In cooperation with the Texas Water Development Board and
the Harris-Galveston Coastal Subsidence District

Evaluation of Ground-Water Flow and Land-Surface Subsidence Caused by Hypothetical Withdrawals in the Northern Part of the Gulf Coast Aquifer System, Texas

Scientific Investigations Report 2005–5024

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

Evaluation of Ground-Water Flow and Land-Surface Subsidence Caused by Hypothetical Withdrawals in the Northern Part of the Gulf Coast Aquifer System, Texas

By Mark C. Kasmarek, Brian D. Reece, and Natalie A. Houston

In cooperation with the Texas Water Development Board and
the Harris-Galveston Coastal Subsidence District

Scientific Investigations Report 2005–5024

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

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

U.S. Geological Survey, Reston, Virginia: 2005
For sale by U.S. Geological Survey, Information Services
Box 25286, Denver Federal Center
Denver, CO 80225

For more information about the USGS and its products:
Telephone: 1-888-ASK-USGS
World Wide Web: http://www.usgs.gov/

Suggested citation:

Kasmarek, M.C., Reece, B.D., and Houston, N.A., 2005, Evaluation of ground-water flow and land-surface subsidence caused by hypothetical withdrawals in the northern part of the Gulf Coast aquifer system, Texas: U.S. Geological Survey Scientific Investigations Report 2005–5024, 70 p.

Contents

Figures

Datums

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).

Evaluation of Ground-Water Flow and Land-Surface Subsidence Caused by Hypothetical Withdrawals in the Northern Part of the Gulf Coast Aquifer System, Texas

By Mark C. Kasmarek, Brian D. Reece, and Natalie A. Houston

Abstract

During 2003–04 the U.S. Geological Survey, in cooperation with the Texas Water Development Board (TWDB) and the Harris-Galveston Coastal Subsidence District (HGCSD), used the previously developed Northern Gulf Coast Ground-Water Availability Modeling (NGC GAM) model to evaluate the effects of hypothetical projected withdrawals on ground-water flow in the northern part of the Gulf Coast aquifer system and land-surface subsidence in the NGC GAM model area of Texas. The Gulf Coast aquifer system comprises, from the surface, the Chicot and Evangeline aquifers, the Burkeville confining unit, the Jasper aquifer, and the Catahoula confining unit. Two withdrawal scenarios were simulated. The first scenario comprises historical withdrawals from the aquifer system for 1891–2000 and hypothetical projected withdrawals for 2001–50 compiled by the TWDB (TWDB scenario). The projected withdrawals compiled by the TWDB are based on ground-water demands estimated by regional water planning groups. The second scenario is a "merge" of the TWDB scenario with an alternate set of projected withdrawals from the Chicot and Evangeline aquifers in the Houston metropolitan area for 1995–2030 provided by the HGCSD (HGCSD scenario).

Under the TWDB scenario withdrawals from the entire system are projected to be about the same in 2050 as in 2000. The simulated potentiometric surfaces of the Chicot aquifer for 2010, 2020, 2030, 2040, and 2050 show relatively little change in configuration from the simulated 2000 potentiometric surface (maximum water-level depths in southern Harris County 150–200 feet below NGVD 29). The simulated decadal potentiometric surfaces of the Evangeline aquifer show the most change between 2000 and 2010. The area of water levels 250–400 feet below NGVD 29 in western Harris County in 2000 shifts southeastward to southern Harris County, and water levels recover to 200–250 feet below NGVD 29 by 2010. Water levels in southern Harris County recover to 150–200 feet below NGVD 29 by 2020 and remain in that range through 2050. A relatively small cone of depression in southern Montgomery County that did not appear in the 2000 surface develops and enlarges during the projected period, with a maximum depth of 250–300 feet below NGVD 29 in 2030, 2040, and 2050. The simulated decadal potentiometric surfaces of the Jasper aquifer each have a major cone of depression centered in southern Montgomery County that was minimally developed in 2000 but reaches depths of 550–650 feet below NGVD 29 in the 2020, 2030, 2040, and 2050 surfaces. Under the TWDB scenario the percentage of withdrawals supplied by net recharge increases from 75 percent in 2000 to 87 percent in 2050, and the percentage of withdrawals supplied by storage decreases from 25 percent in 2000 to 13 percent in 2050.

Under the HGCSD scenario, withdrawals from the Chicot and Evangeline aquifers increase about 74 percent during 1995–2030; Jasper aquifer withdrawals are unchanged from those of the TWDB scenario. For the 2010, 2020, and 2030 potentiometric surfaces of the Chicot and Evangeline aquifers, the substantially greater withdrawals of the HGCSD scenario relative to those of the TWDB scenario result in progressively deeper cones of depression than those in the potentiometric surfaces associated with the TWDB scenario—for the Chicot aquifer in southern Harris County, 400–450 feet below NGVD 29 in 2030; for the Evangeline aquifer in southern Montgomery County, 700–750 feet below NGVD 29 in 2030. Although Jasper aquifer withdrawals are the same for both scenarios, the major cone of depression centered in southern Montgomery County in the 2030 potentiometric surface is 50 feet deeper at its center (600–700 feet below NGVD 29) than the cone in the 2030 surface under the TWDB scenario. Under the HGCSD scenario, the percentage of withdrawals supplied by net recharge decreases from 72 percent in 1995 to 57 percent in 2030, and the percentage of withdrawals supplied by storage increases from 28 percent in 2000 to 43 percent in 2030. About 85 percent of the increase supplied by storage is from the compaction of clay.

Land-surface subsidence in the major area of subsidence centered in Harris and Galveston Counties during 2000–50 that results from simulating the TWDB withdrawal scenario expands slightly to the west and increases in places. The maximum change occurs in the Conroe area where subsidence increases from about 4 to about 13 feet during the projected period. Land-surface subsidence in the major area of subsidence during 1995–2030 that results from simulating the HGCSD withdrawal scenario increases substantially. For example, in east-central Harris County maximum subsidence increases from about 10–11 feet in 1995 to 22 feet in 2030.

The hypothetical projected withdrawal scenarios are estimates of future withdrawals and might not represent actual future withdrawals. The simplifying assumptions that the downdip limit of freshwater flow in each hydrogeologic unit is a stable, sharp interface across which no flow occurs and that the base of the system is a no-flow boundary become less realistic and thus increase the uncertainty in results as drawdowns increase. The presence of uncertainty dictates that the results of the predictive simulations described in this report be used with caution in any decision-making process.

Introduction

The northern part of the Gulf Coast aquifer system in Texas supplies most of the water for municipal, industrial, and agricultural uses in an approximately 25,000-square-mile (mi^2) area that includes the Houston metropolitan area. From land surface downward, the aquifer system comprises the Chicot and Evangeline aquifers, the Burkeville confining unit, the Jasper aquifer, and the Catahoula confining unit. These hydrogeologic units are composed of interbedded sand, clay, and silt. Withdrawals of large quantities of ground water that began around 1900 have resulted in declines in the potentiometric surfaces of the aquifers of tens to hundreds of feet and subsequent land-surface subsidence of as much as about 10 feet (ft), primarily in the Houston metropolitan area.

During 1999–2004, the U.S. Geological Survey (USGS), in cooperation with the Texas Water Development Board (TWDB) and the Harris-Galveston Coastal Subsidence District (HGCSD), conducted a study as a part of the TWDB Ground-Water Availability Modeling (GAM) program to develop a computer model to simulate ground-water flow and land-surface subsidence in the northern part of the Gulf Coast aquifer system in Texas (Kasmarek and Robinson, 2004) (fig. 1). The objective of the GAM program is to provide reliable, timely data on ground-water availability to the citizens of Texas to ensure adequacy of water supplies or recognition of inadequacy of supplies throughout the 50-year planning (or projected) period 2001–50 (Texas Water Development Board, 2004). The ground-water-flow model of Kasmarek and Robinson (2004) (hereinafter, the Northern Gulf Coast [NGC] GAM model) was calibrated in a series of transient simulations using distributed, historical withdrawals from 1891 through 2000. Hypothetical withdrawals to represent potential future water demand during the GAM 50-year projected period 2001–50 were not simulated as a part of the Kasmarek and Robinson (2004) study.

During 2003–04 the USGS, again in cooperation with the TWDB and the HGCSD, conducted a second-phase, or follow-up, study using the NGC GAM model to evaluate the effects of hypothetical projected withdrawals on ground-water flow and land-surface subsidence in the NGC GAM model area. Two withdrawal scenarios were simulated in this NGC GAM study. The first scenario comprises historical withdrawals for 1891–2000 (Kasmarek and Robinson, 2004) and hypothetical projected withdrawals for 2001–50 compiled by the TWDB (Cindy Ridgeway, Texas Water Development Board, written commun., 2004) from the Chicot, Evangeline, and Jasper aquifers (and nominally, the Burkeville confining unit) throughout the NGC GAM model area. This scenario is referred to hereinafter as the TWDB scenario (or TWDB dataset). The second scenario is a "merge" of the TWDB scenario with an alternate set of hypothetical projected withdrawals from the Chicot and Evangeline aquifers in the Houston metropolitan area for 1995–2030 provided by the HGCSD (Tom Michel, Harris-Galveston Coastal Subsidence District, written commun., 2004). This scenario is referred to hereinafter as the HGCSD scenario (or HGCSD dataset).

The purpose of this report is to describe the results of NGC GAM model simulations of the TWDB and the HGCSD withdrawal scenarios. The report briefly describes the two scenarios and then describes the simulated effects of the two scenarios on potentiometric surfaces (water levels), selected water-budget components, and land-surface subsidence. Limitations on the use of the NGC GAM model results also are discussed.

Description of the Northern Gulf Coast Ground-Water Availability Modeling Model

The USGS MODFLOW finite-difference model (Harbaugh and McDonald, 1996; Leake and Prudic, 1991) was used to simulate ground-water flow and land-surface subsidence. The NGC GAM model comprises four layers, one for each of the three aquifers and the Burkeville confining unit. The base of the Jasper aquifer/top of the Catahoula confining unit is simulated as a no-flow boundary. Each layer consists of 137 rows and 245 columns of uniformly spaced grid cells, each cell representing 1 mi^2. The northwestern no-flow boundaries of the hydrogeologic units are the northwestern extent of the updip outcrop sediments. The estimated downdip limit of freshwater (dissolved solids concentration of 10,000 milligrams per liter) in each hydrogeologic unit is the southeastern no-flow boundary of each. The southwestern and northeastern no-flow boundaries of the hydrogeologic units coincide with ground-water-flow divides associated with major streams—the Lavaca River to the southwest and the Sabine River to the northeast. The NGC GAM model was calibrated in a series of transient simulations using distributed, historical withdrawals from 1891 through 2000 with 68 stress periods of variable, but mostly

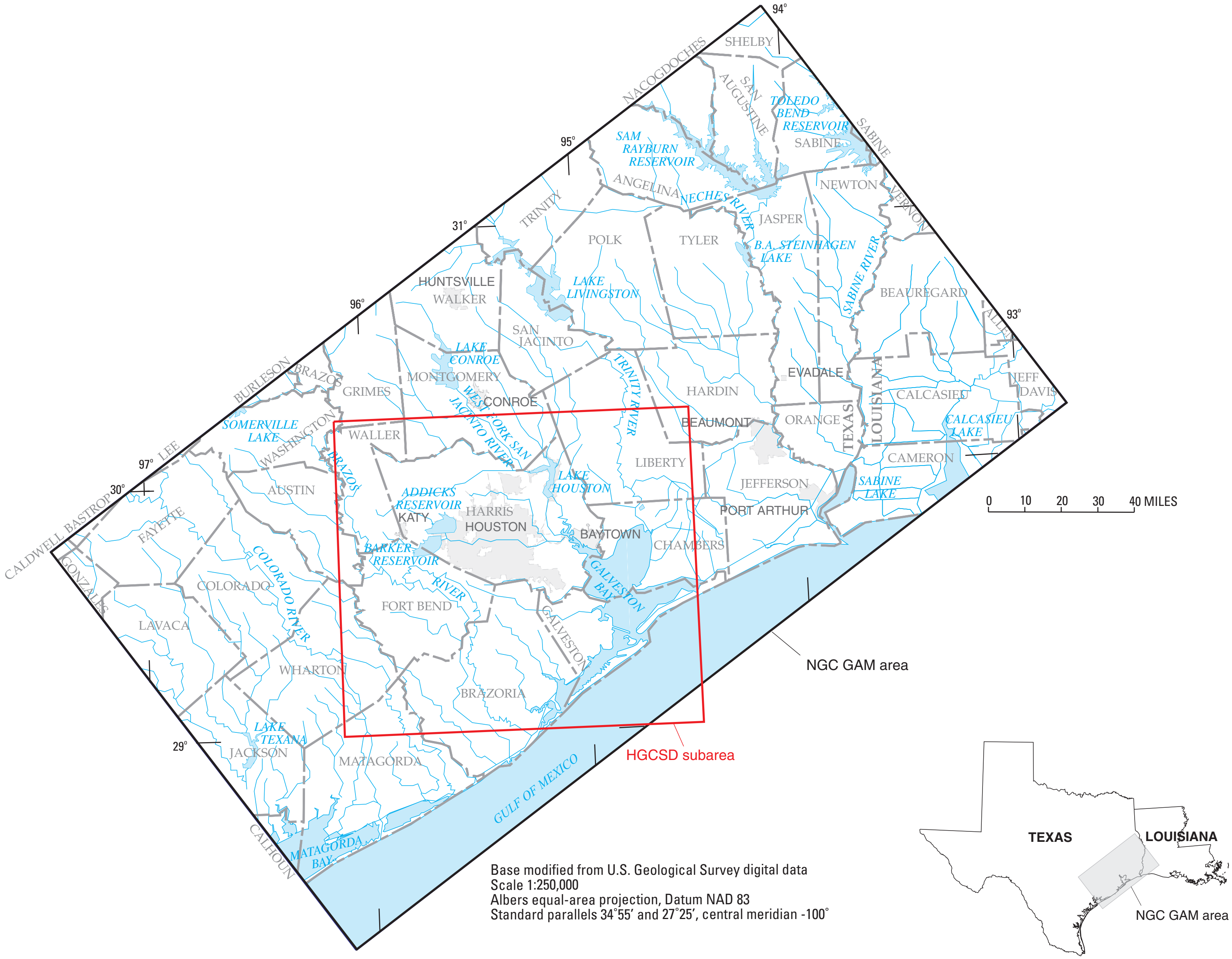


Figure 1. Location of Northern Gulf Coast Ground-Water Availability Modeling (NGC GAM) model area and the Harris-Galveston Coastal Subsidence District (HGCSD) subarea, Texas.

annual, length until simulated potentiometric surfaces, land-surface subsidence, and selected water-budget components reasonably reproduced field measured (or estimated) aquifer responses.

More information about the hydrogeology of the aquifer system, the NGC GAM model design and input datasets, calibration procedure, and simulation results are in Kasmarek and Robinson (2004). Simulations of hypothetical withdrawals indicated the need for modifications to the NGC GAM model input data of Kasmarek and Robinson (2004). Those modifications, and their effects on the NGC GAM model calibration, are documented in appendix 1 of this report.

Acknowledgments

The authors thank the Texas Water Development Board, the Harris-Galveston Coastal Subsidence District, and the Fort Bend Subsidence District for their assistance in compiling pertinent hydrogeologic and withdrawal data. The authors also thank Robert K. Gabrysch, U.S. Geological Survey (retired) for his advice and insight on land-surface subsidence and the hydrogeology of the Houston area.

Hypothetical Withdrawals

The hypothetical withdrawals consist of the projected parts of the TWDB and HGCSD withdrawal scenarios described below. Hypothetical projected withdrawals for the two scenarios were developed to provide representation of possible future withdrawal rates.

Description of Texas Water Development Board Scenario

The TWDB scenario comprises historical withdrawals for 1891–2000 and hypothetical projected withdrawals for 2001–50 from the Chicot, Evangeline, and Jasper aquifers (and nominally, the Burkeville confining unit) throughout the NGC GAM model area. The hypothetical projected withdrawals were compiled by the TWDB (Cindy Ridgeway, Texas Water Development Board, written commun., 2004). They are based on ground-water demands estimated by regional water planning groups in the NGC GAM model area (Texas Water Development Board, 2002). The hypothetical projected withdrawals, in units of acre-feet per year, were contained in spreadsheets subdivided by aquifer (Gulf Coast aquifer [system] or Brazos River alluvium only), county, stream basin, water-user group (aggregation of similar users/suppliers in an area), water-use category (municipal [major cities], manufacturing, mining, power generation, livestock, irrigation, and county-other [rural domestic]), and year.

The USGS distributed the hypothetical projected withdrawals vertically among the hydrogeologic units and spatially to the individual model cells of each unit using the methods described in appendix 2 of this report, converted the withdrawals to NGC GAM model units of cubic feet per day, and appended the projected withdrawals (50 annual stress periods) onto the historical withdrawals for simulation.

Figure 2 shows the withdrawals from the three aquifers for the NGC GAM model area from 2000 to 2050 for the TWDB scenario. For the three aquifers combined, hypothetical projected withdrawals increase about 8 percent during 2000–10 from about 850 to about 920 million gallons per day (Mgal/d), decrease to about 830 Mgal/d in 2030, and gradually increase to nearly 850 Mgal/d, the rate at the beginning of the projected period, by 2050. For the Chicot aquifer, projected withdrawals increase 20 percent during the first decade of the period from about 400 to about 480 Mgal/d, then stabilize to rates within 4 percent of that rate through 2050. For the Evangeline aquifer, projected withdrawals decrease about 7 percent during the first decade of the period from about 420 to about 390 Mgal/d in 2010. Withdrawals continue to decrease during the next decade so that by 2020 the rate is about 315 Mgal/d, a decrease of 25 percent from the rate in 2000. From 2020 through 2050, rates stabilize to levels within 4 percent of the 2020 rate. Current (2004) and projected withdrawals from the Jasper aquifer are much less than those from the other two aquifers. For the Jasper aquifer, projected withdrawals during the first decade of the period increase about 42 percent from about 36 to about 51 Mgal/d in 2010, then stabilize to rates within 6 percent of that rate through 2050. Negligible withdrawals compared to those of the aquifers (maximum about 2 Mgal/d) are projected for the Burkeville confining unit during 2001–50.

Description of Harris-Galveston Coastal Subsidence District Scenario

The HGCSD scenario consists of the TWDB scenario with an alternate set of projected withdrawals from the Chicot and Evangeline aquifers in the Houston metropolitan area (HGCSD subarea) for 1995 through 2030. The HGCSD subarea (fig. 1) encompasses the jurisdictional area of the HGCSD and immediately adjacent areas. The withdrawals for the HGCSD subarea were merged into the TWDB dataset—that is, HGCSD Chicot and Evangeline aquifer withdrawals replaced historical (1995–2000) and TWDB projected (2001–30) Chicot and Evangeline aquifer withdrawals in the subarea.

These data reflect different estimation and distribution processes than those of the TWDB data. The HGCSD projected withdrawals were developed by Turner Collie & Braden (1996) on the basis of projected water demand in Harris, Galveston, and Fort Bend Counties and adjacent parts of Austin, Brazoria, Chambers, Grimes, Liberty, Matagorda, Montgomery, Waller, and Wharton Counties for 1995–2030. Projected water demand during the period was based on projected population. Population projections, associated water demand, and withdrawals were developed for the cells of a MODFLOW model grid encompassing the HGCSD subarea (LBG-Guyton Associates,

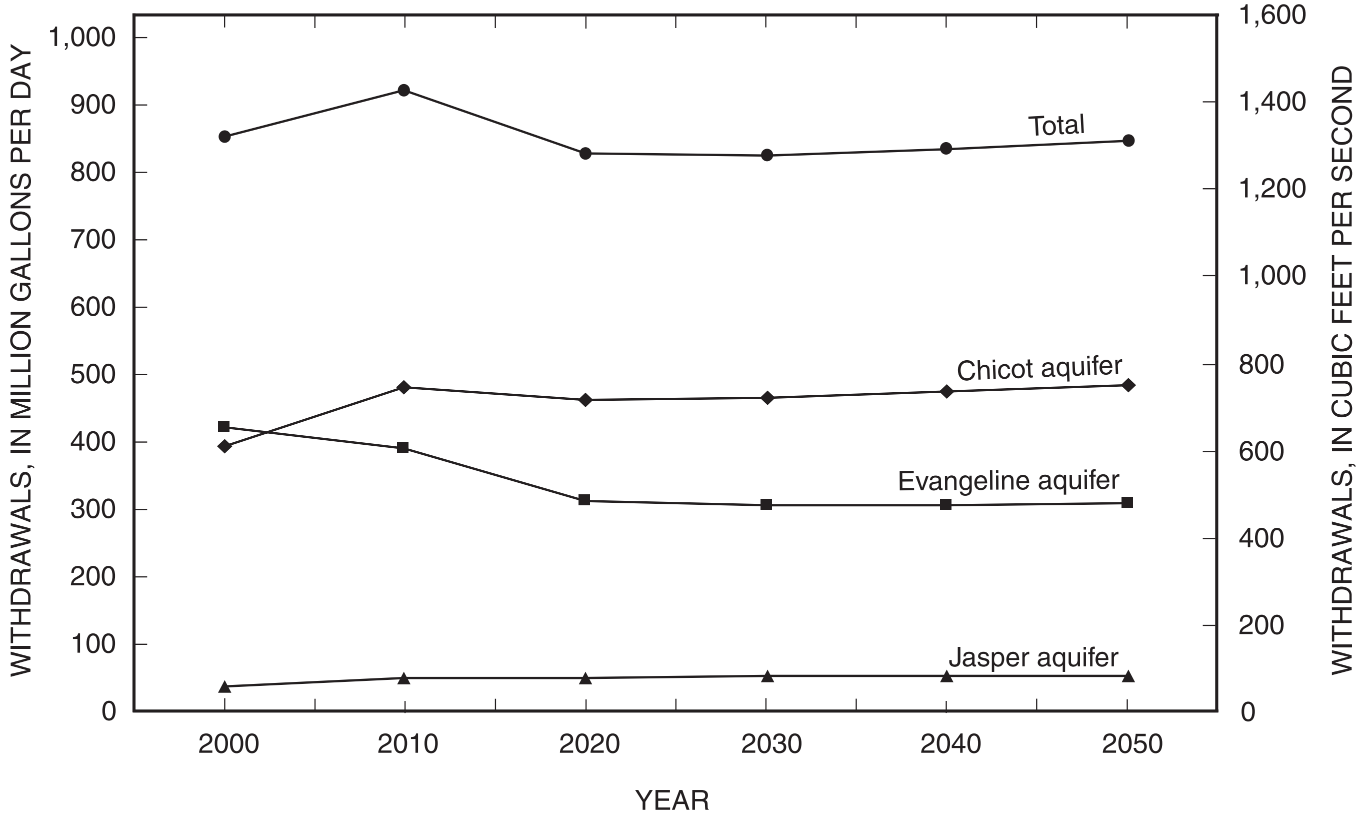


Figure 2. Withdrawals in the Chicot, Evangeline, and Jasper aquifers in the NGC GAM model area from 2000 to 2050, TWDB withdrawal scenario.

1997). The grid orientation is that of USGS 7.5-minute topographic quadrangles encompassing the HGCSD subarea, and each cell represents a 2.5-minute quadrangle area (about 7 mi^2) within the applicable 7.5-minute quadrangle. The projected withdrawals, in units of cubic feet per day, were thus contained in a MODFLOW-readable file composed of rows and columns representing Chicot and Evangeline aquifer withdrawals distributed among the cells of a model grid.

The USGS redistributed the HGCSD withdrawals from their original grid cells to grid cells of the NGC GAM model using the methods described in appendix 2 of this report and formatted the withdrawals into annual stress periods for input to the NGC GAM model. To summarize the results of this merge of TWDB and HGCSD datasets in the context of NGC GAM model layers:

Layers 1 and 2 (Chicot and Evangeline aquifers)—

- Within HGCSD subarea—1995–2030, HGCSD dataset
- Outside HGCSD subarea—1891–2030, TWDB dataset

Layers 3 and 4 (Burkeville confining unit and Jasper aquifer)—

- Within HGCSD subarea—1891–2030, TWDB dataset
- Outside HGCSD subarea—1891–2030, TWDB dataset

Figure 3 shows withdrawals from the three aquifers for the NGC GAM model area from 1995 to 2030 for the HGCSD scenario. As described above, Jasper aquifer withdrawals are the same as for the TWDB scenario. Unlike in the TWDB scenario, projected withdrawals from the Chicot and Evangeline aquifers for the HGCSD scenario increase continuously during 1995–2030. Also, projected withdrawals from both the Chicot and Evangeline aquifers for the period are substantially larger than those of the TWDB scenario. Total withdrawals from all three aquifers increase about 74 percent from about 875 Mgal/d in 1995 to about 1,520 Mgal/d in 2030. For the Chicot aquifer, projected withdrawals increase continuously from about 420 Mgal/d in 1995 to about 520, 590, and 670 Mgal/d in 2010, 2020, and 2030, respectively, an approximately 60-percent increase during the period. For the Evangeline aquifer, projected withdrawals increase continuously at a greater rate from about 420 Mgal/d in 1995 to about 580, 670, and nearly 800 Mgal/d in 2010, 2020, and 2030, respectively, an approximately 90-percent increase during the period.

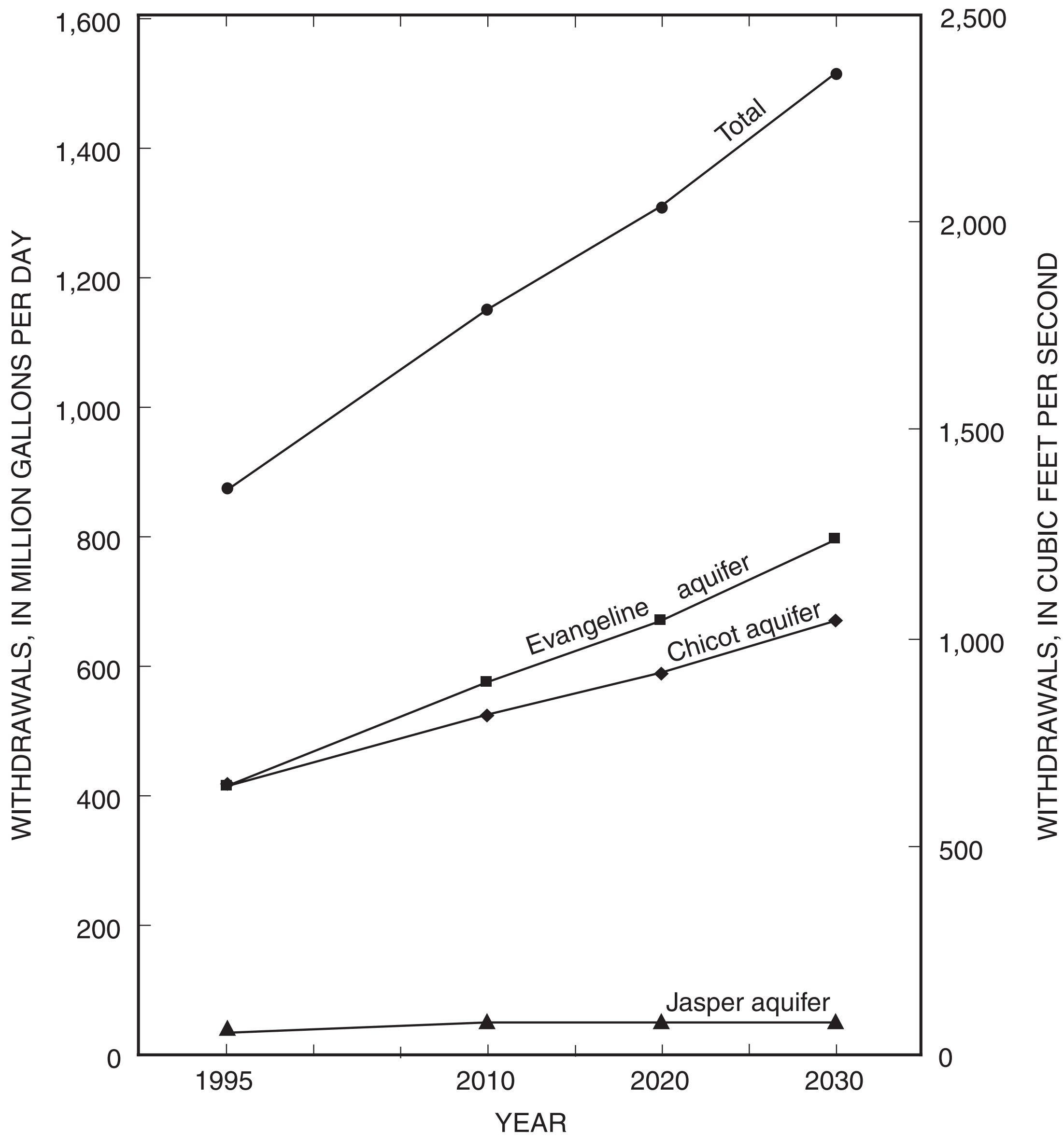


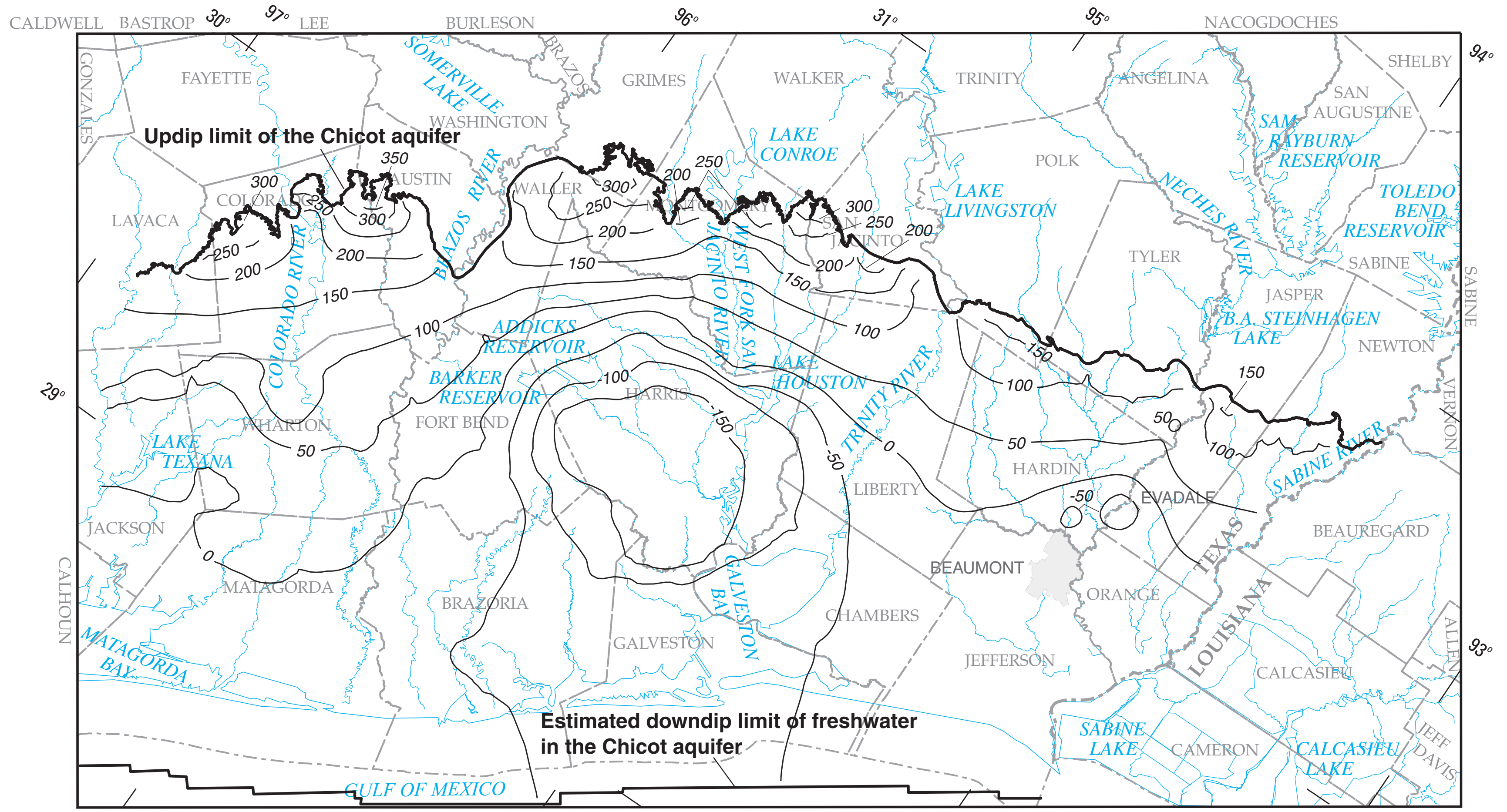
Figure 3. Withdrawals in the Chicot, Evangeline, and Jasper aquifers in the NGC GAM model area from 1995 to 2030, HGCSD withdrawal scenario.

Evaluation of Ground-Water Flow

The evaluation of ground-water flow comprises descriptions of potentiometric-surface maps (water levels) of the aquifers and selected water-budget components resulting from simulation of the TWDB and HGCSD withdrawal scenarios. HGCSD and TWDB results are compared.

Results Using Texas Water Development Board Scenario

The simulated potentiometric surfaces of the Chicot aquifer for 2000, 2010, 2020, 2030, 2040, and 2050 (figs. 4–9) that result from the TWDB withdrawal scenario show relatively little change in configuration over time. The broad area 150–200 ft below NGVD 29 at the center of the major cone of depression in southern Harris County in the simulated 2000 surface (fig. 4) remains similarly configured in the 2010 surface (fig. 5). In the 2020 surface (fig. 6), this area is smaller than in the 2000 and 2010 surfaces and becomes smaller still in the 2030 and 2040 surfaces (figs. 7, 8). A small cone of depression 150–200 ft below NGVD 29 in northern Brazoria County appears in the 2020, 2030, and 2040 surfaces. In the 2050 surface (fig. 9), the area 150–200 ft below NGVD 29 is similarly configured to that in the 2030 surface and has coalesced with the small cone of depression in northern Brazoria County.



Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—— -150 —— **Simulated potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 4. Simulated 2000 potentiometric surface of the Chicot aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.

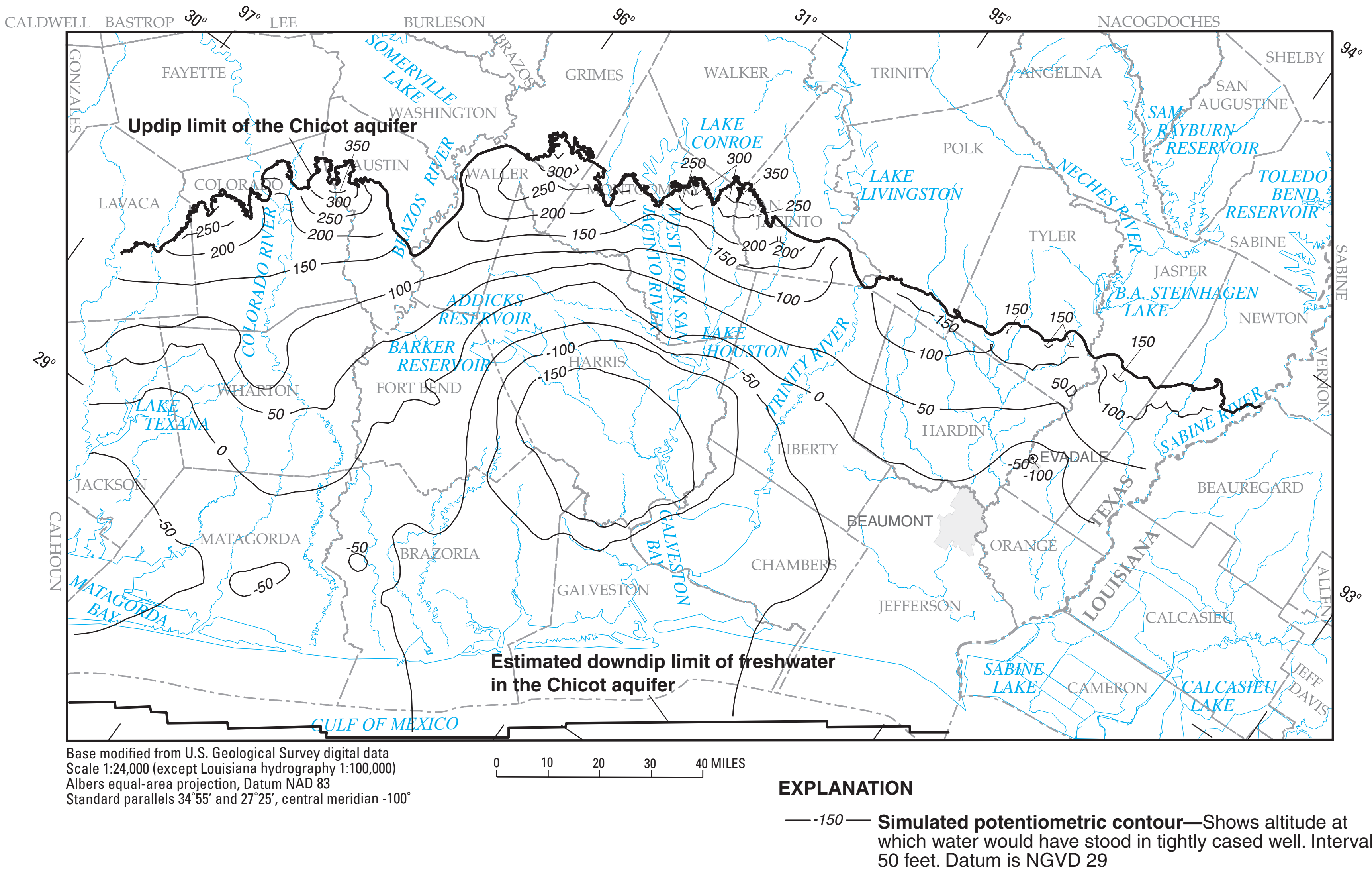
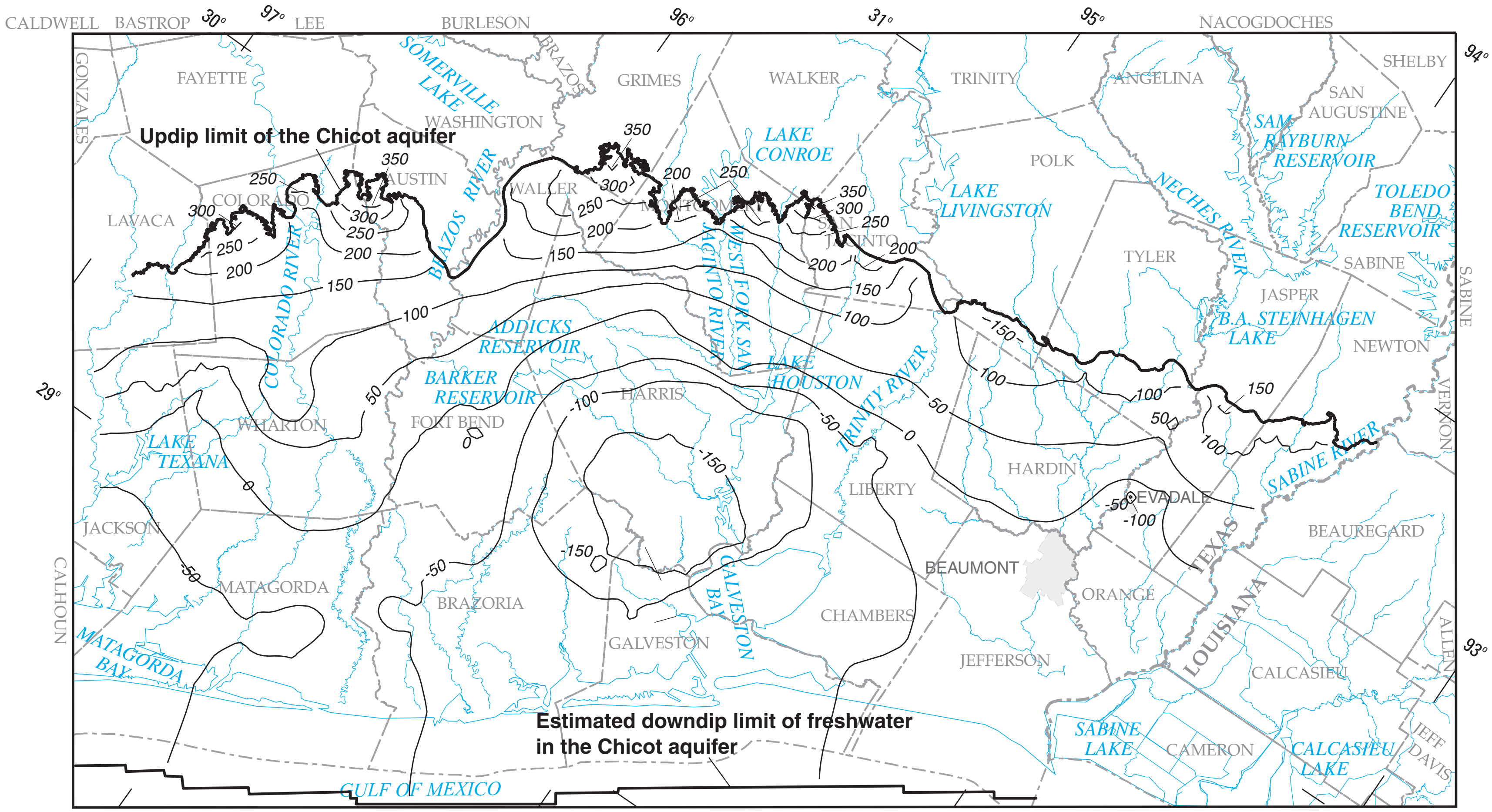


Figure 5. Simulated 2010 potentiometric surface of the Chicot aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



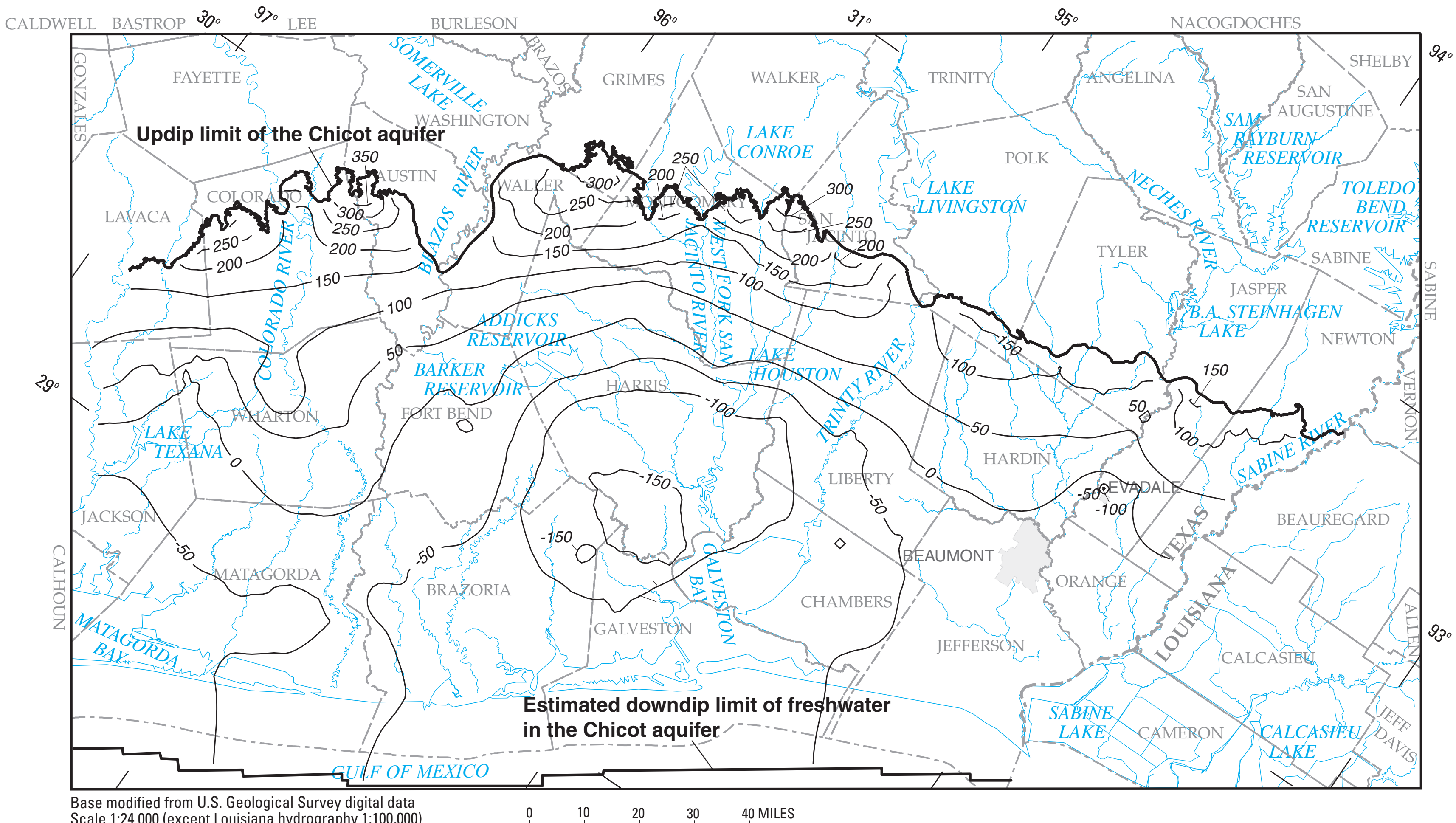
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—*-150*— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 6. Simulated 2020 potentiometric surface of the Chicot aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.

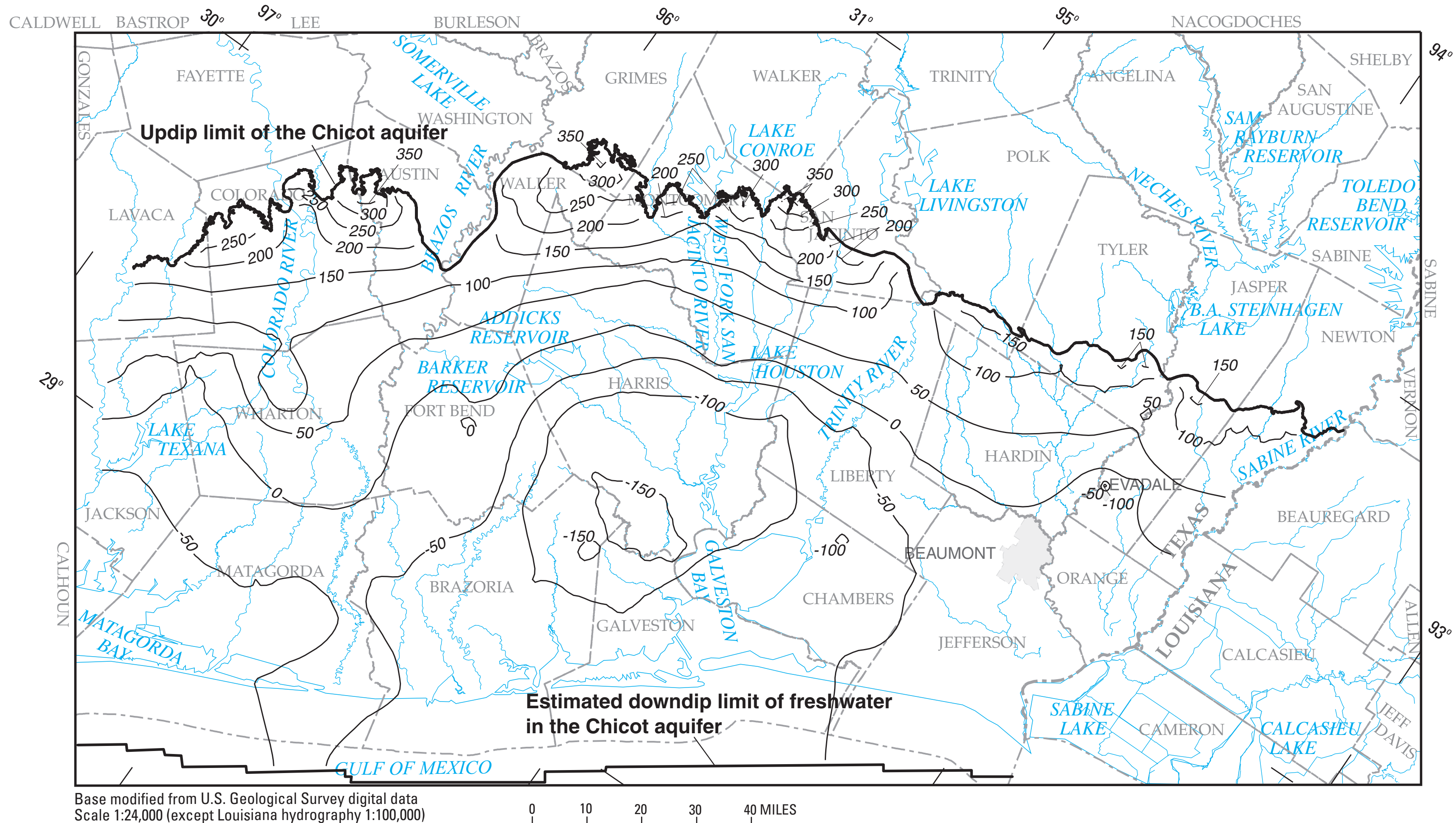


Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

EXPLANATION

—-150— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

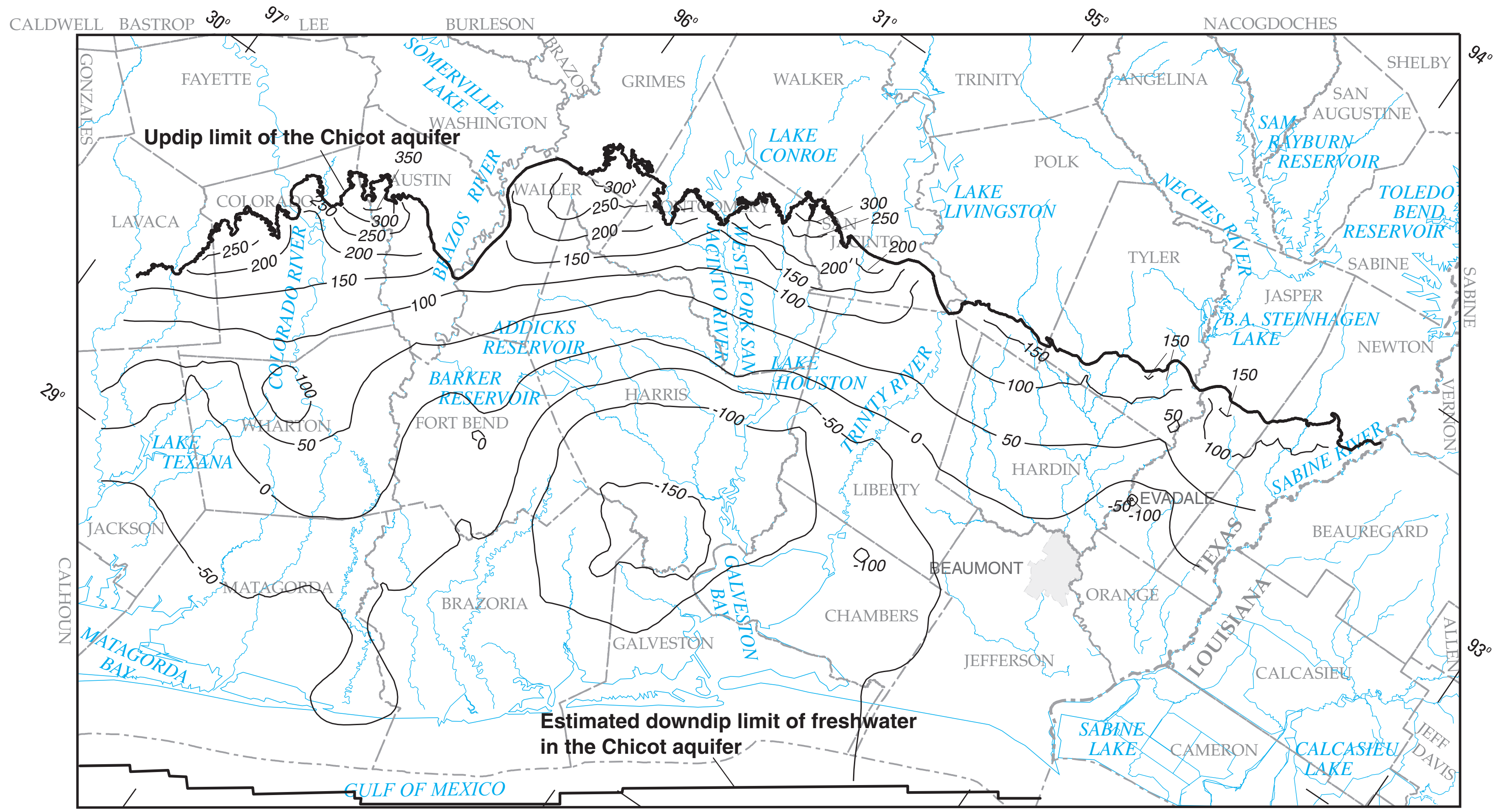
Figure 7. Simulated 2030 potentiometric surface of the Chicot aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



EXPLANATION

—— -150 —— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 8. Simulated 2040 potentiometric surface of the Chicot aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

EXPLANATION

—-150— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 9. Simulated 2050 potentiometric surface of the Chicot aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.

In the second of three principal areas of withdrawals, the coastal irrigation area centered in Wharton and Jackson Counties, an area of water levels 50–100 ft below NGVD 29 first appears in southeastern Jackson and southwestern Matagorda Counties in the 2010 surface and expands eastward in Matagorda County over time. In the third principal area of withdrawals, the Evadale-Beaumont area (southern Jasper and Hardin Counties), little or no change in Chicot aquifer water levels over the TWDB projected period is evident.

The simulated potentiometric surfaces of the Evangeline aquifer for 2000, 2010, 2020, 2030, 2040, and 2050 (figs. 10–15) show the most change between 2000 (fig. 10) and 2010 (fig. 11). Water levels 250–400 ft below NGVD 29 in the major cone of depression in the simulated 2000 Evangeline aquifer potentiometric surface in western Harris County do not appear in the 2010 surface; for 2010, the area of deepest water levels shifts southeastward to southern Harris County and recovers to 200–250 ft below NGVD 29. However, another, smaller cone of depression 200–250 ft below NGVD 29 appears in the 2010 surface in southern Montgomery County, a feature that did not appear in the 2000 surface. The 2020 Evangeline aquifer potentiometric surface (fig. 12) indicates continued water-level recovery in southern Harris County, with an area of water levels 150–200 ft below NGVD 29 the deepest there. The relatively small cone of depression 200–250 ft below NGVD 29 in the 2010 surface in southern Montgomery County is slightly larger in the 2020 surface. For 2030, 2040, and 2050 (figs. 13–15) the Evangeline aquifer surfaces are essentially stable at levels comparable to those of 2020 in southern Harris County; but the cone of depression in southern Montgomery County becomes slightly larger each decade, with maximum depths of 250–300 ft below NGVD 29 in 2030, 2040, and 2050.

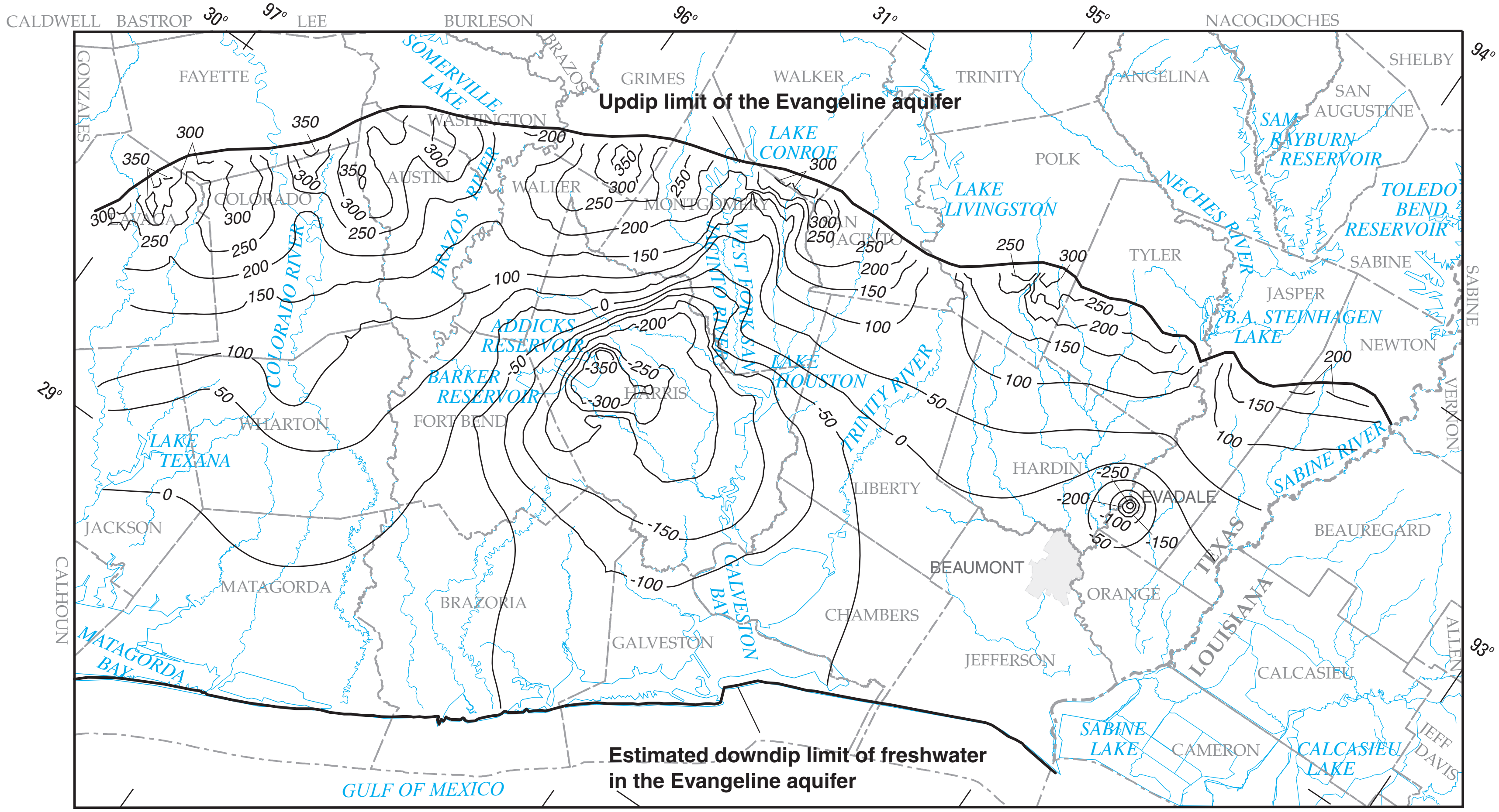
In the coastal irrigation area, negligible change in Evangeline aquifer water levels is evident throughout the projected period, except for the appearance of an area 50–100 ft below NGVD 29 in southeastern Jackson and southwestern Matagorda Counties in 2010 and slight expansion of that area in Matagorda County over time. In the Evadale-Beaumont area, the simulated cone of depression in the Evangeline aquifer recovers from a maximum of 250–300 ft below NGVD 29 in 2000 to 150–200 ft below NGVD 29 in 2010. For the remainder of the projected period, negligible change appears in the simulated Evadale-Beaumont cone of depression.

The simulated potentiometric surfaces of the Jasper aquifer for 2000, 2010, 2020, 2030, 2040, and 2050 (figs. 16–21) each have a major cone of depression centered in southern Montgomery County. This feature is minimally developed in the simulated 2000 surface (fig. 16) but reaches a depth of 500–600 ft below NGVD 29 in the 2010 surface (fig. 17). Essentially all of the approximately 42-percent increase in simulated Jasper aquifer withdrawals between 2000 and 2010 (fig. 2) is concentrated in southern Montgomery County. The maximum depth of the cone increases to 550–650 ft below NGVD 29 in the 2020, 2030, 2040, and 2050 surfaces (figs. 18–21). Lateral expansion of the cone is minimal between 2030 and 2050. No noticeable change in Jasper aquifer water levels appears in the coastal irrigation area or the Evadale-Beaumont area during the projected period.

Water-budget components for 2000, 2010, 2030, and 2050 that result from simulating the TWDB withdrawal scenario are shown in figures 22–25. Projected withdrawals from the aquifer system increase about 8 percent during 2000–10, then decrease to rates close to those of 2000 for the remainder of the projected period (fig. 2). In response, net recharge (recharge minus natural discharge, simulated using the MODFLOW general-head boundary package [Kasmarek and Robinson, 2004]) increases from 995 cubic feet per second (ft^3/s) in 2000 to 1,067 ft^3/s in 2010, 1,105 ft^3/s in 2030, and 1,144 ft^3/s in 2050. In units of inches per year (in/yr) over the NGC GAM model area (25,121 mi^2), net recharge increases from 0.54 in/yr in 2000 to 0.62 in/yr in 2050. Although simulated net recharge increases about 15 percent over the projected period, the amount of water supplied by storage (sum of sand storage and storage from inelastic compaction of clay) over the projected period decreases about 48 percent. Simulated storage increases about 11 percent during 2000–10 from 326 to 363 ft^3/s, then decreases about 52 percent to about 173 ft^3/s in 2030, and then decreases slightly to 168 ft^3/s in 2050. The major fraction of the 158-ft^3/s decrease in storage (about 80 percent) from 2000 to 2050 is in sand storage. Although under the TWDB scenario withdrawals from the entire system are projected to be about the same in 2050 as in 2000, the percentage of withdrawals supplied by net recharge increases from 75 percent in 2000 to 87 percent in 2050, and the percentage of withdrawals supplied by storage decreases from 25 percent in 2000 to 13 percent in 2050.

Results Using Harris-Galveston Coastal Subsidence District Scenario

The simulated 1995 potentiometric surface of the Chicot aquifer resulting from the HGCSD withdrawal scenario (fig. 26) shows a cone of depression in southern Harris County about the same as that in the simulated 2000 potentiometric surface resulting from the TWDB withdrawal scenario (fig. 4). For the 2010, 2020, and 2030 Chicot aquifer potentiometric surfaces associated with the HGCSD scenario (figs. 27–29), the substantially greater Chicot aquifer withdrawals of the HGCSD scenario relative to those of the TWDB scenario (figs. 2, 3) result in progressively deeper cones of depression in southern Harris County than those in the potentiometric surfaces associated with the TWDB scenario (figs. 5–7). Projected water levels near the Harris-Fort Bend County line reach depths of 250–300 ft below NGVD 29 in 2010 (fig. 27), 300–350 ft below NGVD 29 in 2020 (fig. 28), and 400–450 ft below NGVD 29 in 2030 (fig. 29). Also notable in the HGCSD Chicot aquifer potentiometric surfaces is a developing cone of depression in northern Galveston County that reaches depths of 200–250 ft below NGVD 29 in 2020 and 250–300 ft below NGVD 29 in 2030; and a small cone of depression in northeastern Brazoria County 300–350 ft below NGVD 29 in 2030.



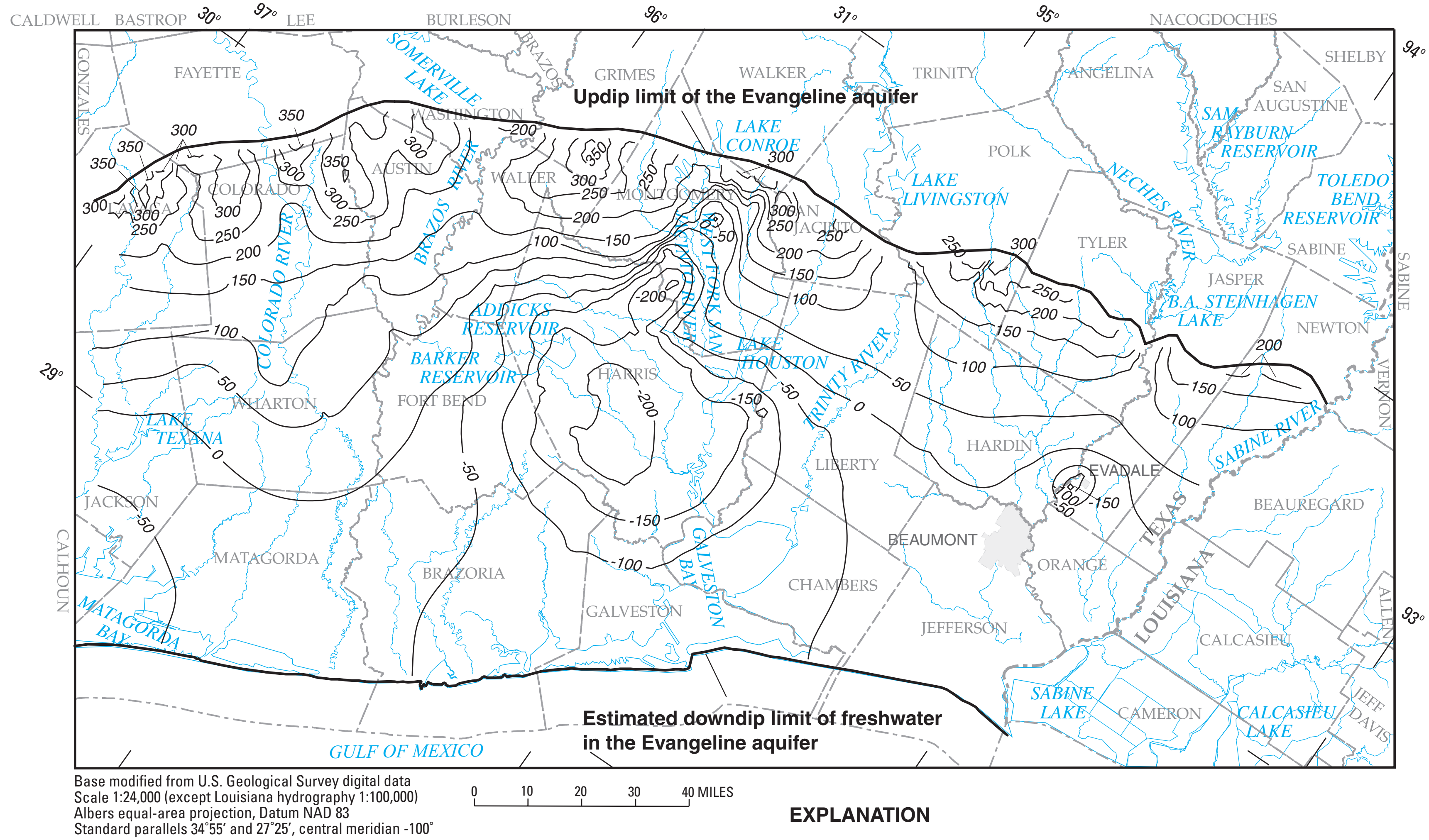
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—— -150 —— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

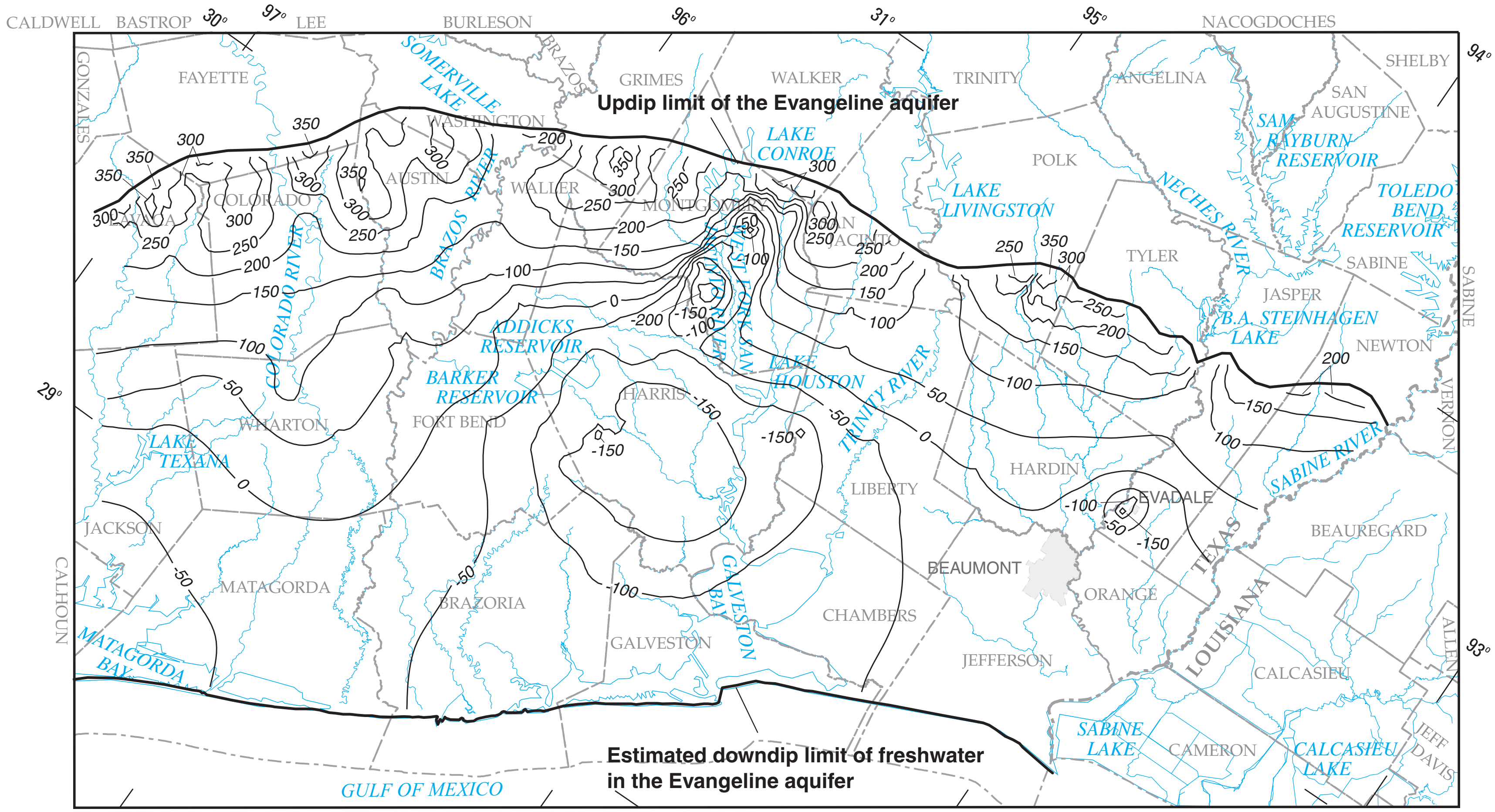
Figure 10. Simulated 2000 potentiometric surface of the Evangeline aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



EXPLANATION

—-150— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 11. Simulated 2010 potentiometric surface of the Evangeline aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



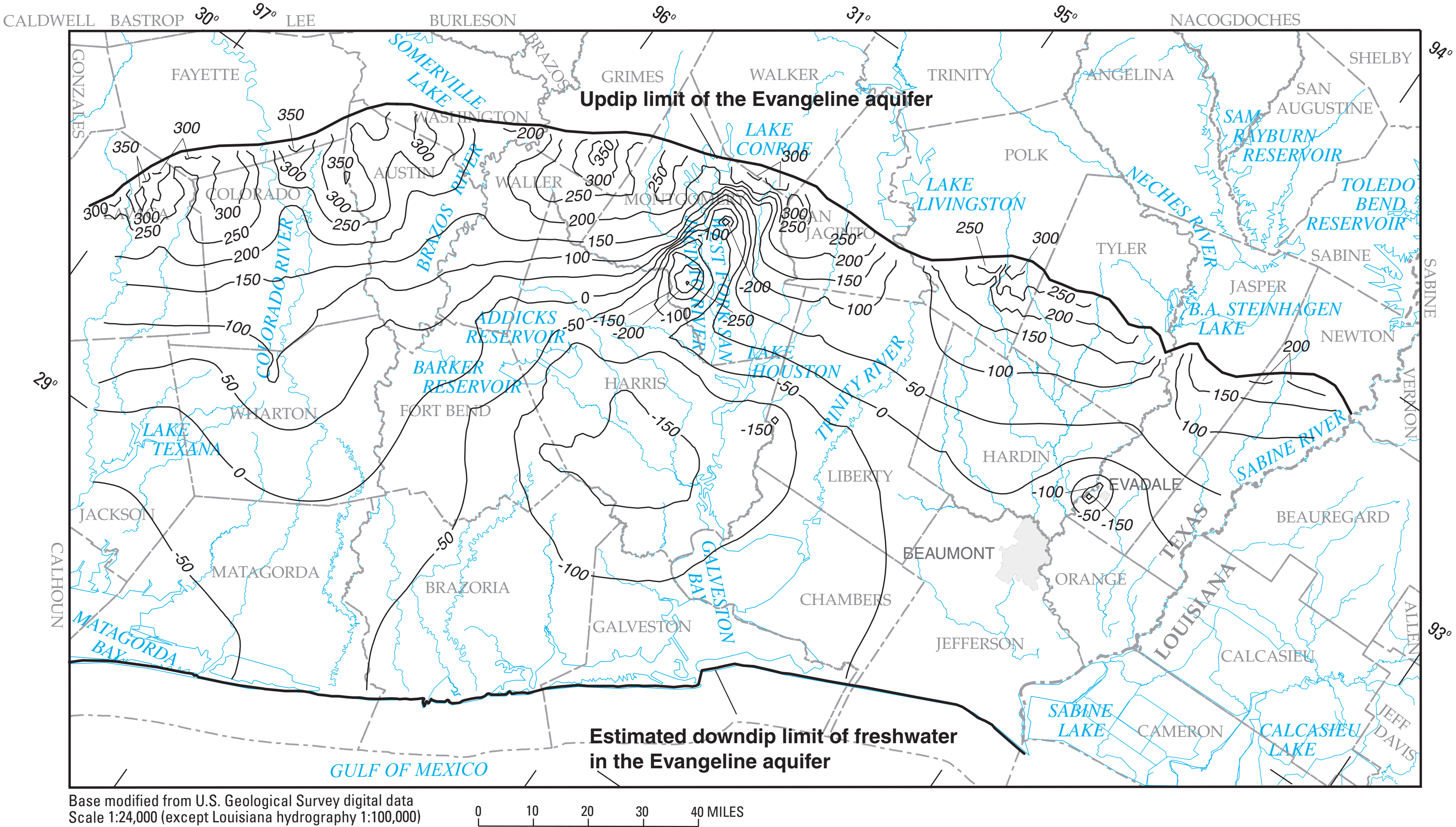
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—— -150 —— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 12. Simulated 2020 potentiometric surface of the Evangeline aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.

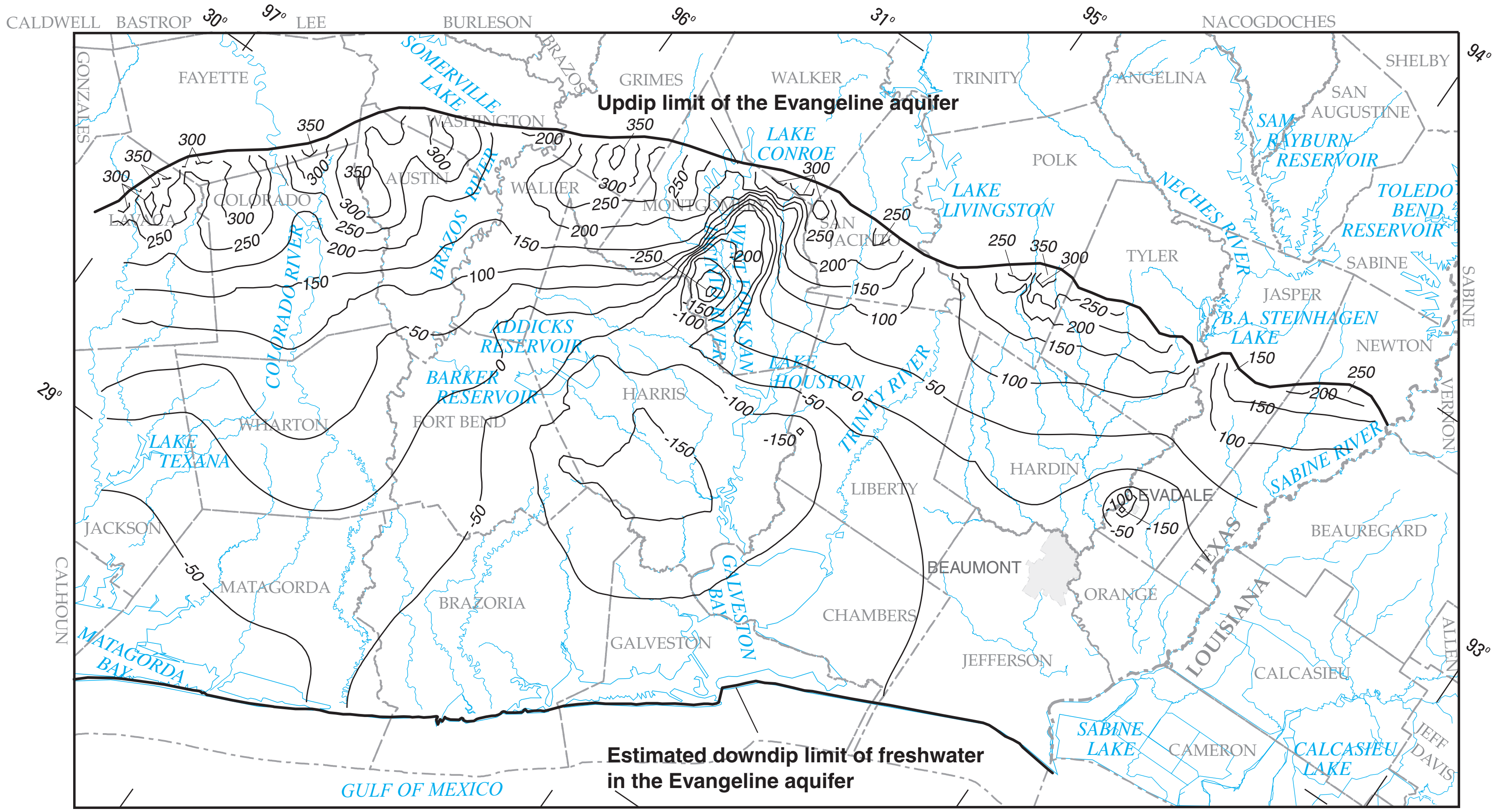


Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

EXPLANATION

—-150— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 13. Simulated 2030 potentiometric surface of the Evangeline aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



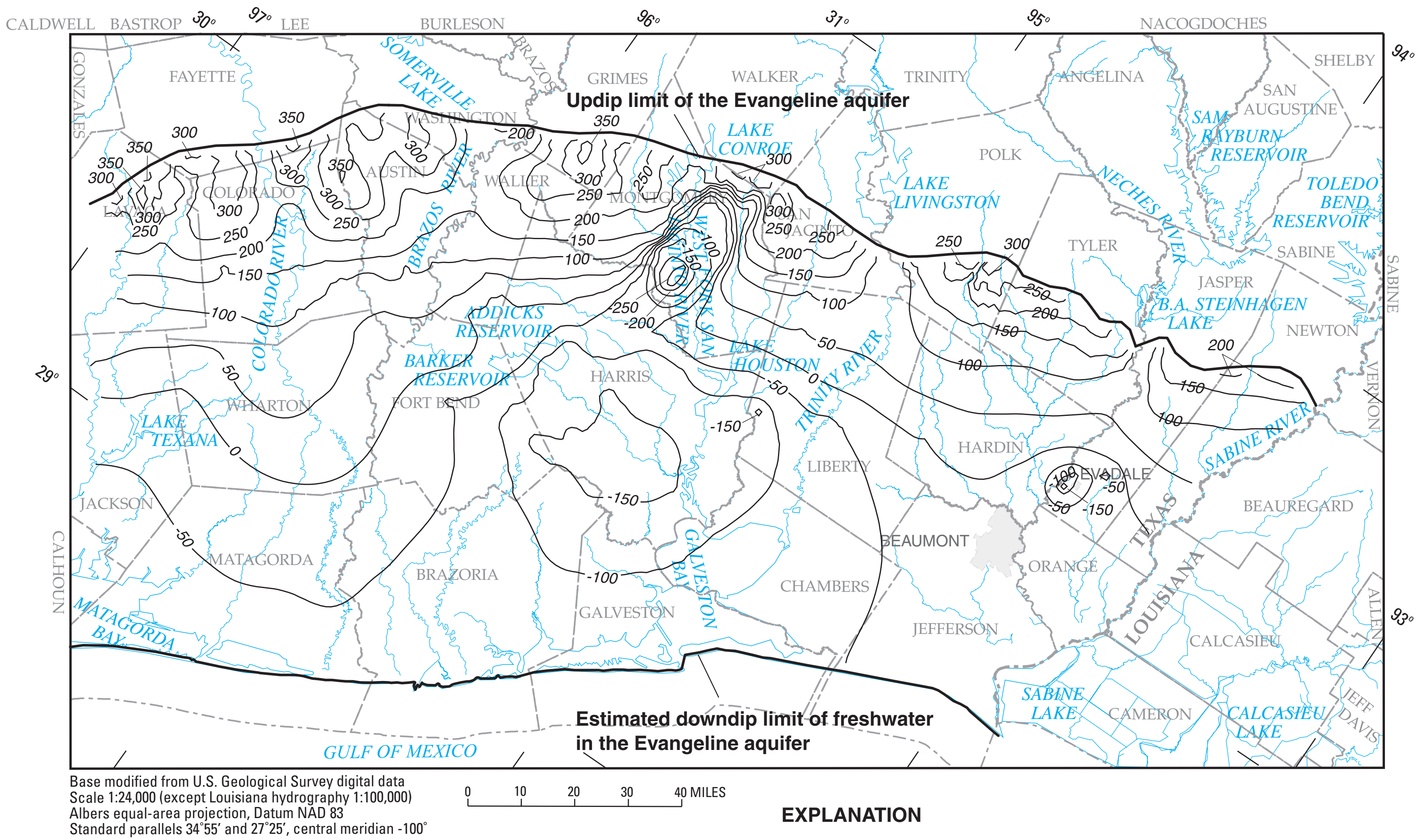
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—— -150 —— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

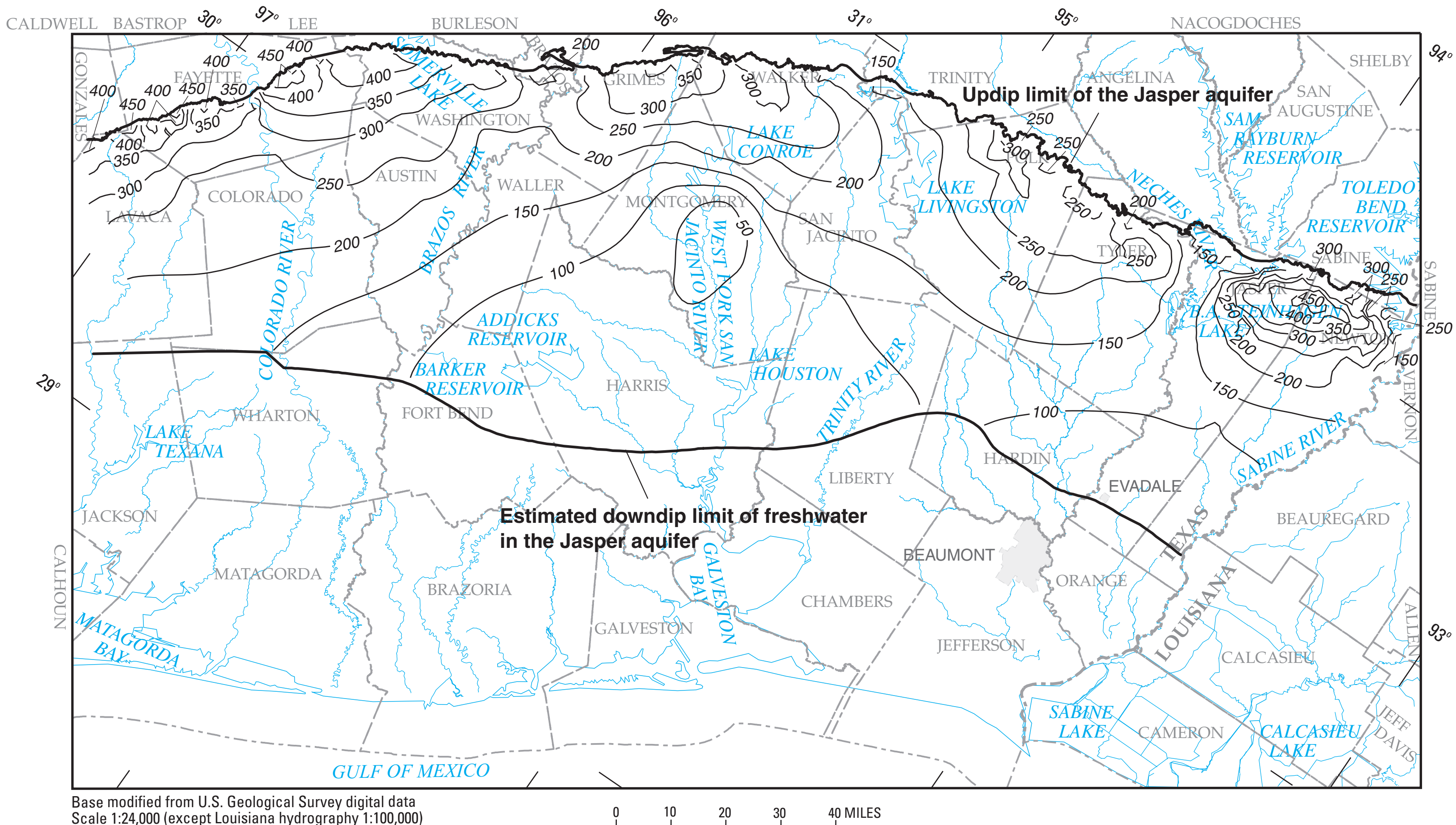
Figure 14. Simulated 2040 potentiometric surface of the Evangeline aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



EXPLANATION

-150 **Simulated potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 15. Simulated 2050 potentiometric surface of the Evangeline aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.

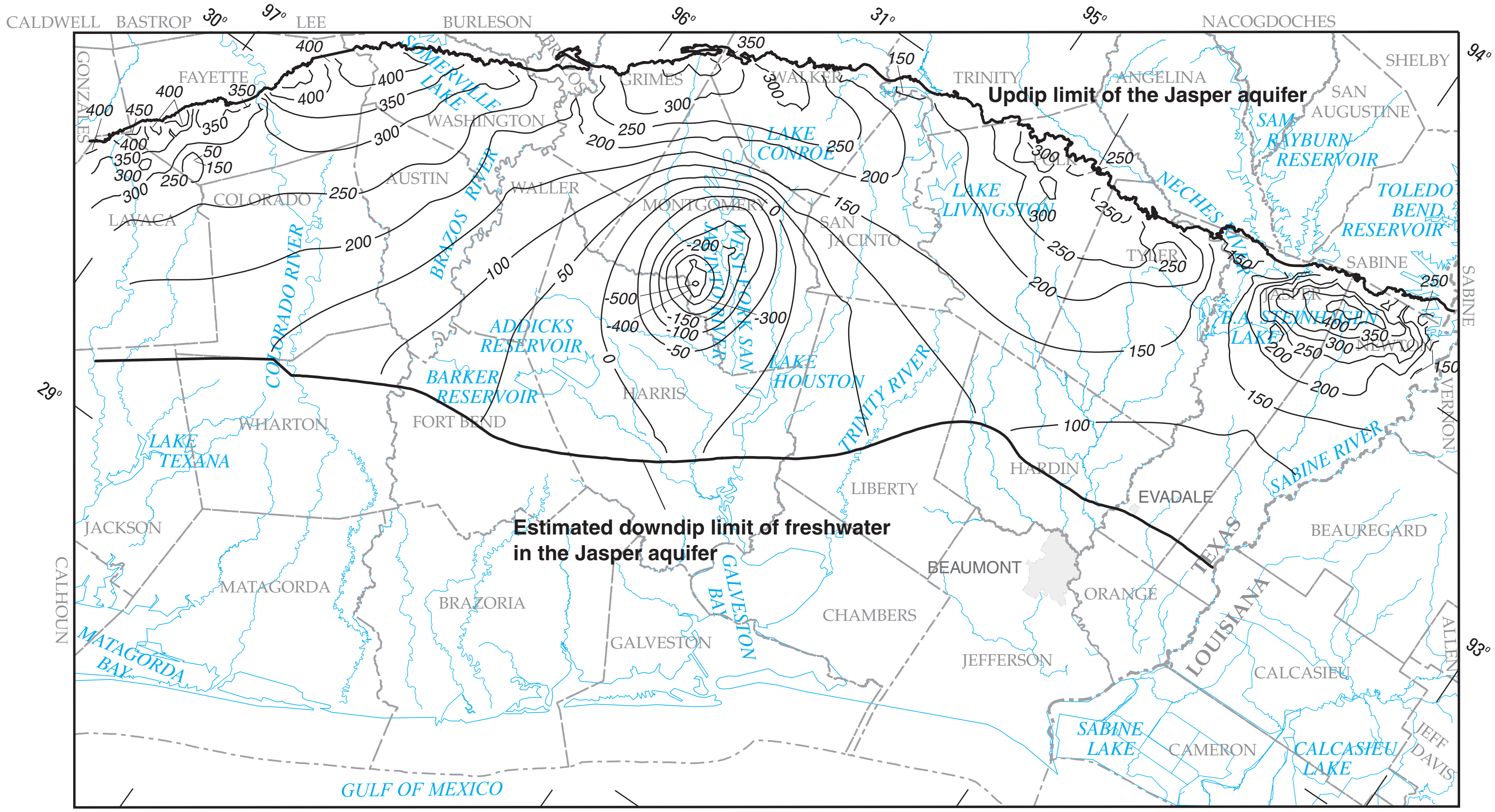


Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

EXPLANATION

—*150*— **Potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 16. Simulated 2000 potentiometric surface of the Jasper aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



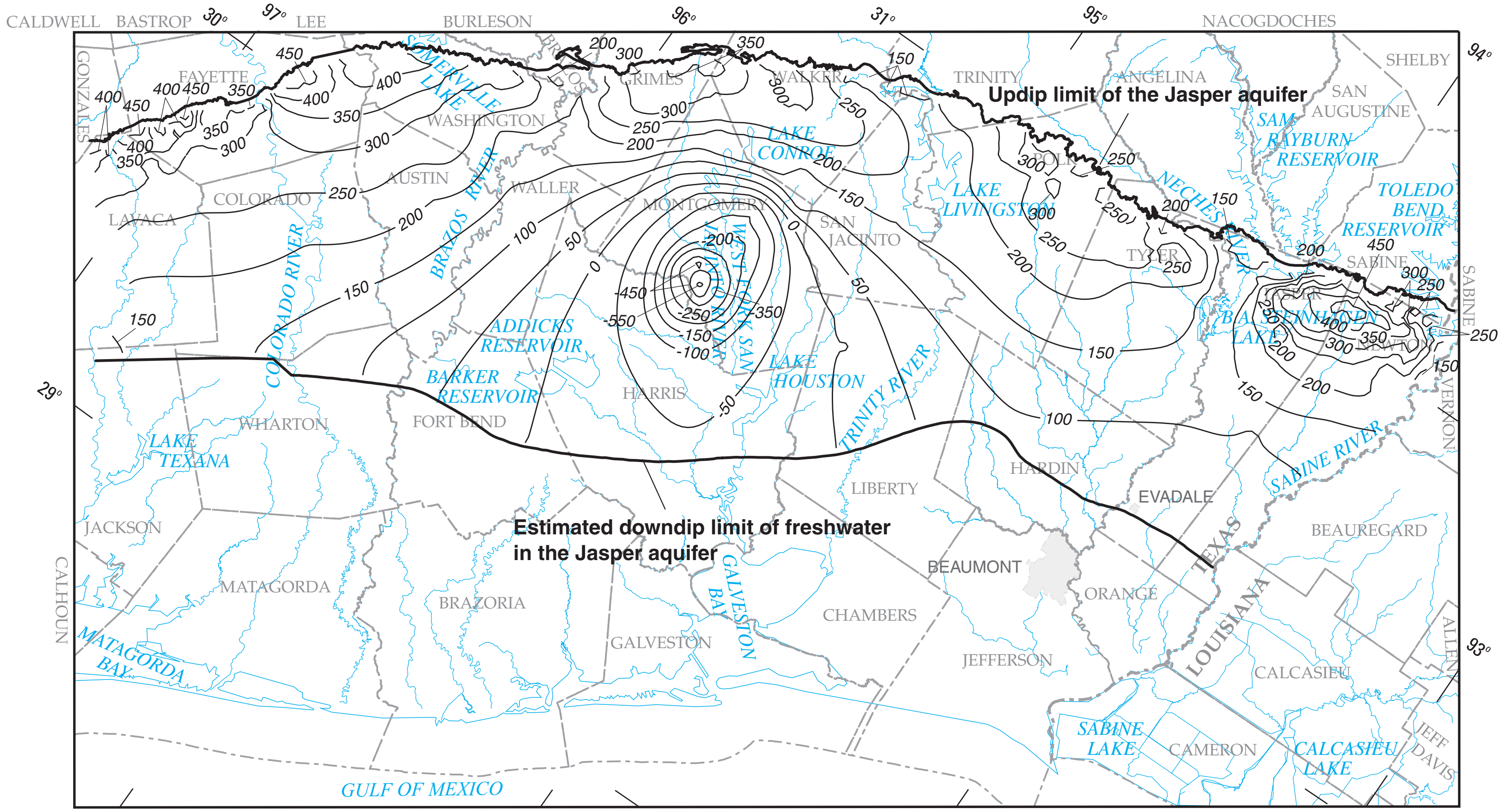
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—-150— **Potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Intervals 50 and 100 feet. Datum is NGVD 29

Figure 17. Simulated 2010 potentiometric surface of the Jasper aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



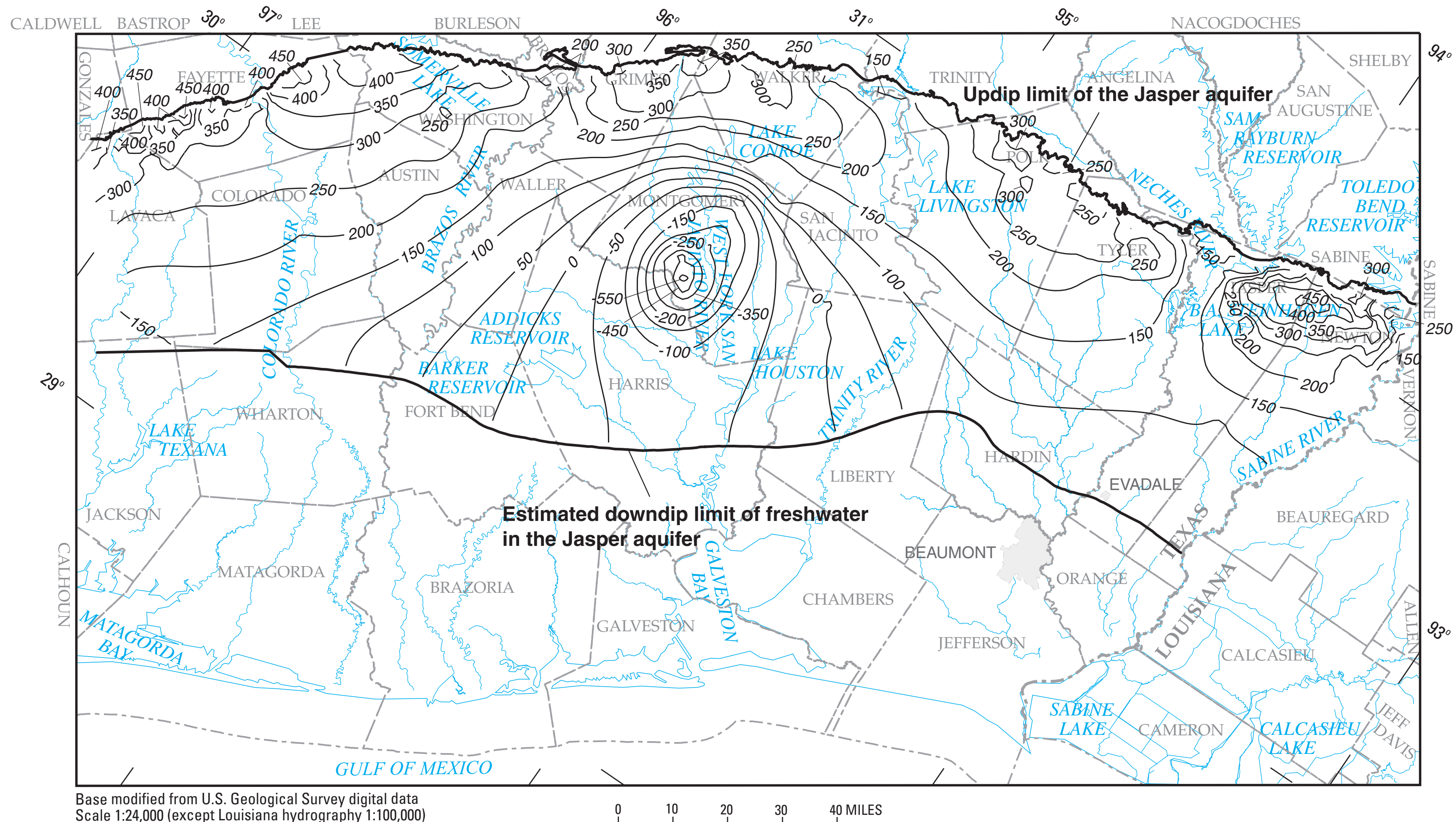
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—-150— **Potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Intervals 50 and 100 feet. Datum is NGVD 29

Figure 18. Simulated 2020 potentiometric surface of the Jasper aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.

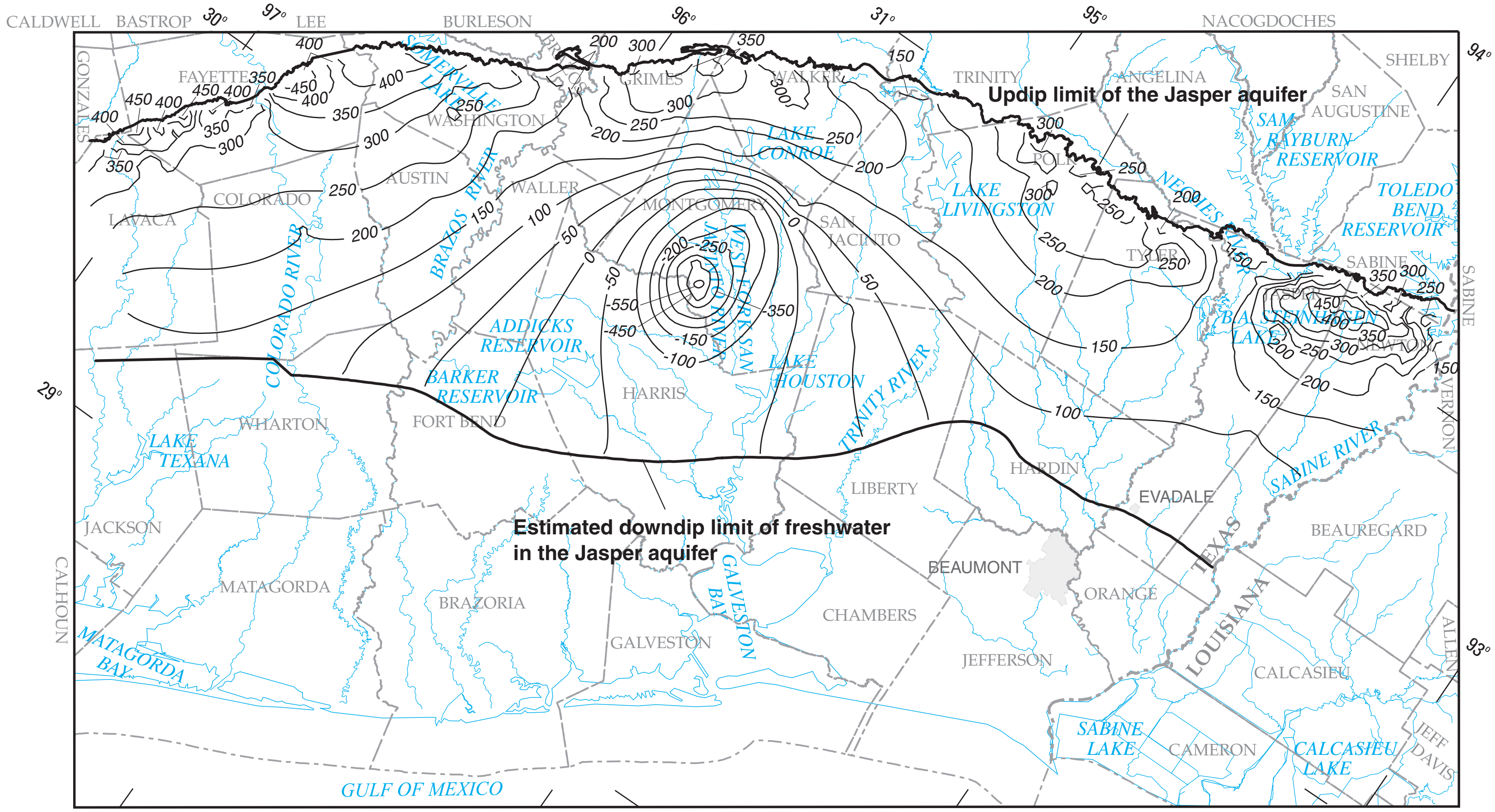


Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

EXPLANATION

-150 **Potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Intervals 50 and 100 feet. Datum is NGVD 29

Figure 19. Simulated 2030 potentiometric surface of the Jasper aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



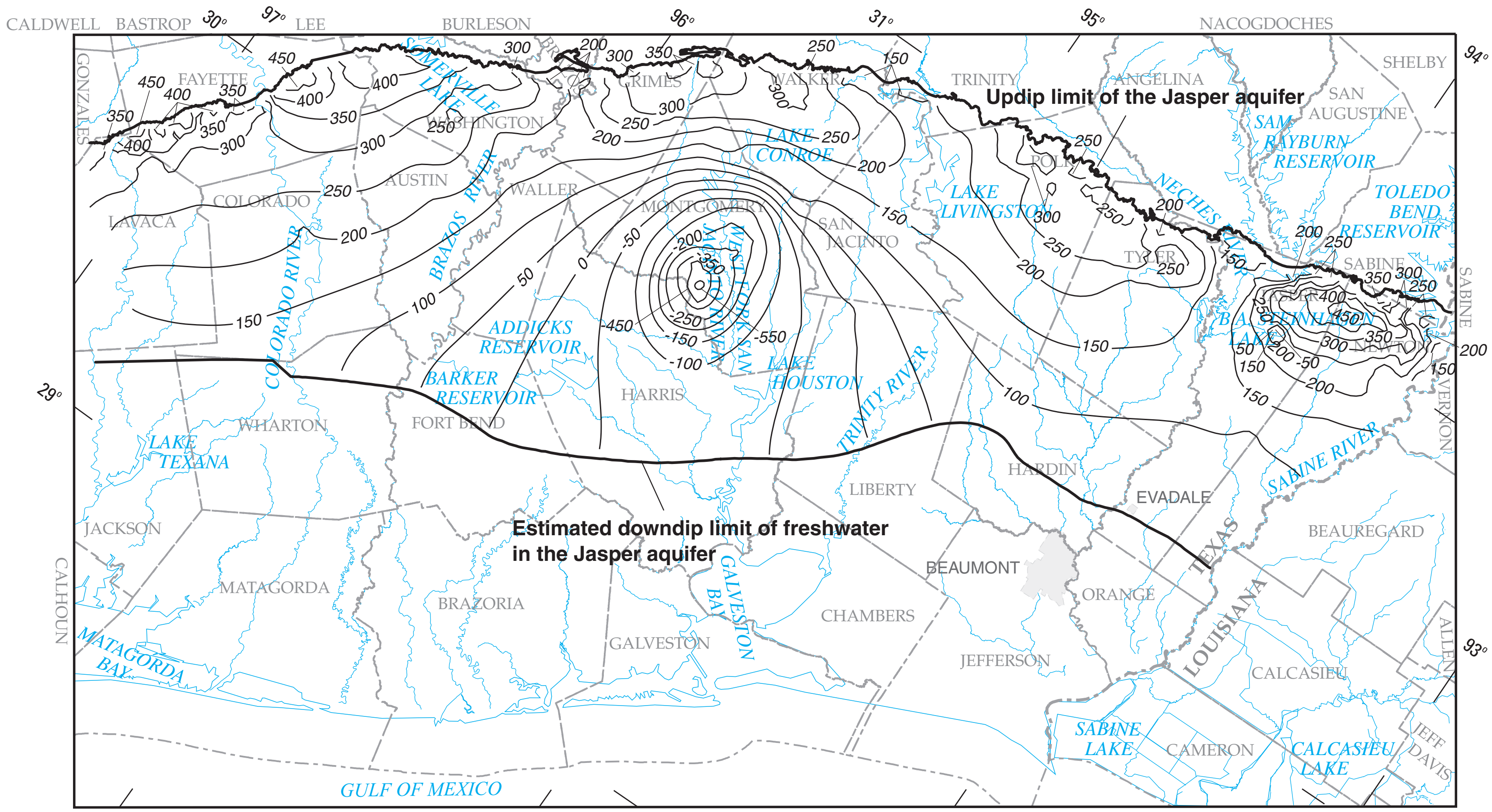
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—-150— **Potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Intervals 50 and 100 feet. Datum is NGVD 29

Figure 20. Simulated 2040 potentiometric surface of the Jasper aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



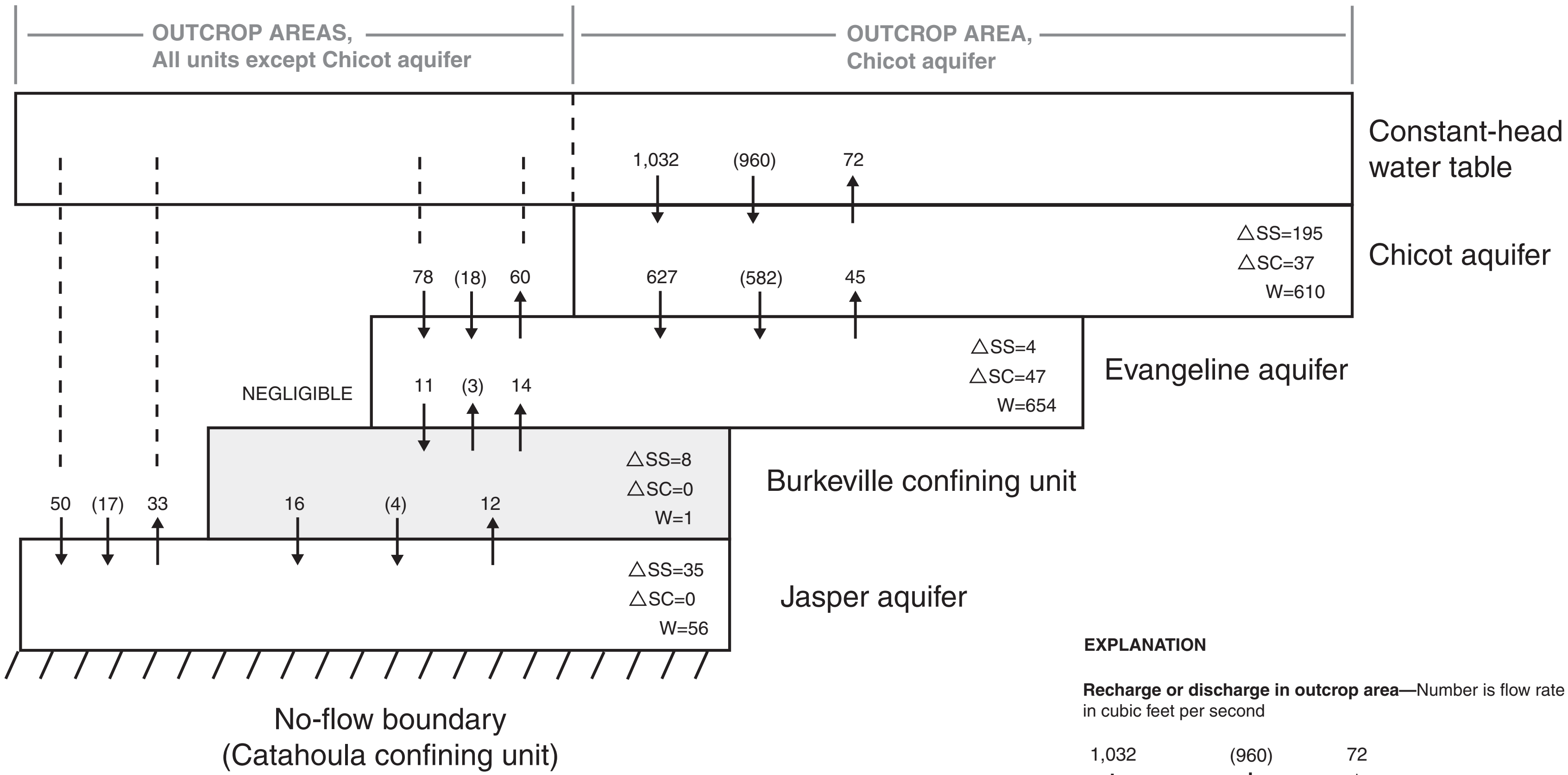
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—— -150 —— **Potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Intervals 50 and 100 feet. Datum is NGVD 29

Figure 21. Simulated 2050 potentiometric surface of the Jasper aquifer in the NGC GAM model area resulting from TWDB withdrawal scenario.



WATER BALANCE

RECHARGE + △SS + △SC = NATURAL DISCHARGE + W

1,160 + 242 + 84 = 165 + 1,321

1,486 = 1,486

EXPLANATION

Recharge or discharge in outcrop area—Number is flow rate in cubic feet per second

1,032 ↓ RECHARGE (960) ↓ NET 72 ↑ NATURAL DISCHARGE

Leakage through bottom of hydrogeologic unit—Number is flow rate in cubic feet per second

627 ↓ DOWNWARD (582) ↓ NET 45 ↑ UPWARD

△SS Net rate of release of water from sand storage, in cubic feet per second

△SC Net rate of release of water from inelastic clay compaction, in cubic feet per second

W Withdrawal rate, in cubic feet per second

Figure 22. Simulated 2000 water-budget components of the hydrogeologic units of the NGC GAM model resulting from TWDB withdrawal scenario.

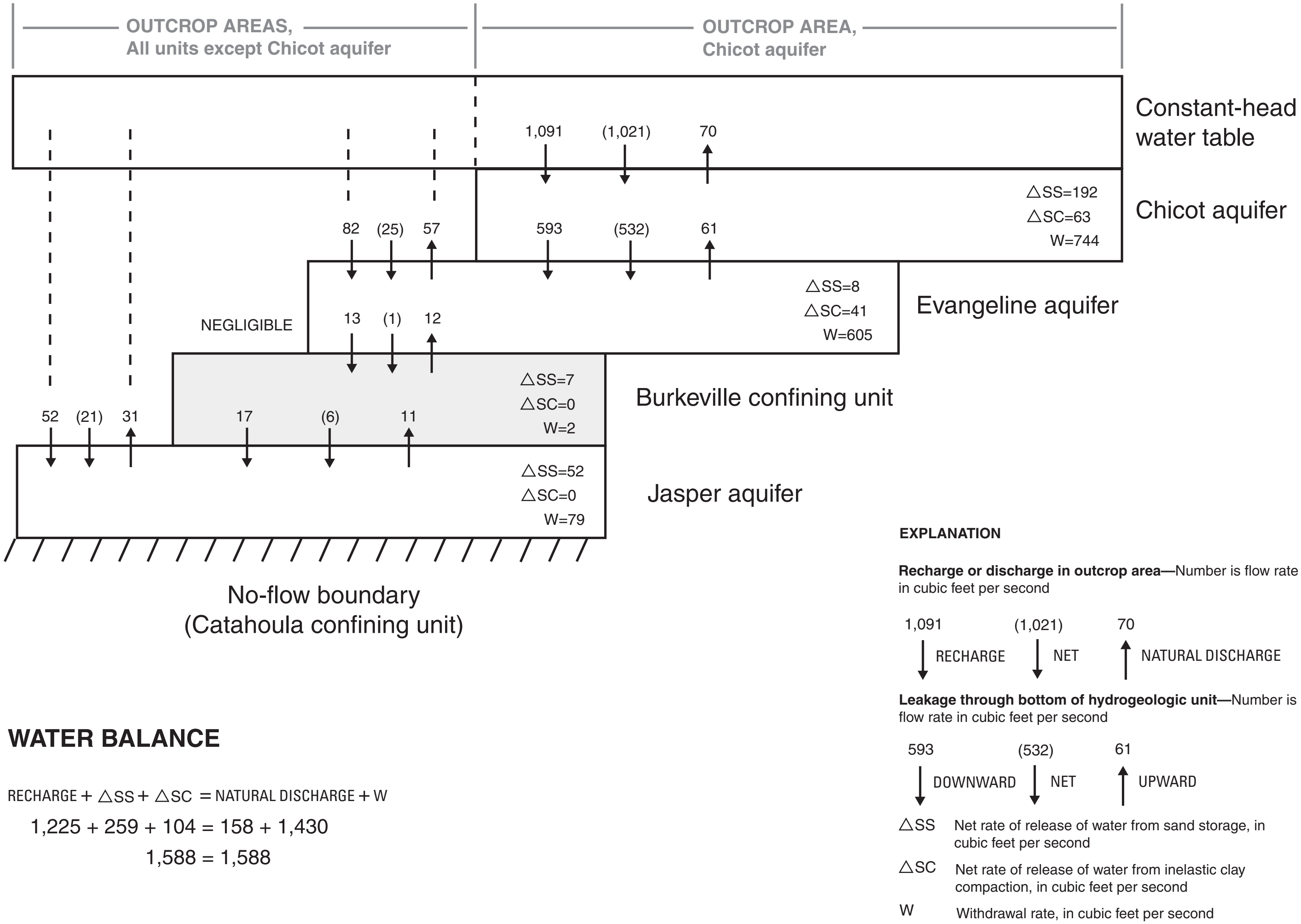


Figure 23. Simulated 2010 water-budget components of the hydrogeologic units of the NGC GAM model resulting from TWDB withdrawal scenario.

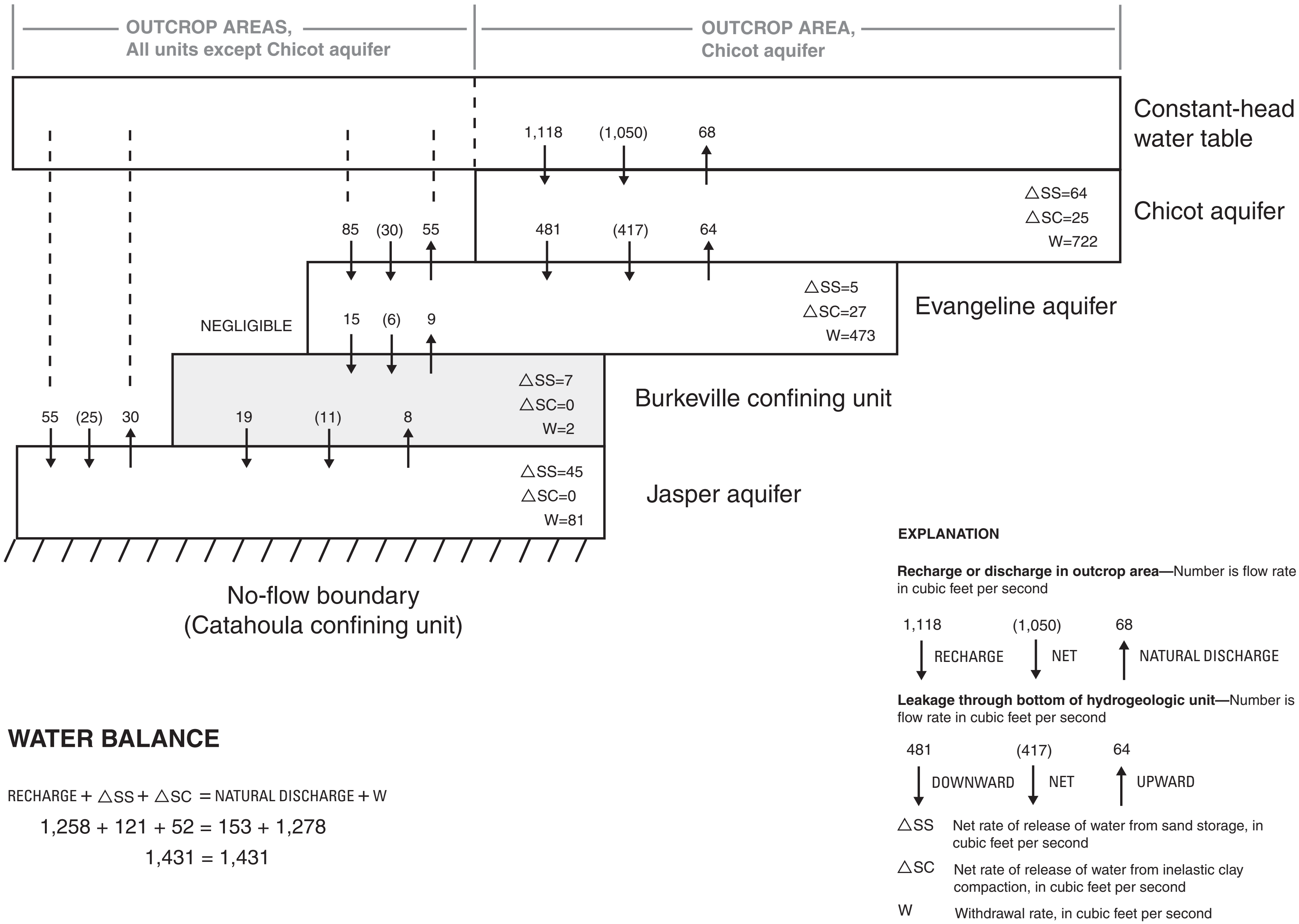
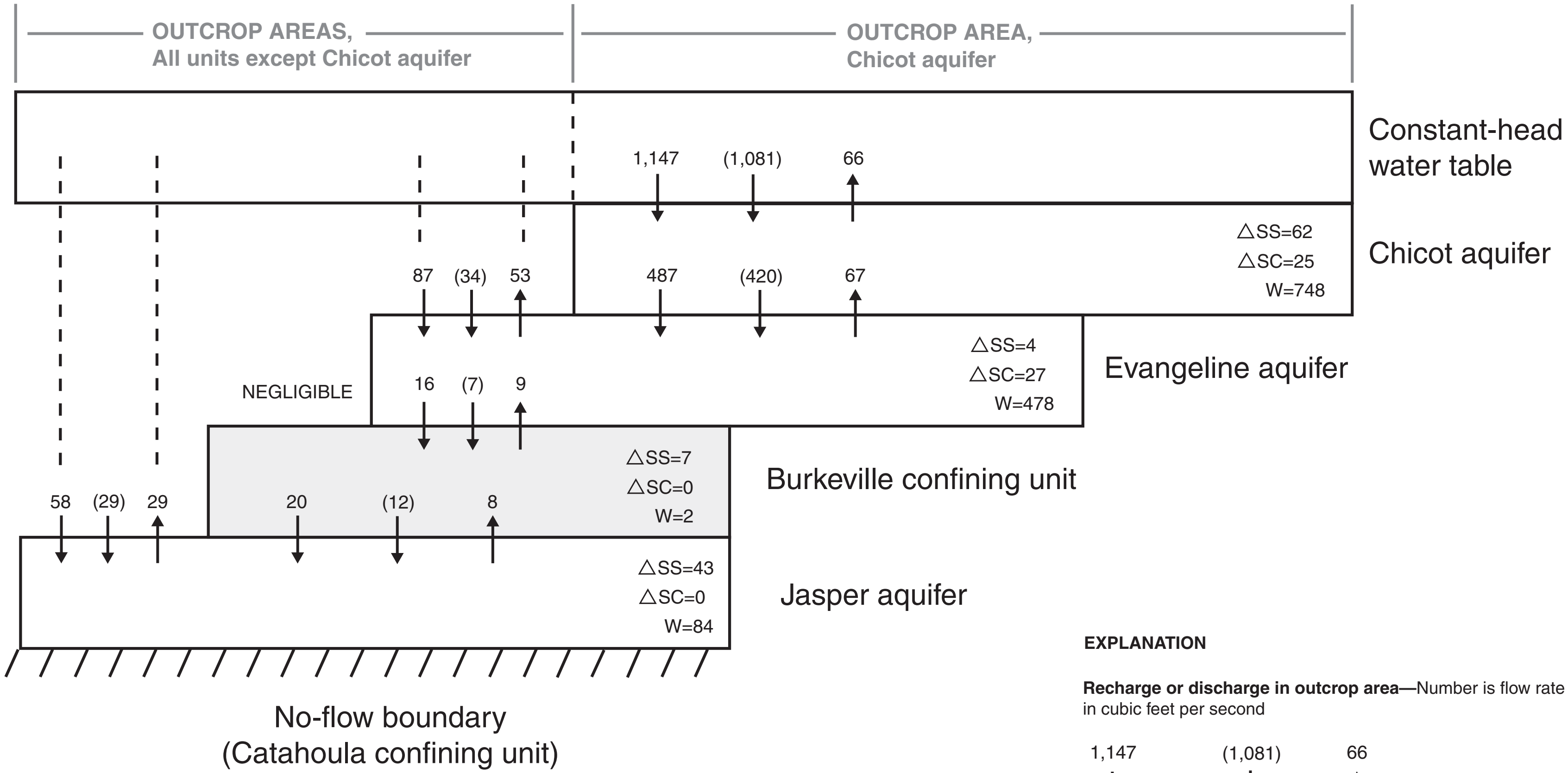


Figure 24. Simulated 2030 water-budget components of the hydrogeologic units of the NGC GAM model resulting from TWDB withdrawal scenario.



WATER BALANCE

RECHARGE + ΔSS + ΔSC = NATURAL DISCHARGE + W

1,292 + 116 + 52 = 148 + 1,312

1,460 = 1,460

EXPLANATION

Recharge or discharge in outcrop area—Number is flow rate in cubic feet per second

1,147 RECHARGE (1,081) NET 66 NATURAL DISCHARGE

Leakage through bottom of hydrogeologic unit—Number is flow rate in cubic feet per second

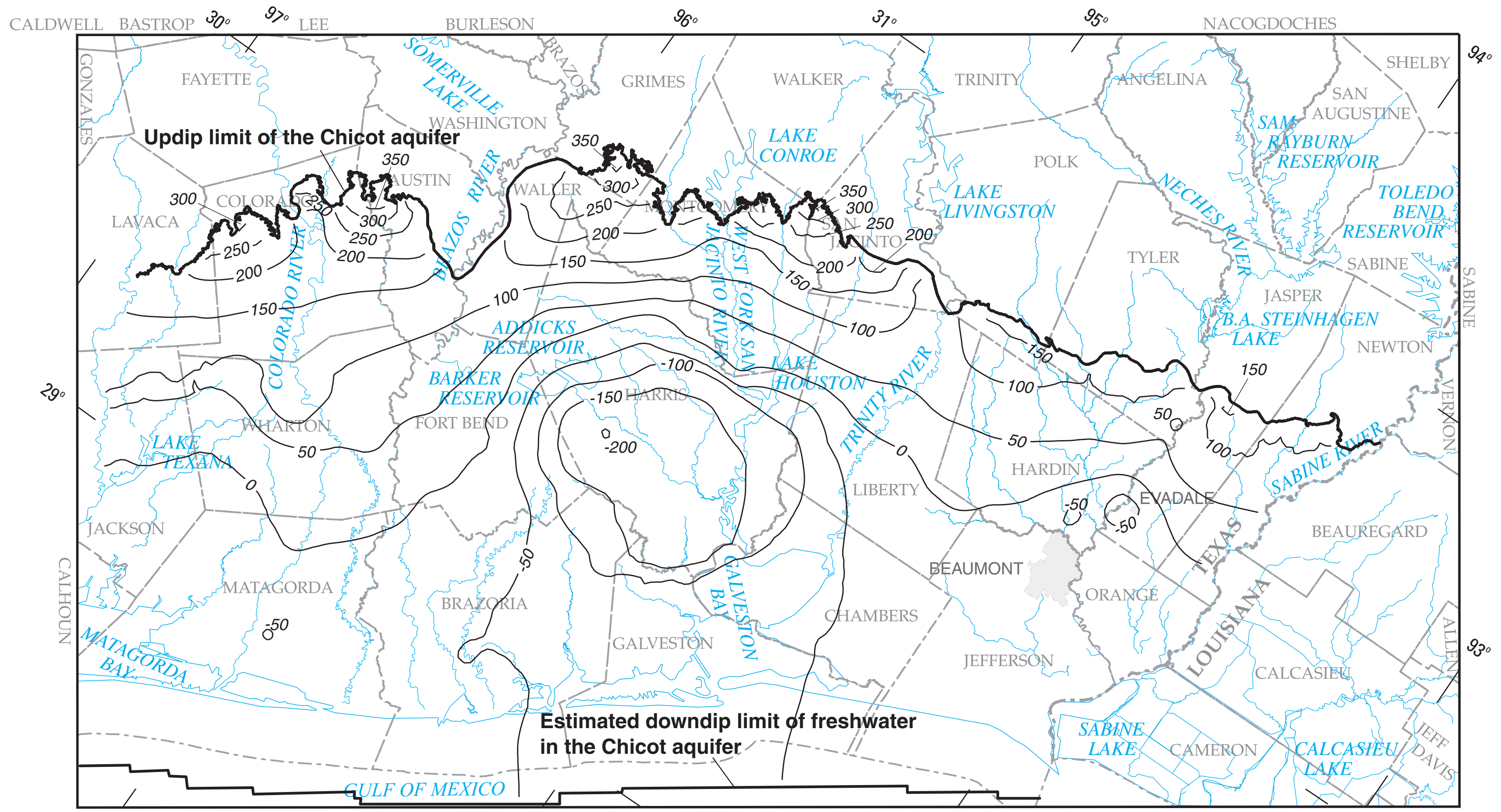
487 DOWNWARD (420) NET 67 UPWARD

ΔSS Net rate of release of water from sand storage, in cubic feet per second

ΔSC Net rate of release of water from inelastic clay compaction, in cubic feet per second

W Withdrawal rate, in cubic feet per second

Figure 25. Simulated 2050 water-budget components of the hydrogeologic units of the NGC GAM model resulting from TWDB withdrawal scenario.



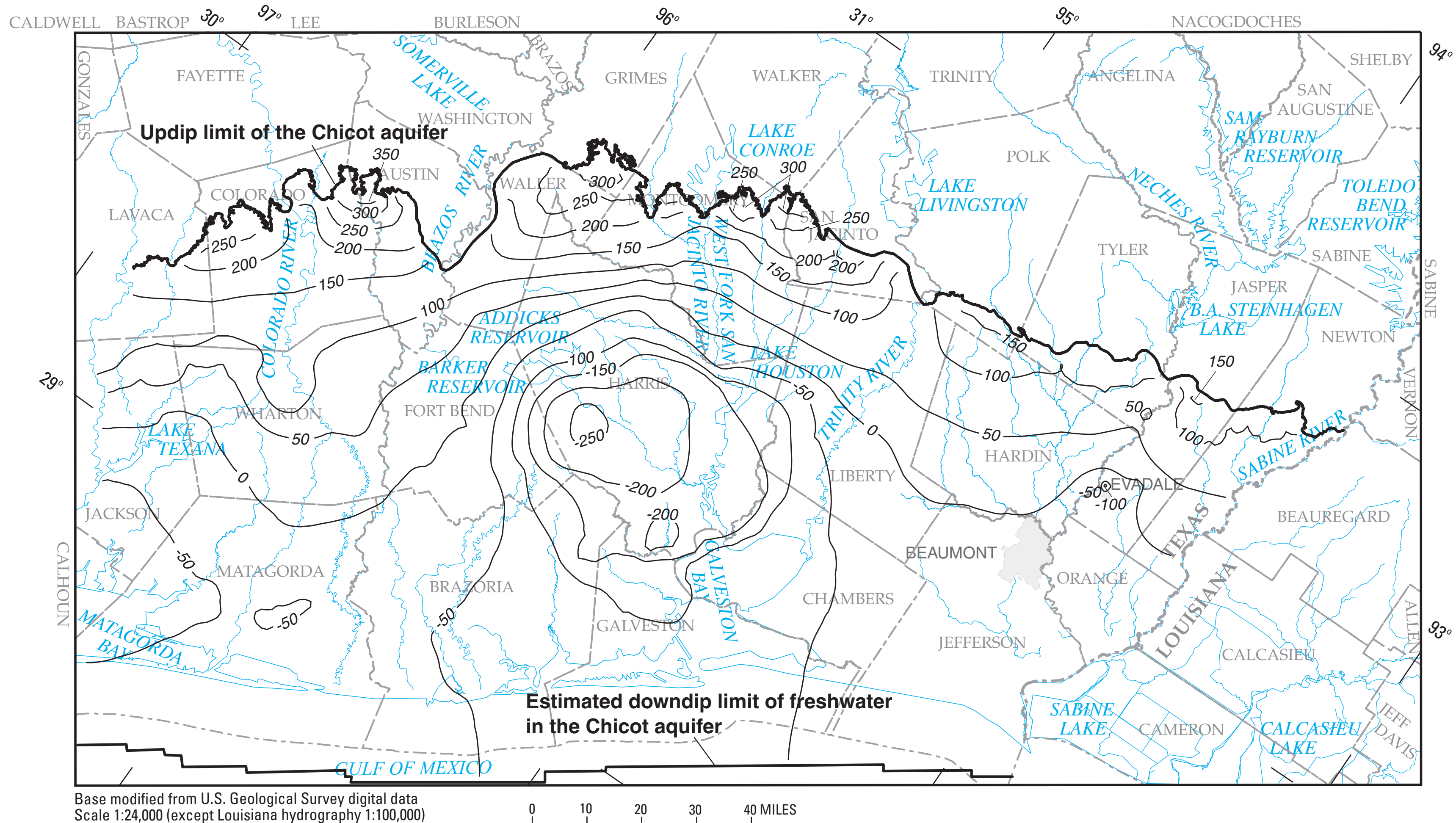
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—-150— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 26. Simulated 1995 potentiometric surface of the Chicot aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.

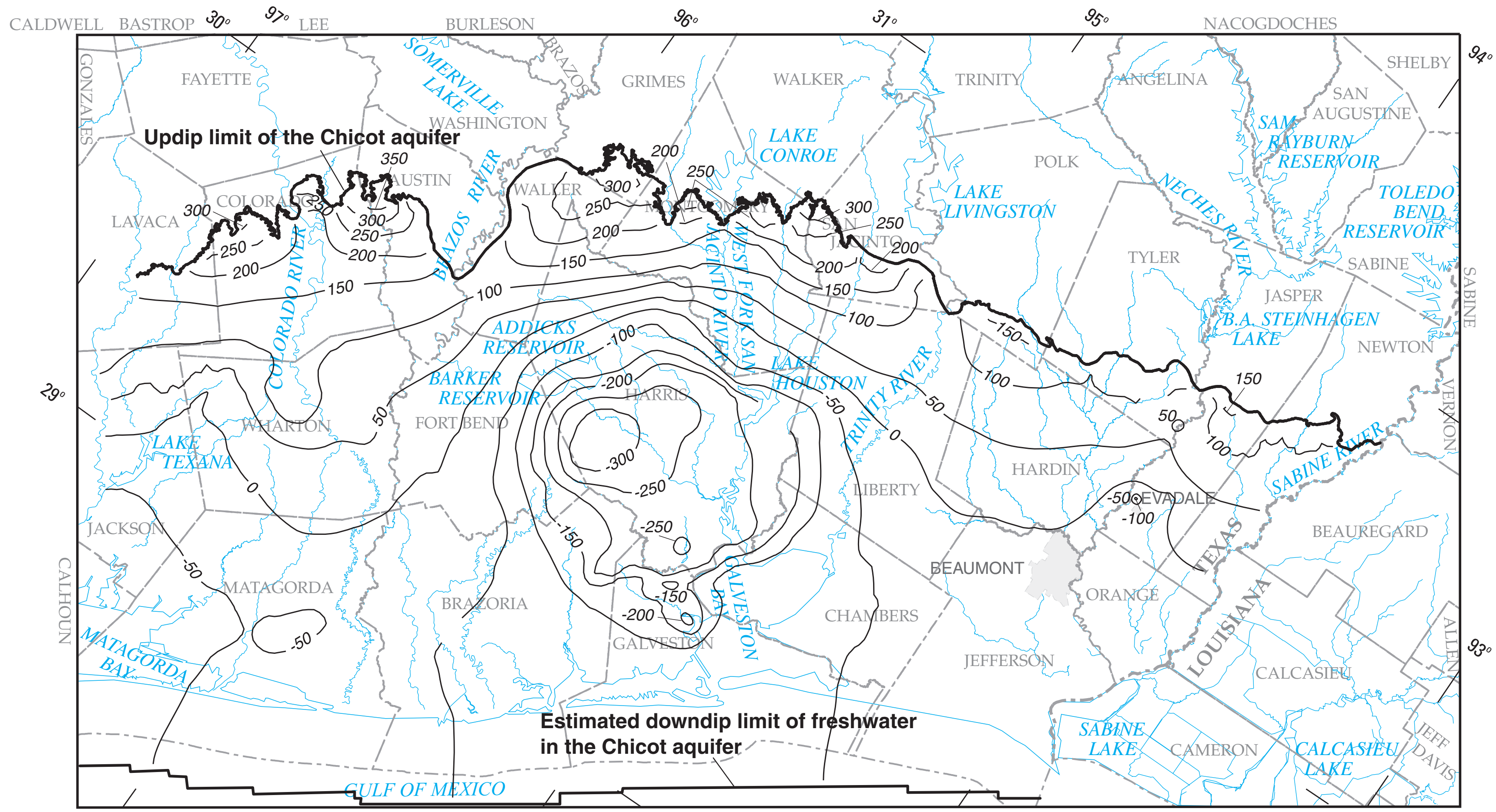


Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

EXPLANATION

—— -150 —— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 27. Simulated 2010 potentiometric surface of the Chicot aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.



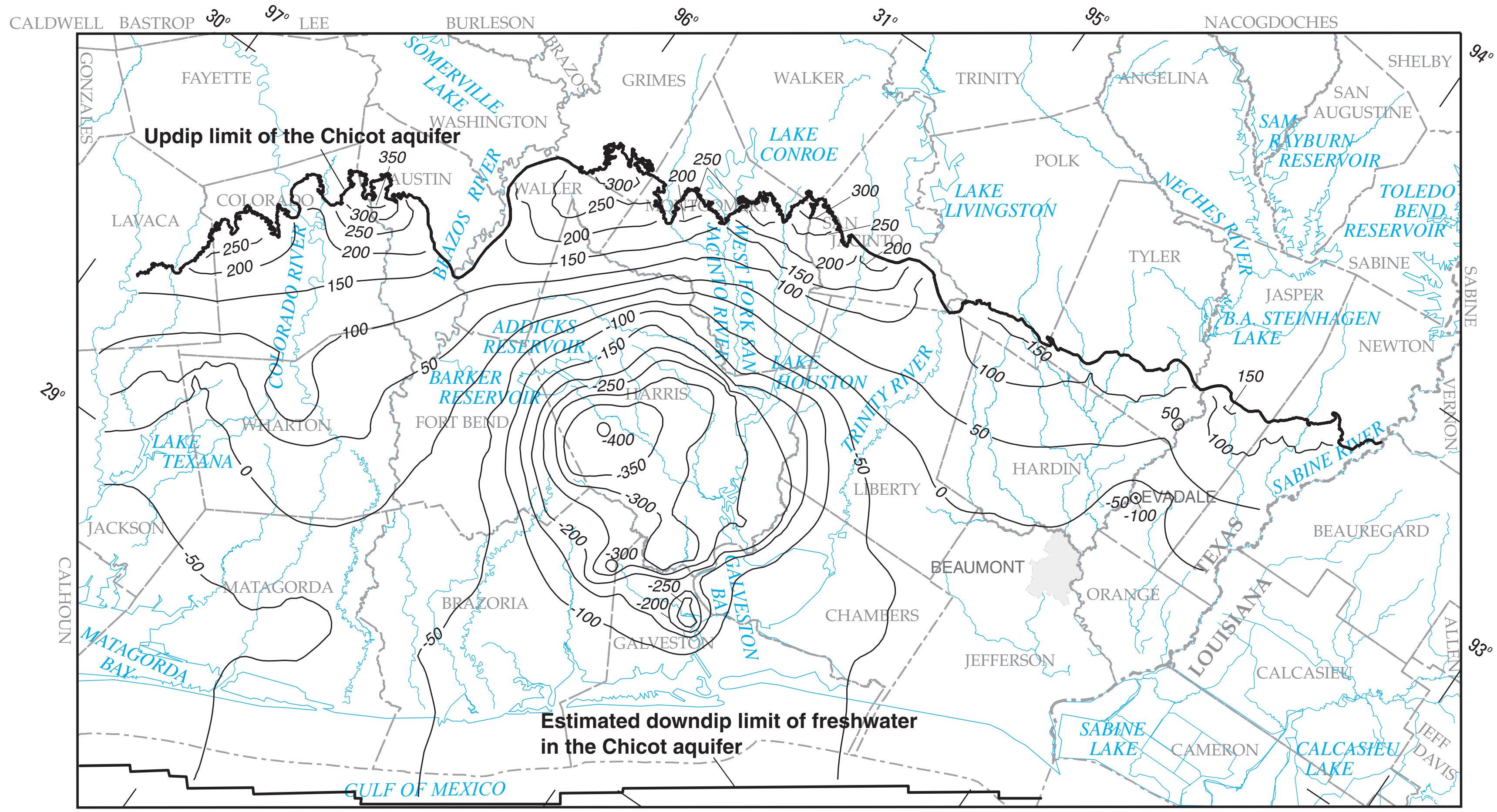
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—-150— **Simulated potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 28. Simulated 2020 potentiometric surface of the Chicot aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.



Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—-150— **Simulated potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 29. Simulated 2030 potentiometric surface of the Chicot aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.

For the Evangeline aquifer, comparable simulated 1995 HGCSD and 2000 TWDB withdrawals result in similar potentiometric surfaces for the HGCSD scenario (fig. 30) and the TWDB scenario (fig. 10). But unlike the decreasing or stable Evangeline aquifer withdrawals of the TWDB scenario for 2010, 2020, and 2030, progressively larger increases in withdrawals in the HGCSD scenario for 2010, 2020, and 2030 result in substantially deeper cones of depression in the simulated HGCSD potentiometric surfaces (figs. 31–33) than in the simulated TWDB potentiometric surfaces (figs. 11–13) for those years. For 2010, simulated water levels in western Harris County (major cone of depression associated with HGCSD scenario has shifted westward relative to that of the TWDB scenario) reach depths of 350–400 ft below NGVD 29; and in southern Montgomery County, 300–350 ft below NGVD 29 (fig. 31). For 2020, simulated water levels in western Harris County reach depths of 450–500 ft below NGVD 29; and in southern Montgomery County, 500–550 ft below NGVD 29 (fig. 32). For 2030, simulated water levels in western Harris County reach depths of 500–550 ft below NGVD 29; and in southern Montgomery County, depths of 700–750 ft below NGVD 29 (fig. 33).

Jasper aquifer withdrawals for 1995 and 2000 are within 6 percent, which accounts for similar 1995 and 2000 potentiometric surfaces for the HGCSD scenario (fig. 34) and the TWDB scenario (fig. 16). Although Jasper aquifer withdrawals are the same for both scenarios, the major cone of depression centered in southern Montgomery County in the HGCSD potentiometric surfaces for 2010, 2020, and 2030 (figs. 35–37) is slightly different from that feature in the TWDB potentiometric surfaces for those years (figs. 17–19). The differences likely are attributable to differences in projected Chicot and Evangeline aquifer withdrawals. For 2010 the differences in the surfaces are minimal and deepest water levels are 500–600 ft below NGVD 29. For 2020, the cone expands slightly farther to the south under the HGCSD scenario; deepest water levels are 550–650 ft below NGVD 29. For 2030, the cone expands still farther south and is 50 ft deeper at its center (600–700 ft below NGVD 29) than the cone in the comparable surface under the TWDB scenario.

Water-budget components for 1995, 2010, 2020, and 2030 that result from simulating the HGCSD withdrawal scenario are shown in figures 38–41. Not surprisingly, projected withdrawals of the HGCSD scenario greater than those of the TWDB scenario cause greater changes in the sources of water that supply withdrawals than the changes that result from the TWDB scenario. In response to projected withdrawals from the aquifer system that increase about 32 percent during 1995–2010 and about 15 percent during each of the following two decades (fig. 3), simulated net recharge increases from 974 ft^3/s in 1995 to 1,094 ft^3/s in 2010, 1,204 ft^3/s in 2020, and 1,329 ft^3/s in 2030. In units of inches per year over the NGC GAM model area, net recharge increases from 0.53 in/yr in 1995 to 0.72 in/yr in 2030. Rather than a long-term decrease in the amount of water supplied by storage as with the relatively unchanging TWDB scenario, the amount of water supplied by storage increases substantially over time with the HGCSD scenario—and the increase primarily is from the compaction of clay, which has implications for subsidence as described in the section "Evaluation of Land-Surface Subsidence/Results Using HGCSD Scenario." Between 1995 and 2030, the amount of water supplied by storage increases about 168 percent (from 382 to 1,022 ft^3/s), and about 85 percent of that increase (543 ft^3/s) is from compaction of clay. Under the HGCSD scenario, a projected increase in withdrawals from the entire system of about 74 percent during 1995–2030 causes the percentage of withdrawals supplied by net recharge to decrease from 72 percent in 1995 to 57 percent in 2030, and the percentage of withdrawals supplied by storage to increase from 28 percent in 2000 to 43 percent in 2030.

Evaluation of Land-Surface Subsidence

The evaluation of land-surface subsidence comprises descriptions of subsidence maps resulting from simulation of the TWDB and HGCSD withdrawal scenarios. Not surprisingly, larger withdrawals of the HGCSD scenario cause greater subsidence than those of the TWDB scenario during the projected period to 2030.

Results Using Texas Water Development Board Scenario

Land-surface subsidence in the NGC GAM model area for 2000, 2010, 2020, 2030, 2040, and 2050 that results from simulating the TWDB withdrawal scenario is shown in figures 42–47. In the major area of subsidence centered in Harris and Galveston Counties, little difference in the configuration or maximum depths of subsidence is seen between 2000 (fig. 42) and 2010 (fig. 43). For 2020 (fig. 44), the area within the closed 1-ft contour that encompasses the major area of subsidence expands slightly to the west from its 2010 location in Fort Bend and Brazoria Counties, and the area of subsidence in central Montgomery County (Conroe area) deepens from about 6 ft in 2010 to about 9 ft in 2020. For 2030 (fig. 45), the westward expansion of subsidence in Fort Bend and Brazoria Counties and the deepening of the area of subsidence in central Montgomery County noted for 2020 continues; about 9 ft of subsidence in 2020 increases to about 10 ft in central Montgomery County by 2030. For 2040 (fig. 46), the only notable change from 2030 within the closed 1-ft contour that encompasses the major area of subsidence is an increase in the depth of the area of subsidence in central Montgomery County from 10 to 13 ft. For 2050 (fig. 47), the area within the closed 1-ft contour changes little from that of 2040. Maximum depths appear to have stabilized at 2040 levels, except in central Montgomery County where an increase from 13 to 14 ft is seen.

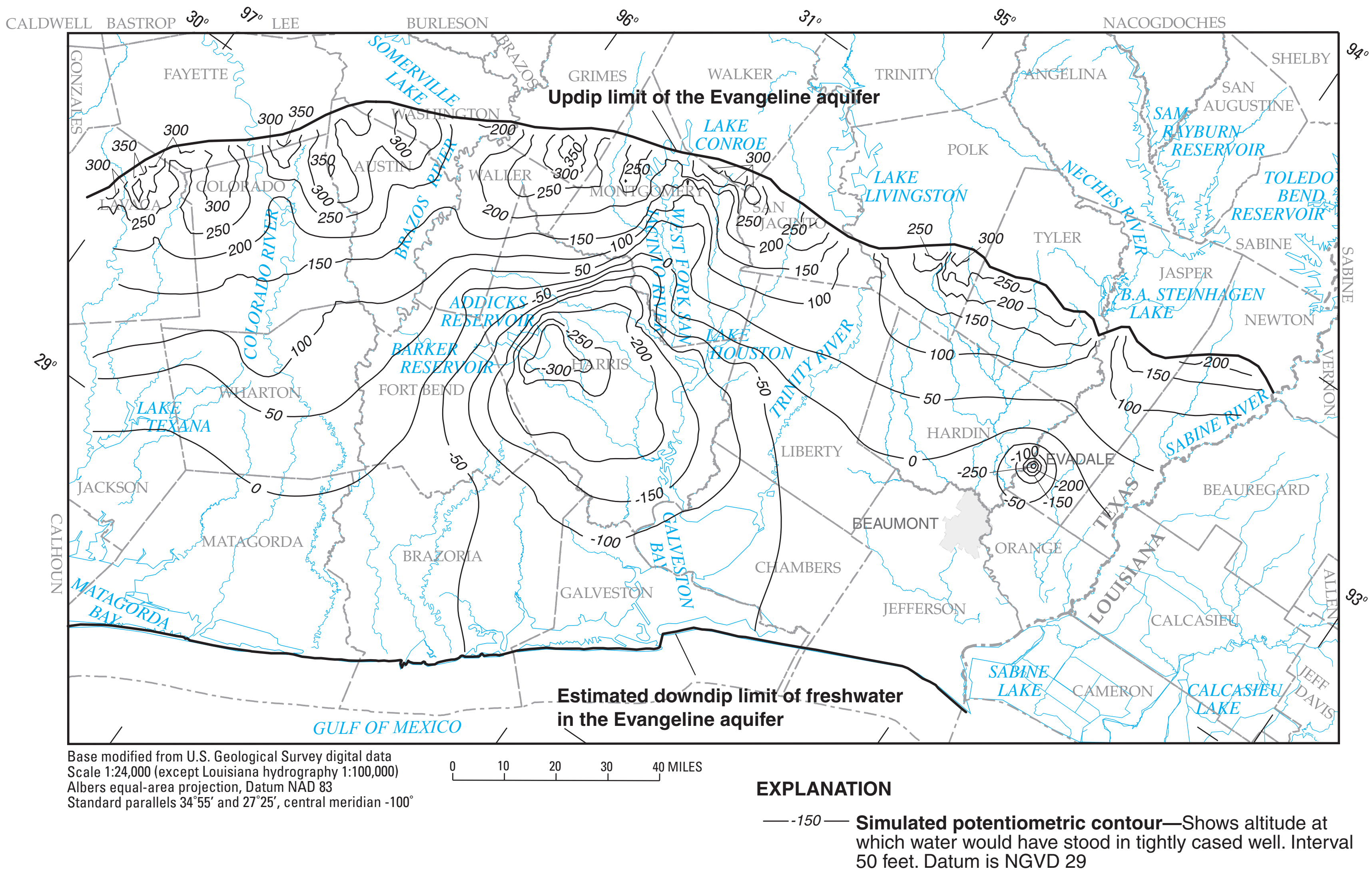
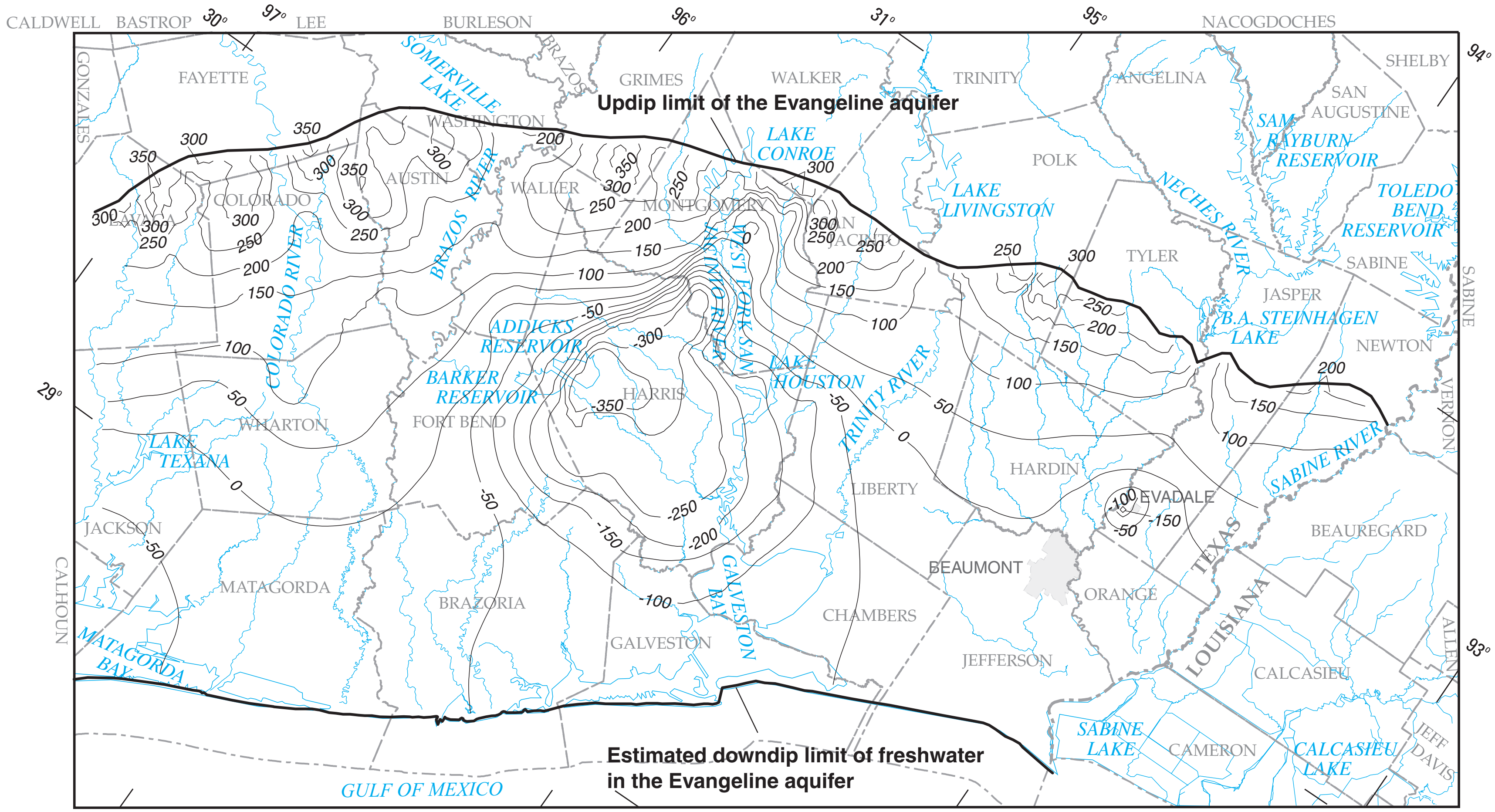


Figure 30. Simulated 1995 potentiometric surface of the Evangeline aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.

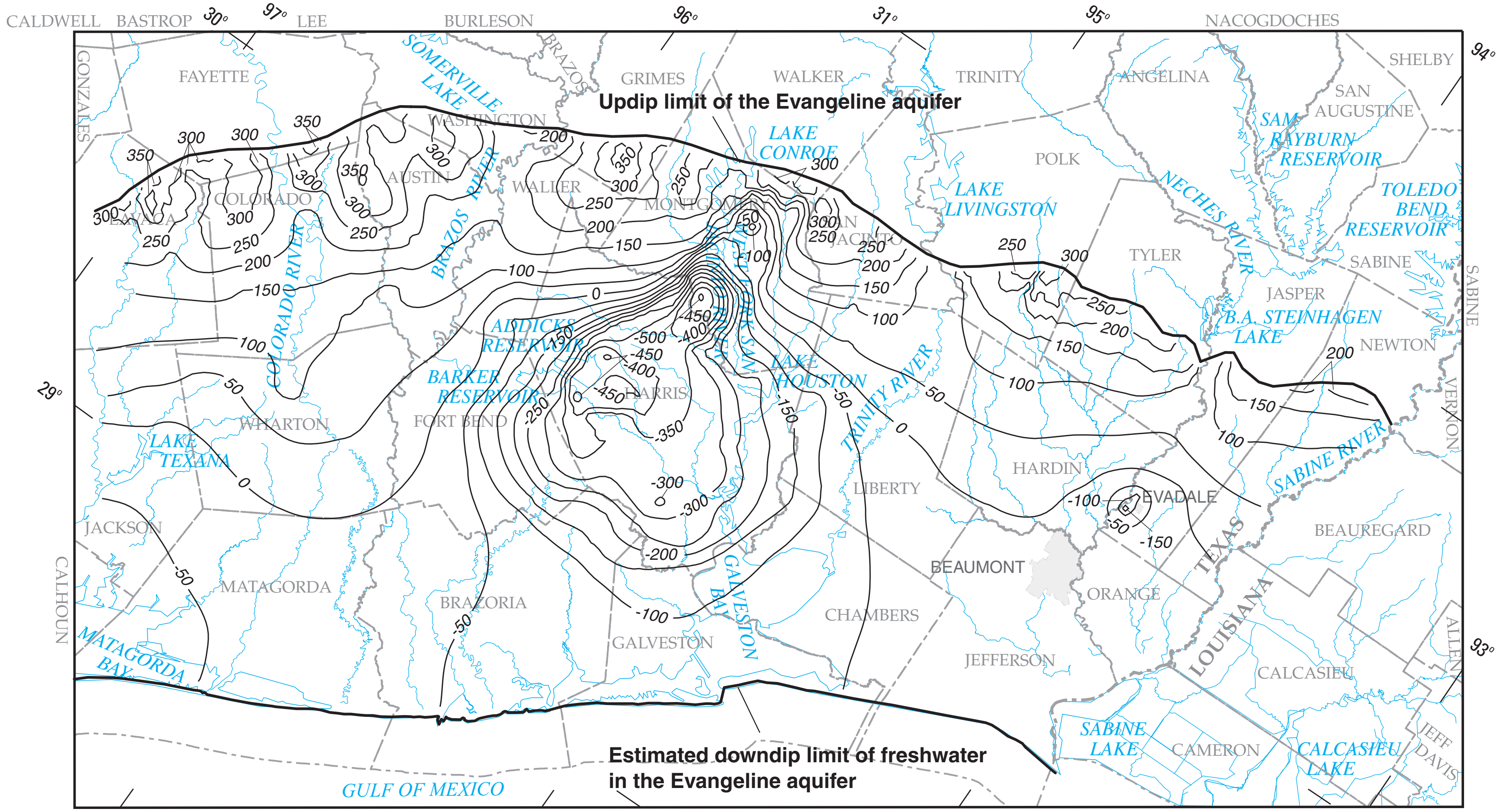


Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

EXPLANATION

-150 **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 31. Simulated 2010 potentiometric surface of the Evangeline aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.



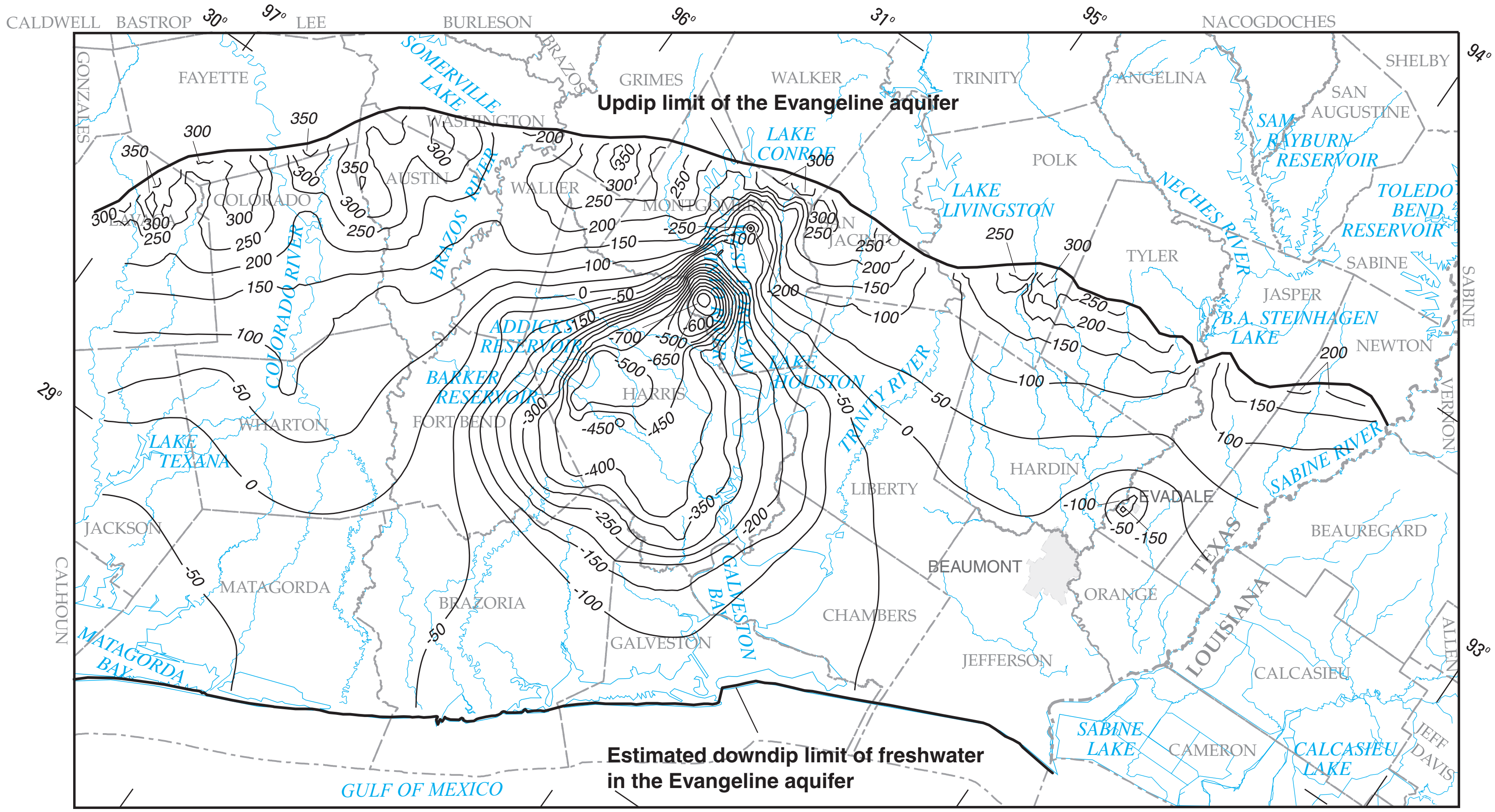
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

——-150—— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 32. Simulated 2020 potentiometric surface of the Evangeline aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.



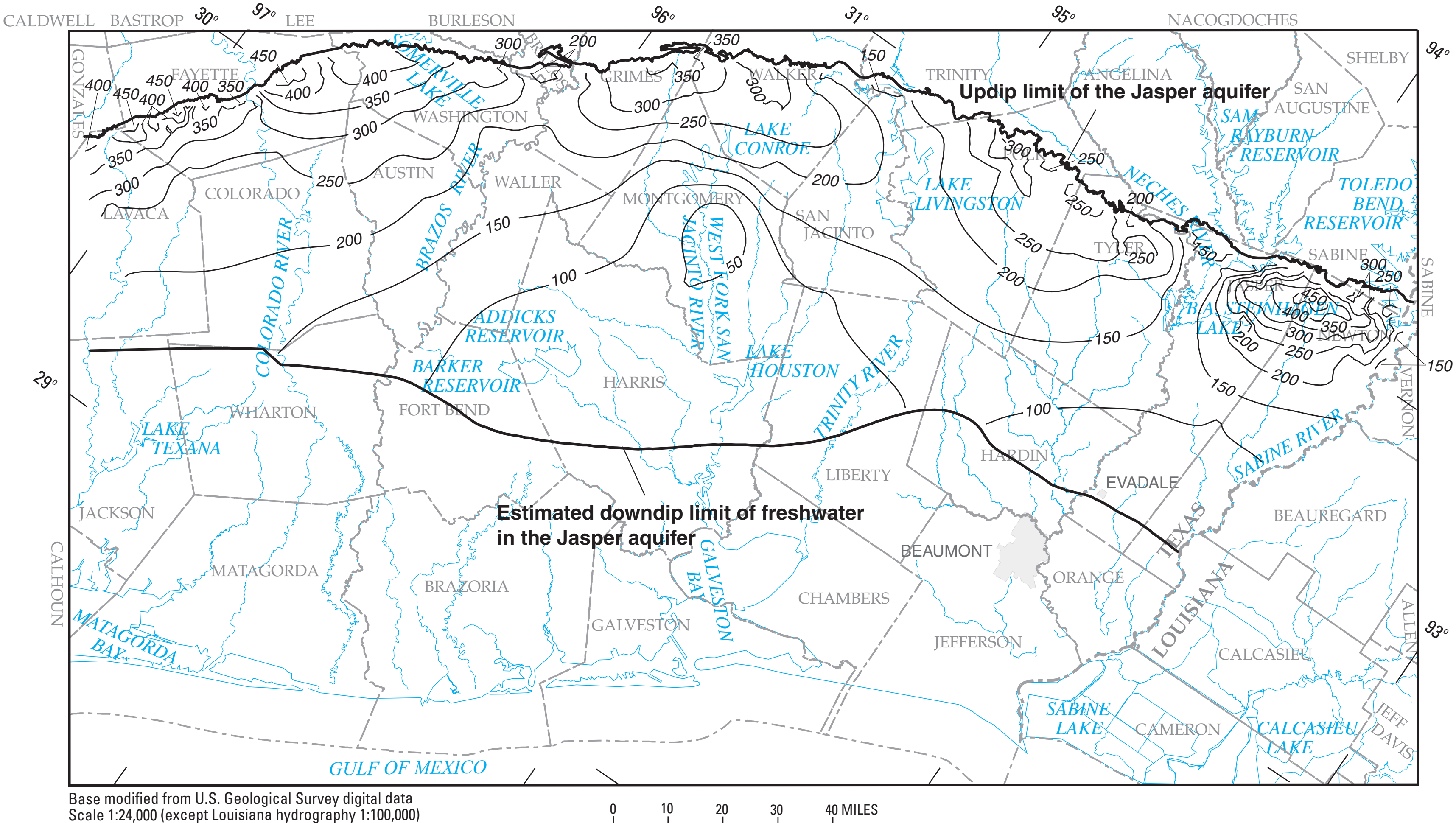
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—*-150*— **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 33. Simulated 2030 potentiometric surface of the Evangeline aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.

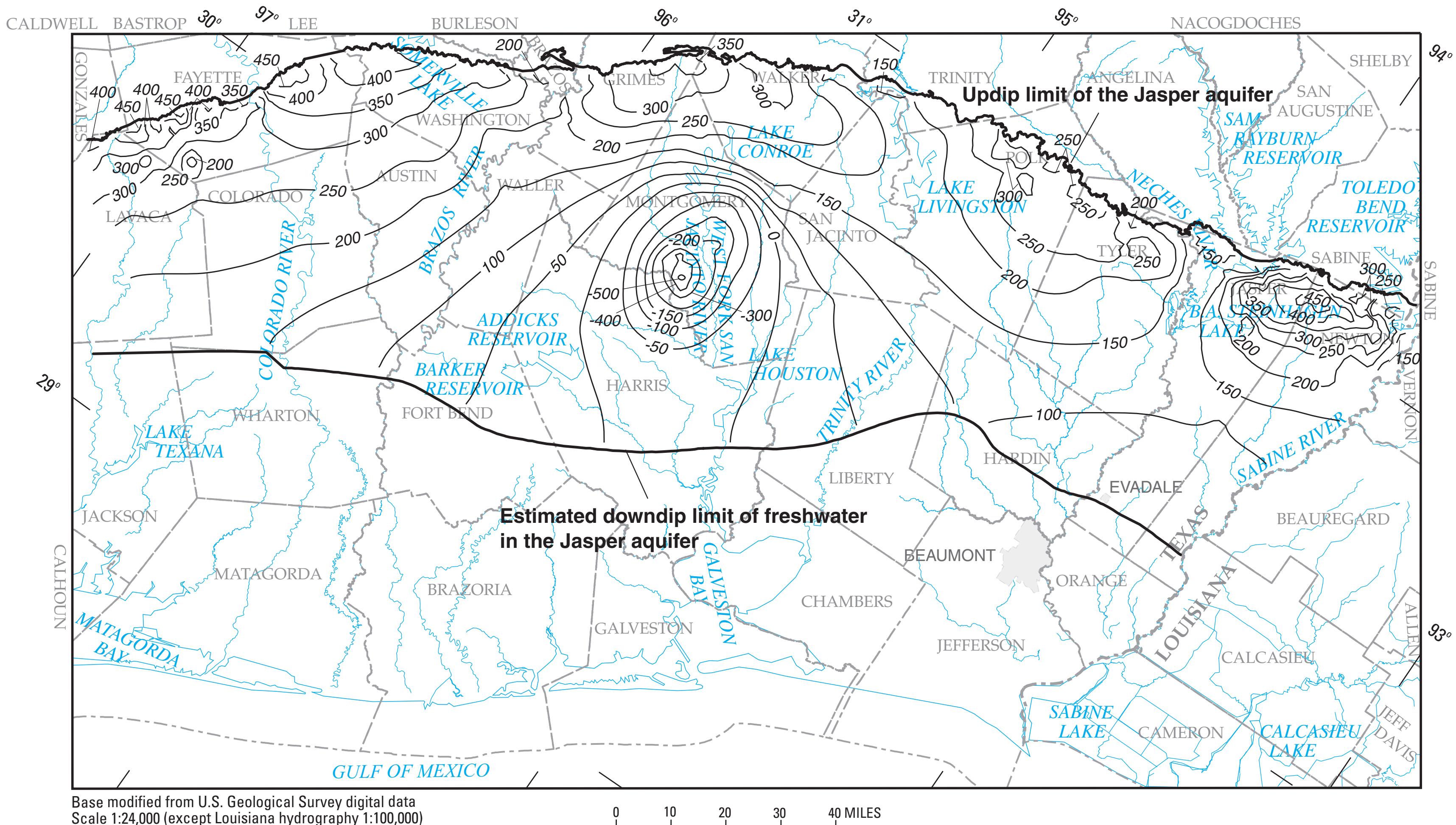


Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

EXPLANATION

— 150 — **Potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NGVD 29

Figure 34. Simulated 1995 potentiometric surface of the Jasper aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.

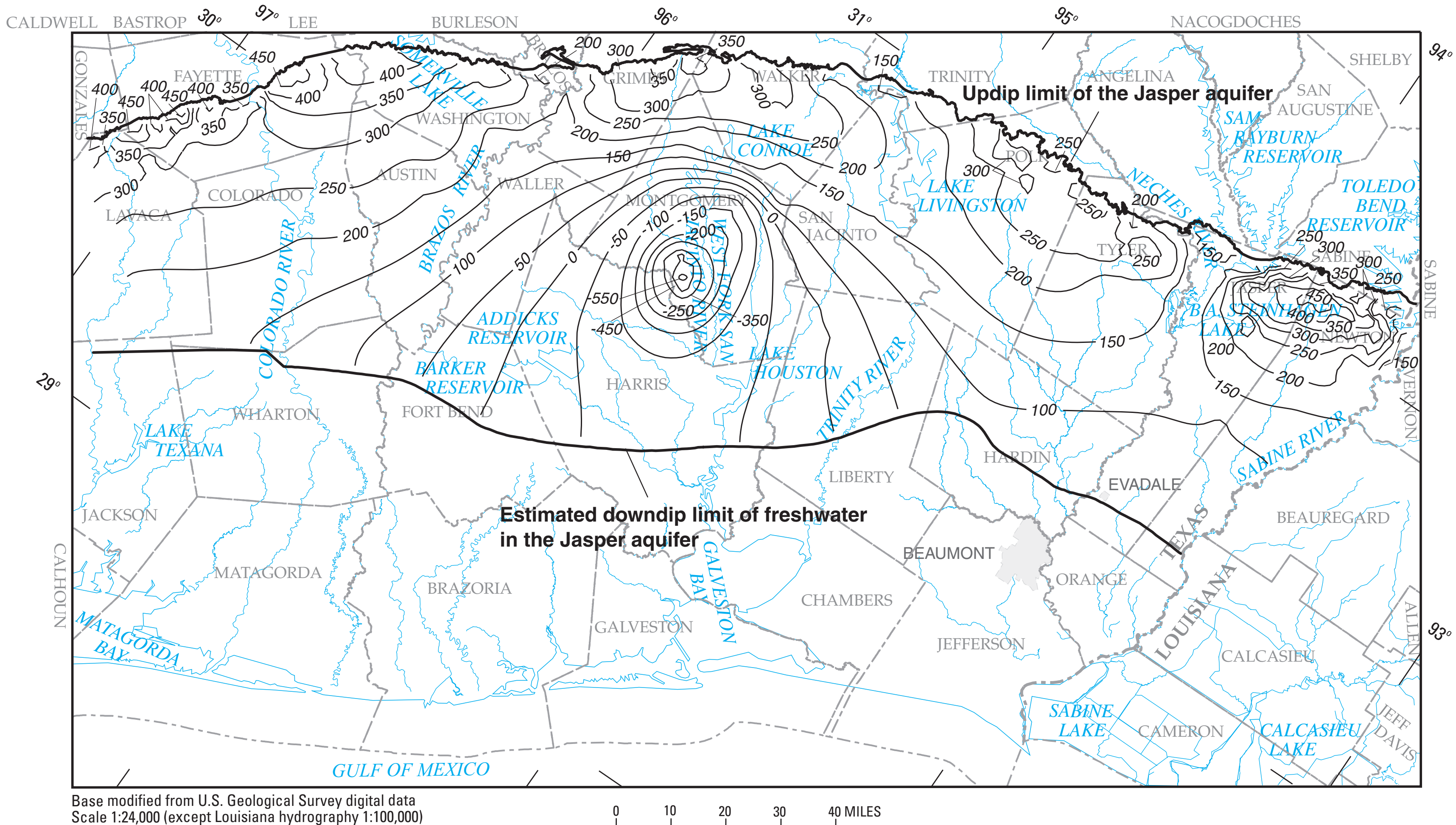


Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

EXPLANATION

—-150— **Potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Intervals 50 and 100 feet. Datum is NGVD 29

Figure 35. Simulated 2010 potentiometric surface of the Jasper aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.

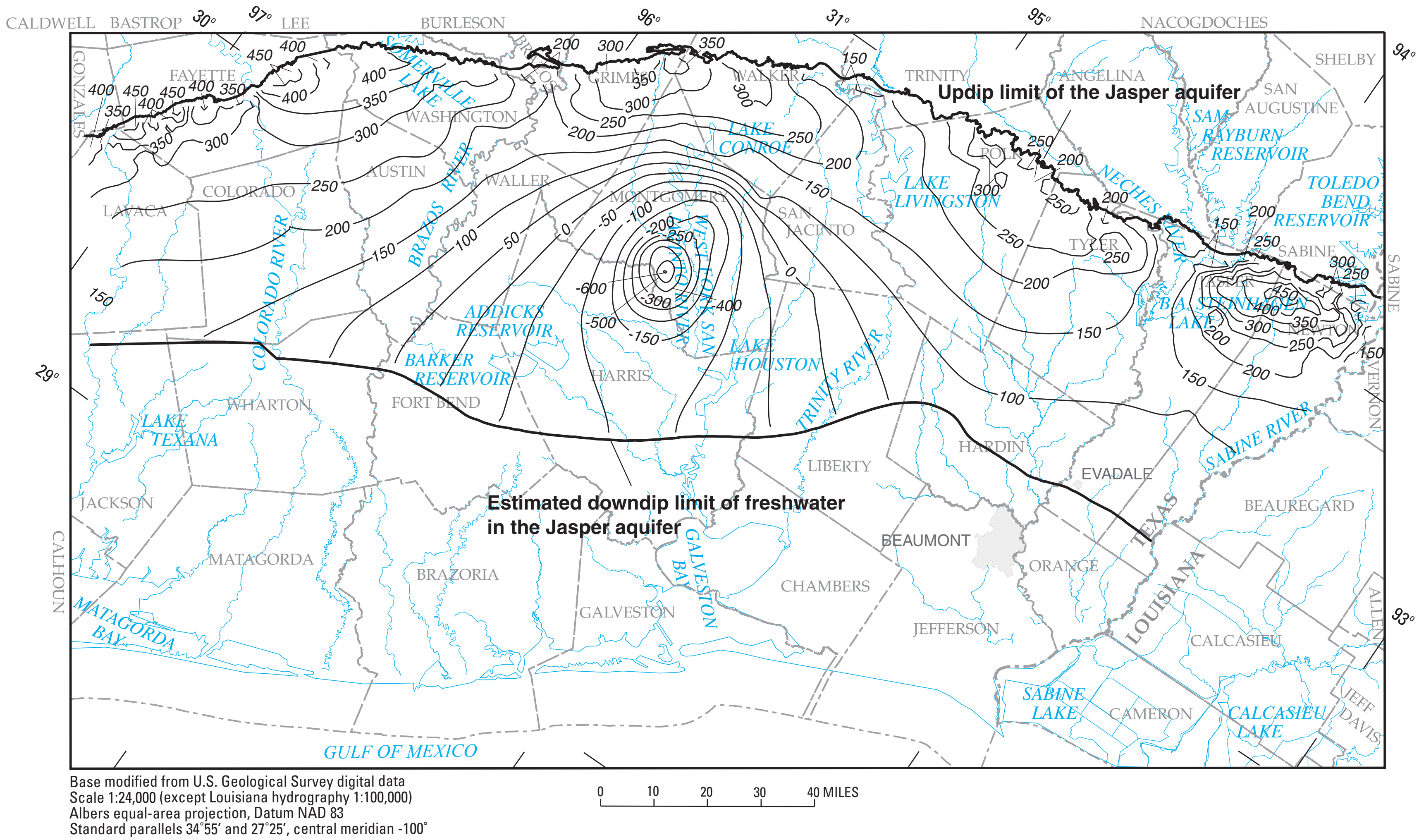


Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

EXPLANATION

—-150— **Potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Intervals 50 and 100 feet. Datum is NGVD 29

Figure 36. Simulated 2020 potentiometric surface of the Jasper aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.



EXPLANATION

—*-150*— **Potentiometric contour—**Shows altitude at which water would have stood in tightly cased well. Intervals 50 and 100 feet. Datum is NGVD 29

Figure 37. Simulated 2030 potentiometric surface of the Jasper aquifer in the NGC GAM model area resulting from HGCSD withdrawal scenario.

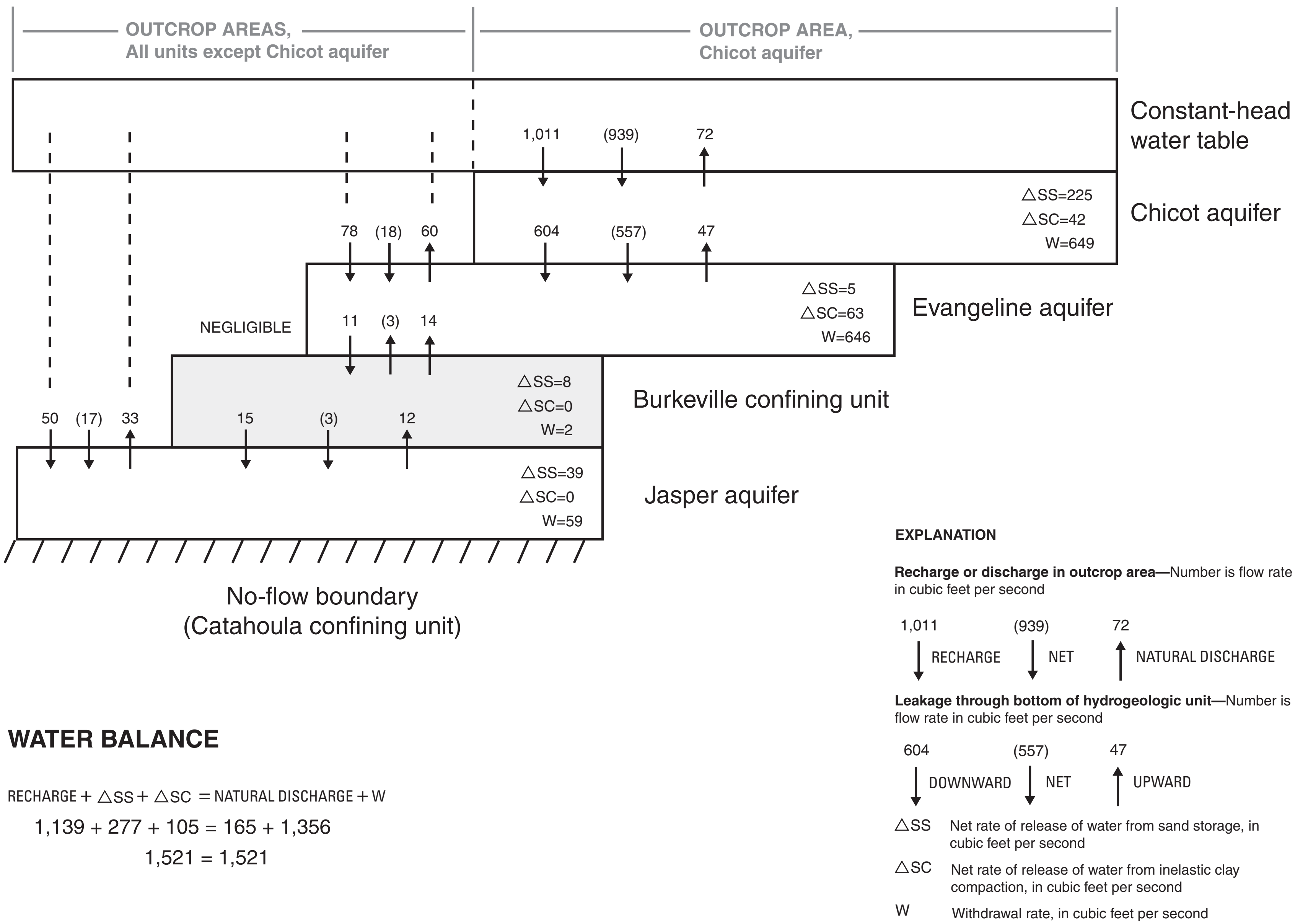


Figure 38. Simulated 1995 water-budget components of the hydrogeologic units of the NGC GAM model resulting from HGCSD withdrawal scenario.

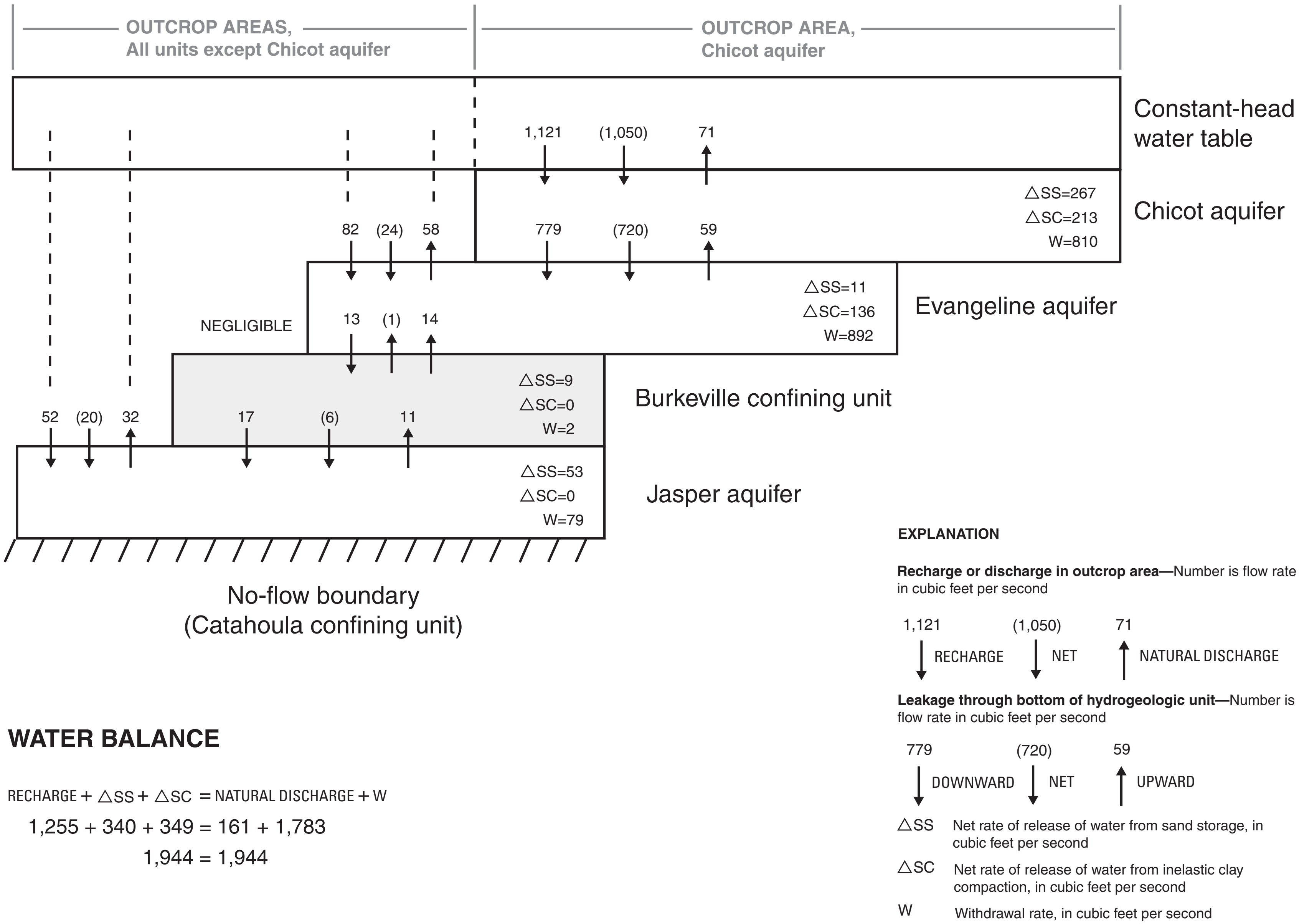


Figure 39. Simulated 2010 water-budget components of the hydrogeologic units of the NGC GAM model resulting from HGCSD withdrawal scenario.

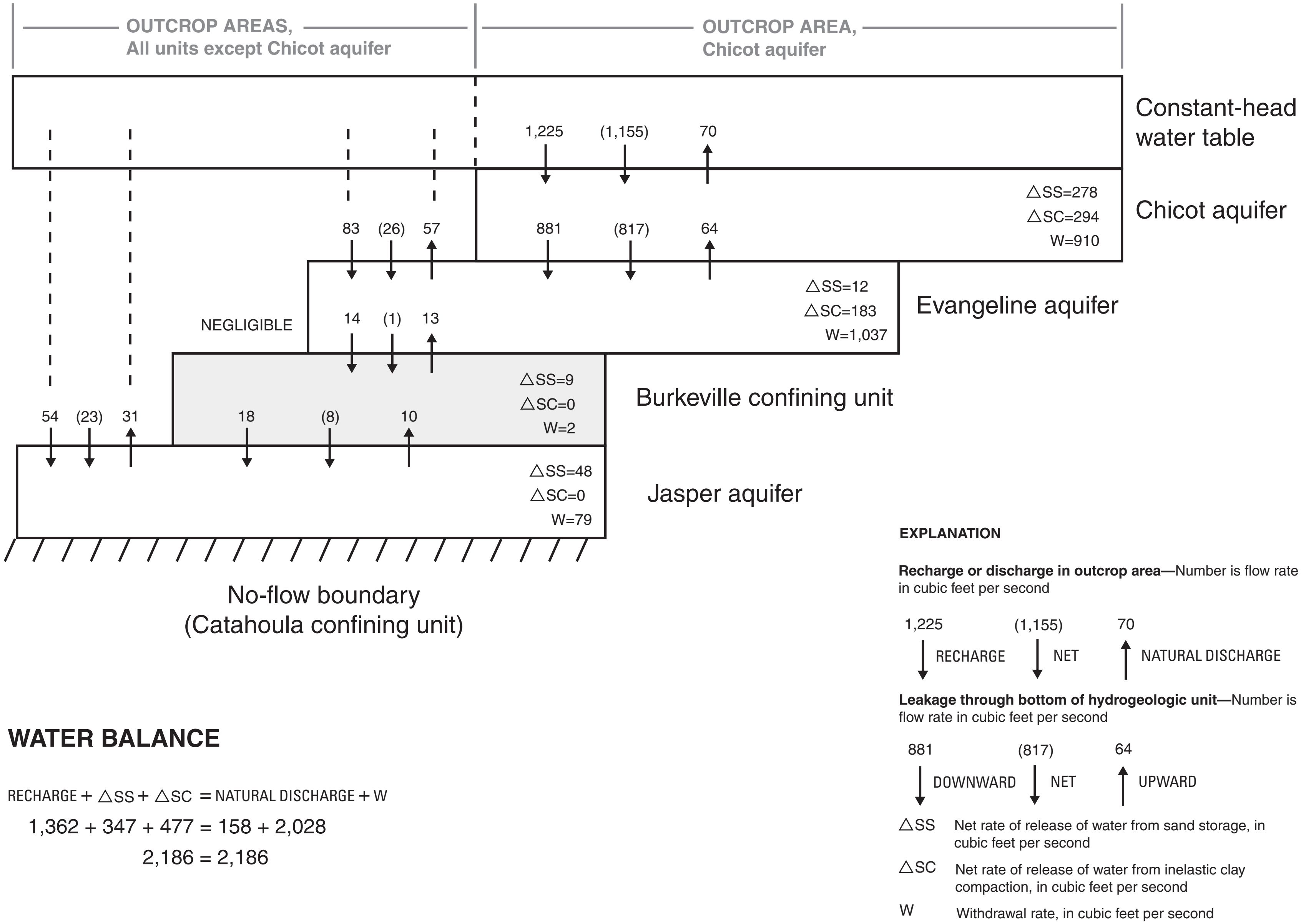


Figure 40. Simulated 2020 water-budget components of the hydrogeologic units of the NGC GAM model resulting from HGCSD withdrawal scenario.

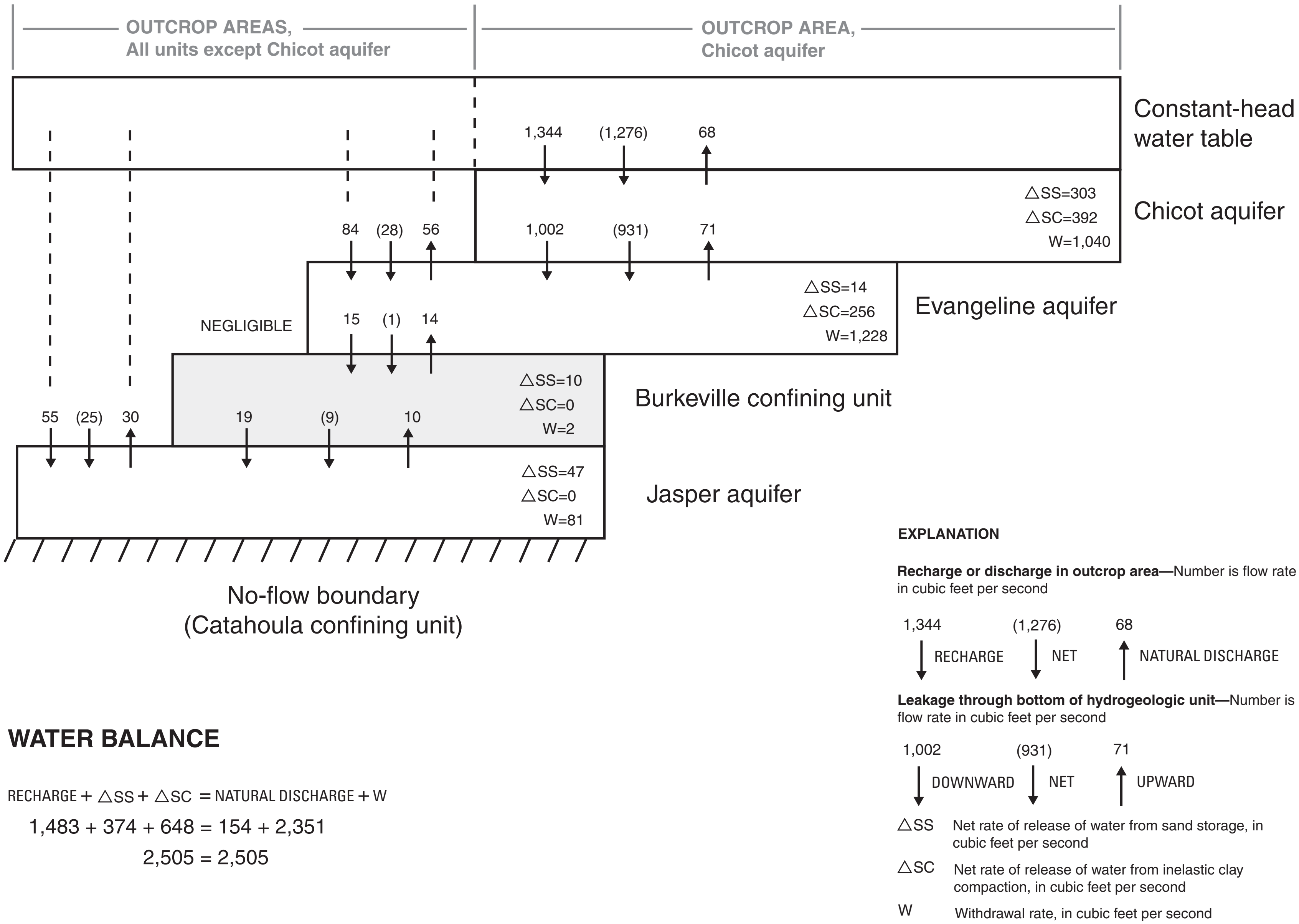
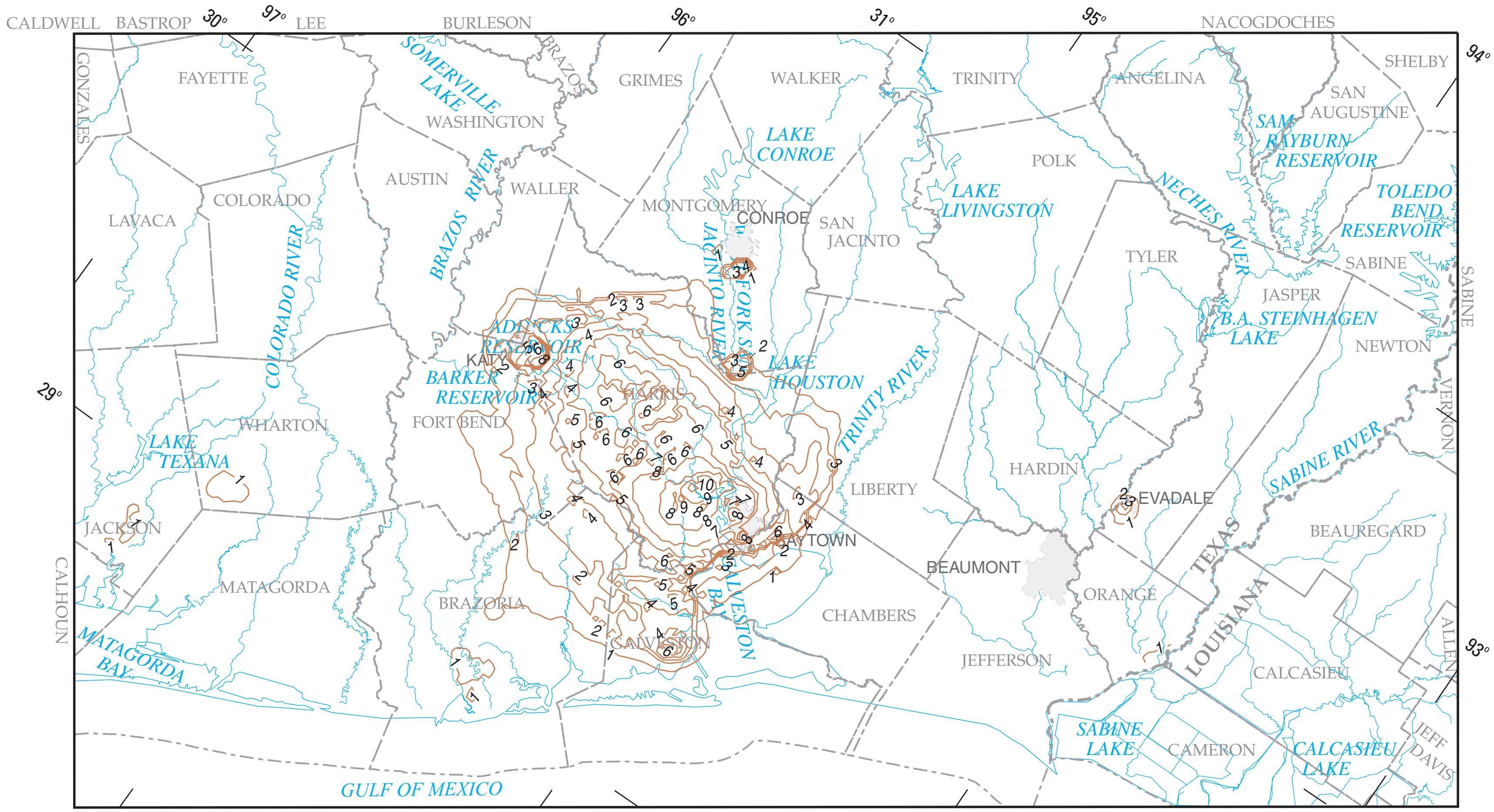


Figure 41. Simulated 2030 water-budget components of the hydrogeologic units of the NGC GAM model resulting from HGCSD withdrawal scenario.



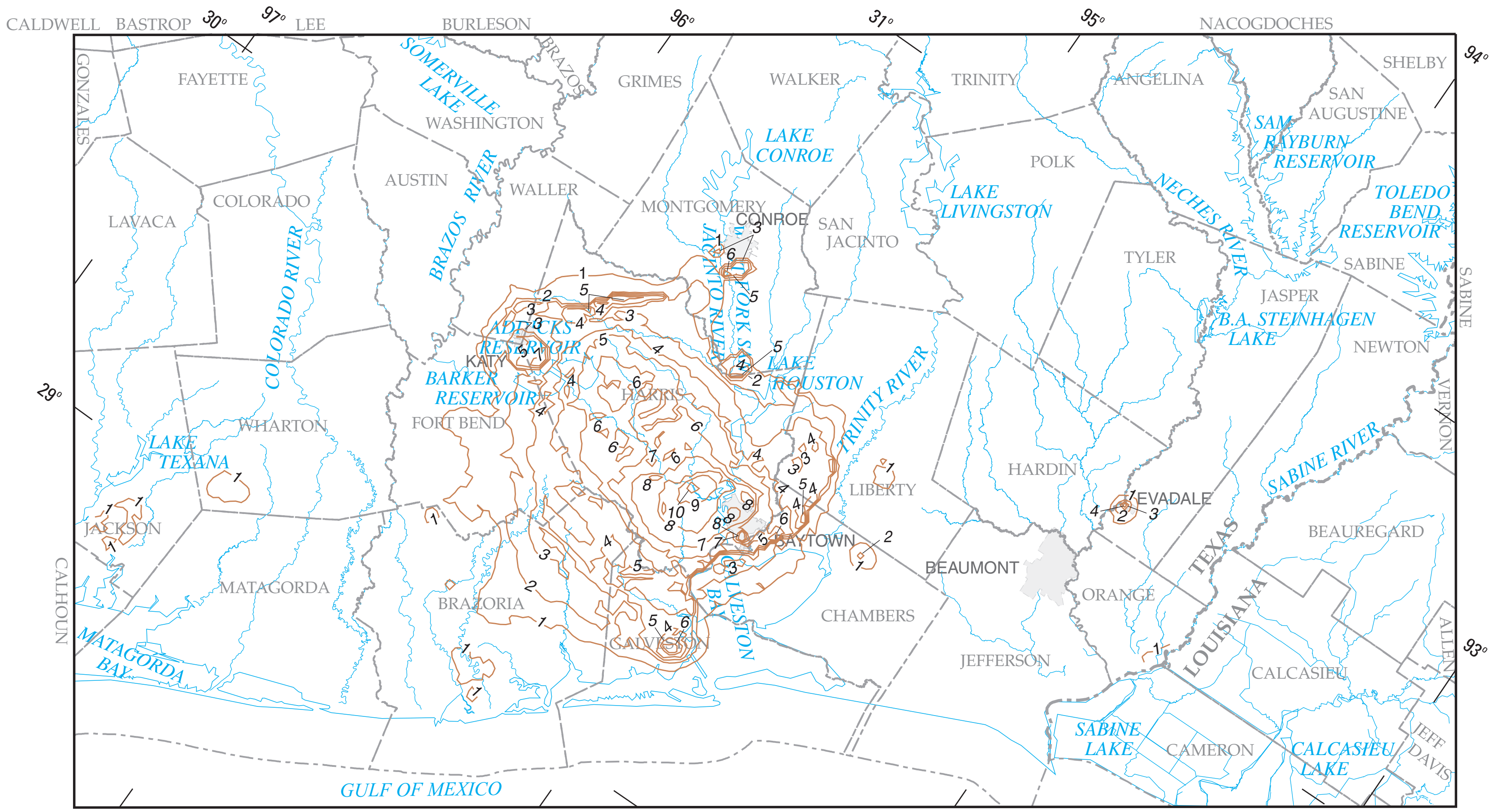
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

5 — **Simulated land-surface subsidence contour**—Interval variable, in feet

Figure 42. Simulated 2000 land-surface subsidence in the NGC GAM model area resulting from TWDB withdrawal scenario.



Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

— 5 — **Simulated land-surface subsidence contour—**Interval variable, in feet

Figure 43. Simulated 2010 land-surface subsidence in the NGC GAM model area resulting from TWDB withdrawal scenario.

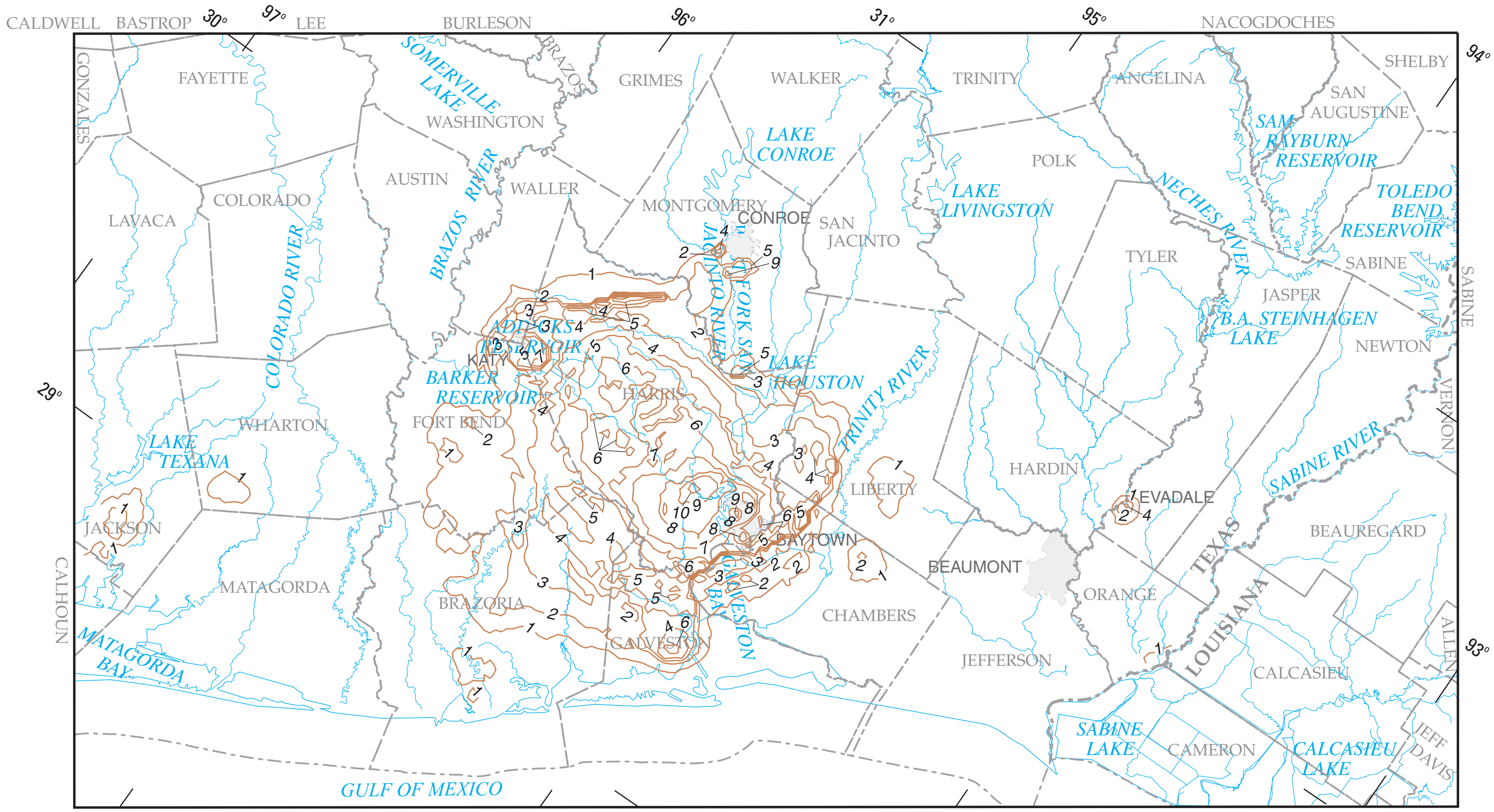


Figure 44. Simulated 2020 land-surface subsidence in the NGC GAM model area resulting from TWDB withdrawal scenario.

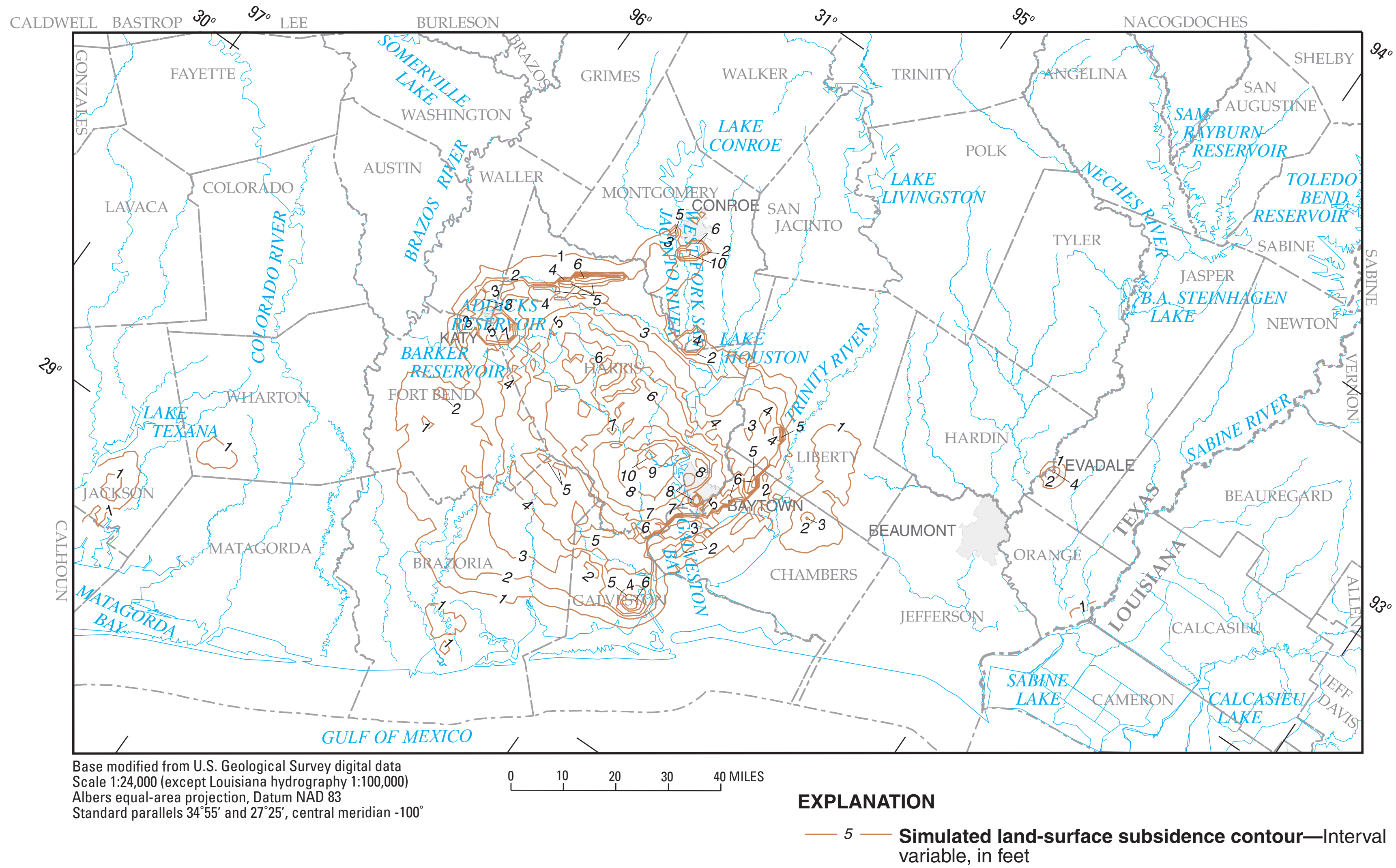


Figure 45. Simulated 2030 land-surface subsidence in the NGC GAM model area resulting from TWDB withdrawal scenario.

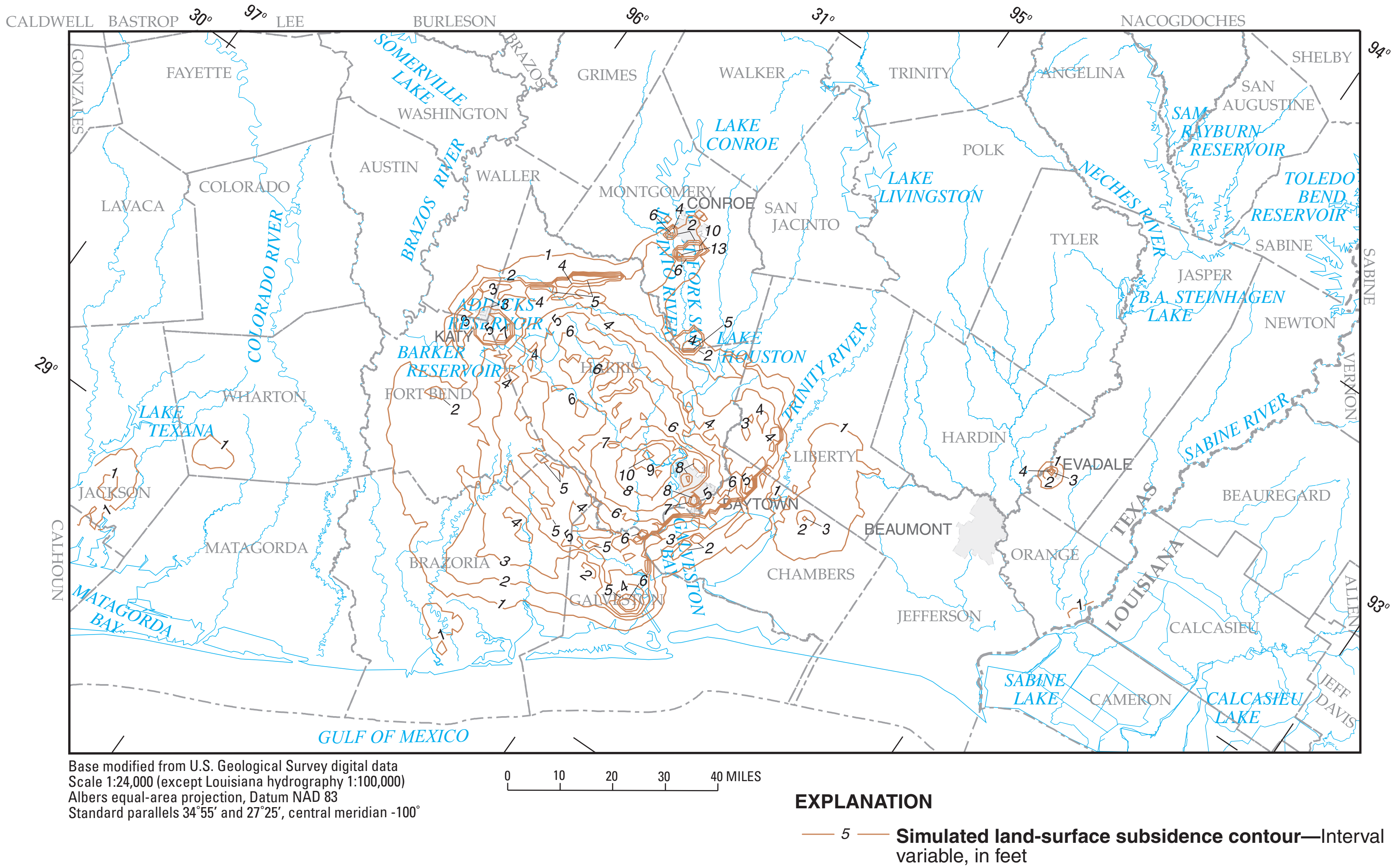
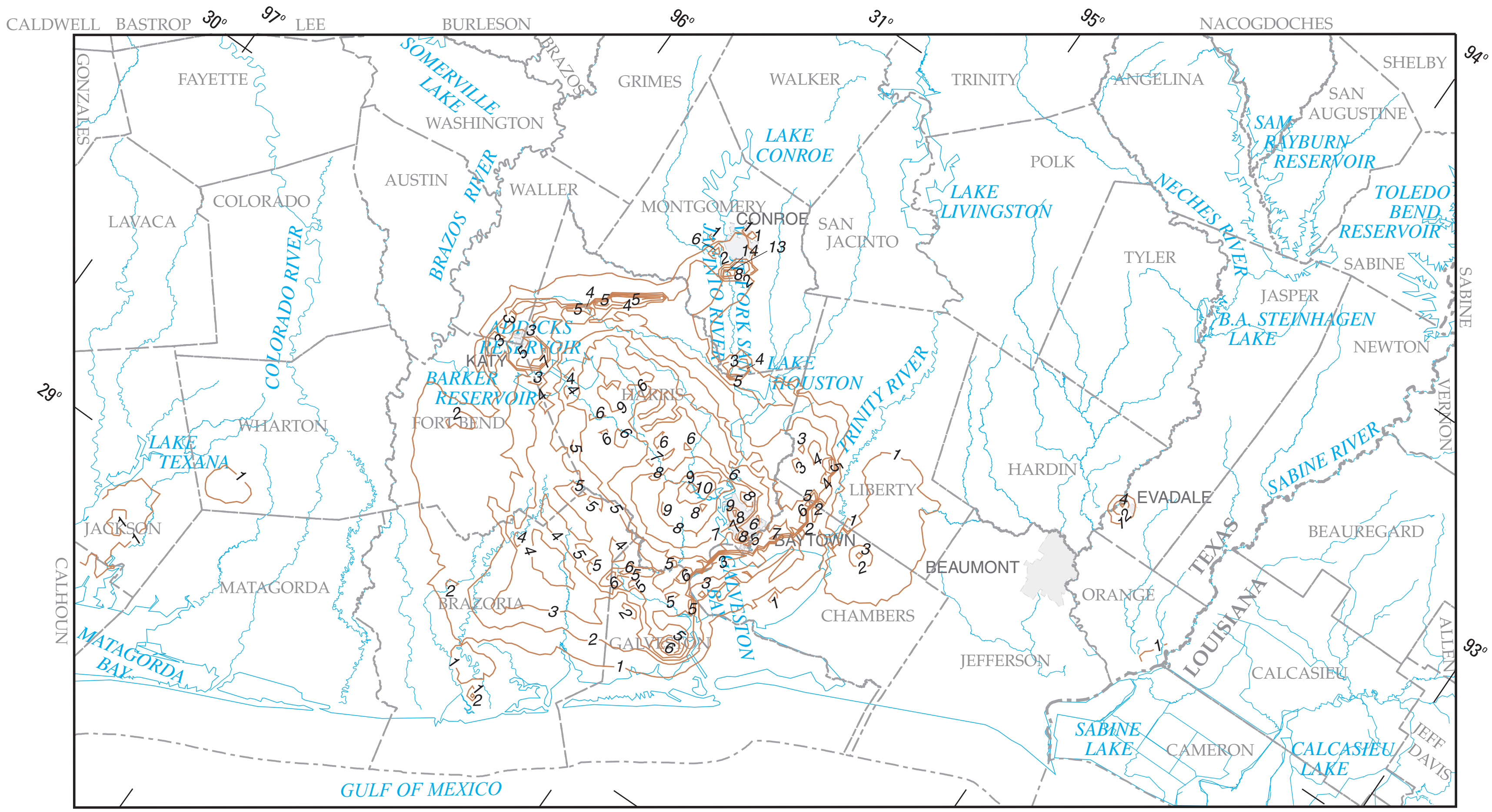


Figure 46. Simulated 2040 land-surface subsidence in the NGC GAM model area resulting from TWDB withdrawal scenario.



Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

5 — **Simulated land-surface subsidence contour—**Interval variable, in feet

Figure 47. Simulated 2050 land-surface subsidence in the NGC GAM model area resulting from TWDB withdrawal scenario.

Some relatively small areas of land-surface subsidence are indicated outside the closed 1-ft contour that encompasses the major area of subsidence during the projected period. In the coastal irrigation area centered in Wharton and Jackson Counties, subsidence of about 1 ft appears in parts of each of those counties in each of the decadal maps. The only noticeable change during the projected period is an enlargement of the area of subsidence in Jackson County between 2000 and 2010 and a slightly greater enlargement between 2010 and 2020 (figs. 42–44). In the Evadale-Beaumont area, the relatively small area of subsidence about 3 ft deep on the 2000 map increases to 4 ft in the 2010 and subsequent maps through 2050. A small area of about 1 ft of subsidence in southern Brazoria County is stable on each of the 2000–50 maps. In Liberty and Chambers Counties, small areas of about 1 ft of subsidence that do not appear in 2000 are indicated in each of those counties for 2010. These two areas expand throughout the simulation, coalesce in 2030, and nearly coalesce with the major area of subsidence centered in the Harris-Galveston County area in 2040 and 2050. The subsidence deepens in a small area in Chambers County to about 3 ft in 2030, 2040, and 2050.

Results Using Harris-Galveston Coastal Subsidence District Scenario

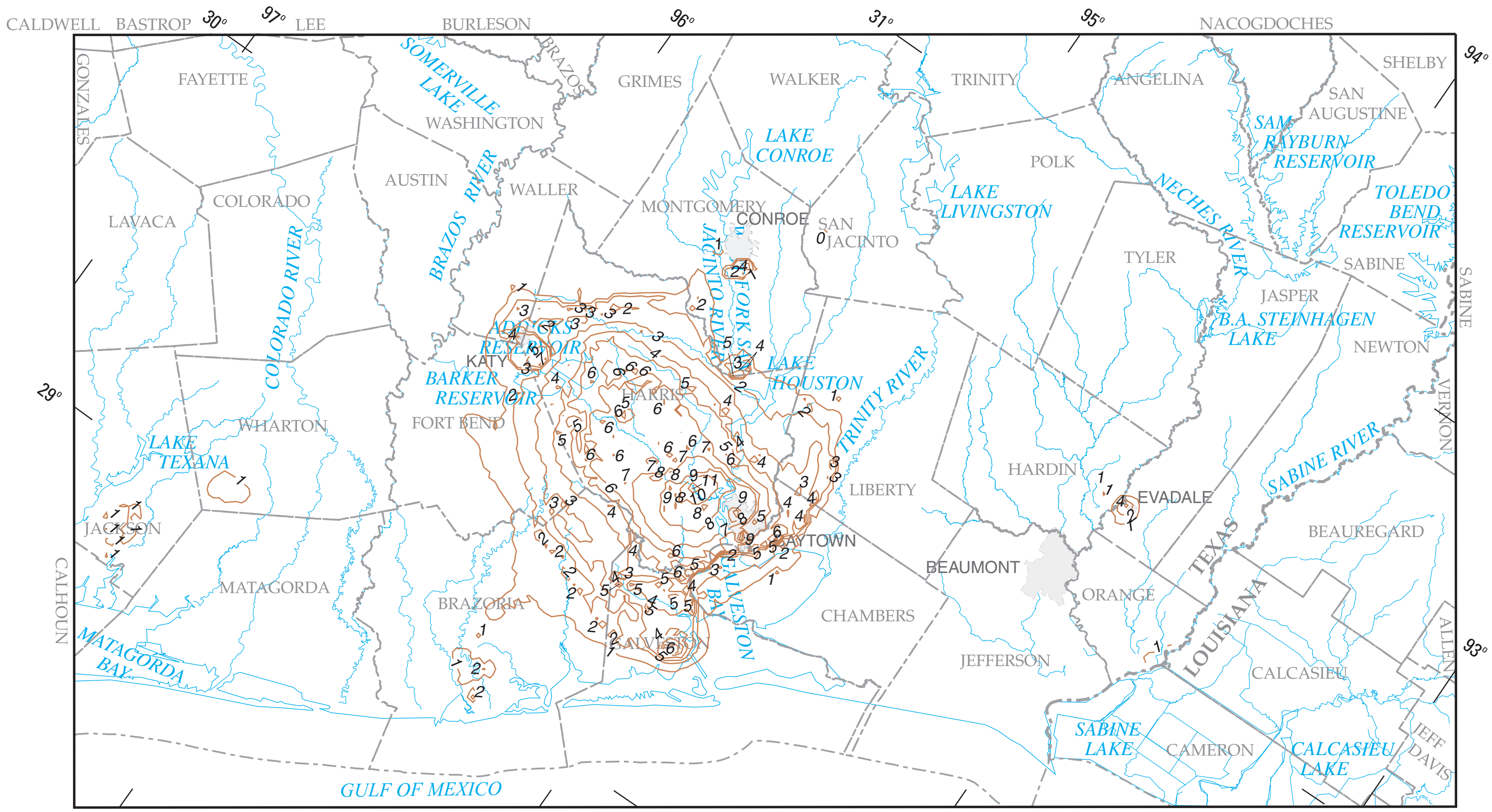
Land-surface subsidence in the NGC GAM model area for 1995, 2010, 2020, and 2030 that results from simulating the HGCSD withdrawal scenario is shown in figures 48–51. In the major area of subsidence centered in Harris and Galveston Counties, the configuration and maximum depths of subsidence for 1995 (HGCSD scenario, fig. 48) are nearly the same as those for 2000 (TWDB scenario, fig. 42). Throughout the HGCSD projected period, the area within the closed 1-ft contour that encompasses the major area of subsidence expands, primarily in Fort Bend County, and the depths of subsidence increase substantially. For example, in east-central Harris County, maximum subsidence of about 10–11 ft in 1995 (fig. 48) increases to about 13 ft in 2010 (fig. 49), 17 ft in 2020 (fig. 50), and 22 ft in 2030 (fig. 51). In central Montgomery County (Conroe area), maximum subsidence of about 4 ft in 1995 increases to about 7 ft in 2010, 12 ft in 2020, and 17 ft in 2030. In west-central Harris County (Katy area), maximum subsidence of about 7 ft in 1995 increases to about 9 ft in 2010, 11 ft in 2020, and 14 ft in 2030. These or similar results would be expected as simulated withdrawals increase with time, given the simulated increases with time in the amount of water supplied by storage derived from the compaction of clay.

Limitations on Use of Model Results

In the documentation of the NGC GAM model (Kasmarek and Robinson, 2004), factors that limit the ability of the NGC GAM model to reliably predict aquifer-system responses to future conditions were described. Some of the factors pertain to assumptions, or simplifications, about the aquifer system necessary to reduce the complexity of the system so that its functions can be described mathematically and simulated numerically. Some pertain to the model input data and the uncertainty, bias, and non-uniqueness associated with the different datasets of aquifer-system properties and conditions. And some pertain to the scale of application of the NGC GAM model, which necessarily is regional rather than local because of the size of the model grid cells (1 mi^2). Site-specific analysis is precluded because aquifer properties and conditions are averaged over the area of each cell. These factors contribute a cumulative uncertainty to the results of predictive aquifer-system simulations.

In addition to the factors described that cause uncertainty in simulation results, there is uncertainty associated with each of the two projected withdrawal scenarios. The hypothetical projected withdrawal scenarios are estimates of future withdrawals and might not represent actual future withdrawals. The effects that variations in rainfall might have on future withdrawals, and thus on aquifer-system responses, are unknown and add uncertainty. The simplifying assumptions that the downdip limit of freshwater flow in each hydrogeologic unit is a stable, sharp interface across which no flow occurs, and that the base of the system at the Jasper aquifer/Catahoula confining-unit boundary is no-flow, become less realistic and thus contribute greater uncertainty in results as drawdowns increase. In other words, the potential for lateral and vertical saline-water encroachment into freshwater zones, which the NGC GAM model does not simulate, increases as drawdowns increase.

The presence of uncertainty dictates that the results of the NGC GAM predictive simulations described in this report be used with caution in any decision-making process. The information on the potentiometric-surface maps, water-budget diagrams, and subsidence maps is meant to be more of a guide or indicator of issues or areas of potential concern than a predictor of specific future conditions in all areas. For example, whether water levels in the Jasper aquifer in southern Montgomery County would decline to 500–600 ft below NGVD 29 by 2010 under the TWDB withdrawal scenario as indicated (fig. 17), or whether the actual decline would be 300 –400 ft below NGVD 29, is less of the message than the fact that deep water levels in the Jasper aquifer in southern Montgomery County likely would be an issue of concern. Similarly, whether subsidence in east-central Harris County would increase 9 ft between 2010 and 2030 under the HGCSD scenario (figs. 49, 51) is less of the message than the fact that a relatively large fraction of the water necessary to supply projected withdrawals likely would come from compaction of clay, which in turn would increase subsidence in east-central Harris County enough that subsidence might be an issue of concern.



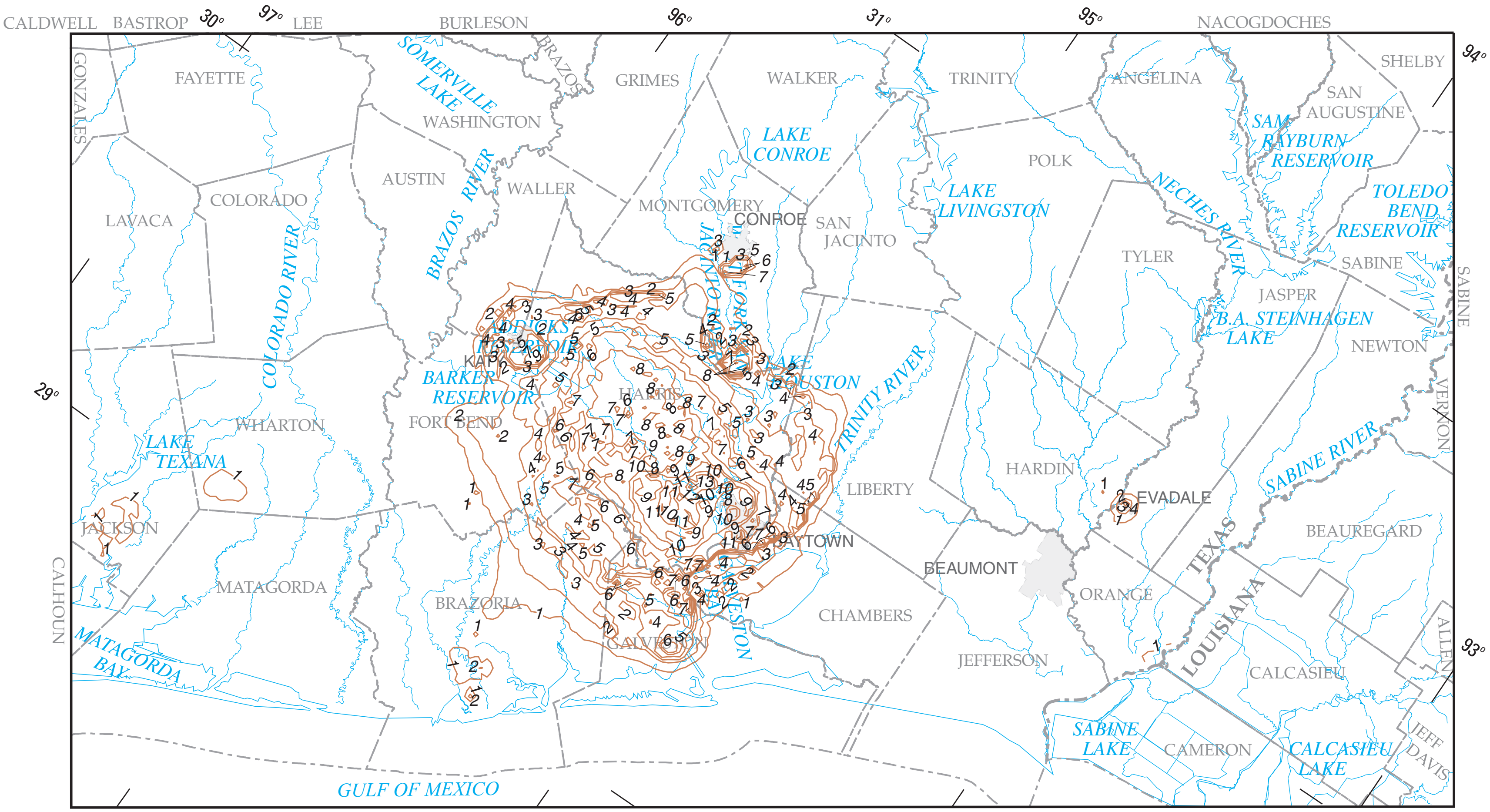
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—— 5 —— **Simulated land-surface subsidence contour—**Interval variable, in feet

Figure 48. Simulated 1995 land-surface subsidence in the NGC GAM model area resulting from HGCSD withdrawal scenario.



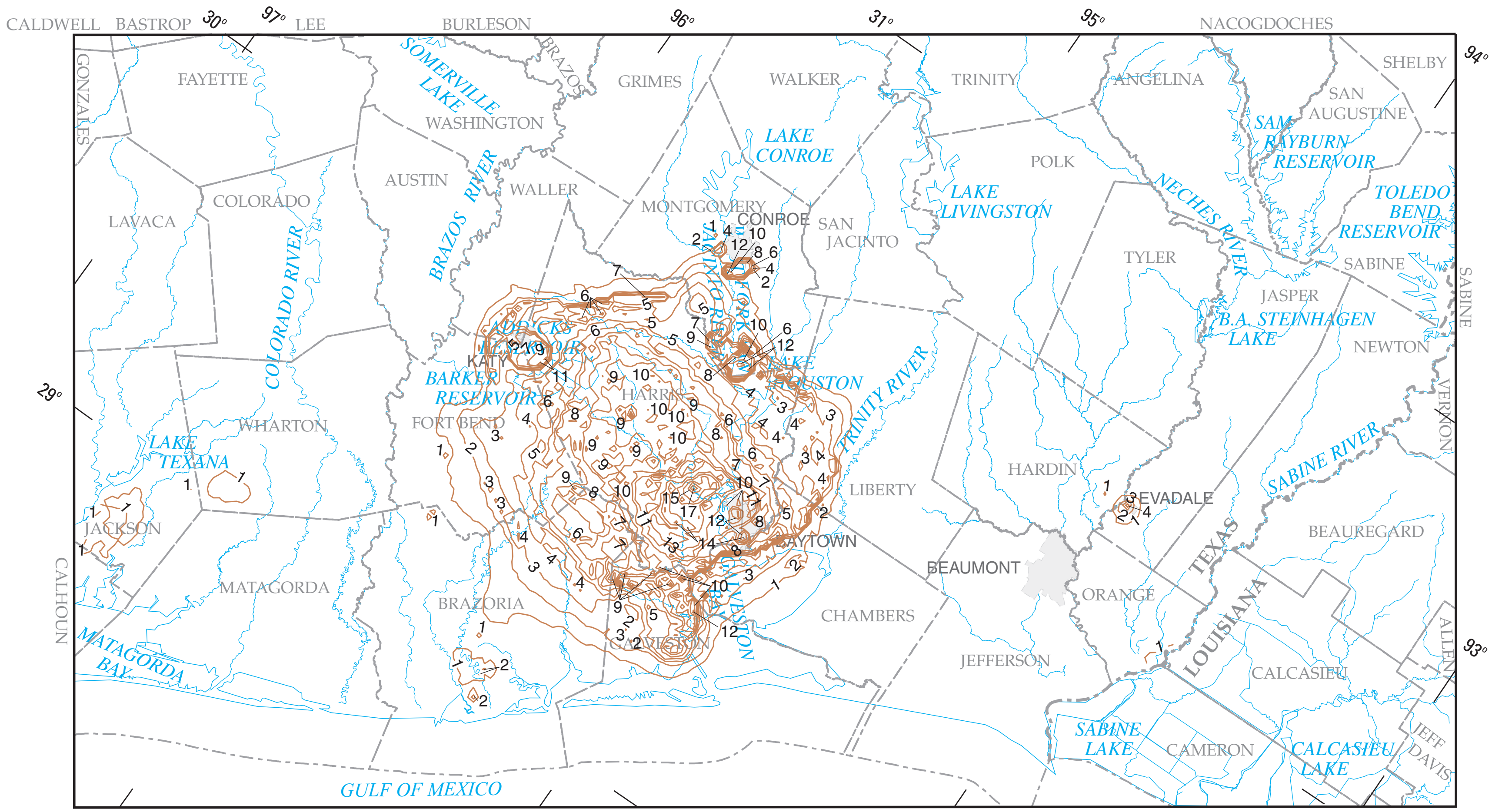
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

— *5* — **Simulated land-surface subsidence contour**—Interval variable, in feet

Figure 49. Simulated 2010 land-surface subsidence in the NGC GAM model area resulting from HGCSD withdrawal scenario.



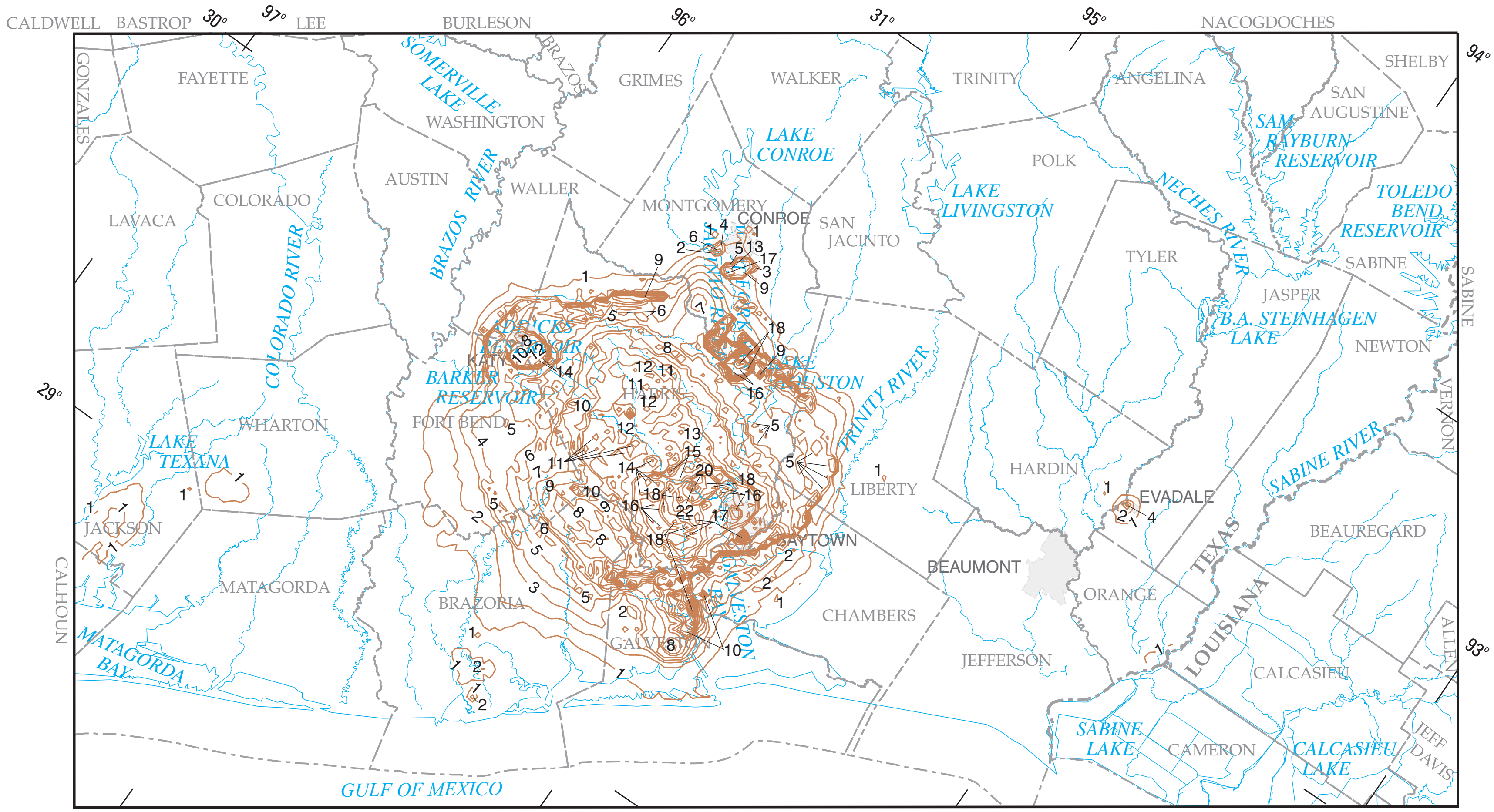
Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

5 — **Simulated land-surface subsidence contour—**Interval variable, in feet

Figure 50. Simulated 2020 land-surface subsidence in the NGC GAM model area resulting from HGCSD withdrawal scenario.



Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection, Datum NAD 83
Standard parallels 34°55′ and 27°25′, central meridian -100°

0 10 20 30 40 MILES

EXPLANATION

—— 5 —— **Simulated land-surface subsidence contour**—Interval variable, in feet

Figure 51. Simulated 2030 land-surface subsidence in the NGC GAM model area resulting from HGCSD withdrawal scenario.

Summary

From land surface downward, the Gulf Coast aquifer system comprises the Chicot and Evangeline aquifers, the Burkeville confining unit, the Jasper aquifer, and the Catahoula confining unit. During 1999–2004, the U.S. Geological Survey (USGS), in cooperation with the Texas Water Development Board (TWDB) and the Harris-Galveston Coastal Subsidence District (HGCSD), conducted a study as a part of the TWDB Ground-Water Availability Modeling (GAM) program to develop a northern Gulf Coast (NGC) GAM model to simulate ground-water flow and land-surface subsidence. The NGC GAM model, which is a USGS MODFLOW finite-difference model, comprises four layers, one for each of the three aquifers and the Burkeville confining unit. The base of the Jasper aquifer/top of the Catahoula confining unit is simulated as a no-flow boundary. Each layer consists of 137 rows and 245 columns of uniformly spaced grid cells, each cell representing 1 mi^2.

During 2003–04 the USGS, again in cooperation with the TWDB and the HGCSD, conducted a follow-up study (this report) using the NGC GAM model to evaluate the effects of hypothetical projected withdrawals on ground-water flow and land-surface subsidence in the approximately 25,000-mi^2 NGC GAM model area. Two withdrawal scenarios were simulated. The first scenario comprises historical withdrawals from the aquifer system for 1891–2000 and hypothetical projected withdrawals for 2001–50 compiled by the TWDB (TWDB scenario, or dataset). The projected withdrawals compiled by the TWDB are based on ground-water demands estimated by regional water planning groups. In the TWDB scenario, withdrawals increase about 8 percent during 2000–10 from about 850 to about 920 Mgal/d, decrease to about 830 Mgal/d in 2030, and gradually increase to nearly 850 Mgal/d, the rate at the beginning of the projected period, by 2050. The second scenario is a “merge” of the TWDB scenario with an alternate set of projected withdrawals from the Chicot and Evangeline aquifers in the Houston metropolitan area for 1995–2030 provided by the HGCSD (HGCSD scenario, or dataset). In the HGCSD scenario, withdrawals from the Chicot and Evangeline aquifers (Jasper aquifer withdrawals are the same as those in the TWDB scenario) increase continuously during 1995–2030 so that total withdrawals from the system increase about 74 percent from about 875 Mgal/d in 1995 to about 1,520 Mgal/d in 2030.

The simulated potentiometric surfaces of the Chicot aquifer for 2010, 2020, 2030, 2040, and 2050 that result from the TWDB withdrawal scenario show relatively little change in configuration from the simulated 2000 potentiometric surface of the Chicot aquifer and relatively little change in configuration over time. In the Harris-Galveston County area, a broad area of water levels 150–200 ft below NGVD 29 at the center of the major cone of depression in southern Harris County decreases in size during the projected period. In the coastal irrigation area centered in Wharton and Jackson Counties, an area of water levels 50–100 ft below NGVD 29 first appears in southeastern Jackson and southwestern Matagorda Counties in the 2010 surface and expands eastward in Matagorda County over time. In the Evadale-Beaumont area (southern Jasper and Hardin Counties), little or no change in Chicot aquifer water levels over the TWDB projected period is evident.

The simulated potentiometric surfaces of the Evangeline aquifer for 2000, 2010, 2020, 2030, 2040, and 2050 show the the most change between 2000 and 2010. The area of water levels 250–400 ft below NGVD 29 in the major cone of depression in the simulated 2000 surface in western Harris County shifts southeastward to southern Harris County, and water levels recover to 200–250 ft below NGVD 29 by 2010. Water levels in southern Harris County recover to 150–200 ft below NGVD 29 by 2020 and remain in that range through 2050. A relatively small cone of depression in southern Montgomery County that did not appear in the 2000 surface develops and enlarges during the projected period, with a maximum depth of 250–300 ft below NGVD 29 in 2030, 2040, and 2050. In the coastal irrigation area, negligible change in Evangeline aquifer water levels is evident throughout the projected period, except for the appearance of an area 50–100 ft below NGVD 29 in southeastern Jackson and southwestern Matagorda Counties in 2010 and slight expansion of that area in Matagorda County over time. In the Evadale-Beaumont area, 100 ft of recovery in the simulated cone of depression occurs by 2010, and for the remainder of the projected period, there is negligible change.

The simulated potentiometric surfaces of the Jasper aquifer for 2000, 2010, 2020, 2030, 2040, and 2050 each have a major cone of depression centered in southern Montgomery County. This minimally developed feature in the 2000 simulated Jasper aquifer potentiometric surface has a maximum depth of 550–650 ft below NGVD 29 in the 2020, 2030, 2040, and 2050 surfaces. No noticeable change in Jasper aquifer water levels appears in the coastal irrigation area or the Evadale-Beaumont area during the projected period.

Simulated net recharge (recharge minus natural discharge) under the TWDB scenario increases from 995 ft^3/s (0.54 in/yr) in 2000 to 1,144 (0.62 in/yr) in 2050, and the amount of water supplied by storage (sum of sand storage and storage from inelastic compaction of clay) decreases from 326 ft^3/s in 2000 to 168 ft^3/s in 2050. Although withdrawals from the entire system are projected to be about the same in 2050 as in 2000, the percentage of withdrawals supplied by net recharge increases from 75 percent in 2000 to 87 percent in 2050, and the percentage of withdrawals supplied by storage decreases from 25 percent in 2000 to 13 percent in 2050.

For the 2010, 2020, and 2030 Chicot aquifer potentiometric surfaces associated with the HGCSD scenario, the substantially greater Chicot aquifer withdrawals of the HGCSD scenario relative to those of the TWDB scenario result in progressively deeper cones of depression in southern Harris County (400–450 ft below NGVD 29 in 2030) than those in the potentiometric surfaces associated with the TWDB scenario. Unlike the decreasing or stable Evangeline aquifer withdrawals of the TWDB scenario, progressively larger increases in withdrawals in the HGCSD scenario for 2010, 2020, and 2030 result in substantially deeper cones of depression in the

simulated HGCSD potentiometric surfaces than in the simulated TWDB potentiometric surfaces for those years. For 2030, simulated water levels in western Harris County reach depths of 500–550 ft below NGVD 29; and in southern Montgomery County, depths of 700–750 ft below NGVD 29. Although Jasper aquifer withdrawals are the same for both scenarios, the major cone of depression in the Jasper aquifer centered in southern Montgomery County in the 2030 potentiometric surface is 50 ft deeper at its center (600–700 ft below NGVD 29) than the cone in the 2030 surface under the TWDB scenario.

Simulated net recharge under the HGCSD scenario increases from 974 ft^3/s (0.53 in/yr) in 1995 to 1,329 ft^3/s (0.72 in/yr) in 2030. The amount of water supplied by storage increases about 168 percent (from 382 to 1,022 ft^3/s) under the HGCSD scenario, and about 85 percent of that increase (543 ft^3/s) is from the compaction of clay. During 1995–2030 the percentage of withdrawals supplied by net recharge decreases from 72 percent in 1995 to 57 percent in 2030, and the percentage of withdrawals supplied by storage increases from 28 percent in 2000 to 43 percent in 2030.

Land-surface subsidence in the major area of subsidence centered in Harris and Galveston Counties during 2000–50 that results from simulating the TWDB withdrawal scenario expands slightly to the west and increases in places. The maximum change occurs in the Conroe area where subsidence increases from about 4 to about 13 ft during the projected period. Land-surface subsidence in the major area of subsidence during 1995–2030 that results from simulating the HGCSD withdrawal scenario increases substantially. For example, in east-central Harris County maximum subsidence increases from about 10–11 ft in 1995 to 22 ft in 2030. These or similar results would be expected under the HGCSD scenario as simulated withdrawals increase with time, given the simulated increases with time in the amount of water supplied by storage derived from the compaction of clay.

In addition to factors involving model assumptions, input data, and scale of application that give rise to uncertainty in simulation results, additional uncertainty in simulation results is associated with each of the two projected withdrawal scenarios. The hypothetical projected withdrawal scenarios are estimates of future withdrawals and might not represent actual future withdrawals. The simplifying assumptions that the downdip limit of freshwater flow in each hydrogeologic unit is a stable, sharp interface across which no flow occurs, and that the base of the system at the Jasper aquifer/Catahoula confining-unit boundary is no-flow, become less realistic and thus increase the uncertainty in results as drawdowns increase. The presence of uncertainty dictates that the results of the predictive simulations described in this report be used with caution in any decision-making process.

References

Harbaugh, A.W., and McDonald, M.G., 1996, User's documentation for MODFLOW–96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 96–485, 56 p.

Kasmarek, M.C., and Robinson, J.L., 2004, Hydrology and simulation of ground-water flow and land-surface subsidence in the northern part of the Gulf Coast aquifer system, Texas: U.S. Geological Survey Scientific Investigations Report 2004–5102, 111 p.

LBG-Guyton Associates, 1997, Ground-water model review and conversion: Prepared for Harris-Galveston Coastal Subsidence District, Friendswood, Tex., 18 p.

Leake, S.A., and Prudic, D.E., 1991, Documentation of a computer program to simulate aquifer-system compaction using the modular finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A2, 68 p.

Texas Commission on Environmental Quality, 2004, Search the water utility database (WUD): accessed August–October 2004 at URL http://www3.tnrcc.state.tx.us/iwud

Texas Water Development Board, 2002, Water for Texas - 2002—Volumes I–III: Texas Water Development Board, Document No. GP–7–1, 155 p.

Texas Water Development Board, 2003, Groundwater database reports: accessed March 2003 at URL http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWDatabaseReports/GWdatabaserpt.htm

Texas Water Development Board, 2004, GAM groundwater availability modeling: accessed March 10, 2004, at URL http://www.twdb.state.tx.us/gam/

Turner Collie & Braden, Inc., 1996, Update of population and water demand forecasts for the Harris-Galveston Coastal Subsidence District: Turner Collie & Braden, Inc., project number 11–00246–005, 36 p.

U.S. Environmental Protection Agency, 2004, Facility registry system—Search the Envirofacts facility tables: accessed November 2004 at URL http://www.epa.gov/enviro/html/fii/fii_query_java.html

U.S. Geological Survey, 2004, Land Cover Characterization Program—National land cover/MRLC: Earth Resources Observation Systems (EROS) Data Center, accessed May 27, 2004, at URL http://landcover.usgs.gov/index.asp

Appendix 1—Modifications to Northern Gulf Coast Ground-Water Availability Modeling Model Based on Simulations of Hypothetical Withdrawals

Appendix 1—Modifications to Northern Gulf Coast Ground-Water Availability Modeling Model Based on Simulations of Hypothetical Withdrawals

In the process of simulating TWDB and HGCSD hypothetical projected withdrawals, interim results indicated a need for reassessment of selected input data for the model of Kasmarek and Robinson (2004). Accordingly, input data changes were made, and the NGC GAM model was recalibrated in a series of trial-and-error simulations, each beginning with the steady-state model and proceeding to the transient model of historical and hypothetical projected withdrawals. The changes are summarized below by area. The root mean square errors between simulated and measured 2000 potentiometric surfaces resulting from the TWDB scenario before and after model modifications are shown in table a1.1. The simulated 2000 water-budget components resulting from the TWDB scenario before and after model modifications are shown in table a1.2.

Table a1.1. Root mean square (RMS) errors between simulated and measured 2000 Chicot, Evangeline, and Jasper aquifer potentiometric surfaces resulting from the TWDB scenario before and after model modifications described in appendix 1.

Aquifer	RMS error, in percent	
	Before (Kasmarek and Robinson, 2004)	After
Chicot	30.7	31.0
Evangeline	40.1	45.0
Jasper	33.8	37.9

Table a1.2. Simulated 2000 water-budget components resulting from the TWDB scenario before and after model modifications described in appendix 1.

[units, cubic feet per second]

Component	Before (Kasmarek and Robinson, 2004, fig. 73)	After (fig. 22)
Sources		
Recharge	965	1,160
Net release from sand storage	410	242
Net release from clay compaction	106	84
Discharges		
Natural discharge	161	165
Withdrawals	1,322	1,321

Area Near Harris-Montgomery County Line Between Houston and Conroe

Simulated head declines in the Jasper aquifer in an area of about 200 mi^2 that were considered excessive prompted review of input values of transmissivity (and component hydraulic conductivity) and historical withdrawals in the area. Hydraulic conductivity values assigned to model cells of the Evangeline and Jasper aquifers in the area appeared anomalously low relative to those of cells in surrounding areas. No hydrogeologic evidence for the low values could be established. A comparison of late 1990s simulated withdrawals in the area with the distribution of known wells in the area indicated that some late 1990s withdrawals from the Jasper aquifer might not be accounted for in the NGC GAM model dataset of historical withdrawals. The anomalously low hydraulic conductivity values arrived at during the original calibration could have resulted from attempts to match measured head declines created by withdrawals unaccounted for in the NGC GAM model. Despite the possibility of missing late 1990s Jasper aquifer withdrawals, no changes were made to the dataset of historical withdrawals before recalibration in the area. Input data were changed in the recalibration process as follows:

- Evangeline aquifer hydraulic conductivity in 388 cells was increased from an average of 2.64 to an average of 2.86 feet/day (ft/d).

- Jasper aquifer hydraulic conductivity in 208 cells was decreased from an average of 1.42 to an average of 0.63 ft/d.

Coastal Irrigation Area Centered in Wharton and Jackson Counties

In parts of Wharton, Jackson, and Matagorda Counties, a sudden decrease in the number of Evangeline aquifer model cells containing withdrawals was noted as simulation progressed from the last historical stress period (2000) to the first projected stress period (2001). So many more Evangeline aquifer model cells contained withdrawals for 2000 than for 2001 that the transition appeared unrealistic. Upon investigation, it was discovered that some late 1990s withdrawals in those counties that should have been assigned to the Chicot aquifer had been inadvertently assigned to the Evangeline aquifer. Because the NGC GAM model had been calibrated with those incorrectly assigned withdrawals, some recalibration was done after correctly assigning withdrawals. Input data were changed in the recalibration process as follows:

- Vertical hydraulic conductance between the water table and the immediately adjacent deeper zone (general head boundary [GHB] conductance) of the Chicot aquifer in 1,395 cells was increased from an average of 74.7 to an average of 344.6 feet squared per day (ft^2/d).
- Chicot aquifer storativity in 730 cells was decreased from an average of 0.14 to an average of 0.017.
- Chicot aquifer hydraulic conductivity in 792 cells was decreased from an average of 96.6 to an average of 48.3 ft/d.

Area Between Conroe and Updip Limit of Chicot Aquifer

Several dry cells (water-level decline to altitude below altitude of base of aquifer) in an area of about 80 mi^2 persisted throughout simulations of both the historical and projected periods. Unrealistically small GHB conductances of the Chicot aquifer in dry cells were identified as the primary cause. Some recalibration was done to maintain simulated water levels above the altitudes of the base of the aquifer. Input data were changed in the recalibration process as follows:

- Chicot aquifer GHB conductance in 115 cells was increased from an average of 0.17 to an average of 1,950 ft^2/d.
- Chicot aquifer hydraulic conductivity in 213 cells was increased from an average of 0.03 to an average of 0.10 ft/d.
- Evangeline aquifer hydraulic conductivity in 709 cells was increased from an average of 0.51 to an average of 0.60 ft/d.

Area in Northeastern Fort Bend County

Unrealistically large water-level gradients in simulations of the HGCSD scenario in an area of about 160 mi^2 in Fort Bend County near the confluence of the Fort Bend-Harris-Brazoria County lines prompted re-evaluation of selected input data there. Consequently, some recalibration was done to lessen the gradients. Input data were changed in the recalibration process as follows:

- Chicot aquifer GHB conductance in 156 cells was increased from an average of 81 to an average of 449 ft^2/d.
- Chicot aquifer hydraulic conductivity in 53 cells was increased from an average of 3.28 to an average of 10.4 ft/d.

Area in Central Harris County

Unrealistically large water-level gradients in simulations of the TWDB scenario in an area of about 20 mi^2 in central Harris County prompted re-evaluation of selected input data there, and some recalibration was done to lessen the gradients. Input data were changed in the recalibration process as follows:

- Chicot aquifer storativity in 11 cells was increased from an average of 0.0004 to an average of 0.005.
- Evangeline aquifer hydrauilic conductivity in 19 cells was increased from an average of 0.12 to an average of 0.20 ft^2/d.

Appendix 2—Description of Methods for Distributing Withdrawals to Model Cells

Appendix 2—Description of Methods for Distributing Withdrawals to Model Cells

Texas Water Development Board Scenario

All withdrawals for the NGC GAM model area were assigned to either the Gulf Coast aquifer [system] or the Brazos River alluvium in the TWDB spreadsheets. Subdividing Gulf Coast aquifer [system] withdrawals into the four hydrogeologic units of the NGC GAM model is addressed among methods described below. All Brazos River alluvium withdrawals were reassigned as Chicot withdrawals.

Point-Source Withdrawals

The spatial (lateral) distribution of point-source withdrawals among NGC GAM model cells remained constant from stress period to stress period during simulations unless, for a particular stress period, point-source withdrawals for one or more cells became zero and no nonpoint-source withdrawals were assigned to those cells; in that case, those cells became non-withdrawal cells. The assumption was made that the water users in a particular water-user group during the projected period would be the same as the water users during the historical period, unless additional point-source water users in that group were identified in the spreadsheets.

Municipal

Hypothetical projected withdrawals for municipalities for the NGC GAM model area for the period 2001–50 were based on estimated ground-water demands provided by regional water planning groups (RWPG) and compiled by the TWDB. Municipalities were identified by water-user information provided by the TWDB (Cindy Ridgeway, Texas Water Development Board, written commun., 2004).

Point-source (well) locations were obtained from the Texas Commission on Environmental Quality (2004) Public Water System database, and the Texas Water Development Board (2003) State well database. If no point sources could be located for a municipality, an artificial point source was placed (using geographic information system [GIS] technology) at one of the following points, as applicable: centroid of city, centroid of zip code area, or centroid of basin/county/hydrogeologic-unit intersect area.

Point-source withdrawals were assigned to a hydrogeologic unit or units (vertically distributed) through an automated process[1] using the location and the screened interval(s) or well depth, or both, before the spatial distribution of withdrawals. Withdrawals also were assigned to a point source in an automated process on the basis of the water-user group, water user, water-use category, county, and source basin.

Withdrawals within each unique assemblage (group of wells) were divided (laterally distributed) evenly among the wells in that assemblage. For example, if an assemblage comprised 20 wells, each well was assigned 1/20th of the withdrawal (Q/20) for that assemblage. If one of the 20 wells in the assemblage was screened 60 percent in the Chicot aquifer and 40 percent in the Evangeline aquifer, then the withdrawal rate for that well would have been allocated accordingly, 0.6 times Q/20 to the Chicot aquifer and 0.4 times Q/20 to the Evangeline aquifer.

Manufacturing, Mining, and Power Generation

Hypothetical projected withdrawals for manufacturing, mining, and power generation (industrial uses) for the NGC GAM model area for the period 2001–50 were based on estimated ground-water demands provided by RWPGs and compiled by the TWDB. Industrial users were identified by water-user information provided by the TWDB (Cindy Ridgeway, Texas Water Development Board, written commun., 2004).

As for municipal point-source locations, industrial point-source locations were obtained from the Texas Commission on Environmental Quality (2004) Public Water System database and the Texas Water Development Board (2003) State well database; and additionally from the U.S. Environmental Protection Agency (2004) Envirofacts facilities database. If no point sources could be located for an industrial user, an artificial point source was placed (using GIS technology) at one of the following points, as applicable: centroid of city, centroid of zip code area, or centroid of basin/county/hydrogeologic-unit intersect area.

Point-source withdrawals were assigned to a hydrogeologic unit by an automated process[1] using the spatial location and the screened interval(s) or well depth, or both. Withdrawals also were assigned to a point source in an automated process on the basis of water-user group, water user, water-use category, county, and source basin. Withdrawals within each unique assemblage were divided evenly among the point sources in that assemblage, per the example in the "Municipal" section.

[1] An automated GIS-based hydrogeologic-unit identification program was developed to associate point sources with hydrogeologic units (model layers). The program identifies all the units that exist at the latitude and longitude of a point source. The program then assigns a unit to the point source on the basis of its screened interval(s) or well depth, or both. This program identified 1,435 point sources automatically. One-hundred and forty-five point sources were assigned to one or more units manually, which was necessary for point sources lacking sufficient descriptive information for automated assignment.

Nonpoint-Source Withdrawals

The spatial (lateral) distribution of nonpoint-source withdrawals among NGC GAM model cells remained constant from stress period to stress period during simulations unless, for a particular stress period, nonpoint-source withdrawals for one or more cells became zero and no point-source withdrawals were assigned to those cells; in that case, those cells became non-withdrawal cells. The nonpoint-source distributions for the projected period were coincident with those of the historical period (Kasmarek and Robinson, 2004).

Nonpoint-source withdrawals were simulated as artificial point sources, one per model cell per category (livestock [per rangeland category], irrigation [per crop category], and county-other), on the basis of information in the Texas Water Development Board (2003) State well database. Withdrawals were assigned to hydrogeologic units (vertically distributed) by joining attributes from the database to the artificial points using GIS techniques. If information in the database was not available to assign hydrogeologic units, nonpoint-source withdrawals were assigned to the respective outcropping hydrogeologic unit.

Livestock

Hypothetical projected withdrawals for livestock for the NGC GAM model area for the period 2001–50 were based on estimated ground-water demands provided by RWPGs and compiled by the TWDB by county and basin. Within each county/basin area, livestock areas were laterally distributed over rangeland on the basis of land-use maps, using the categories "herbaceous rangeland," "shrub and brush rangeland," and "mixed rangeland" from the U.S. Geological Survey (2004) national land cover. Withdrawals were assigned to these livestock areas through an automated process on the basis of water-use category, county, and basin. Withdrawals within each unique livestock assemblage (group of artificial point sources) were divided evenly among the model grid cells in that assemblage.

Irrigation

Hypothetical projected withdrawals for irrigation for the NGC GAM model area for the period 2001–50 were based on estimated ground-water demands provided by RWPGs and compiled by the TWDB by county and basin. Within each county/basin area, irrigated areas were laterally distributed for the land-use categories "row crops," "orchards/vineyards," and "small grains" obtained from the U.S. Geological Survey (2004) national land cover. Withdrawals were assigned to these irrigated areas in an automated process on the basis of water-use category, county, and basin. Withdrawals within each unique irrigation assemblage were divided evenly among the model grid cells in that assemblage.

County-Other

Hypothetical projected withdrawals for county-other (primarily rural domestic) for the NGC GAM model area for the period 2001–50 were based on estimated ground-water demands provided by RWPGs and compiled by the TWDB by county and basin. The county-other areas of withdrawal were distributed within each county/basin excluding urban areas and using a 1-mile buffer around surficial water bodies. Withdrawals were assigned to county-other areas of withdrawal in an automated process on the basis of water-use category, county, and basin. Withdrawals within each unique county-other assemblage were divided evenly among the model grid cells in that assemblage.

Harris-Galveston Coastal Subsidence District Scenario (Merge of HGCSD Dataset into TWDB Dataset)

The merge of the HGCSD subarea dataset with the TWDB dataset was done using raster (cell-based) data analysis. This process provided accurate transfer of withdrawal values from the coarse (about 7 mi^2) HGCSD model grid cells to the finer (1 mi^2) NGC GAM model grid cells (fig. a2.1). Raster data analysis also preserved HGCSD model grid cell values that might otherwise be affected by the approximately 36-degree difference in orientation between the NGC GAM and HGCSD model grids. The merge was done only for layers 1 and 2 (Chicot and Evangeline aquifers) in the coincident NGC GAM and HGCSD model areas for the period 1995–2030. All raster data analysis described below was done using a 100- by 100-ft raster cell size.

Vector NGC GAM model grid cells in the coincident model areas were identified and converted to a raster grid. All raster cells (about 2,800) within an NGC GAM model grid cell were grouped into a raster zone (NGC GAM zone) identified by its corresponding NGC GAM sequence number.

For each of the 72 simulated layer/year combinations (two layers, 36 years), vector HGCSD model grid cells were converted to a raster grid, vertically integrated to match cell-for-cell to the raster NGC GAM zones. All raster cells (about 20,000) within an HGCSD model grid cell were assigned a withdrawal value according to the following equation:

raster cell withdrawal = (HGCSD model grid cell withdrawal, in cubic feet per day / HGCSD model grid cell area, in square feet) x area of raster cell, in square feet

This normalization process allowed for the summation of raster-cell withdrawals within an NGC GAM model grid cell regardless of which HGCSD model grid cell(s) contained the initial source of withdrawal. The withdrawal assigned to an NGC GAM model grid cell for the HGCSD scenario was then replaced with this summed value of raster-cell withdrawals.

NGC GAM model grid cells at the boundary of the coincident areas of the NGC GAM and HGCSD model grids were assigned withdrawals on the basis of the percentage of the model grid cell area that is coincident with an HGCSD model grid cell(s). If more than 95 percent of the area of an NGC GAM model grid cell was outside the coincident area, the original NGC GAM model grid cell withdrawal was retained. Otherwise the NGC GAM model grid cell withdrawal was computed as the sum of (1) the original NGC GAM model grid cell withdrawal times the fraction of noncoincident NGC GAM model grid cell area plus (2) the raster-cell withdrawals in the coincident area.

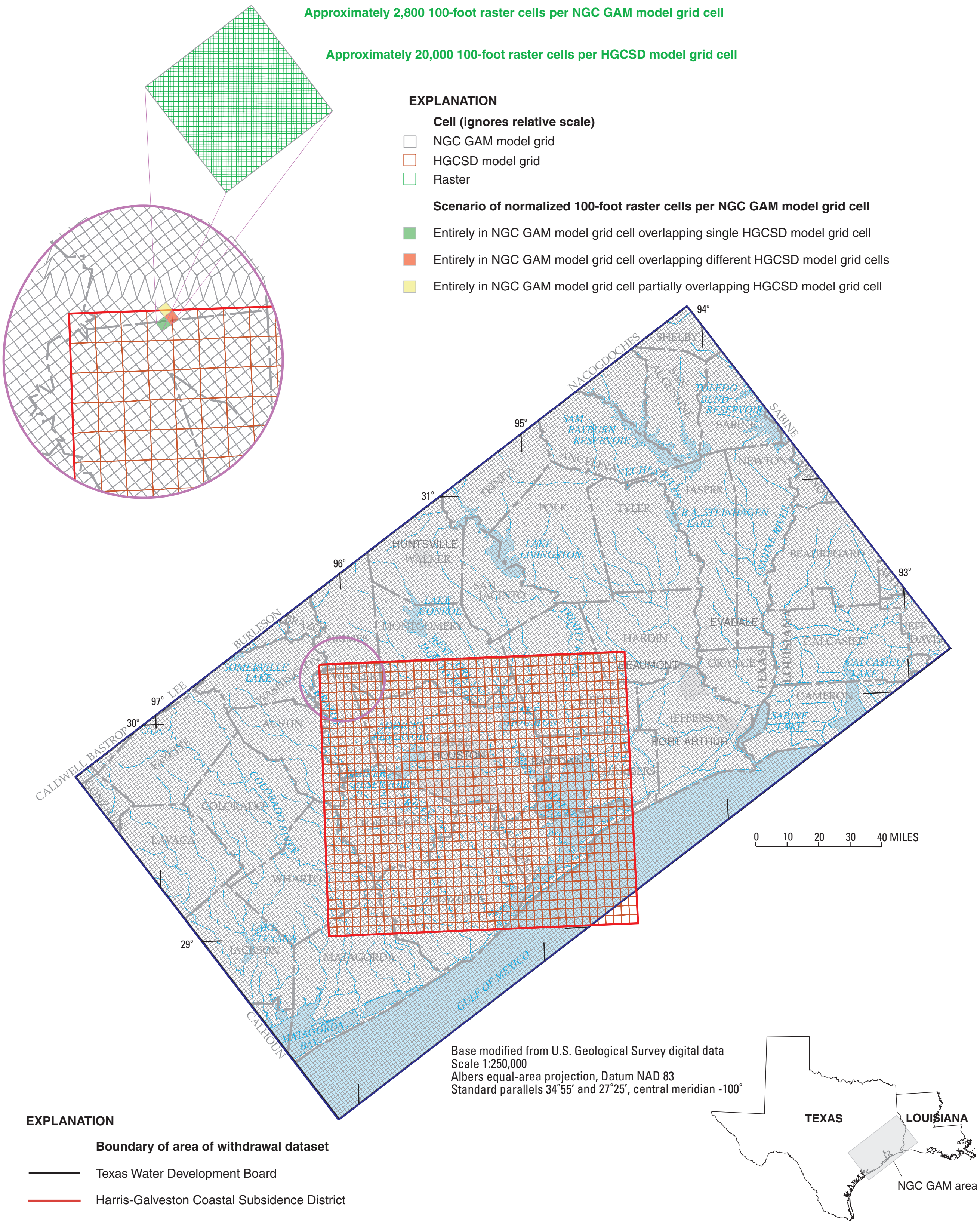


Figure a2.1. Relations between NGC GAM model grid cells, HGCSD model grid cells, and raster cells associated with merge of HGCSD dataset into TWDB dataset.

Prepared by the USGS Texas Water Science Center:
U.S. Geological Survey
8027 Exchange Drive
Austin, TX 78754–4733

Information regarding water resources in Texas is available at URL
http: //tx.usgs.gov/