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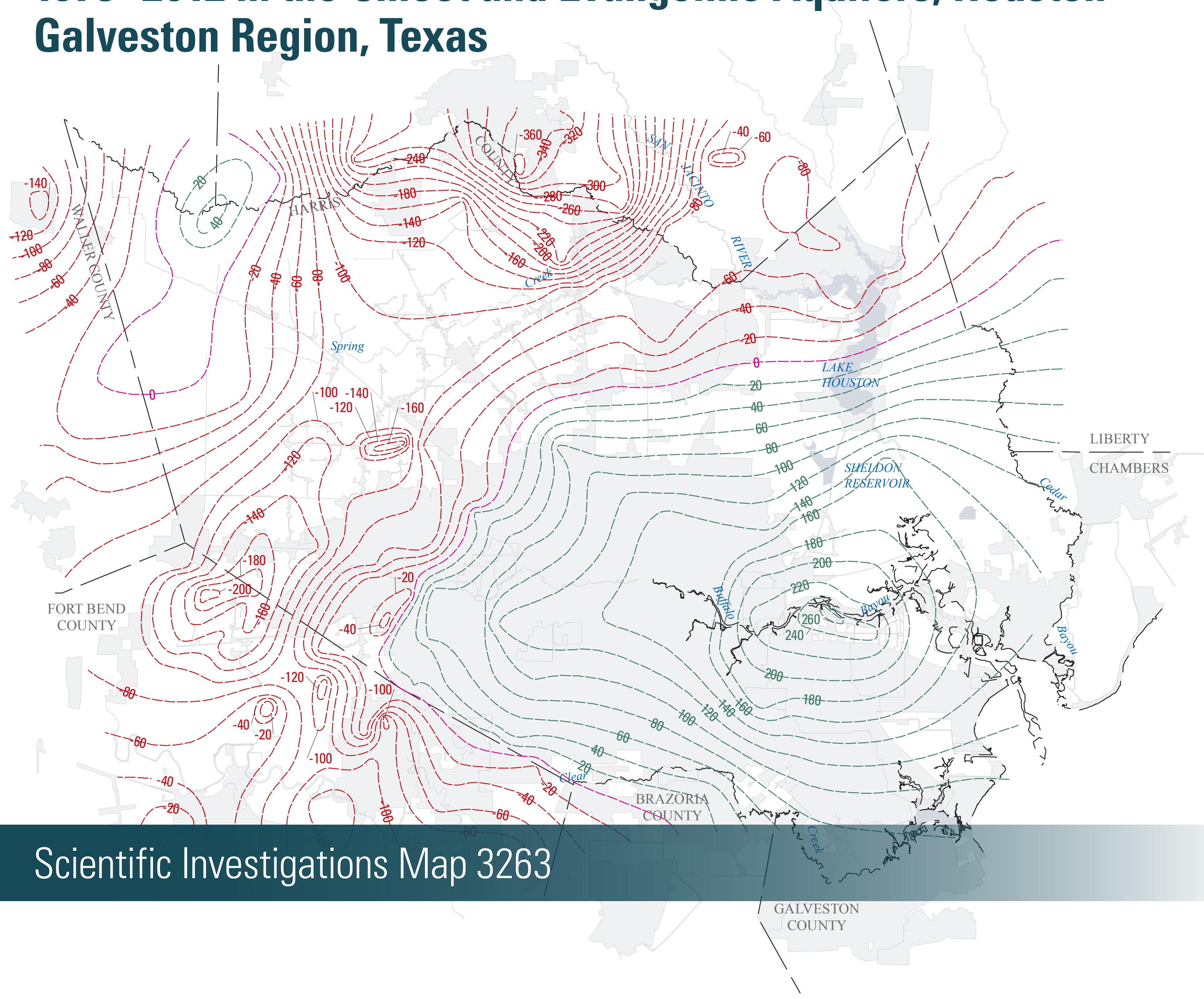
Water-Level Altitudes 2013 and Water-Level Changes in the Chicot, Evangeline, and Jasper Aquifers and Compaction 1973–2012 in the Chicot and Evangeline Aquifers, Houston-Galveston Region, Texas



Scientific Investigations Map 3263

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Water-Level Altitudes 2013 and Water-Level Changes in the Chicot, Evangeline, and Jasper Aquifers and Compaction 1973–2012 in the Chicot and Evangeline Aquifers, Houston-Galveston Region, Texas

By Mark C. Kasmarek, Michaela R. Johnson, and Jason K. Ramage

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

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29) or the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Water-Level Altitudes 2013 and Water-Level Changes in the Chicot, Evangeline, and Jasper Aquifers and Compaction 1973–2012 in the Chicot and Evangeline Aquifers, Houston-Galveston Region, Texas

By Mark C. Kasmarek, Michaela R. Johnson, and Jason K. Ramage

Abstract

Most of the subsidence in the Houston-Galveston region, Texas, has occurred as a direct result of groundwater withdrawals for municipal supply, commercial and industrial use, and irrigation that depressured and dewatered the Chicot and Evangeline aquifers, thereby causing compaction mostly in the clay and silt layers of the aquifer sediments. This report, prepared by the U.S. Geological Survey in cooperation with the Harris-Galveston Subsidence District, City of Houston, Fort Bend Subsidence District, Lone Star Groundwater Conservation District, and Brazoria County Groundwater Conservation District, is one in an annual series of reports depicting water-level altitudes and water-level changes in the Chicot, Evangeline, and Jasper aquifers and measured compaction of subsurface sediments in the Chicot and Evangeline aquifers in the Houston-Galveston region. The report contains maps depicting approximate water-level altitudes for 2013 (represented by measurements made during December 2012–February 2013) for the Chicot, Evangeline, and Jasper aquifers; maps depicting 1-year (2012–13) water-level changes for each aquifer; maps depicting 5-year (2008–13) water-level changes for each aquifer; maps depicting long-term (1990–2013 and 1977–2013) water-level changes for the Chicot and Evangeline aquifers; a map depicting long-term (2000–13) water-level changes for the Jasper aquifer; a map depicting locations of borehole-extensometer sites; and graphs depicting measured compaction of subsurface sediments at the extensometers during 1973–2012. Tables listing the data used to construct each water-level map for each aquifer and the compaction graphs are included.

In 2013, water-level-altitude contours for the Chicot aquifer ranged from 200 feet (ft) below North American Vertical Datum of 1988 (hereinafter, datum) in a small area in southwestern Harris County to 200 ft above datum in central to west-central Montgomery County. Water-level changes during 2012–13 in the Chicot aquifer ranged from a 58-ft decline to a 37-ft rise. Contoured 5-year and long-term changes in water levels in the Chicot aquifer ranged from a 30-ft decline to an 80-ft rise (2008–13), from a 120-ft decline to a 100-ft rise (1990–2013), and from an 80-ft decline to a 200-ft rise (1977–2013). In 2013, water-level-altitude contours for the Evangeline aquifer ranged from 300 ft below datum in south-central Montgomery County to 200 ft above datum in southeastern Grimes and northwestern Montgomery Counties. Water-level changes for 2012–13 in the Evangeline aquifer ranged from a 37-ft decline to a 68-ft rise. Contoured 5-year and long-term changes in water levels in the Evangeline aquifer ranged from an 80-ft decline to an 80-ft rise (2008–13), from a 220-ft decline to a 220-ft rise (1990–2013), and from a 360-ft decline to a 260-ft rise (1977–2013). In 2013, water-level-altitude contours for the Jasper aquifer ranged from 200 ft below datum in south-central Montgomery and north-central Harris Counties to 250 ft above datum in northwestern Montgomery County and extending into northeastern Grimes and south-central Walker Counties. Water-level changes for 2012–13 in the Jasper aquifer ranged from a 36-ft decline to an 87-ft rise. Contoured changes in water levels in the Jasper aquifer ranged from a 100-ft decline to 20-ft rise (2008–13) and from a 220-ft decline to no change (2000–13).

Compaction of subsurface sediments (mostly in the clay and silt layers) of the Chicot and Evangeline aquifers was recorded continuously by 13 borehole extensometers at 11 sites that were either activated or installed between 1973 and 1980. For the period of record beginning in 1973 (or later depending on activation or installation date) and ending in December 2012, cumulative measured compaction by 12 of the 13 extensometers ranged from 0.100 ft at the Texas City-Moses Lake extensometer to 3.632 ft at the Addicks extensometer (data were used from only one of two extensometers at one site). The rate of compaction varies from site to site because of differences in groundwater withdrawals near each site and differences among sites in the clay-to-sand ratio in the subsurface sediments. Therefore, it is not possible to extrapolate or infer a rate of compaction for adjacent areas based on the rate of compaction measured at a nearby extensometer.

Introduction

The Houston-Galveston region, Texas—consisting of Harris, Galveston, Fort Bend, Montgomery, Brazoria, Chambers, Liberty, San Jacinto, Walker, Grimes, Waller Counties (fig. 1)—represents one of the largest areas of subsidence in the United States (Coplin and Galloway, 1999). Allen (1969) described ground-surface displacement (land-surface subsidence) as the last step of a variety of subsurface displacement mechanisms that included (among others) compaction of subsurface sediments by loading, drainage, vibration, and hydrocompaction. According to Coplin and Galloway (1999, p. 40), by 1979, as much as 10 feet (ft) of subsidence had occurred in the Houston-Galveston region, and approximately 3,200 square miles (mi^2) of the 11,000-mi^2 geographic area had subsided more than 1 ft. Comparing land-surface altitudes for 1915–17 to those for 2001, Kasmarek, Gabrysch, and Johnson (2010, sheet 2) determined that as much as 13 ft of subsidence has occurred in southeastern Harris County during the historical period.

Groundwater withdrawn from the Chicot, Evangeline, and Jasper aquifers has been the primary source of water for municipal supply, industrial and commercial use, and irrigation in the Houston-Galveston region since the early 1900s (Kasmarek and Robinson, 2004). Land-surface subsidence caused by fluid withdrawals was first documented in the Houston-Galveston region in conjunction with the Goose Creek Oil Field in southeastern Harris County (fig. 1) (Pratt and Johnson, 1926). Most of the subsidence in the Houston-Galveston region has occurred as a direct result of groundwater withdrawals that have depressured and dewatered the Chicot and Evangeline aquifers, thereby causing compaction of the aquifer sediments (Winslow and Doyle, 1954; Winslow and Wood, 1959; Gabrysch and Bonnet, 1975; Gabrysch, 1984; Holzer and Bluntzer, 1984; Kasmarek, Gabrysch, and Johnson, 2010).

Subsidence is of particular concern in low-lying coastal areas such as the Houston-Galveston region. Land subsidence in the region has increased the frequency and severity of flooding (Coplin and Galloway, 1999). Low-pressure weather systems such as tropical storms and hurricanes (National Oceanic and Atmospheric Administration, 2008) cause high tides and high rates of precipitation, and subsidence exacerbates the effects of storm surge and impedes stormwater runoff by creating areas of low land-surface elevations where water accumulates. Subsidence has shifted the shoreline along Galveston Bay (fig. 1) and adjacent areas in the Houston-Galveston region, thereby changing the distribution of wetlands and aquatic vegetation (Coplin and Galloway, 1999).

To address the issues associated with land-surface subsidence and subsequent increased flooding, the 64th Texas State Legislature in 1975 authorized the establishment of the Harris-Galveston Subsidence District (HGSD) (fig. 1) to regulate and reduce groundwater withdrawals in Harris and Galveston Counties (Harris-Galveston Subsidence District, 2010). In cooperation with the HGSD, the U.S. Geological Survey (USGS) has monitored water levels in wells screened in the Chicot and Evangeline aquifers and compaction of subsurface sediments in Harris and Galveston Counties since 1976. The USGS has published annual reports depicting water-level altitudes and water-level changes for the Chicot and Evangeline aquifers in the Houston-Galveston region beginning with the 1977 water-level-altitude maps (Gabrysch, 1979). Subsequently, annual reports were published depicting water-level altitudes and water-level changes for the Fort Bend subregion (encompassing Fort Bend County and adjacent areas) beginning with the 1990 water-level report (Kasmarek, 1997). The USGS published its first annual reports of water-level altitudes and water-level changes for the Jasper aquifer in the Houston-Galveston region (primarily Montgomery County) beginning in 2000 (Kasmarek and Houston, 2007). The cumulative compaction data from a network of 13 borehole extensometers in the Houston-Galveston region have been presented in USGS reports of annual water-level altitudes and water-level changes since 1981 (compaction for the period 1973–81 [Gabrysch and Ranzau, 1981]). Earlier USGS reports documented the occurrence of subsidence in the study area determined by the reoccupation and releveling of a network of benchmarks by using spirit-leveling techniques for the periods 1906–51 (Winslow and Doyel, 1954), 1906–78, 1943–78, and 1973–78 (Gabrysch, 1984). Most recently, Kasmarek and others (2012) depicted 2012 water-level altitudes and water-level change for various periods in the Chicot, Evangeline, and Jasper aquifers, and compaction measured by borehole extensometers during 1973–2011 in the Chicot and Evangeline aquifers.

Subsequent to establishing the HGSD, the Texas State Legislature established an additional subsidence district (Fort Bend Subsidence District [FBSD]) and two groundwater conservation districts (Lone Star Groundwater Conservation District [LSGCD] and [most recently] Brazoria County Groundwater Conservation District [BCGCD]) in the Houston-Galveston region to provide for the regulation of groundwater withdrawals in areas within their jurisdiction. The FBSD was established by the 71st Texas State Legislature in 1989 and has jurisdiction throughout Fort Bend County (fig. 1). The FBSD is divided into area A, which includes the Richmond-Rosenberg subarea, and area B. The primary purpose of the FBSD is to regulate groundwater withdrawal to prevent subsidence that contributes to flooding (Fort Bend Subsidence District, 2009). The LSGCD was established by the 77th Texas State Legislature in 2001 and has jurisdiction throughout Montgomery County (fig. 1). The purpose of the LSGCD is to conserve, protect, and enhance the groundwater resources of Montgomery County (Lone Star Groundwater Conservation District, 2011). The BCGCD was established by the 78th Texas State Legislature in 2003 with the purpose to “maintain the quality and availability of the county’s groundwater resource for current users and future generations” (Brazoria County Groundwater Conservation District, 2008). Regulatory plans to gradually decrease groundwater withdrawals by increased usage of surface-water supplies

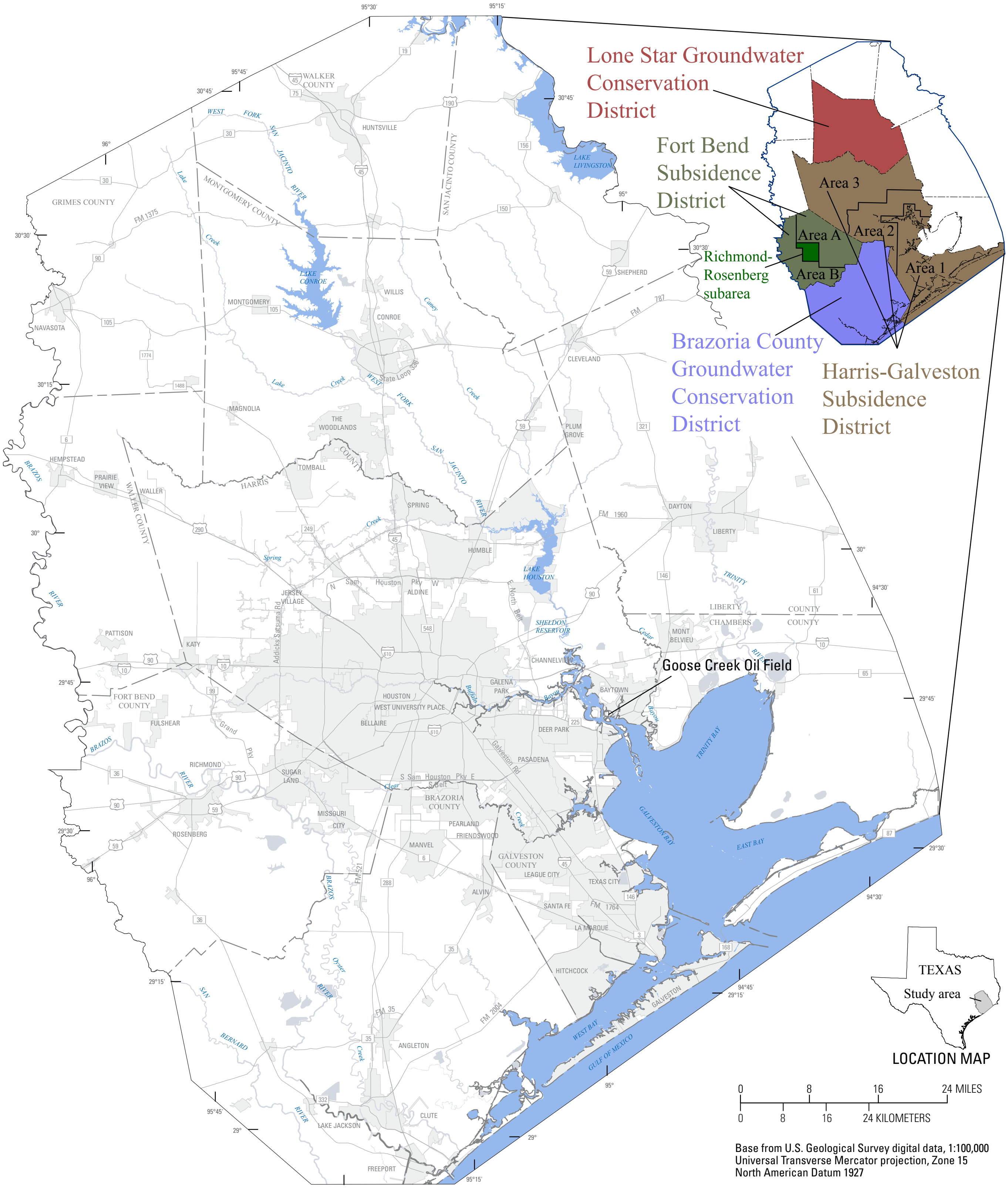

Figure 1. Locations of groundwater-regulatory districts and the Houston-Galveston region study area, Texas.

are being phased in; the historical, current (2013), and future groundwater management plans of each district are available on their respective Web sites (Brazoria County Groundwater Conservation District, 2008; Fort Bend Subsidence District, 2009; Harris-Galveston Subsidence District, 2010; Lone Star Groundwater Conservation District, 2011). Currently (2013), groundwater withdrawals are not being regulated by a groundwater conservation district in Liberty and Chambers Counties.

In 1976 the HGSD began implementing its first groundwater regulatory plan (Harris-Galveston Subsidence District, 2010). An extensive well-monitoring network was established by 1977, and water-level data were collected and used to create the first published water-level-altitude maps of the Chicot and Evangeline aquifers in the Houston-Galveston area (Gabrysch, 1979). The FBSD adopted its groundwater management plan in 1990 (Fort Bend Subsidence District, 2009), and in cooperation with the FBSD, an increased number of water wells were inventoried by the USGS in Fort Bend, Harris, Brazoria, and Waller Counties in 1989 and 1990. A more comprehensive water-level-altitude report for the Chicot and Evangeline aquifers was published by the USGS in 1991 (Barbie and others, 1991), and when updated well data became available, that water-level-altitude report was revised in 1997 (Kasmarek, 1997). Similarly, after the creation of the LSGCD in 2001, the USGS first published a water-level-altitude map for the Jasper aquifer in the Houston-Galveston region (primarily Montgomery County) (Coplin, 2001). In 2004, 2006, and again in 2007, as additional well data with reliable water-level-measurement data were inventoried, revised water-level-altitude maps for the Jasper aquifer were prepared (Kasmarek and Lanning-Rush, 2004; Kasmarek, Houston, and Brown, 2006; Kasmarek and Houston, 2007). In comparison to the 2001 (Coplin, 2001) and 2004 (Kasmarek and Lanning-Rush, 2004) map report versions, the 2007 version of the water-level-altitude map was the most comprehensive for the Jasper aquifer in the study area (Kasmarek and Houston, 2007) prepared to date. Since 2007, similarly comprehensive maps for the Jasper aquifer have been included in the annual series of reports that depict water-level altitudes and water-level changes in the Chicot, Evangeline, and Jasper aquifers and compaction in the Chicot and Evangeline aquifers in the Houston-Galveston region (Kasmarek and Houston, 2008; Kasmarek and others, 2009; Kasmarek and others, 2010; Johnson and others, 2011; Kasmarek and others, 2012).

Purpose and Scope

This report is one in an annual series of reports that depict water-level altitudes and water-level changes in the Chicot, Evangeline, and Jasper aquifers and compaction in the Chicot and Evangeline aquifers in the Houston-Galveston region. The report also describes the hydrogeology of the study area and provides an overview of the mechanism of compaction and land-surface subsidence.

This report contains regional-scale maps (sheets 1–14) depicting 2013 water-level measurements in wells screened in the Chicot, Evangeline, and Jasper aquifers; maps depicting 1-year (2012–13) water-level changes for each aquifer; maps depicting 5-year (2008–13) water-level changes for each aquifer; maps depicting long-term (1990–2013 and 1977–2013) water-level changes for the Chicot and Evangeline aquifers; and a map depicting long-term (2000–13) water-level change for the Jasper aquifer. The point and contour data depicted on the maps for all three aquifers (Chicot, Evangeline, and Jasper) are available for download from the Web index page for this report (http://pubs.usgs.gov/sim/3263/), as are metadata compliant with Federal Geographic Data Committee mandated guidelines.

In addition to maps depicting water-level altitudes and changes in the Chicot, Evangeline, and Jasper aquifers, this report also contains a map that depicts the locations of the 11 borehole-extensometer sites in Harris and Galveston Counties activated or installed between 1973 and 1980 (sheet 15). At these sites, borehole extensometers continuously record measured compaction of subsurface sediments of the Chicot and Evangeline aquifers. Graphs of these data from 12 of the 13 extensometers from 1973 (or later depending on activation or installation date) through 2012 are provided on sheet 16. Tables listing the data used to construct each water-level map for each aquifer and the graphs of measured compaction of subsurface sediments also are included, as well as a brief description of the methods used for map construction.

Hydrogeology of the Study Area

The three primary aquifers in the Gulf Coast aquifer system are the Chicot, Evangeline, and Jasper (figs. 2–4), which are composed of laterally discontinuous deposits of gravel, sand, silt, and clay. The youngest and uppermost Chicot aquifer consists of Holocene- and Pleistocene-age sediments; the underlying Evangeline aquifer consists of Pliocene- and Miocene-age sediments; and the oldest and most deeply buried Jasper aquifer consists of Miocene-age sediments (fig. 2) (Baker, 1979, 1986). Through time, geologic and hydrologic processes created accretionary sediment wedges (stacked sequences of sediments) more than 7,600 ft thick at the coast (fig. 2) (Chowdhury and Turco, 2006). The sediments composing the Gulf Coast aquifer system were deposited by fluvial-deltaic processes and subsequently were eroded and redeposited (reworked) by large episodic changes in sea level that occurred as a result of oscillations between glacial and interglacial climate conditions (Lambeck and others, 2002). The Gulf Coast aquifer system consists of hydrogeologic units that dip and thicken from northwest to southeast (fig. 2); the aquifers thus crop out in bands inland from and approximately parallel to the coast and become progressively more deeply buried and confined toward the coast. The Burkeville confining

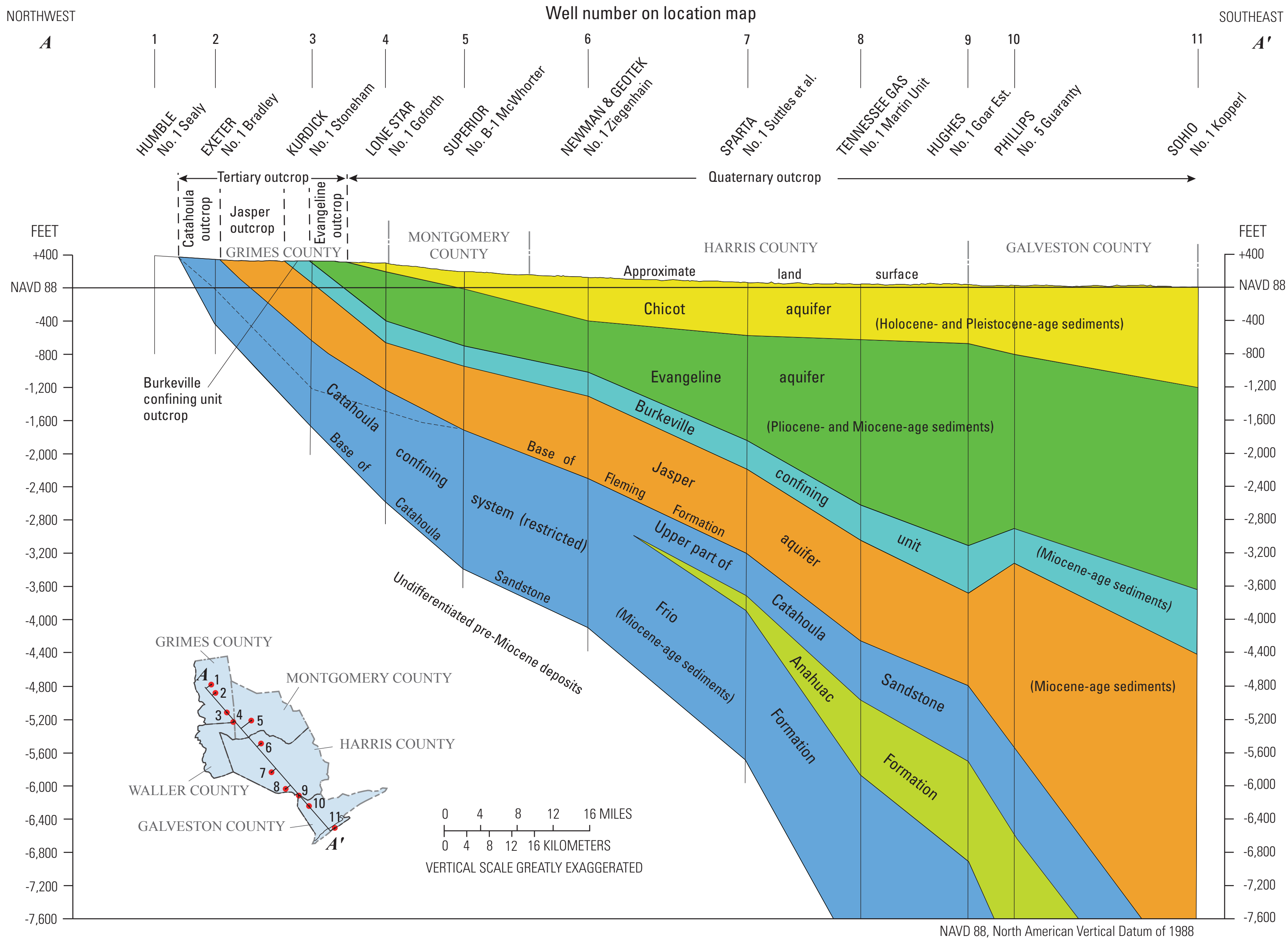

Figure 2. Hydrogeologic section of the Gulf Coast aquifer system in Harris County and adjacent counties, Texas (modified from Baker, 1979, fig. 4).

unit separates the Evangeline and Jasper aquifers and restricts groundwater flow between the two aquifers. There is no confining unit between the Chicot and Evangeline aquifers; therefore, the aquifers are hydraulically connected, which allows groundwater flow between the aquifers (fig. 2). Because of this hydraulic connection, water-level changes that occur in one aquifer can affect water levels in the adjoining aquifer (Kasmarek and Robinson, 2004). Evidence of this water-level interaction is substantiated by the two long-term water-level-change maps (1977–2013, sheets 5 and 10) that indicate that the areas where water-levels have declined or risen are approximately coincident for the Chicot and the Evangeline aquifers. The Chicot aquifer can be differentiated from the geologically similar Evangeline aquifer on the basis of hydraulic conductivity (Carr and others, 1985, p. 10) and where each aquifer outcrops—the Chicot aquifer outcrops closer to the coast compared to the Evangeline aquifer. The Jasper aquifer outcrops inland from the Evangeline aquifer. The Jasper can be differentiated from the Evangeline aquifer on the basis of water levels, which are shallower (closer to land surface) in the Jasper aquifer compared to those in the Evangeline aquifer. In the downdip parts of the aquifer system, the Jasper aquifer can be differentiated from the Evangeline aquifer on the basis of stratigraphic position in relation to the Burkeville confining unit (figs. 2–4).

The hydrogeologic cross section *A–A´* (fig. 2) extends through the Houston-Galveston region from northwestern Grimes County, continues southeastward through Montgomery and Harris Counties, terminates at the coast in Galveston County, and depicts the three aquifers thickening and dipping toward the coast from their updip limits. Comparisons of cross sections *A–A´* (fig. 2), B–B’ (fig. 3), and C–C’ (fig. 4) indicates that the thicknesses of the three aquifers similarly increase downdip towards the coast. Conversely, in central Harris, southern Montgomery, and Grimes Counties, the sediments of the updip Chicot and Evangeline aquifers become progressively thinner (fig. 2), and in northern Montgomery and Grimes County, the thickness of the sediments composing the Chicot aquifer are effectively insufficient for groundwater withdrawal (fig. 2). The hydrogeologic cross section *C–C´* (fig. 4) through Montgomery County (which extends into extreme northern Harris County) similarly indicates decreases in sediment thickness updip towards the northwest.

Water in the Chicot, Evangeline, and Jasper aquifers is fresh (less than 1,000 milligrams per liter [mg/L] dissolved solids concentration) in the Houston-Galveston region, but it becomes more saline in the downdip and more deeply buried parts of the aquifers near the coast (Baker, 1979). In the groundwater-flow system, precipitation falling on the land either discharges to streams or infiltrates into the unconfined updip sediments recharging the aquifers as the water flows downward into the aquifer and coastward (Kasmarek and Robinson, 2004). Water that does not discharge to streams flows to intermediate and deep zones of the system southeastward of the outcrop areas, and there the water is withdrawn and discharged by wells or is naturally discharged by diffuse upward leakage in topographically low areas near the coast (Kasmarek and Robinson, 2004).Water in the coastal, deep zones of the aquifers is denser, with dissolved solids concentrations greater than 1,000 mg/L. This higher density water causes the lower density freshwater that has not been captured and withdrawn by wells to be redirected as diffuse upward leakage to shallow zones of the confined downdip areas of the aquifer system and to be ultimately discharged to coastal brackish water bodies (Kasmarek and Robinson, 2004).

Subsidence and Compaction Processes

Subsidence can occur as a result of potentiometric surface declines in unconsolidated confined aquifers (Galloway and others, 1999). By 1979, as much as 10 ft of land-surface subsidence had occurred in the Houston-Galveston region, and approximately 3,200 mi^2 of the 11,000-mi^2 geographic area had subsided more than 1 ft (Coplin and Galloway, 1999). Potentiometric surface declines cause a decrease in hydraulic pressure (depressuring) that creates a load on the skeletal matrix of the sediments in the aquifer and adjacent confining units (fig. 5). Because sand layers are more transmissive and less compressible than are clay layers, sand layers depressure more rapidly compared to clay and silt layers. In addition, when groundwater withdrawals are decreased, pressure equilibrium is reestablished more rapidly in the sand layers compared to the clay and silt layers, and the amount of compaction of the sand layers is usually minor compared to the amount of compaction of the clay and silt layers (Trahan, 1982; Galloway and others, 1999). The clay layers are often interbedded within the sand layers, and when depressuring occurs, the clay layers dewater more slowly compared to the sand layers. The compressibility of the clay layers is dependent on the thickness and hydraulic characteristics of the clay layers and the vertical stress of the saturated and unsaturated sediment overburden. Slow drainage of the clay layers continues to occur until the excess residual pore pressure in the clay layers equilibrates with the pore pressure of the adjacent sand layers. As dewatering progresses, compaction of the clay and silt layers continues until pressure equilibrium is attained. A similar loading process can occur in sand layers; however, a major difference is that the orientation of the individual clay and silt grains realigns as depressuring and dewatering progresses, becoming perpendicular to the applied vertical overburden load (Galloway and others, 1999). Essentially, the water stored in the clay and silt layers prior to depressuring provides interstitial pore-space support to the skeletal matrix of the clay. As water levels decline, the clay layers dewater and depressure, allowing the individual clay and silt grains composing the clay layer to reorient and compact. Additionally, compaction of the clay and silt layers reduces the porosity and groundwater-storage capacity of the clay layers (fig. 5). Because most compaction of subsurface sediments is inelastic, about 90 percent of the compaction is permanent and only a small amount of rebound of the

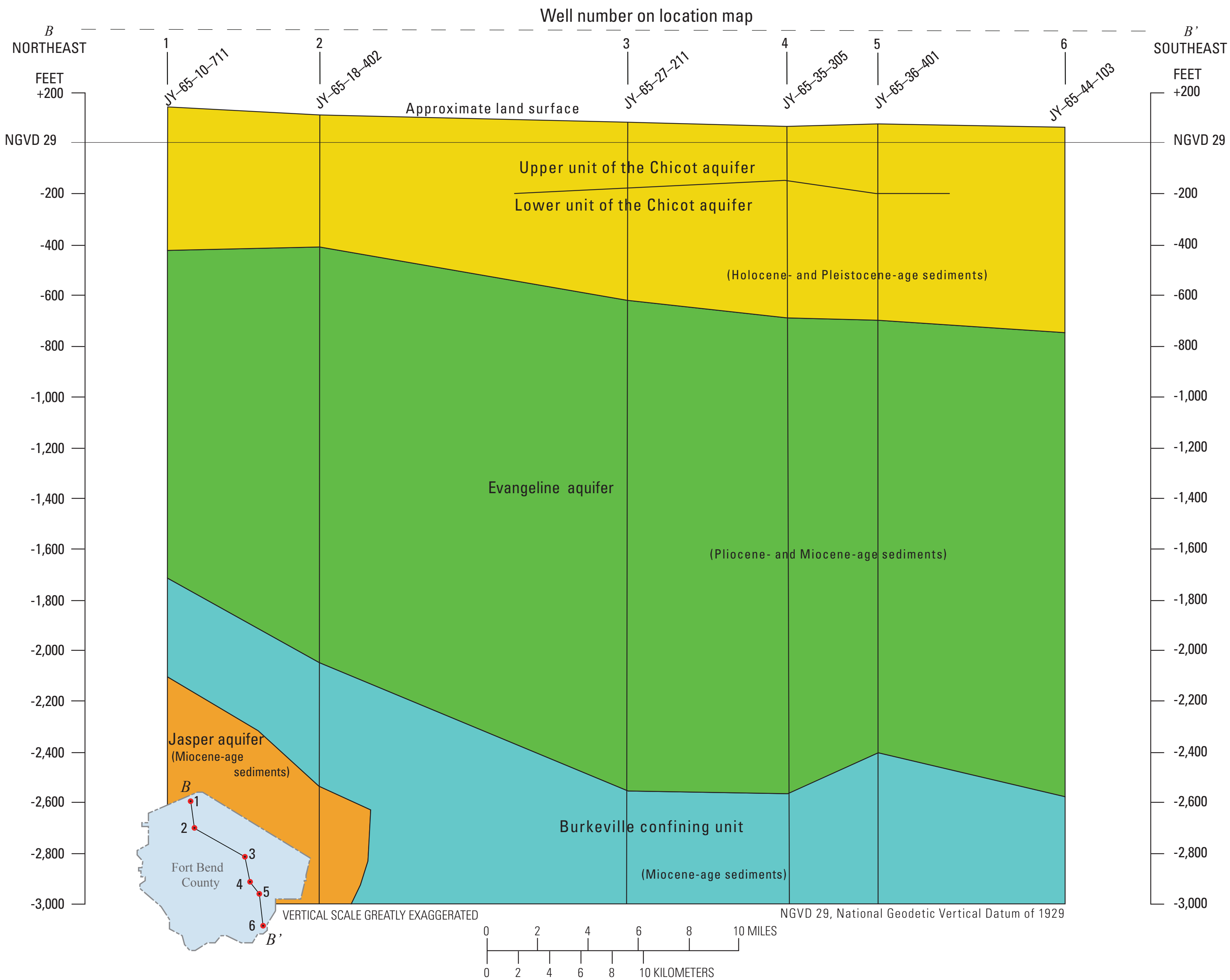

Figure 3. Hydrogeologic section of the Gulf Coast aquifer system in Fort Bend County, Texas (modified from Wesselman, 1972, fig. 30).

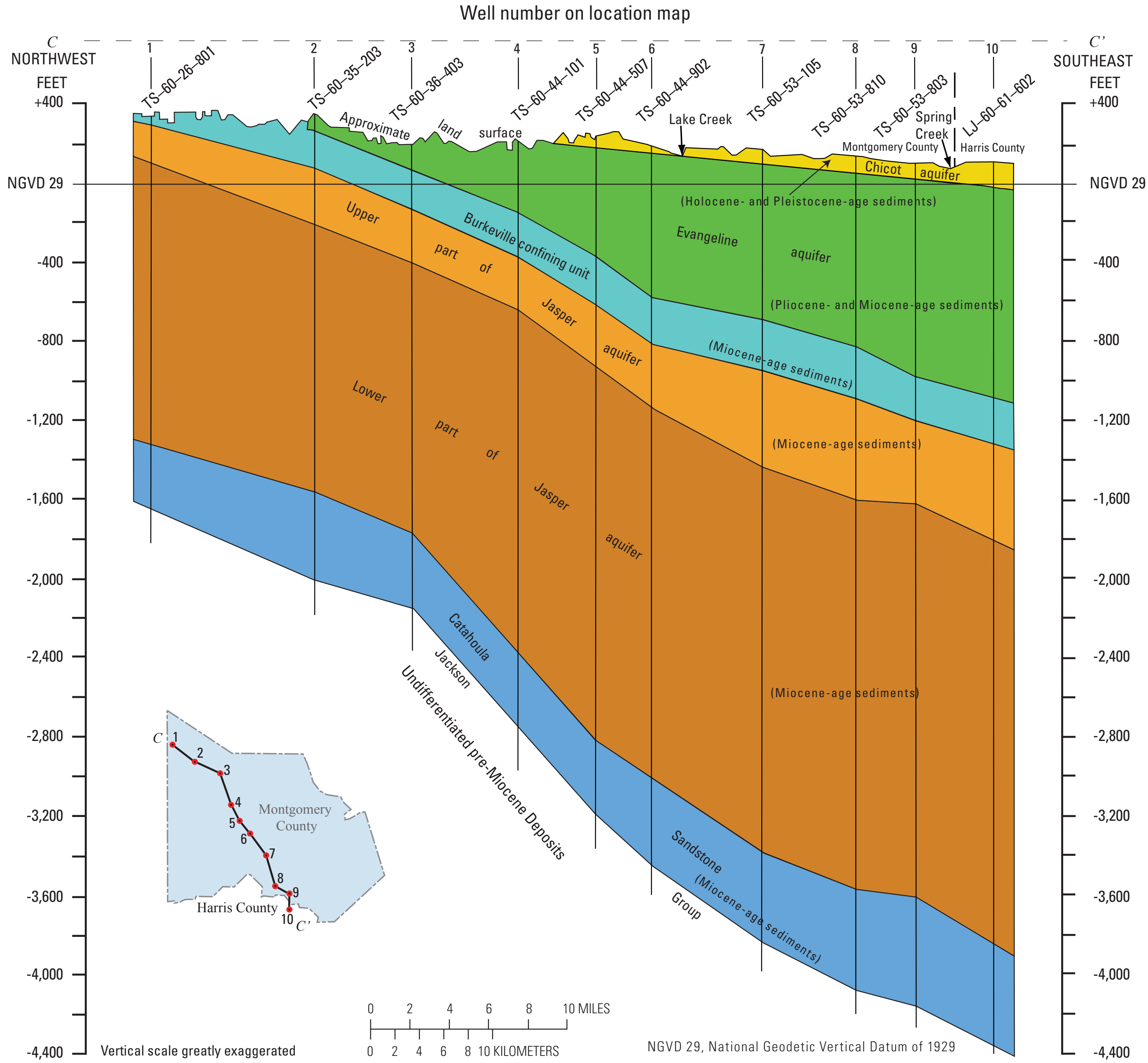

Figure 4. Hydrogeologic section of the Gulf Coast aquifer system in Montgomery and Harris Counties, Texas (modified from Popkin, 1971, fig. 29).

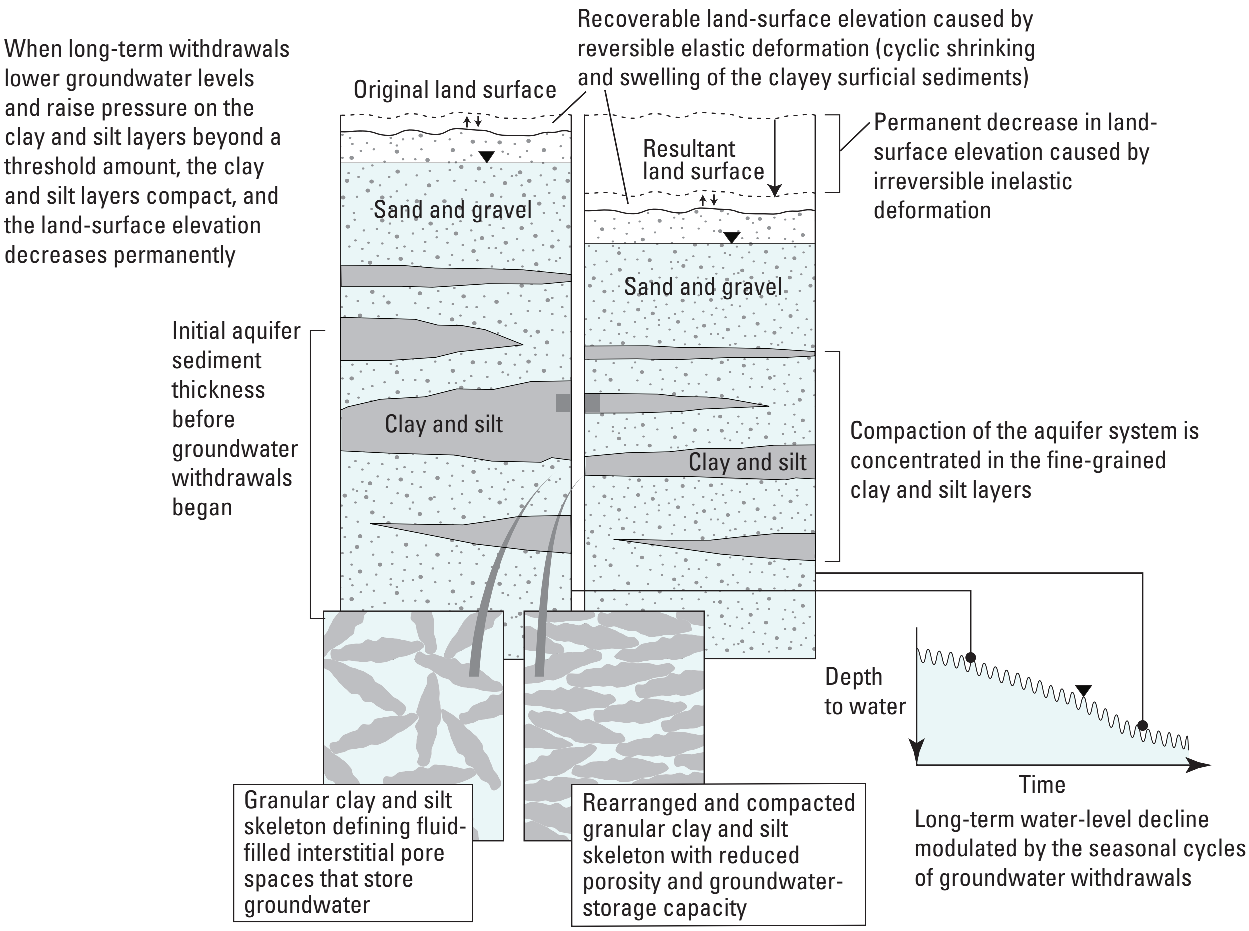

Figure 5. Mechanism of subsidence caused by potentiometric surface declines induced by groundwater withdrawals in an aquifer composed of sand, clay, and silt (modified from Galloway and others, 1999, p. 9).

land-surface altitude occurs (Gabrysch and Bonnet, 1975). Although the compaction of one thin clay and silt layer generally will not cause a noticeable decrease in the land-surface altitude, when numerous stacked clay and silt- and sand-layer sequences (characteristic of the Gulf Coast aquifer system) depressure and compact, subsidence often occurs (Gabrysch and Bonnet, 1975).

Data Collection and Analysis Methods

Water-level data were obtained from wells by measuring the depth to water below land surface at each well. Measurements were made by USGS personnel by using calibrated steel tape, airline, electric water-level tape (Cunningham and Schalk, 2011) and by more than 10 different industrial entities and powerplants operating throughout the study area that use water for hydrocarbon extraction and electrical power generation, respectively. Antecedent pumping conditions and pumping status of nearby wells were not always known, although most wells were pumped at least once daily and some more frequently. At least two water-level measurements were made at each well while the well was not being pumped, and to ensure that the water-level measurement recorded was accurate, additional water-level measurements were made as required. Water-level measurements in wells used to construct sheets 1–14 of this report were collected during December 2012–February 2013 to represent 2013 water-level altitudes (tables 1–3); during the winter months of December through February, water levels of the aquifers in the Houston-Galveston region are usually higher compared to the rest of the year because rates of groundwater withdrawals generally are at a minimum. Subsequently, these data were incorporated into a geographic information system (GIS) as point-data layers and used for the construction of sheets 1–14.

Determination of Water-Level Altitudes

The water-level-altitude data used to construct the water-level-altitude maps for the Chicot, Evangeline, and Jasper aquifers (sheets 1, 6, and 11, respectively) were calculated by subtracting the water-level measurement from the land-surface-altitude value for each point (well). Land-surface altitudes were referenced to the North American Vertical Datum of 1988 (NAVD 88; hereinafter, datum); therefore, the data for each point (well) used for contour configuration on the three approximate water-level-altitude maps (sheets 1, 6, and 11) is referenced to NAVD 88 (tables 1–3). These approximate water-level-altitude contours represent 2013 regional-scale depictions of the water levels in wells in the Chicot, Evangeline, and Jasper aquifers, and the areal extents and locations of these contours represent the combined effects of groundwater withdrawals from all groundwater wells in the study area. Water-level altitudes were depicted with contour intervals of 50 and 100 ft.

Quality Assurance

Protocols for the collection and review of water-level-altitude data were followed as described in the USGS Texas Water Science Center internal document "Quality Assurance Plan for Groundwater Activities" (app. 7.3, "Groundwater Data Management Plan" [Greg P. Stanton, U.S. Geological Survey, written commun., 2010]). All data were archived in the USGS National Water Information System (NWIS) (U.S. Geological Survey, 2013).

The annual (2013) regional-scale depictions of water-level altitudes presented in this report were derived from water-level-measurement data collected during December 2012–February 2013 throughout the 11-county area that includes the greater Houston-Galveston area. The water-level altitudes of the Chicot, Evangeline, and Jasper aquifers are continually changing in response to changes in hydrologic conditions and the rates of groundwater withdrawals and precipitation. Therefore, the water level in any of the three aquifers may have declined or risen since the most recent water-level measurements were made. Antecedent withdrawal rates and pumping status of nearby wells were not always known and could have affected the representativeness of the water-level data that were collected.

Depicting Changes in Water-Level Altitudes

The approximate water-level-change contours (sheets 3–5, 8–10, and 13–14) represent regional-scale depictions of water-level change during selected periods for each aquifer. Delineated areas depicting contours of water-level rise or decline represent water-level changes in the aquifers caused by spatial and temporal changes in groundwater withdrawals. Maps depicting changes in water-level altitudes in the Chicot, Evangeline, and Jasper aquifers were constructed for 1-year (2012–13), 5-year (2008–13), and various long-term (1990–2013 [Chicot and Evangeline], 1977–2013 [Chicot and Evangeline], and 2000–13 [Jasper]) periods. To create the various water-level-change maps, datasets of water-level-change values (difference between the current year [2013] and historical water-level-altitude values) were used. The historical years (1977, 1990, and 2000) when the water-level-altitude maps were created and published as part of the USGS annual map series are coincident with the creation of the HGSD, FBSD, and LSGCD.

For the 1-year (2012–13) water-level-change maps (sheets 2, 7, and 12), water-level changes were computed as the difference between water-level altitude at each point (well) for which a water-level measurement was made in 2012 and in 2013. Water-level changes on the 1-year maps are depicted by using upward pointing triangles to indicate water-level-change rises, downward pointing triangles to indicate water-level-change decreases, and circles indicating no water-level change. Number within the water-level rise and decline triangles indicates the amount of water-level change.

For the 5-year (2008–13) water-level-change maps (sheets 3, 8, and 13), water-level changes were computed the same as for the 1-year maps—the difference between water-level altitude at each point (well) for which a water-level measurement was made in 2008 and in 2013. Changes on the 5-year maps are depicted by contours of equal water-level change. Each 5-year map was constructed by contouring the set of mapped point differences.

For the historical (1977–2013, 1990–2013, 2000–13) water-level-change maps (sheets 4, 5, 9, 10, and 14), water-level changes were computed as the difference between water-level altitude at each point (well) for which a water-level measurement was made in the historical years (1977, 1990, and 2000) and in 2013. For wells measured in 2013 that had no corresponding measurement in the historical year, a GIS raster (gridded surface) (Worboys, 1995) was created from published historical water-level-altitude contours (1977 [Gabrysch, 1979], 1990 [Kasmarek, 1997], and 2000 [Kasmarek and Houston, 2007]). The maps were constructed by contouring the set of mapped point values computed either as the difference in water-level altitude at each point (well) for which a water-level measurement was made in 2013 and in the historical year or as the difference in water-level altitude at that point in 2013 and the water-level altitude on a gridded surface of the historical year water-level-altitude map (Gabrysch, 1979; Kasmarek, 1997; Kasmarek and Houston, 2007). Gridded surface values for the historical year (rather than actual measured values) were used to compute differences (mapped point values) because many of the wells measured in the historical year have been destroyed or were not measured in 2013. For the subset of wells measured in both 2013 and in the historical year, the mapped point values used were the differences in water-level-altitude values between 2013 and the historical year rather than the differences between 2013 water-level-altitude values and historical year gridded surface values.

Borehole Extensometers

To install a borehole extensometer (example shown in fig. 6), a borehole is first drilled to a predetermined depth, generally below the depth of expected water-level decline. A steel outer casing with slip joints, which prevents crumpling and collapse of the well casing as compaction of subsurface sediments (henceforth referred to as compaction) occurs, is then installed in the borehole. A smaller diameter inner pipe (often referred to as the “extensometer pipe”) is inserted inside the outer casing, with the inner pipe terminating within the cement plug and extending above land surface and remaining rigid and fixed as compaction occurs. At land surface, a concrete slab is poured and connected to an array of vertical concrete piers extending down into the water table. The concrete piers connect the slab to the underlying unconsolidated sediments penetrated by the borehole; this construction design helps to eliminate the continuous shrinking and swelling of the clayey surficial sediments associated with soil-moisture changes. A metal gage house (not depicted) is constructed on the slab, and a shaft encoder and analog recorder are mounted to a steel table that is attached to the borehole-extensometer slab. A calibrated steel tape connects the recorder to the top of the inner pipe; because the steel table is anchored to the concrete slab, changes in land-surface altitude can be accurately measured and recorded. These recorded values through time represent the cumulative compaction that has occurred at the extensometer site. The scientific theory and operation of a borehole extensometer is further explained by Gabrysch (1984).

Borehole-extensometer data are used to quantify the rate of compaction in aquifer formations, thereby providing water-resource managers a tool for evaluating the effects on subsidence rates caused by changes in the amount of groundwater withdrawn from the Chicot and Evangeline aquifers. For this report, borehole-extensometer data of the compaction in the Chicot and Evangeline aquifers were evaluated at 13 borehole extensometers at 11 sites in Harris and Galveston Counties (sheet 15, tables 4*A*–4*L*). To quantify the rates of compaction in the aquifer formations, a network of extensometers was installed beginning in 1973 at selected sites throughout Harris and Galveston Counties. Five extensometers were installed in Harris or Galveston County in July 1973: KH–64–33–920 (Texas City-Moses Lake) in Galveston County and LJ–65–22–622 (East End), LJ–65–16–930 (Baytown C–1), LJ–65–16–931 (Baytown C–2), and LJ–65–32–625 (Seabrook) in Harris County. A previous borehole extensometer installed in 1962 in Harris County (LJ–65–32–401 [Johnson Space Center]) was included in the network. Since July 1973, routine measurements of compaction at the Johnson Space Center extensometer have been collected and are included in this report. Additional extensometers were added to the network during 1974–76 in Harris County: LJ–65–12–726 (Addicks) in 1974, LJ–65–23–322 (Pasadena) in 1975, and LJ–65–32–428 (Clear Lake [deep]) and LJ–65–32–424 (Clear Lake [shallow]) in 1976. The last three extensometers in the current (2013) network were installed in Harris County in 1980: LJ–65–07–909 (Lake Houston), LJ–65–14–746 (Northeast), and LJ–65–21–226 (Southwest). Since activation or installation between 1973 and 1980, compaction measurements have been obtained at these 13 extensometers at least monthly, thereby providing site-specific rates of compaction accurate to within 0.001 ft. Measured compaction data from 12 of the 13 borehole extensometers is provided in table 4. Measured compaction data for the Clear Lake (shallow) extensometer are not listed in table 4 or shown on figure 6 because the data from the nearby Clear Lake (deep) extensometer are similar.

Each borehole extensometer has a 10-ft screened interval above the cement plug that allows water to flow into the center pipe and thus functions as a piezometer (small-diameter well used to measure water level in the aquifer). A water-level measurement is made during each extensometer site visit. If the depth of the screened interval is located entirely within the Chicot or Evangeline aquifer, these water-level measurements are considered during construction of the annual water-level-altitude maps for those aquifers.

Water-Level Altitudes and Changes

Locations of wells used to construct the water-level-altitude maps and water-level-change maps for the Chicot, Evangeline, and Jasper aquifers are depicted in appendix 1. The well index numbers on the three maps (appendixes 1–1, 1–2, and 1–3) correspond to tabular data (tables 1, 2, and 3, respectively) for each water-level-altitude maps or water-level-change map.

The Chicot and Evangeline aquifer maps depict approximate water-level altitudes in 2013 and water-level changes for 2012–13, 2008–13, 1990–2013, and 1977–2013 in these aquifers (sheets 1–5 and 6–10, respectively). Maps of long-term water-level change in these aquifers (1977–2013; sheets 5 and 10) depict areas of water-level decline in northern, northwestern, and southwestern Harris County and a broad area of water-level rise in southeastern Harris and northern Galveston Counties.

The Jasper aquifer maps depict approximate water-level altitudes in 2013 and water-level changes for 2012–13, 2008–13, and 2000–13 (sheets 11–14). Depictions of long-term water-level change (2000–13; sheet 14) indicate that water-level declines have occurred in most of Montgomery County and north-central Harris County.

Except for the 2012–13 change maps, the water-level-altitude contours were constructed by using contour intervals relative to the specific range of water-level changes for a given map. Adjusting the contour intervals in this way helped to present a clear depiction of regional-scale water-level changes.

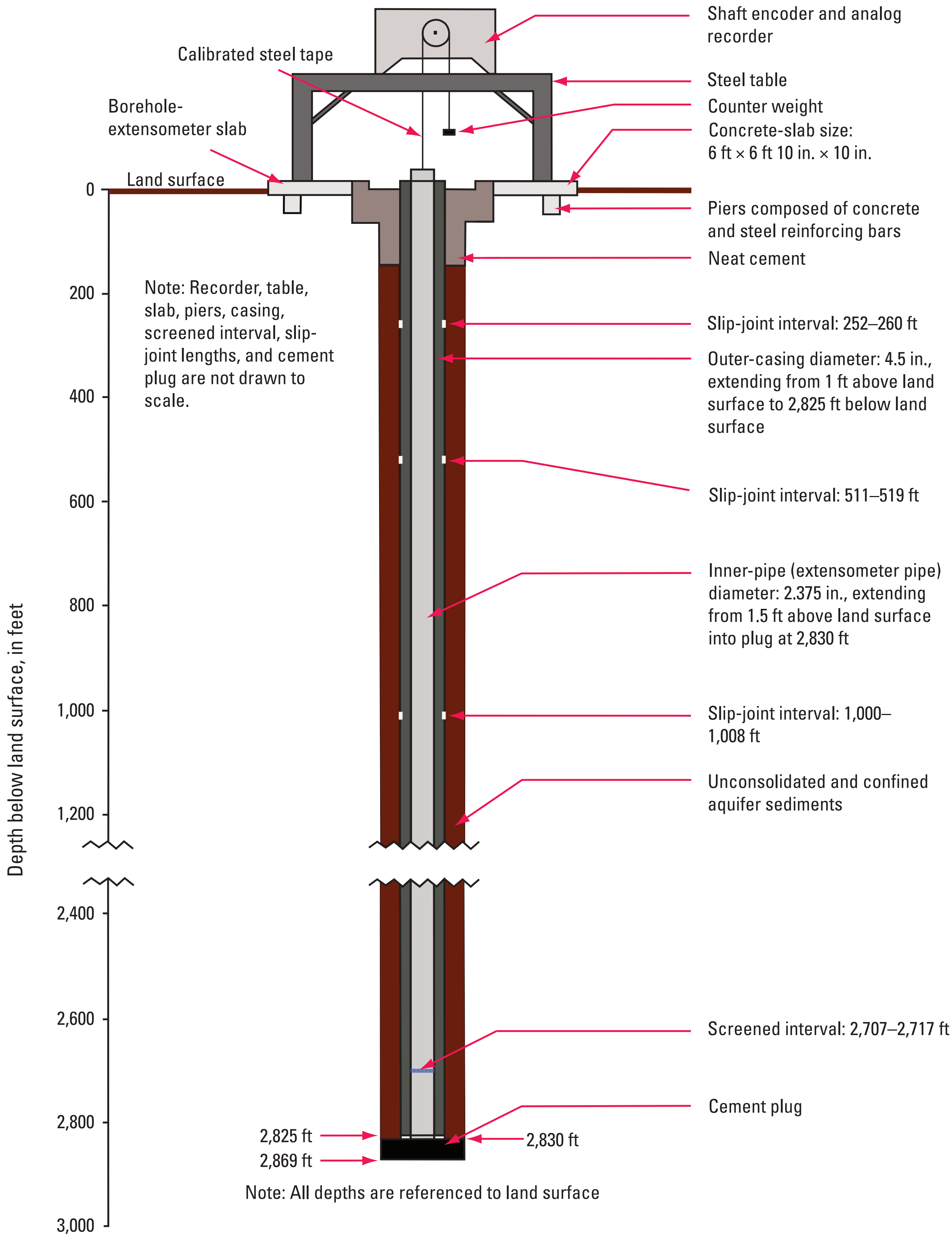

Figure 6. Cross-sectional perspective of the borehole extensometer/piezometer (LJ–65–23–322) located at Pasadena, Texas (ft, foot; in., inch).

Chicot Aquifer

Water-level measurements from 178 wells (table 1) were used to construct the 2013 water-level-altitude map of the Chicot aquifer. In 2013, water-level-altitude contours ranged from 200 ft below datum in a small area in southwestern Harris County to 200 ft above datum in central to west-central Montgomery County south of Lake Conroe (sheet 1). Depictions of water-level change for 2012–13, 2008–13, 1990–2013, and 1977–2013 are presented on sheets 2, 3, 4, and 5, respectively. The numbers of water-level-measurement pairs used to construct the change maps were 166 for 2012–13, 158 for 2008–13, 147 for 1990–2013, and 135 for 1977–2013 (table 1).

Changes in water-level altitudes in the Chicot aquifer during 2012–13, depicted by numbered symbols on the sheets, ranged from a 58-ft water-level decline in southeastern Montgomery County to a 37-ft rise in south-central Harris County (sheet 2). For 2008–13, contoured changes in water-level altitudes ranged from a 30-ft decline in eastern Fort Bend County to an 80-ft rise in west-central Harris County (sheet 3). For 1990–2013, contoured changes in water-level altitude ranged from a 120-ft decline in south-central Montgomery County to a 100-ft rise in southeastern Harris County (sheet 4). At one well near the center of the area inside the contour depicting the 100-ft rise in water level altitude, a water-level rise of 193 ft was recorded (sheet 4). For 1977–2013, contoured changes in water-level altitude ranged from 80-ft declines in northwestern and southwestern Harris County to a 200-ft rise in southeastern Harris County (sheet 5). The long-term water-level change (1977–2013) depictions indicate areas of decline in northern, northwestern, and southwestern Harris County and across central and eastern Fort Bend County, with a broad area of water-level rise in central, eastern, and southeastern Harris and northern Galveston Counties.

Evangeline Aquifer

Water-level measurements from 333 wells (table 2) were used to construct the 2013 water-level-altitude map of the Evangeline aquifer. In 2013, water-level-altitude contours ranged from 300 ft below datum near the boundary between Montgomery and Harris Counties in south-central Montgomery County to 200 ft above datum in southeastern Grimes and northwestern Montgomery Counties (sheet 6). Depictions of water-level change for 2012–13, 2008–13, 1990–2013, and 1977–2013 are presented on sheets 7, 8, 9, and 10, respectively. The numbers of water-level-measurement pairs used to construct the change maps were 290 for 2012–13, 276 for 2008–13, 272 for 1990–2013, and 262 for 1977–2013 (table 2).

The 2012–13 water-level changes in the Evangeline aquifer are depicted by numbered symbols and ranged from a 37-ft water-level decline at two locations in southeastern Montgomery County and at another location in extreme eastern Harris County to a 68-ft rise in southwestern Harris County (sheet 7). For 2008–13, contoured changes in water-level altitude ranged from an 80-ft decline in south-central Montgomery County to an 80-ft rise at two locations in Harris County, one in southwestern and one in north-central Harris County (sheet 8). For 1990–2013, contoured changes in water-level altitude ranged from a 220-ft decline in south-central Montgomery County to a 220-ft rise in southeastern Harris County (sheet 9). For 1977–2013, contoured change ranged from a 360-ft decline in south-central Montgomery County to a 260-ft rise in southeastern Harris County (sheet 10). The long-term water-level-change depictions (1977–2013) indicate areas of decline in northern, northwestern, and southwestern Harris County and in northern Fort Bend County. A broad area of water-level rise was detected in central, eastern, and southeastern Harris County and in the northernmost parts of Brazoria and Galveston Counties.

Jasper Aquifer

Water-level measurements from 92 wells (table 3) were used to construct the 2013 water-level-altitude map of the Jasper aquifer. For 2013, water-level-altitude contours ranged from 200 ft below datum in south-central Montgomery and north-central Harris Counties to 250 ft above datum in northwestern Montgomery County and extending into northeastern Grimes and south-central Walker Counties (sheet 11).

Depictions of water-level change for 2012–13, 2008–13, and 2000–13 are provided on sheets 12, 13, and 14, respectively. The numbers of water-level-measurement pairs used to construct the change maps were 87 for 2012–13, 61 for 2008–13, and 80 for 2000–13 (table 3). For the period 2012–13 in the Jasper aquifer, water-level change (depicted by numbered symbols) ranged from a 36-ft decline in south-central Montgomery County to an 87-ft rise in northwestern Harris County (sheet 12). For 2008–13, contoured changes in water-level altitude ranged from a 100-ft decline in south-central Montgomery County to a small area of 20-ft rise northwestern Harris County (sheet 13). For 2000–13, contoured changes in water-level altitudes declined over most of Montgomery County and northern Harris County, and contoured changes ranged from a 220-ft decline in south-central Montgomery County to no change in extreme northwestern Montgomery County and extending into northeastern Grimes and southwestern Walker Counties (sheet 14).

Compaction of Subsurface Sediments in the Chicot and Evangeline Aquifers

Compaction of subsurface sediments (henceforth referred to as compaction) (mostly in the clay and silt layers because little compaction occurs in sand layers; refer to “Subsidence and Compaction Processes” section) composing the Chicot and Evangeline aquifers was recorded continuously at the 13 borehole extensometers at 11 sites (sheet 15) by using analog chart recorders. The rate of compaction varied from site to site (sheet 16). Graphs of compaction are presented for 1973 (or later) through 2012 (depending on when each extensometer was activated or installed) for 12 of the 13 extensometers (compaction measured by the shallower of the two extensometers (LJ–65–32–424) located at the Clear Lake site is not included on sheet 16 because the recorded data are similar to those measured by the deeper extensometer (LJ–65–32–428) at the site). Compaction data used for the graphs on sheet 16 are listed in tables 4*A*–*L*.

The selected depth of the extensometer determines the total thickness of sediment over which compaction is measured by the extensometer. Five extensometers measure compaction of the Chicot aquifer (East End, Johnson Space Center, Texas City-Moses Lake, Baytown C–1, and Seabrook, and seven extensometers measure compaction of the Chicot and Evangeline aquifers (Lake Houston, Northeast, Southwest, Addicks, Baytown C–2, Clear Lake, and Pasadena) (sheet 16). From the early 1900s until 2001, as much as 12–13 ft of subsidence had occurred in the Pasadena and Baytown areas in Harris County (Kasmarek, Gabrysch, and Johnson, 2010). The graphs of measured compaction data from installation in 1975 through 2012 for the Pasadena extensometer and from installation in 1973 through 2012 for Baytown C–1 and C–2 extensometers indicate compaction values of 0.648, 1.098, and 1.187 ft, respectively (sheet 16; tables 4*L*, 4*H*, and 4*I*, respectively). Most (77–97 percent) of the land-surface subsidence in the Houston-Galveston region occurred prior to 1973, before the construction of the extensometers (Kasmarek, Johnson, and Ramage, 2010).

Prior to the creation of the HGSD in 1975, the withdrawal of groundwater from the Chicot and Evangeline aquifers was unregulated, and water levels in the aquifers were declining with associated depressuring, dewatering, and compaction (Coplin and Galloway, 1999). By 1977, the withdrawals had resulted in water-level-altitude declines of 300 and 350 ft below datum in the Chicot and Evangeline aquifers, respectively, in southeastern Harris County (Gabrysch, 1979), and correspondingly, by 1979, as much as 10 ft of subsidence had occurred in the Houston-Galveston region (Coplin and Galloway, 1999). The rate of compaction is different at each borehole-extensometer site because of the different groundwater withdrawal rates in the adjacent areas of each site and the varying clay-to-sand ratios of the subsurface sediments. When reductions in groundwater withdrawals were first mandated following the creation of the HGSD in 1975, the rate of groundwater withdrawal began to decrease, as well as the rate of compaction (sheet 16). Coincident with the curtailment of groundwater withdrawals, water levels of the aquifers began to rise. The decreases in groundwater withdrawals allowed the water levels in the Chicot and Evangeline aquifers to rise (recover) as much as 200 ft and 260 ft, respectively (1977–2013 long-term water-level-change maps [sheets 5 and 10]) in the areas encompassing the extensometer sites.

Compaction data discussed in this report ends on the last site visit in December 2012, and the cumulative measured compaction (sheet 16) ranged from 0.100 ft (table 4*G*) at the Texas City-Moses Lake borehole extensometer solely in the Chicot aquifer to as much as 3.632 ft (table 4*E*) at the Addicks extensometer in the Chicot and Evangeline aquifers. The graphs of cumulative compaction data indicate that the compaction rates were substantially higher when the borehole extensometers were initially installed compared to compaction rates in subsequent years. These asymptotic compaction-rate decreases are directly related to the rise in water levels in the aquifers as groundwater withdrawals were decreased in response to regulatory mandates of the HGSD. As the water levels in the aquifers began to rise and recover, the hydrostatic pressure increased, and excess residual pore pressure equilibrated; hence, the rates of compaction progressively decreased. Coinciding with compaction-rate decreases, the long-term water-level changes for 1990–2013 and 1977–2013 in the Chicot and Evangeline aquifers (sheets 4 and 5 and sheets 9 and 10, respectively) indicate that, except for the Addicks extensometer, the locations of these extensometers coincide with the relatively large area of water-level rise. Compaction data from the Addicks extensometer (table 4*E*) indicate a consistent rate of compaction beginning from when it was installed in mid-1974 to about mid-2003. The reason the rate remained steady during this period is that the extensometer is located in Regulatory Area 3 of the HGSD and, as such, was not scheduled for a 30-percent groundwater reduction until 2010 (Harris-Galveston Subsidence District, 2010). Therefore, from mid-1974 through mid-2003, groundwater withdrawal continued unabated in the area adjacent to the Addicks extensometer site with an associated compaction rate of about 0.1 ft per year. Additionally, the rate of compaction during August 2003–December 2003 decreased to about 0.004 ft because an adjacent public-supply well field was inoperative during this period. For December 2003 until about March 2006, recorded data indicate an increase (rebound) in land-surface altitude of about 0.030 ft, followed by little net change in land-surface altitude between March 2006 (3.501 ft total compaction) and May 2009 (3.506 ft total compaction). Compaction resumed (albeit at a slower rate than previously) in June 2009 and continued through the most recent measurement in December 2012 of 3.632 ft (table 4*E*; sheet 16). The graph of compaction data obtained from the Seabrook extensometer indicates a seasonal sinusoidal pattern in the altitude of the land surface caused by decreases in altitude during the hot and dry summer months followed by increases in altitude during the cooler and wetter winter months. During the summer months the surficial clayey sediments desiccate and shrink, but as the heat of the summer dissipates and the cooler and wetter months arrive, the sediments rehydrate and swell, thereby causing the altitude of the land surface to increase and rebound.

Compaction data for the Texas City-Moses Lake borehole extensometer indicates that the rate of compaction not only has been halted but also, since January 1981, a slight land-surface rise of approximately 0.093 ft has occurred (table 4G; sheet 16). The graphs of compaction data for the Pasadena, Clear Lake, Seabrook, Baytown C–1 and C–2, and Johnson Space Center extensometers indicate a slight increase in land-surface altitude from late 1978 to early 1980 because a ruptured natural gas well pressurized the confined aquifer system and caused water levels to rise in the area adjacent to the well (Gabrysch, 1984). Over a period of about 2 years, the pressure in the aquifer slowly dissipated, and the process of compaction subsequently returned to similar rates that existed before the pressuring event. The graphs of compaction data for the two Baytown extensometers indicate a noticeable amount of seasonal variation from late 1973 to late 1982, which was determined to be caused by the expansive (shrinking and swelling) characteristics of the montmorillonitic clay within the aquifer sediments. To address the problem of shrinking and swelling of clayey sediments at the borehole-extensometer sites, in 1982, a modification was made to the original design of the borehole extensometers by installing a system of vertical piers that are anchored to the concrete slabs of the extensometers and extend downward to the depth of the water table (fig. 6). By comparing the compaction graphs before and after 1982, it can be seen that these design modifications improved the accuracy of the data.

Data Limitations

Most land-surface altitudes for wells in this report are estimates from USGS 1:24,000 scale 7.5-minute topographic quadrangle maps (topographic quadrangle maps). Land-surface altitudes for 2009 and later for the wells in Harris County are derived from the digital elevation model of the 2001 Tropical Storm Allison Recovery Project that used light detection and ranging (lidar) technology (Harris County Flood Control District, Tropical Storm Allison Recovery Project, 2002). These altitudes are referenced to NAVD 88 by using Corpscon version 6 (U.S. Army Corps of Engineers, 2006). The lidar data were contoured at a 1-ft interval, providing 0.5-ft accuracy. The topographic quadrangle maps for the Gulf Coast area were typically contoured at a 5-ft interval, thereby providing 2.5-ft accuracy; thus, the lidar data provide about five times better accuracy when compared to topographic quadrangle maps (Kasmarek, Gabrysch, and Johnson, 2010). In addition, the topographic quadrangle maps have not been updated with changes in land-surface altitude that might have occurred since their initial and various publication dates. The effects of land-surface-altitude changes on water-level-change maps need to be accounted for if the change maps are to accurately reflect differences between current year and previous year water-level-altitude maps (each of which reflects the best available land-surface altitudes of wells).

The depictions of water-level altitudes and changes at any specific location are considered to represent a regional-scale approximation and, as such, are not intended for use in engineering or other design applications. The water-level measurements collected for this report were rounded to the nearest foot; the values depicted on the maps represent a mathematical approximation that could vary as much as plus or minus 0.5 ft, in addition to accuracies associated with the source data. Use of these data for critical or local-scale applications is not advised without full awareness of the data limitations. Users need to exercise discretion when drawing conclusions or making policy decisions on the basis of these contoured depictions.

Compaction data recorded at each borehole-extensometer site (sheet 16) indicate the measured compaction for subsurface sediments above the depth of the cement plug (fig. 6); any compaction or vertical movement that occurs below these depths is not measured by the extensometer. Depending on the total depth of the borehole extensometer, the compaction for a given extensometer could represent solely the sediments of the Chicot aquifer (for example, the Baytown C–1 extensometer) or represent the sediments of both the Chicot and Evangeline aquifers (for example, the Addicks extensometer). In addition to differences in the rates of groundwater withdrawals in the areas of each extensometer site, the clay-to-sand ratio is different at each site; hence, the rate of compaction varies from site to site (sheet 16). Therefore, it is not possible to extrapolate or infer a rate of compaction for an area on the basis of the rate of compaction measured at a nearby extensometer.

Summary

The Houston-Galveston region, Texas—consisting of Harris, Galveston, Fort Bend, Montgomery, Brazoria, Chambers, Liberty, San Jacinto, Walker, Grimes, and Waller Counties—represents one of the largest areas of subsidence in the United States. By 1979, as much as 10 feet (ft) of land-surface subsidence had occurred in the Houston-Galveston region, and approximately 3,200 square miles (mi^2) of the 11,000-mi^2 geographic area had subsided more than 1 ft. Groundwater withdrawn from the Chicot, Evangeline, and Jasper aquifers has been the primary source of water for municipal supply, industrial and commercial use, and irrigation in the Houston-Galveston region since the early 1900s. Most of the subsidence in the Houston-Galveston region has occurred as a direct result of groundwater withdrawals that depressured and dewatered the Chicot and Evangeline aquifers, thereby causing compaction of the aquifer sediments. To address the issues associated with land-surface subsidence and subsequent increased flooding, the 64th Texas State Legislature in 1975 authorized the establishment of the Harris-Galveston Subsidence District to regulate and reduce groundwater withdrawals in Harris and Galveston Counties. Subsequently, the Texas State

Legislature established the Fort Bend Subsidence District in 1989 and the Lone Star Groundwater Conservation District in 2001 to regulate groundwater withdrawals in Fort Bend and Montgomery Counties, respectively. The Brazoria County Groundwater Conservation District was established by the Texas State Legislature in 2003 with the purpose to maintain the quality and availability of the county's groundwater resource for current users and future generations. This report—prepared by the U.S. Geological Survey in cooperation with the Harris-Galveston Subsidence District, City of Houston, Fort Bend Subsidence District, Lone Star Groundwater Conservation District, and Brazoria County Groundwater Conservation District—is one in an annual series of reports depicting water-level altitudes and water-level changes in the Chicot, Evangeline, and Jasper aquifers and compaction in the Chicot and Evangeline aquifers in the Houston-Galveston region.

The report contains maps depicting approximate 2013 water-level altitudes for the Chicot, Evangeline, and Jasper aquifers; maps depicting 1-year (2012–13) water-level changes for each aquifer; maps depicting 5-year (2008–13) changes for each aquifer; maps depicting long-term (1990–2013 and 1977–2013) water-level changes for the Chicot and Evangeline aquifers; a map depicting long-term (2000–13) water-level changes for the Jasper aquifer; a map depicting locations of borehole-extensometer sites; and graphs depicting borehole-extensometer-measured compaction beginning in 1973 (or later depending on when the extensometer site was activated or installed) through December 2012. Tables listing the data used to construct each water-level map for each aquifer and the measured-compaction graphs are included.

Water levels in wells screened in the Chicot, Evangeline, and Jasper aquifers were measured during December 2012–February 2013 (water levels usually are higher in winter compared to the rest of the year). Water-level measurements from 178 wells were used to construct the 2013 water-level-altitude map of the Chicot aquifer, and contours of the 2013 water-level altitudes in this aquifer ranged from 200 ft below the North American Vertical Datum of 1988 (NAVD 88, hereinafter, datum) in a small area in southwestern Harris County to 200 ft above datum in central to west-central Montgomery County. Water-level changes in the Chicot aquifer for 2012–13 ranged from a 58-ft decline to a 37-ft rise. Contoured water-level-altitudes changes for 2008–13 ranged from a 30-ft decline to an 80-ft rise, for 1990–2013 contours ranged from a 120-ft decline to a 100-ft rise, and for 1977–2013 contours ranged from an 80-ft decline to a 200-ft rise. Water-level measurements from 333 wells were used to construct the 2013 water-level-altitude map of the Evangeline aquifer, and contours of the 2013 water-level altitudes in this aquifer ranged from 300 ft below datum in south-central Montgomery County to 200 ft above datum in southeastern Grimes and northwestern Montgomery Counties. Water-level changes in the Evangeline aquifer for 2012–13 ranged from a 37-ft decline to a 68-ft rise. Contoured water-level changes for 2008–13 ranged from an 80-ft decline to an 80-ft rise, for 1990–2013 contours ranged from a 220-ft decline to a 220-ft rise, and for 1977–2013 contours ranged from a 360-ft decline to a 260-ft rise. Water-level measurements from 92 wells were used to construct the 2013 water-level-altitude map of the Jasper aquifer, and contours of the 2013 water-level altitudes in the Jasper aquifer ranged from 200 ft below datum in south-central Montgomery and north-central Harris Counties to 250 ft above datum in northwestern Montgomery County and extending into northeastern Grimes and south-central Walker Counties. Water-level changes in the Jasper aquifer for 2012–13 ranged from a 36-ft decline to an 87-ft rise. Contoured water-level changes for 2008–13 ranged from a 100-ft decline to a 20-ft rise, and for 2000–13 contours ranged from a 220-ft decline to no change. For the Chicot and Evangeline aquifers, the long-term water-level-change depictions (1977–2013) indicate areas of decline in northern, northwestern, and southwestern Harris County and in eastern and northern Fort Bend County. A broad area of water-level rise was detected in central, eastern, and southeastern Harris County and in the northernmost parts of Brazoria and Galveston Counties. For the Jasper aquifer, depictions of water-level change (2000–13) show that water-level declines have occurred in most of Montgomery and north-central Harris Counties.

Compaction of subsurface sediments (mostly in the clay and silt layers) composing the Chicot and Evangeline aquifers was recorded continuously at the 13 borehole extensometers at 11 sites, since the extensometers were either activated or installed between 1973 and 1980. The rates of compaction measured by each extensometer were greater when the extensometers were initially installed compared to compaction rates in subsequent years. When reductions in groundwater withdrawals were mandated following the creation of the Harris-Galveston Subsidence District in 1975, the rate of groundwater withdrawal began to decrease along with the rate of compaction. Coincident with the curtailment of groundwater withdrawals, the water levels of the aquifers began to rise. Water levels in the Chicot and Evangeline aquifers have risen as much as 200 and 260 ft, respectively, as depicted on the 1977–2013 long-term water-level-change maps. For the period of record beginning in 1973 (or later) and ending in December 2012, cumulative measured compaction at 12 of the 13 borehole extensometers in the Chicot and Evangeline aquifers ranged from 0.100 ft at the Texas City-Moses Lake extensometer (KH–64–33–920) to 3.632 ft at the Addicks extensometer (LJ–65–12–726). The rate of compaction varies from site to site because of differences in groundwater withdrawals near each site and differences among sites in the clay-to-sand ratio of the subsurface sediments. Therefore, it is not possible to extrapolate or infer a rate of compaction for an area on the basis of the rate of compaction measured at a nearby borehole extensometer.

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