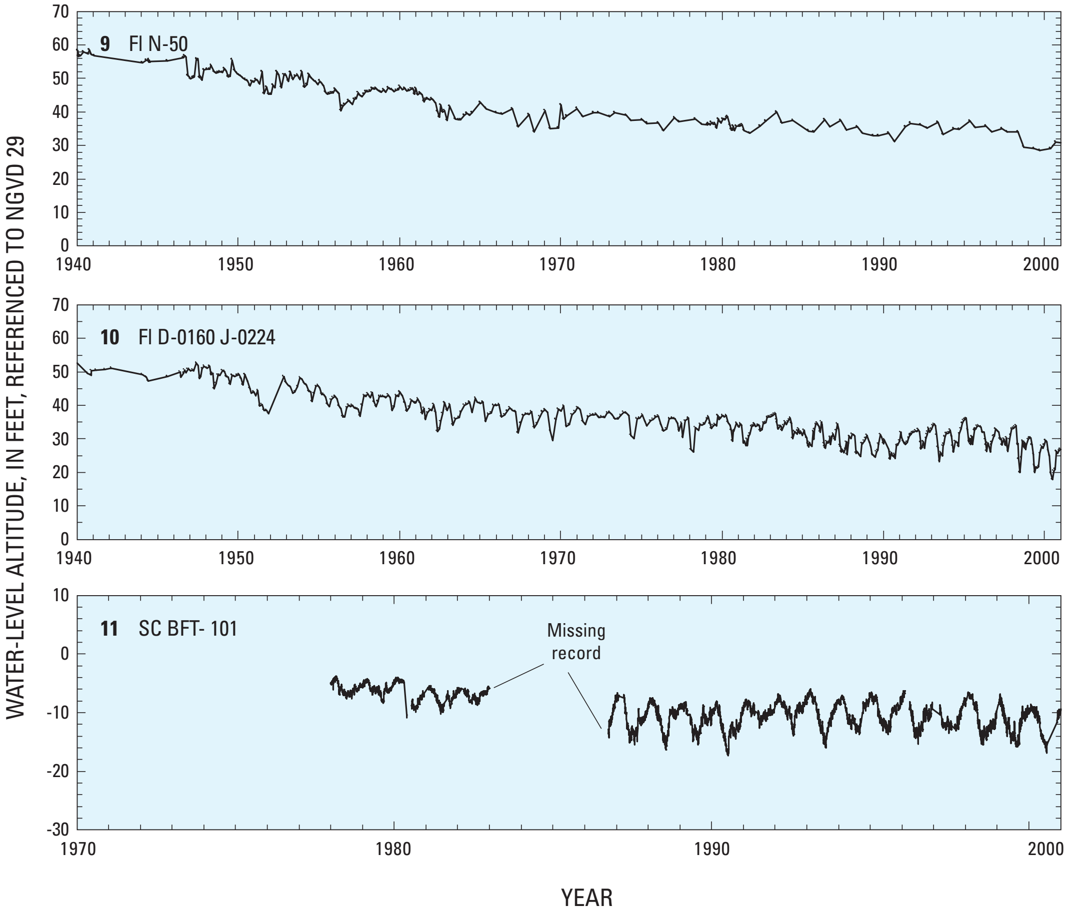


Figure 42. Selected hydrographs from wells open to the Upper Floridan aquifer, South Carolina and Florida. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 37.)

Representative hydrographs from wells screened in the regional Pearl River aquifer are shown in figure 46; locations are indicated in figure 43. Periods of record generally began in the late 1970s, making long-term interpretations difficult. The hydrograph for well CHN-44, located near the city of Charleston, shows that, despite annual fluctuations, the general trend in water-level altitude was downward. From 1980 to 1990, the water level declined approximately 10 ft; from 1990 through 2000, the decline had moderated and levels were lowered an additional 5 ft. In Colleton County, S.C., the water level in COL- 97 also indicates a downward trend throughout the period of record. From 1980 to 2000, water levels declined about 9 ft. In southwestern Georgia, water levels varied as much as 20 ft seasonally in wells 11L001 and 12M001; however, the overall trend in the aquifer here was a moderate decline for the period of record. From 1980 to 2000, water levels declined about 15 ft in both wells. The water level in well 31Z015, proximate to the Savannah River in Burke County, Ga., declined about 10 ft from beginning of the period of record to 1989; subsequent periodic data indicate a slight rise in water levels.

Chattahoochee River Aquifer

The Chattahoochee River aquifer is composed of sand, sandstone, gravel, and minor limestone beds that are locally interbedded and interlaminated with clay, shale, marl, mudstone, and chalk that range in age from upper Cretaceous to Paleocene. Geologic units that comprise the regional aquifer in western Georgia from youngest to oldest include the Clayton Formation, Providence sand, Ripley Formation, Cussetta sand, Blufftown Formation, and the upper part of the Eutaw Formation. In eastern Georgia and South Carolina, the regional Chattahoochee River aquifer includes the Steel Creek Formation and part of the Peedee Formation and units of the Black Creek Group. The aquifer also contains the local Midville aquifer (Clark and others, 1985) and the stratigraphically equivalent Middendorf Formation in eastern Georgia and South Carolina.

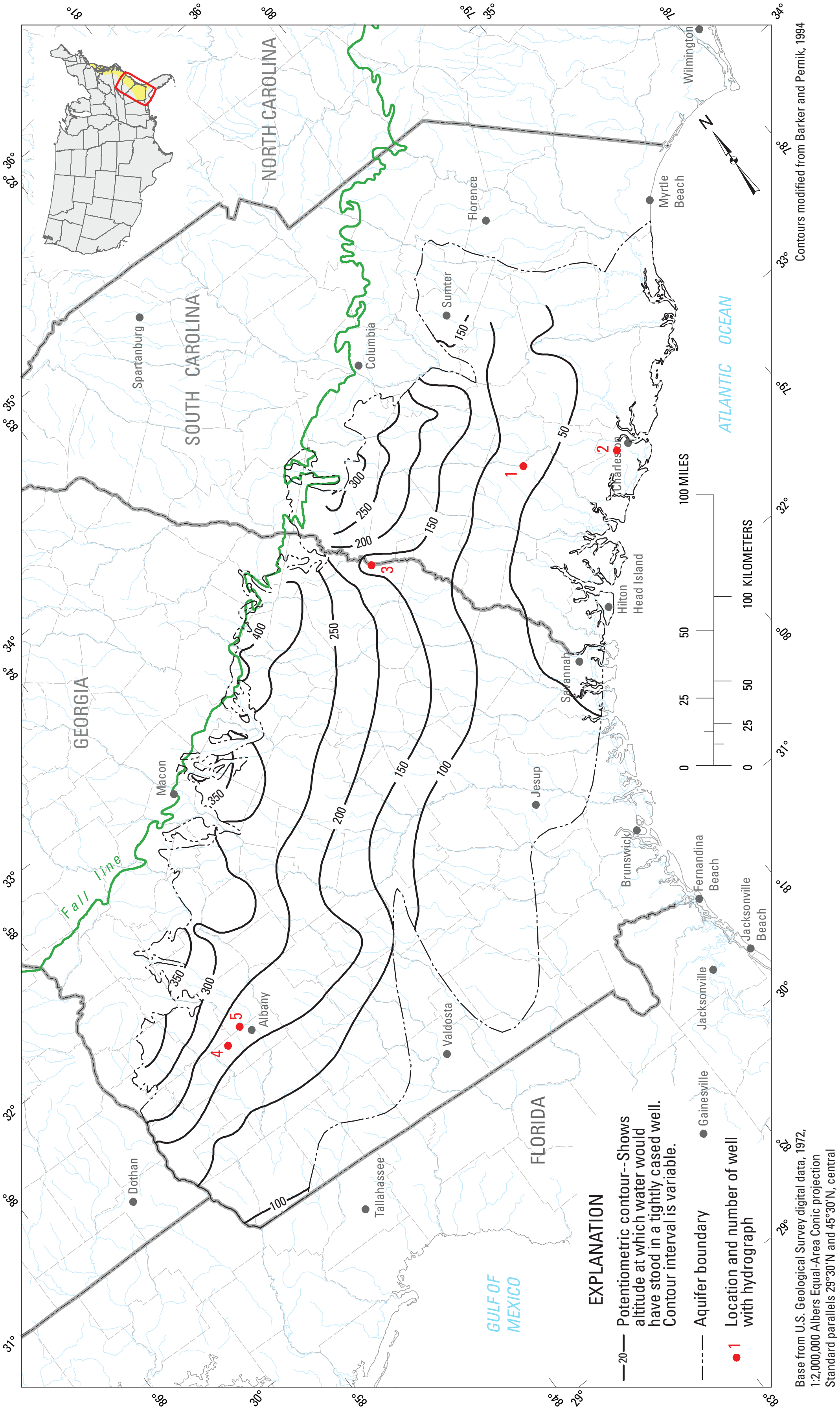
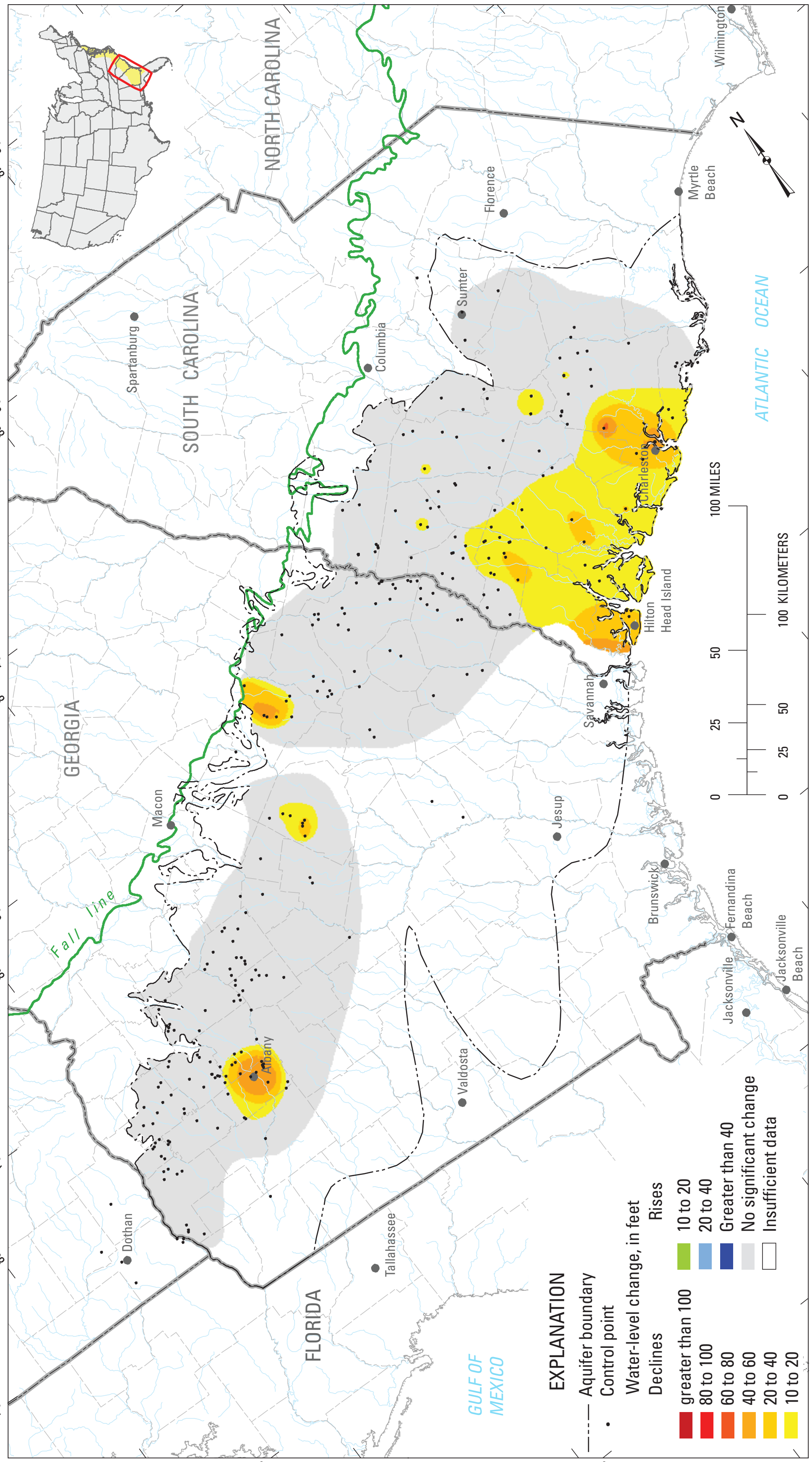
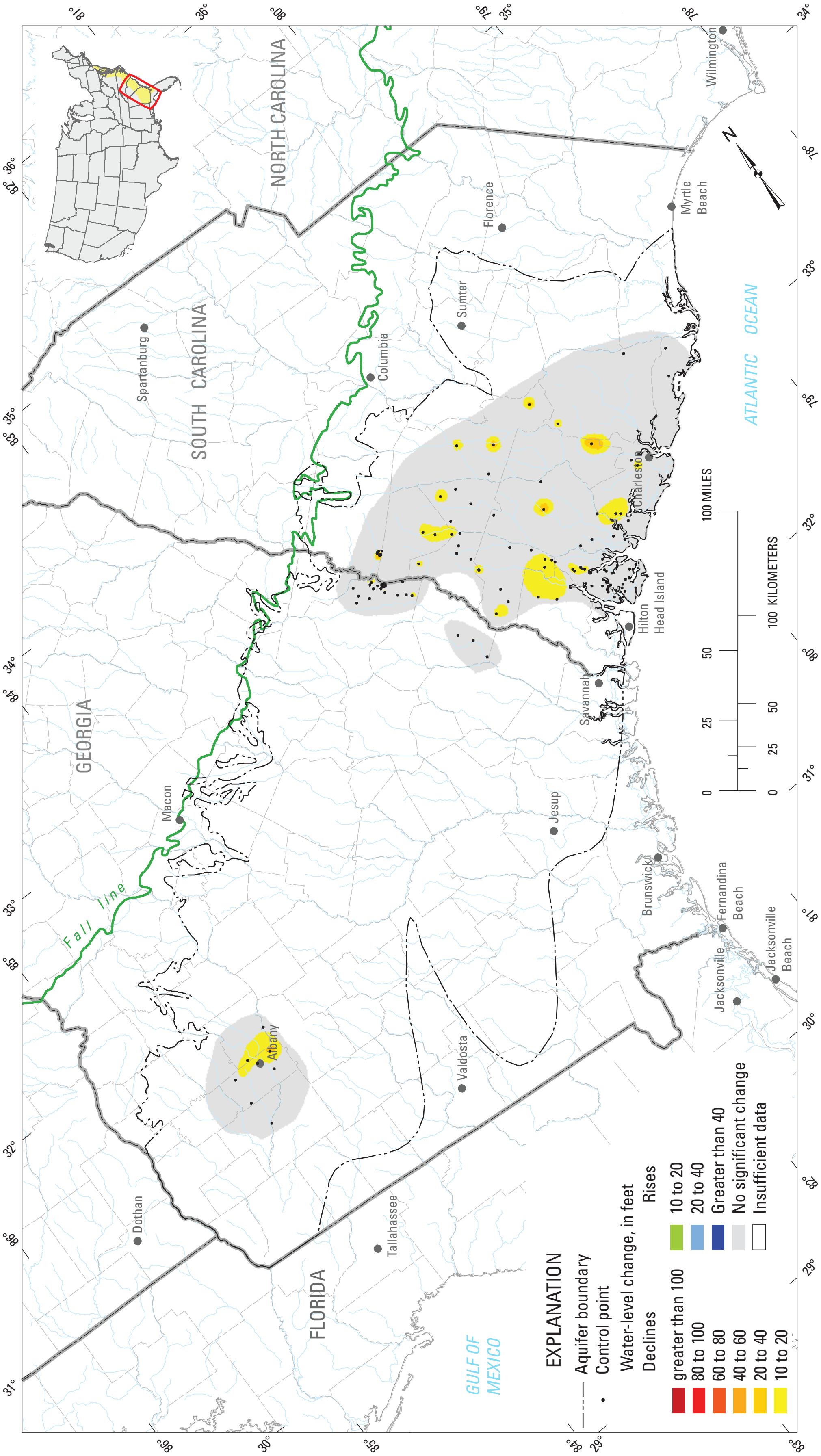


Figure 43. Simulated potentiometric surface of the Pearl River aquifer, prior to development.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 44. Estimated water-level changes in the Pearl River aquifer, predevelopment to circa 1980.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30′N and 45°30′N, central meridian 96°00′W

Figure 45. Estimated water-level changes in the Pearl River aquifer, circa 1980 to 2000.

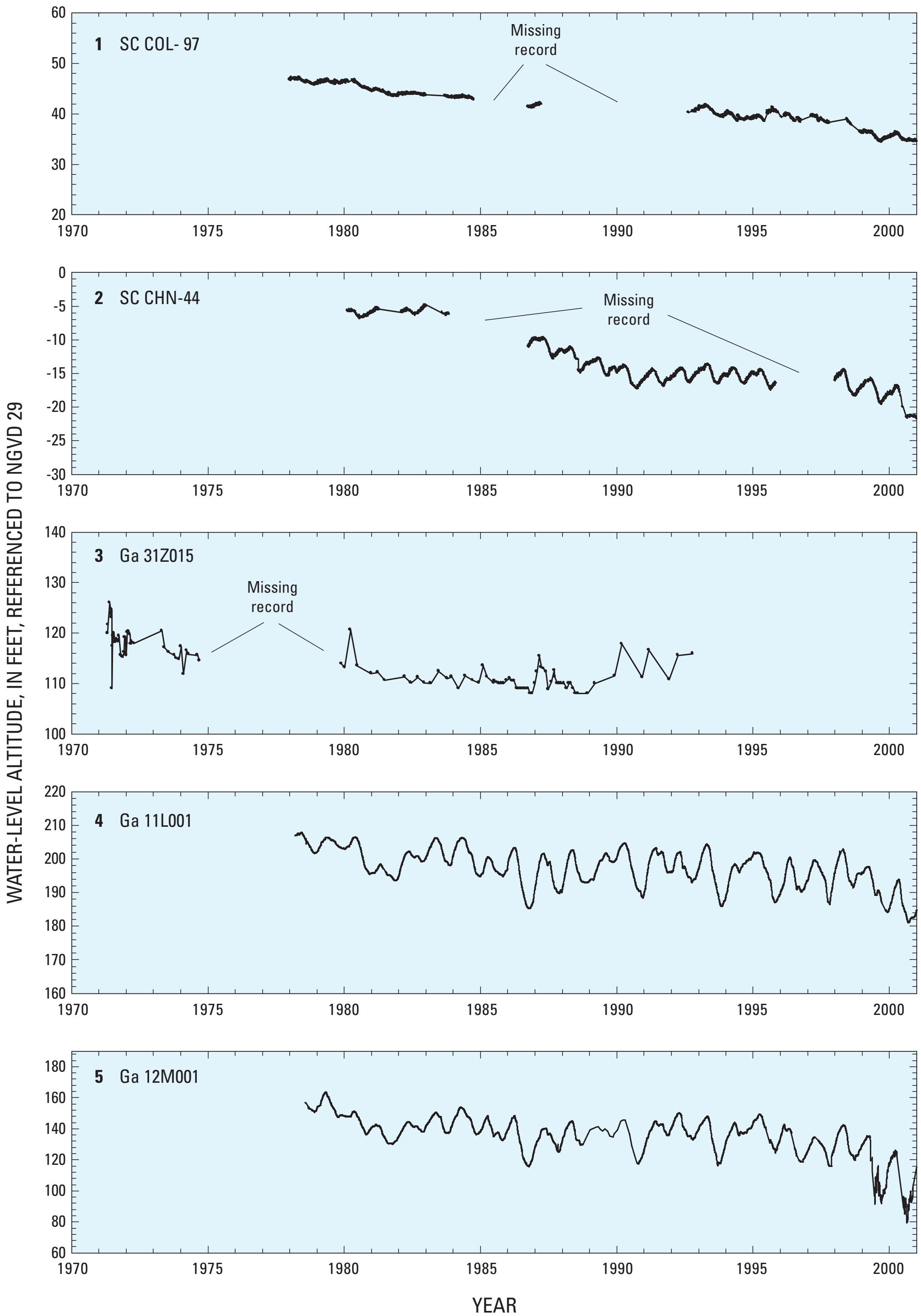


Figure 46. Selected hydrographs from wells screened in the Pearl River aquifer. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 43.)

The simulated prepumping potentiometric surface for the Chattahoochee River aquifer is shown in figure 47. Ground water flowed from potentiometric highs in the outcrop area towards the Chattahoochee River, along the Alabama-Georgia border, and the Pee Dee River in South Carolina. Much of the recharge that entered the aquifer in its outcrop area discharged to streams and rivers and little would have flowed downdip to the deeper confined area of the aquifer. Deeply entrenched rivers such as the Chattahoochee, Savannah, and Pee Dee Rivers intersected the aquifer in updip areas and received much of their base flow from aquifer discharge. Further downdip, regional flow in the aquifer followed relatively long flow paths that trended arcuately across the aquifer dip, and discharge was by upward leakance to an overlying aquifer (Barker and Pernik, 1994).

By 1980, large depressions had formed in the potentiometric surface of the regional Chattahoochee River aquifer. A large cone of depression was centered beneath Myrtle Beach, S.C., where the potentiometric surface had fallen to -100 ft NGVD 29. To the southwest, a smaller cone had formed near Georgetown, S.C., where the potentiometric surface had declined to nearly 70 ft below NGVD 29. In the Florence, S.C., area, withdrawals of about 7 Mgal/d have caused ground-water levels to decline (Aucott, 1996), and smaller cones of depression also had formed in Marion and Williamsburg Counties in eastern South Carolina. In southwestern Georgia, pumping within the local Clayton aquifer has resulted in a substantial lowering of heads. Near the updip limit of the aquifer, the Savannah River intersects the aquifer and the overlying confining unit pinches out so that the Chattahoochee River aquifer is in direct contact with the surficial aquifer (Renken, 1996). Prior to pumping, much of the ground-water flow was discharged to the Savannah River. By 1980, however, some of this discharge was captured by withdrawals near the Augusta, Ga., area, and aquifer heads were lowered.

By 1980, water-level declines occurred over much of the extent of the Chattahoochee River aquifer but were most pronounced in southwestern Georgia and in eastern South Carolina, near the cities of Florence, Myrtle Beach, and Georgetown (fig. 48). In eastern South Carolina, head declines of 20 ft or greater were observed from eastern Darlington to the coastal areas of Horry, Georgetown, and northern Charleston Counties. Water levels in the aquifer have declined substantially from prepumping levels in the Florence area as a result of concentrated withdrawals for public and industrial supply. Prepumping levels in both the subregional Middendorf and Black Creek aquifers in the Florence area were similar; water levels ranged from 115-125 ft NGVD 29. Post-development, water-level altitudes in the subregional aquifers diverged under pumping stresses, and by 1980, water levels in the local Middendorf had declined to altitudes of -46 ft NGVD 29; water levels in the Black Creek aquifer remained near prepumping levels. Declines of more than 140 ft in the Florence area depicted in figure 48 reflect those in the Middendorf aquifer for this period.

In the Myrtle Beach, S.C., area, the subregional Black Creek aquifer was the primary source of water supply, and withdrawals have resulted in water levels that had typically declined 100 ft from prepumping levels and, in places, more than 130 ft. Withdrawals from the aquifer during 1980 near Myrtle Beach were estimated at 10 to 13 Mgal/d (Aucott and Speiran, 1985; Aucott, 1996). Decline was greatest in close proximity to the coast, although declines of 100 ft or greater extended about 4 mi inland and updip, and those of at least 60 ft were observed as far as 14 mi inland. A second area of decline was centered in Georgetown County near the city of Georgetown, where water levels also had declined more than 100 ft from prepumping flow conditions. Along the border of western Georgetown and eastern Williamsburg Counties was a third area of substantial head decline. These three areas had merged and the resultant area of at least 40 ft of decline had encompassed most of Georgetown, eastern Williamsburg, and southern Horry Counties. In the Charleston S.C., area, large-scale head decline was not as widespread, although decline exceeded 60 ft in places. Where the Chattahoochee River aquifer grades into the northern Atlantic Coastal Plain in southeastern North Carolina, water-level decline from prepumping levels was generally less than 20 ft in bordering counties.

Water levels near Sumter, S.C., a major withdrawal center during 1980, declined approximately 40 ft from predevelopment flow conditions. Estimated withdrawals of 11 Mgal/d during 1980 at Sumter were similar to those at Myrtle Beach and greater than those at Florence (Aucott, 1996) but resulted in declines that were relatively minor and isolated from those to the north and east. Similarly, in Allendale and Barnwell Counties, S.C., along the Savannah River, water levels declined from 20 to 30 ft from prepumping levels. Simulated declines of 25 to 50 ft in this area were attributed to substantial withdrawals at the Savannah River plant and the city of Allendale (Faye and Mayer, 1996). Declines in the aquifer in these areas were less severe than those at Florence and Myrtle Beach, probably because of higher transmissivities and proximity to recharge sources (Aucott, 1996).

Substantial water-level decline was observed throughout a large area in southwestern Georgia as a result of withdrawals for irrigation and public supply (Faye and Mayer, 1996). Steepest declines were centered near the border of Dougherty and Terrell Counties, where the maximum decline from prepumping levels of nearly 200 ft occurred near the city of Albany, Ga. Water-level declines in excess of 140 ft extended into the neighboring Counties of Terrell and Lee, and declines of at least 40 ft encompassed an area of more than 1,800 mi^2 from Sumter County in the north to Early County to the southwest. Simulated declines from prepumping to 1980 in the subregional aquifers (Faye and Mayer, 1996) of this area were nearly identical to those observed here.

Substantial declines approaching the updip limit of the aquifer also were noted throughout Washington, Wilkinson, and Twiggs Counties, Ga. Water levels typically declined from 20 to 40 ft but by as much as 50 ft in places in Washington County. In Twiggs County water-level declines of 40 ft

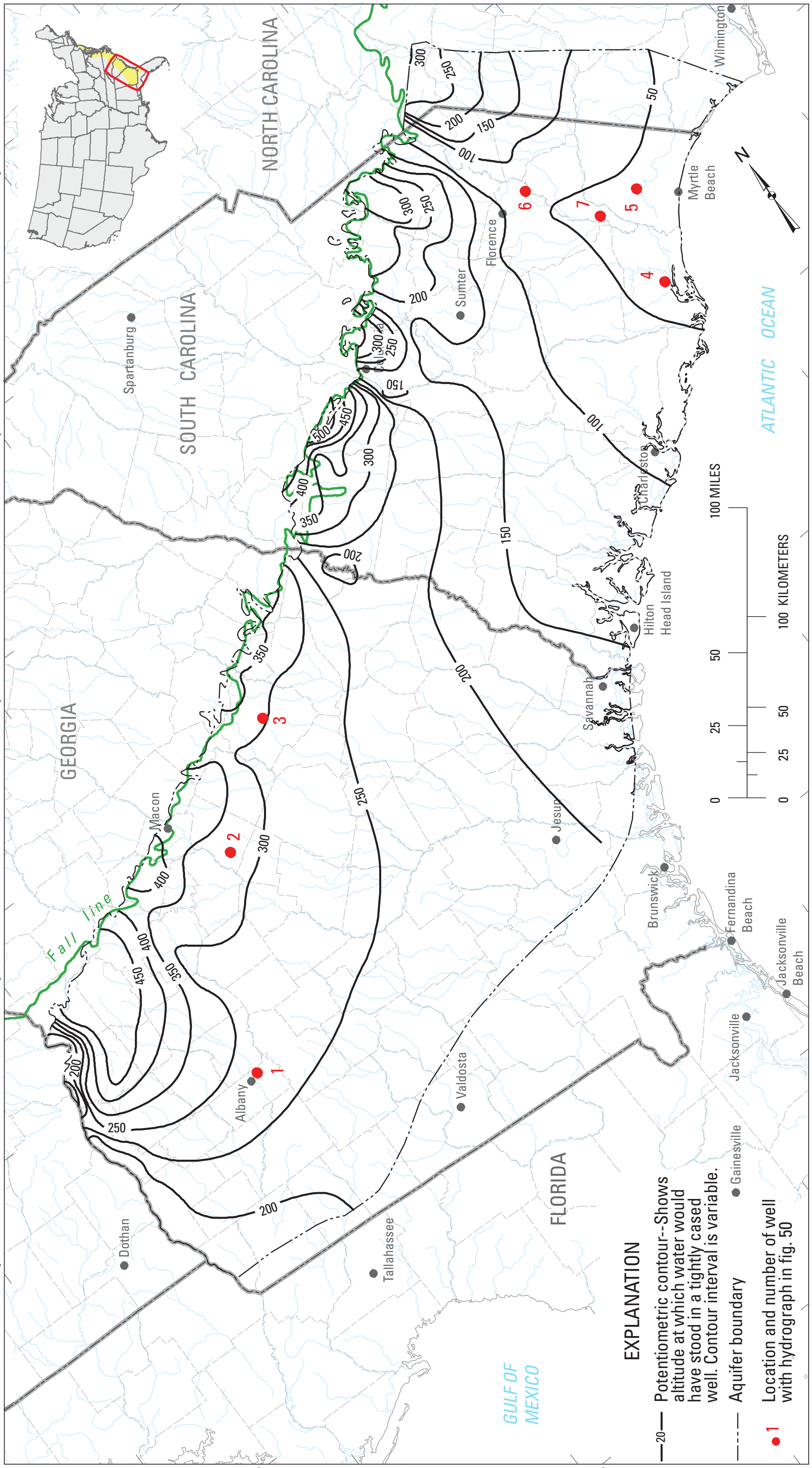
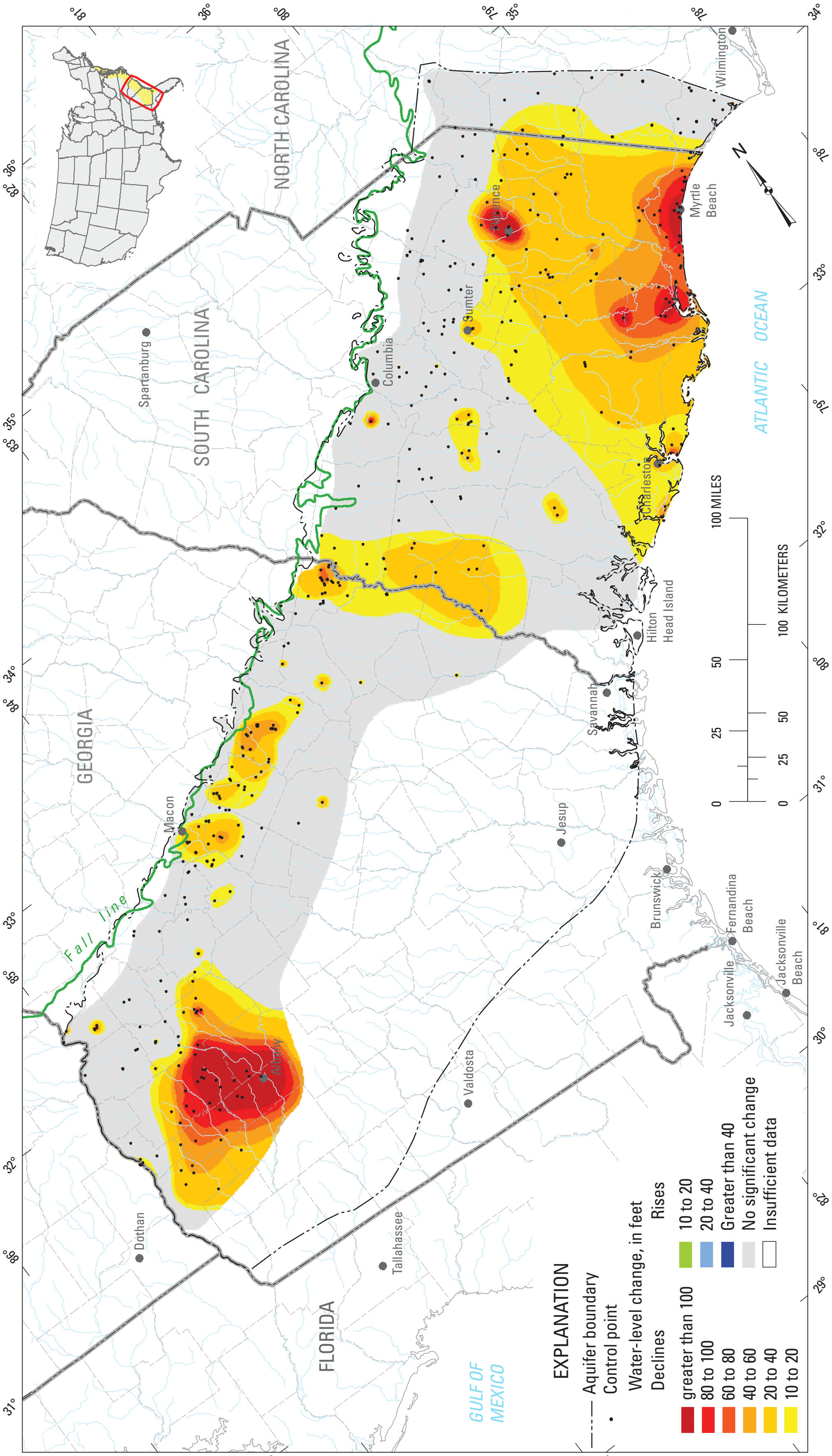


Figure 47. Simulated potentiometric surface of the Chattahoochee River aquifer, prior to development



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection
Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 48. Estimated water-level changes in the Chattahoochee River aquifer, predevelopment to circa 1980.

occurred locally but were typically 15-30 ft, and in Wilkinson County, declines were less severe. Declines probably resulted from substantial pumpage from the Chattahoochee River aquifer for both potable supply and the dewatering of clay pits for the kaolin mining industry. Near the updip limit of the aquifer along the Savannah River, water levels in Richmond County, Ga., had declined by as much as 65 ft from prepumping levels. Similarly, Faye and Mayer (1996) indicated declines of greater than 50 ft in this area, and Clarke and West (1997) reported maximum observed water-level declines of 59 ft prior to 1993 here. During 1980, approximately 25 Mgal/d of ground water was withdrawn throughout Richmond (Fanning, 2003). Recent data indicate that the majority of ground-water withdrawals are from hydrogeologic units comprising the regional Chattahoochee River aquifer; thus a reasonable assumption is that earlier withdrawals were also from the same aquifers, particularly because the aquifer crops out or subcrops in this area (Renken, 1996) and is highly transmissive (Barker and Pernik, 1994).

Data were unavailable in large areas in the downdip part of the aquifer in Georgia. In these areas, the depth to the top of the aquifer is substantial, and most of the regional water supply is from the shallower systems.

Between 1980 and 2000, water levels in the Chattahoochee River aquifer continued to decline throughout eastern South Carolina (fig. 49). Water-level decline was most pronounced in Charleston County where, in the southern part of the county, water levels had declined to nearly -100 ft NGVD 29, or about 180 ft from 1980 flow conditions. Declines of at least 60 ft extended to the central part of the county and updip to the central parts of Berkeley, Dorchester, and Colleton Counties. In northern Charleston County, water-level decline was less severe at nearly 40 ft from 1980 levels. Hockensmith (2003a) documented 89 ft of decline in southern Charleston from 1996 to 2001 and estimated a maximum decline from prepumping conditions of 267 ft. In Georgetown County, distinct cones of depression in coastal and southern Georgetown and eastern Williamsburg Counties have begun to coalesce and form a regional feature within the potentiometric surface of the subregional Black Creek aquifer (Hockensmith, 2003b). This regional cone of depression had deepened subsequent to 1982, and water levels had declined from 60 to more than 100 ft below 1980 levels. The maximum estimated decline from prepumping levels of 205 ft occurred in coastal Georgetown County and near the town of Andrews, in eastern Williamsburg County. Near Myrtle Beach, S.C., however, water levels had recovered by as much as 34 ft from 1980 levels. Water levels in this area had continued to decline through the late 1980s and early 1990s, when conversion to surface water for public supply prompted recovery in the area (Hockensmith, 2003b). In southern North Carolina, water levels declined from 10 to 15 ft in places in the mid– and downdip parts of the aquifer. Stable to modestly rising levels were observed in the updip section.

In Allendale and Barnwell Counties, S.C., water levels in proximity to the Savannah River generally had stabilized. Isolated areas of minor ground-water decline and recovery were observed in nearby Aiken County, S.C. Rises and declines were typically 10 to 15 ft relative to 1980 levels.

Water levels at the center of the cone of depression in Florence, S.C., had declined to -84 ft NGVD 29 by 2001, indicating a change of approximately 55 ft from circa 1980 levels. Withdrawals at Florence averaged 12 Mgal/d (Newcome, 2000), an increase of 70 percent from 1980. Water levels are estimated to have declined more than 180 ft from prepumping levels. Increases in withdrawals resulted in continuing decline in and around Sumter, S.C., where water levels had fallen 12 to 25 ft relative to 1980 levels. Average withdrawals during 2000 of 15 Mgal/d (Newcome, 2000) represent an increase of about 36 percent from 1980.

Water levels in southwestern Georgia had continued to fall; between 1980 and 2000, water levels in the Albany area declined approximately 20 ft near the city and more than 30 ft in western Dougherty County. Withdrawals within the county had increased from 1980 to 2000 (Fanning, 2003), though this included an indeterminate amount from the overlying Floridan aquifer. Water levels in well 13L002, located near the city of Albany Ga., declined approximately 20 ft between 1980 and 2000 to an altitude of 83 ft NGVD 29. Prior to 1980, water levels in this well declined approximately 80 ft from the beginning of record (fig. 50). Estimated prepumping water levels near this well were 250 ft NGVD 29 (Faye and Mayer, 1996), indicating a total decline of about 180 ft. West of here, estimated declines from prepumping conditions were even greater, at about 200 ft.

An area of moderate decline was observed near the western limit of the aquifer in Georgia, extending throughout parts of Jefferson, Burke, Johnson, and Washington Counties. Decline was typically 15 ft from 1980 levels but was in excess of 30 ft in Washington County. Periodic measurements in well 23X027, located in Washington County, Ga., indicate water-level altitudes of about 230 ft NGVD 29 in 1980; from 1985 to 2000, continuous monitoring showed steadily falling water levels to 195 ft NGVD 29 by 2000, a decline of more than 30 ft (fig. 50).

In the updip section of the aquifer, loss of observation points in parts of Twiggs, Washington, and Wilkinson Counties preclude the mapping of changing water-level conditions. Water levels in this area previously declined from prepumping conditions to 1980; increased withdrawals in Washington and Wilkinson Counties (Fanning, 2003) would suggest continued decline in water levels. Reductions in withdrawals in Twiggs County would suggest stable to recovering water levels. The hydrograph of 18U001, located in Twiggs County but to the east of the area of lowered potentiometric head, shows a decline of less than 5 ft from 1980 to 2000.

Hydrographs for GEO-77, HOR-307, and MN-77 show long-term water-level changes in the Chattahoochee River aquifer in eastern South Carolina (fig. 50). Estimated prepumping water levels near well GEO-77 in southern Georgetown County were less than 50 ft NGVD 29 (Aucott and Speiran, 1985a; Barker and Pernik, 1994), and by 1980, water

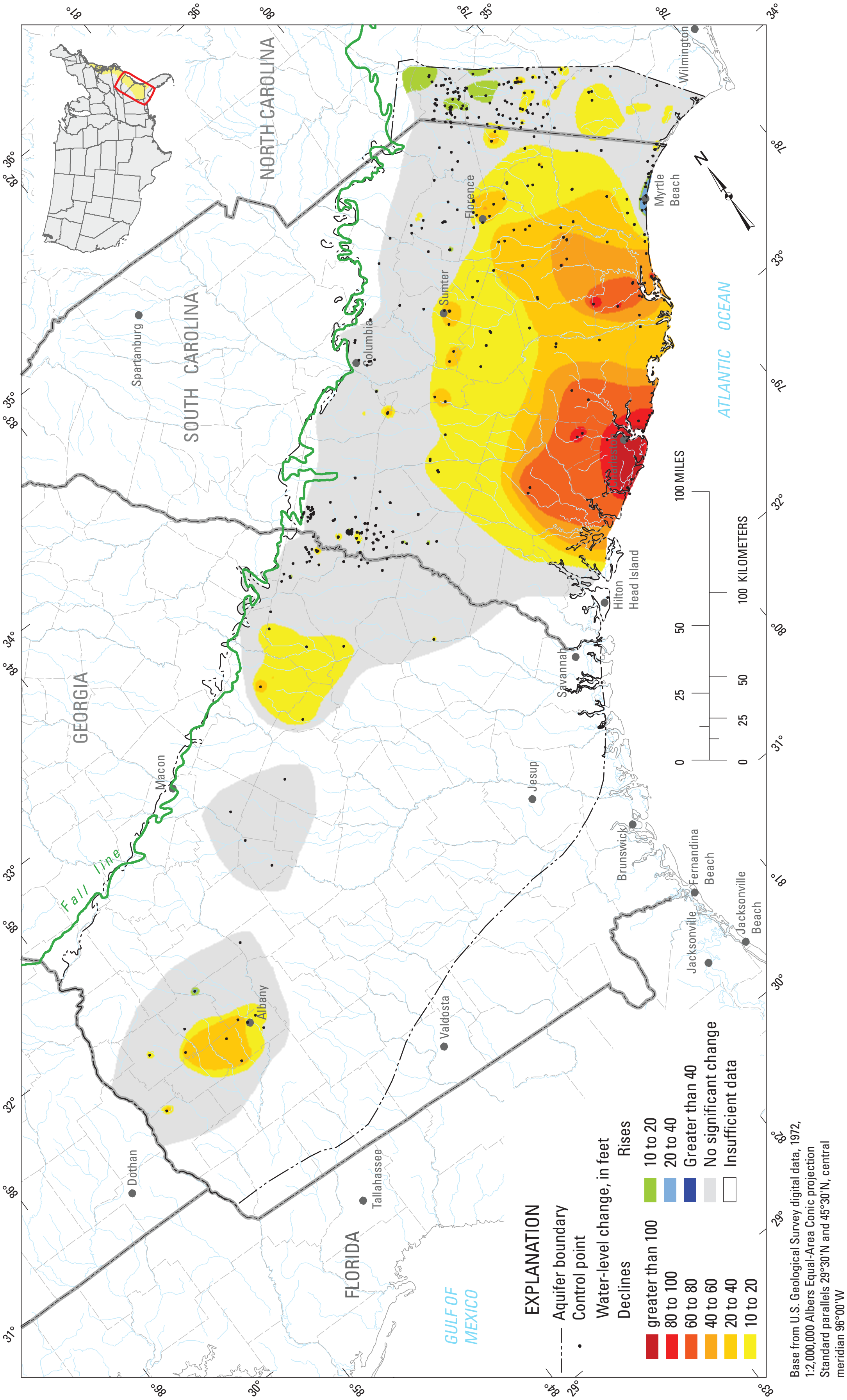


Figure 49. Estimated water-level changes in the Chattahoochee River aquifer, circa 1980 to 2000.

levels had declined about 80 to 90 ft. Between 1980 and 2000, the water level had declined an additional 70 ft, indicating the effects of increased pumping and the deepening of the cone of depression here. In central Horry County, S.C., water levels in well HOR-307 declined 50 ft from 1975 to 1991 but began to rise in 1992 as a result of reduced withdrawals from the local Black Creek aquifer. A single measurement in 2002 indicates nearly 20 ft of recovery since 1992. Well MN-77, in southern Marion County, shows steadily declining water levels throughout the period of record probably because of nearby withdrawals and the propagation of the regional cone of depression in southern Georgetown County (Hockensmith, 2003b). Estimated prepumping levels were 45 ft NGVD 29 (Aucott and Speiran, 1985a; Barker and Pernik, 1994) near here, indicating that, by 2000, total decline was approximately 55 ft.

Water levels in FLO-128, along the eastern edge of the Florence, S.C., cone of depression, declined from 42 ft NGVD 29 in 1982 to 5 ft in 1993. Thereafter, water levels fluctuated, attaining highs of 34 ft NGVD 29 in early 1994 and a low of 4 ft in 1999. Estimated decline from prepumping levels to 2000 was approximately 35 to 45 ft.

Black Warrior River Aquifer

The Black Warrior River aquifer is the lowermost regional aquifer of the Southeastern Atlantic Coastal Plain. The aquifer contains the Tuscaloosa and Atkinson Formations in Georgia and the Cape Fear Formation in eastern Georgia and South Carolina as mapped and defined by Renken (1996). The Black Warrior River aquifer occurs at depths of 1,000 ft or greater throughout most of the southeastern Coastal Plain, and in southeastern Georgia, it is found at a depth of more than 4,500 ft (Renken, 1996).

A consequence of the great depth of the Black Warrior River aquifer is the availability of few wells with water-level data. The lack of data throughout the study area precluded the construction of detailed water-level-change maps; however, several authors have presented generalized potentiometric-surface maps for predevelopment and later stressed conditions. The predevelopment potentiometric surface maps of Miller (1992), Barker and Pernik (1994), Aucott (1996), and Faye and Mayer (1996) are similar where coincident. The simulated prepumping surface from Barker and Pernik (1994) shows the highest water-level altitudes in the aquifer of more than 400 ft in and near the outcrop area in western Georgia; the lowest water levels were less than 100 ft in eastern South Carolina (fig. 51). Water flowed from the potentiometric high in a southeasterly direction paralleling the dip of the formation bedding; however, as water migrated to deeper parts of the confined system, direction of flow trended east-northeast across dip and parallel to the coast toward discharge areas in southeastern North Carolina (Barker and Pernik, 1994). Simulated contours of Faye and Mayer (1996) were similar, except near the outcrop area in western Georgia, where water levels were much greater, up to 700 ft NGVD 29.

In 1980, the only documented withdrawals from the Black Warrior River aquifer within the study area were those for industrial supply along the Chattahoochee River and near the updip extent of the aquifer (Faye and Mayer, 1996). The withdrawals were estimated to be 4.1 Mgal/d during 1976-80. Despite little pumpage from the aquifer within the study area, simulations by Barker and Pernik (1994) indicate groundwater decline from prepumping conditions to 1985 of up to 49 ft. A broad area of 10 to 49 ft of decline extends from the Chattahoochee River eastward into south-central Georgia and in a band extending southeastward about 40 mi from the western extent of the aquifer in South Carolina (fig. 52). Throughout the rest of the aquifer, simulated declines were less than 10 ft. Declines resulted from a combination of factors; the low transmissivity of aquifer sediments, absence of direct recharge and large withdrawals from the overlying Chattahoochee River, and subsequent upward vertical leakage across the confining unit in updip areas (Barker and Pernik, 1994).

Water-level measurements throughout the aquifer are limited, but available data generally indicated a decline from predevelopment flow conditions to 1980. Hydrographs from three wells in Georgia along the Chattahoochee River are shown in figure 52. Water levels in wells 05P001 and 05P002 indicate that, by 1980, declines were approximately 120 and 160 ft, respectively. Faye and Mayer (1996) estimated head decline to 1980 in this area at more than 50 ft. Water levels in well 05P001 continued to decline, and by 1990, heads at both wells were 160 ft lower than prepumping levels. Further north, well 05R004 showed a decline in water level of about 80 ft from predevelopment to 1980. From 1980 to 1989, the water level in this well declined an additional 75 ft, indicating an apparent decline of 155 ft from prepumping conditions. Interpreted declines in this area were much greater than those simulated; possible reasons for the discrepancy might be that the large model cell area of 64 mi^2 may not adequately capture greater declines that may occur locally or that predevelopment heads may have been too high in this area because of limited control data for the deeper parts of the system.

In South Carolina, scattered water-level measurements were consistent with simulated declines. Water-level declines in the updip part of the aquifer ranged from 7 to 19 ft from predevelopment conditions; in the downdip part of the aquifer, declines were as great as 23 ft (fig. 52).

Few water-level measurements from the Black Warrior River aquifer exist for circa 2000. Water levels in several deep wells along the southern coast of South Carolina indicate large declines relative to nearby 1980 observed or simulated

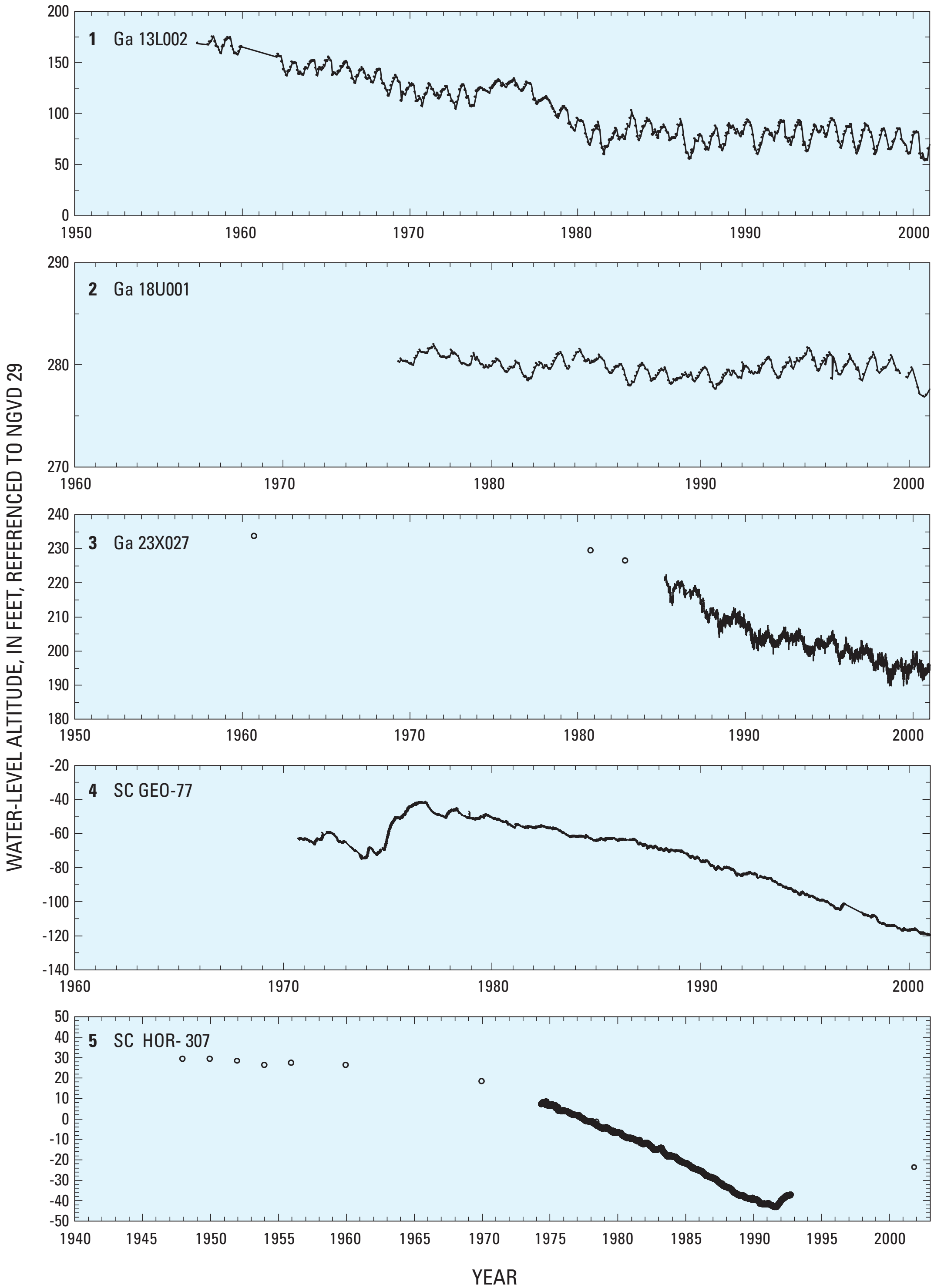


Figure 50. Selected hydrographs from wells screened in the Chattahoochee River aquifer. (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 47.)

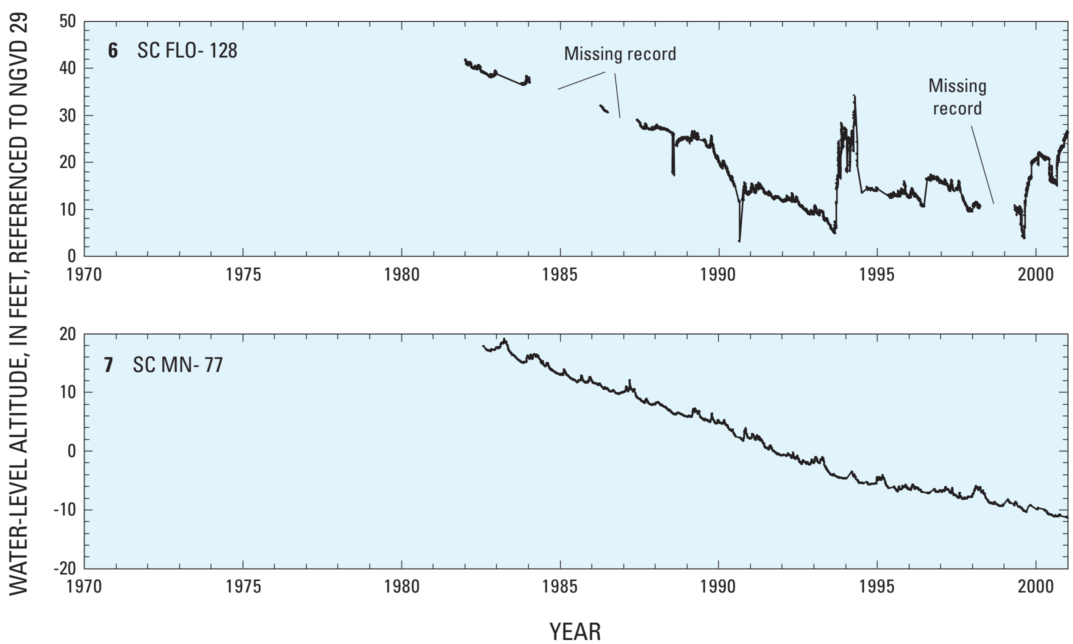
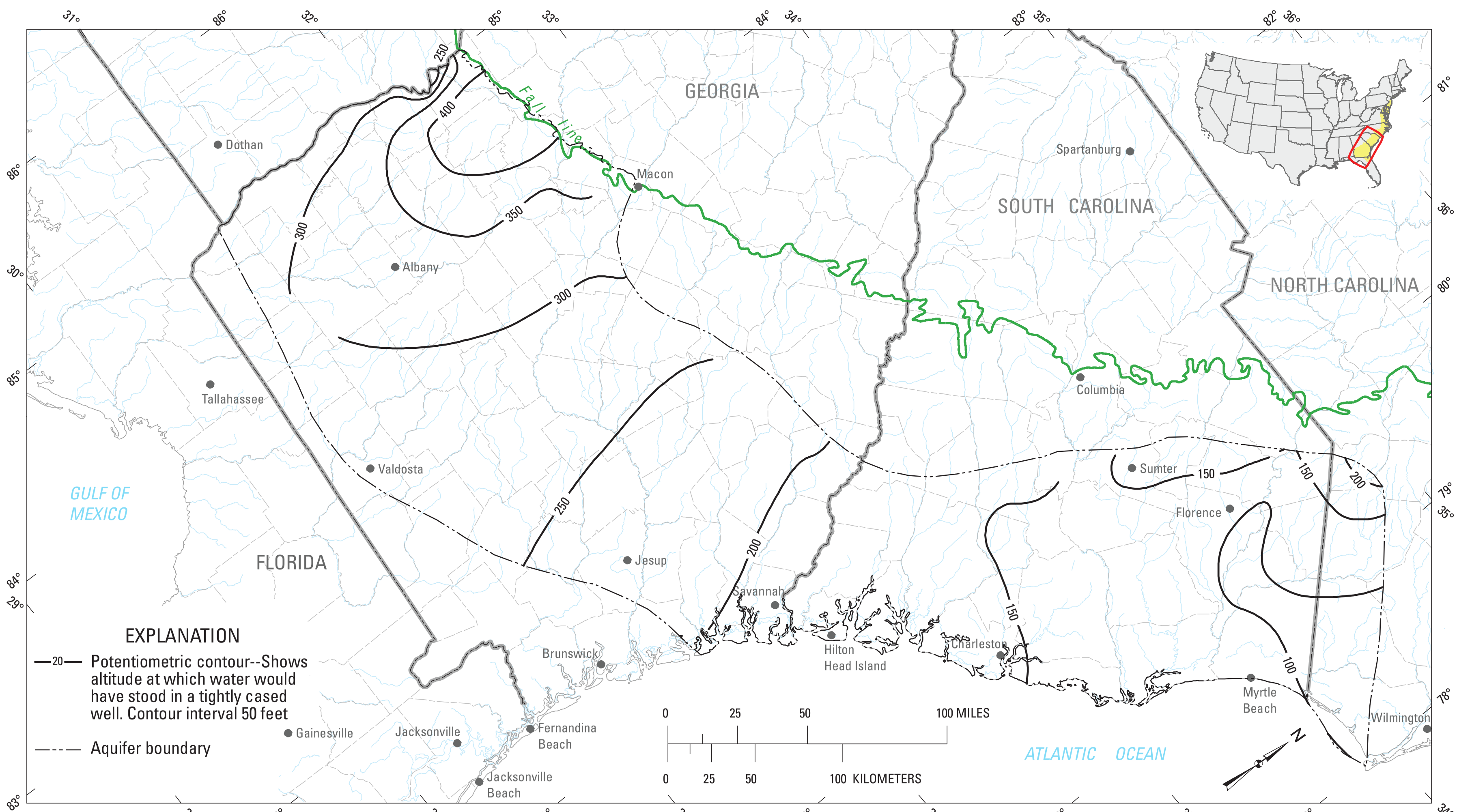
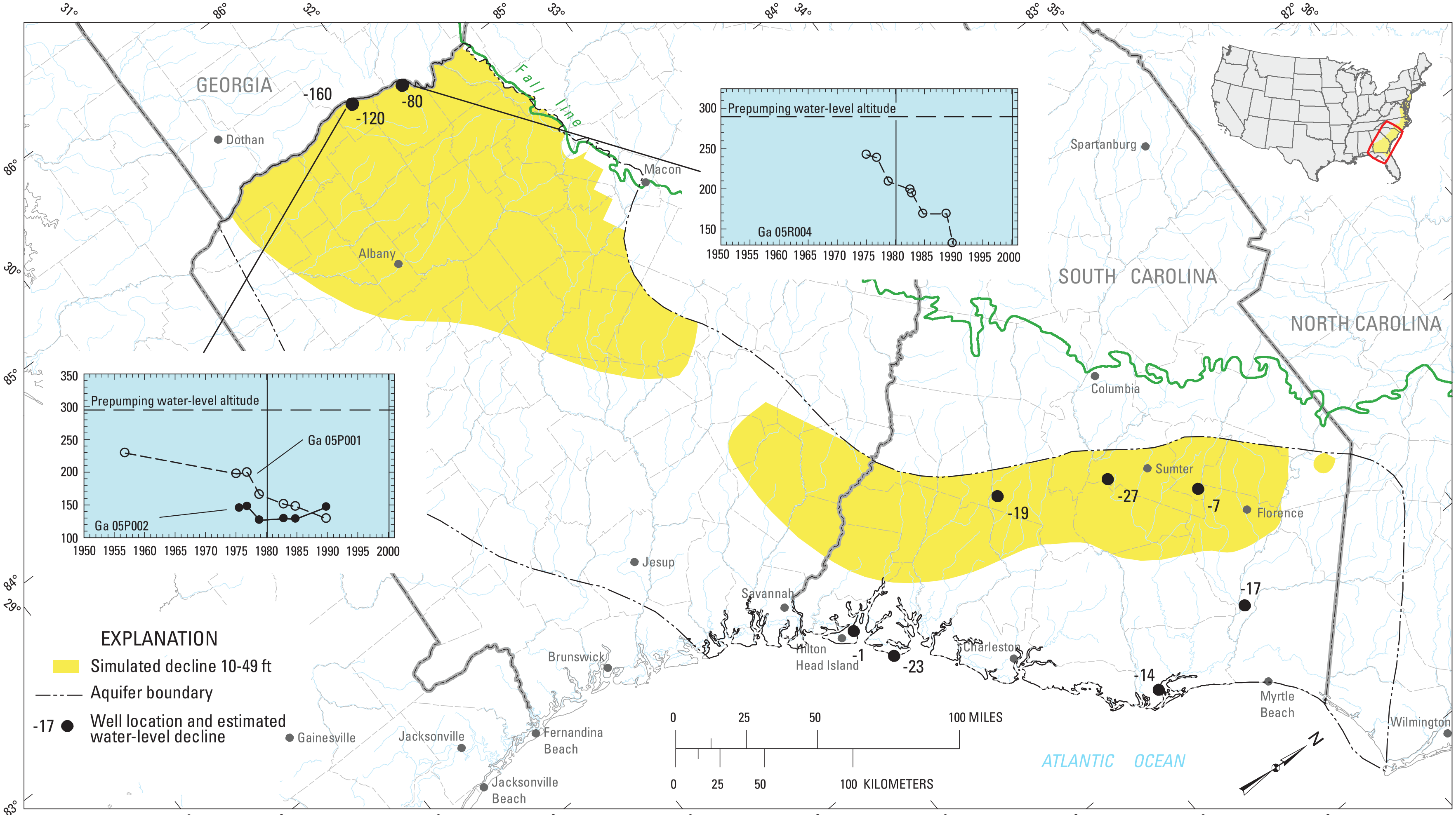


Figure 50. Selected hydrographs from wells screened in the Chattahoochee River aquifer.—Continued (Label in graph shows well number followed by state in which well is located and well name. Well location shown on figure 47.)



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection
Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 51. Simulated potentiometric surface of the Black Warrior River aquifer, prior to development.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic projection Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Modified from Barker and Pernik, 1994

Figure 52. Simulated and observed water-level changes in the Black Warrior River aquifer, predevelopment to 1980-85.

water levels; however, because of the lack of long-term data, regional water-level changes within the aquifer cannot be determined with certainty.

Summary

The Atlantic Coastal Plain aquifer system underlies a large part of the east coast of the United States, extending from Long Island, N.Y., to northern Florida. It is the predominant source of water for more than 20 million people. As the population of the region increases, further demand is being placed on these water resources and the sustainability of the regions water supply is in question. The aquifer system has already been developed extensively over wide areas resulting in substantial declines in water levels and areas of salt-water intrusion.

This report provides a regional assessment of ground-water levels based on measurements from more than 4,000 wells aggregated into 13 regional aquifers characterized in the U.S. Geological Survey's Regional Aquifer-System Analysis Program for the Northern Atlantic Coastal Plain, Southeastern Coastal Plain, and Floridan aquifer systems. Ground-water-level data were compiled for three periods—predevelopment, circa 1980, and circa 2000. Water-level-change maps and selected water-level hydrographs are presented. The nature of regional water-level declines, or rises, within each aquifer system are evaluated on the basis of available water-use data. Regional variability in water-level change in the Atlantic Coastal Plain aquifer system is predominantly the result of regional differences in aquifer properties and changing patterns of ground-water withdrawals.

From predevelopment to circa 1980, water-level declines of more than 100 ft were observed in New Jersey, Delaware, Maryland, Virginia, and North Carolina in the northern Atlantic Coastal Plain. Regional declines were most widespread in the deeper aquifers that were most effectively confined–the Upper, Middle, and Lower Potomac aquifers. Within these aquifers, water levels had declined up to 200 ft in southern Virginia and more than 100 ft in New Jersey, Delaware, Maryland, and North Carolina. Substantial water-level declines also were evident in the regional Lower Chesapeake aquifer in southeastern New Jersey; the Castle Hayne-Piney Point aquifer in Delaware, Maryland, southern Virginia, and east-central North Carolina; in the Peedee-Severn aquifer in east-central New Jersey and southeastern North Carolina; and in the Black Creek-Matawan aquifer in east-central New Jersey and east-central North Carolina. Conversely, declines were least severe in the regional Upper Chesapeake aquifer during this period.

In the southeastern Atlantic Coastal Plain, declines of more than 100 ft in the Chattahoochee River aquifer occurred in eastern South Carolina and in southwestern Georgia, where water levels had declined approximately 140 and 200 ft from prepumping flow conditions, respectively. Within the Upper Floridan aquifer, decline was most pronounced in the coastal areas of Georgia and northern Florida, where ground-water withdrawals were at their highest.

Water-level data for the period circa 1980 to circa 2000 show that conservation measures have served to limit withdrawals in some affected areas, moderating or stabilizing water-level decline, and in some cases, resulting in substantial recovery. In other cases, increases in ground-water withdrawals have resulted in continued rapid water-level declines. From 1980 to 2000, water levels across the regional Upper, Middle, and Lower Potomac aquifers continued to decline across large parts of Delaware, Maryland, Virginia, and North Carolina, and water levels had stabilized or recovered throughout much of Long Island and New Jersey. Substantial water-level recovery had also occurred in east-central New Jersey in the Peedee-Severn and Black Creek-Matawan aquifers and in east-central North Carolina in the Castle Hayne-Piney Point aquifer. Substantial declines from circa 1980 to circa 2000 occurred in the Peedee-Severn aquifer in southern New Jersey, the Beaufort-Aquia aquifer in southern Maryland, and the Black Creek-Matawan and Upper Potomac aquifers in central and southern parts of the coastal plain in North Carolina.

Circa 1980 to circa 2000, water levels within the regional Upper Floridan aquifer had generally stabilized in response to shifting withdrawal patterns and reductions in pumpage at many places within the coastal region. Ground-water levels had stabilized and recovered at the major cones of depression at Savannah, Brunswick, and Jesup, Ga.; had remained about the same in the St. Marys, Ga.,-Fernandina Beach, Fla., area; and were stable to slightly declining in the Jacksonville, Fla., area.

In the southeastern Coastal Plain, water levels in the Chattahoochee River aquifer continued to decline in eastern South Carolina, particularly in and around Charleston and Georgetown Counties, and water levels recovered in Myrtle Beach.

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