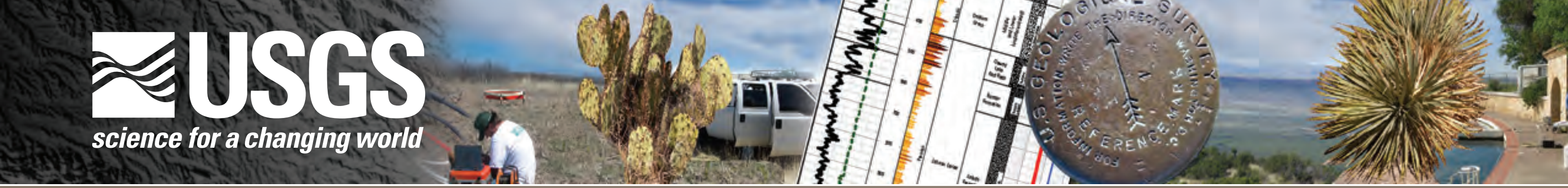
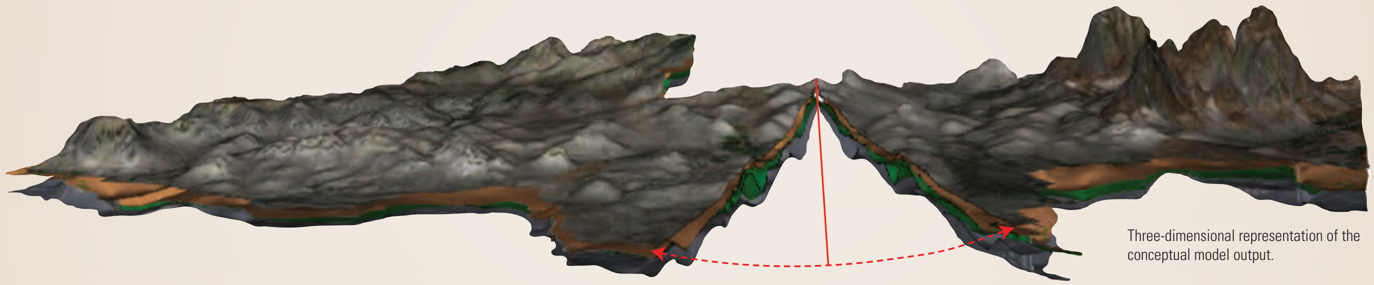


Prepared in cooperation with the Middle Pecos Groundwater Conservation District, Pecos County, City of Fort Stockton, Brewster County, and Pecos County Water Control and Improvement District No. 1

A Multiphased Approach to Groundwater Assessments

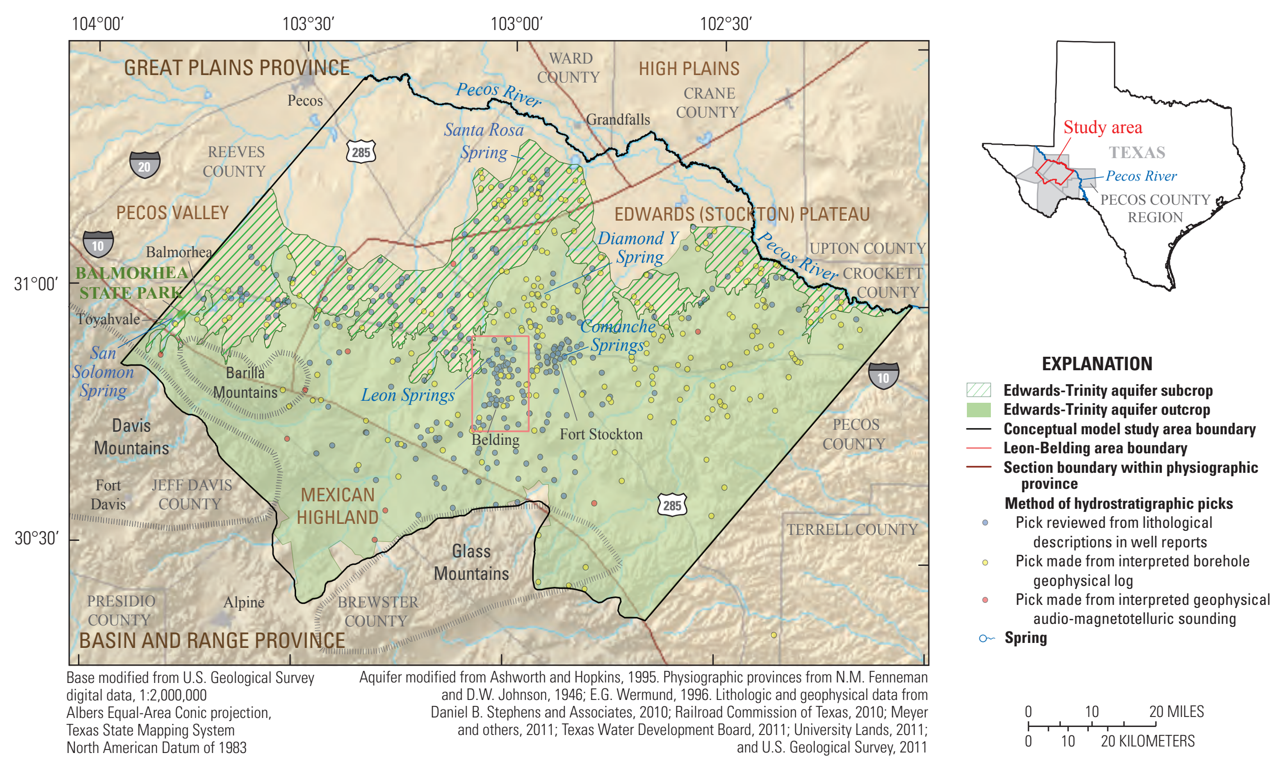
for the Edwards-Trinity and Related Aquifers in the Pecos County Region, Texas



Three-dimensional representation of the conceptual model output.

Introduction

The Edwards-Trinity aquifer is a vital groundwater resource for agricultural, industrial, and public supply uses in the Pecos County region of western Texas (Barker and Ardis, 1992; Freese and Nichols, Inc., and LBG-Guyton, Inc., written commun., 2010). Resource managers would like to understand the future availability of water in the Edwards-Trinity aquifer in the Pecos County region and the effects of the possible increase or temporal redistribution of groundwater withdrawals. To provide resource managers with that information, the U.S. Geological Survey (USGS), in cooperation with the Middle Pecos Groundwater Conservation District, Pecos County, City of Fort Stockton, Brewster County, and Pecos County Water Control and Improvement District No. 1, completed a three-phase study of the Edwards-Trinity and related aquifers in parts of Brewster, Jeff Davis, Pecos, and Reeves Counties (fig. 1).



Base modified from U.S. Geological Survey digital data, 1:2,000,000
Albers Equal-Area Conic projection,
Texas State Mapping System
North American Datum of 1983

Aquifer modified from Ashworth and Hopkins, 1995. Physiographic provinces from N.M. Fenneman and D.W. Johnson, 1946; E.G. Wermund, 1996. Lithologic and geophysical data from Daniel B. Stephens and Associates, 2010; Railroad Commission of Texas, 2010; Meyer and others, 2011; Texas Water Development Board, 2011; University Lands, 2011; and U.S. Geological Survey, 2011

Figure 1. Location of study area and hydrostratigraphic data used to identify tops and bases of the hydrostratigraphic contacts in the Pecos County region, Texas (modified from Bumgarner and others, 2012, figs. 1 and 7).

The first phase was to collect groundwater, surface-water, geochemical, geophysical, and geologic data in the study area and develop a geodatabase of historical and collected data (Pearson and others, 2012). Data compiled in the first phase of the study were used to develop the conceptual model in the second phase of the study (Bumgarner and others, 2012). The third phase of the study involved the development and calibration of a numerical groundwater-flow model of the Edwards-Trinity aquifer to simulate groundwater conditions based on various groundwater-withdrawal scenarios (Clark and others, 2014).

Analysis of well, geophysical, geochemical, and hydrologic data contributed to the development of the conceptual model in phase 1. Lithologic information obtained from well reports and geophysical data was used to describe the hydrostratigraphy and structural features of the groundwater-flow system, and aquifer-test data were used to estimate aquifer hydraulic properties. Geochemical data were used to evaluate groundwater-flow paths, water-rock interaction, aquifer interaction, and the mixing of water from different sources in phase 2. Groundwater-level data also were used to evaluate aquifer interaction, as well as to develop a potentiometric-surface map, delineate regional groundwater divides, and describe regional groundwater-flow paths. During phase 3, the data collected and compiled along with the conceptual information in the study area were incorporated into a numerical groundwater-flow model to evaluate the sustainability of recent (2008) and projected water-use demands on groundwater resources in the study area.

Hydrogeologic Framework

Subsurface data were obtained from well reports; natural gamma, electric, and electromagnetic induction borehole geophysical logs; and audio-magnetotelluric soundings. The subsurface data were used to map the top and base surfaces of the Edwards-Trinity aquifer (fig. 2), the top of the Trinity Group of the Edwards-Trinity aquifer, and the lateral and vertical relations of overlying and underlying aquifers where they occur in order to develop the hydrostratigraphy of the study area and evaluate structural features.

In the study area, the Edwards-Trinity aquifer ranged in thickness from about 5 feet (ft) to about 797 ft. The aquifer is thinnest in the eastern part of the study area, near the northwestern slope of the Glass Mountains, and near the northeastern slope of the Davis Mountains. Some of the thickest sections of the Edwards-Trinity aquifer were in the Pecos, Monument Draw, and Belding-Coyanosa Trough areas.

Normal fault zones were delineated on the basis of interpretations of cross sections of the top and base surfaces of the Edwards-Trinity aquifer. Faults in the study area appear to have formed as growth and collapse features as sediments were deposited along the margins of more resistant rocks and structures, such as the Glass Mountains, and as overlying sediments collapsed into the voids created by the dissolution of Permian-age evaporite deposits. The fault zones delineate domains in the hydrogeologic framework that generally align with previously identified structural features. Each fault zone represents a series of parallel and transverse faults that result in an overall displacement between two adjacent fault blocks (fig. 3).

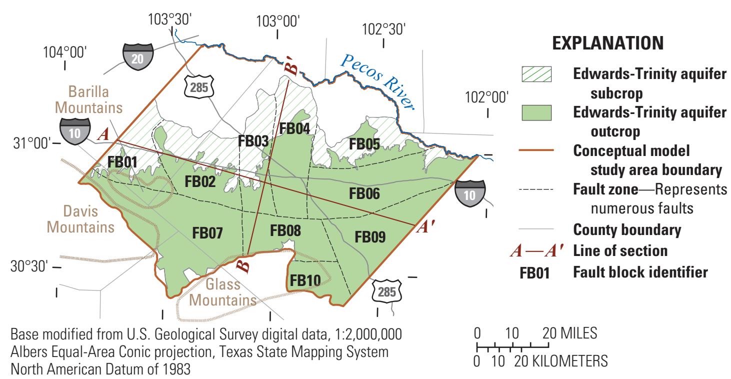


Figure 3. Locations of fault zones and fault blocks within the study area, Pecos County region, Texas, delineated on the basis of the interpretation of multiple cross sections of interpolated hydrostratigraphic contacts (modified from Bumgarner and others, 2012, fig. 17).

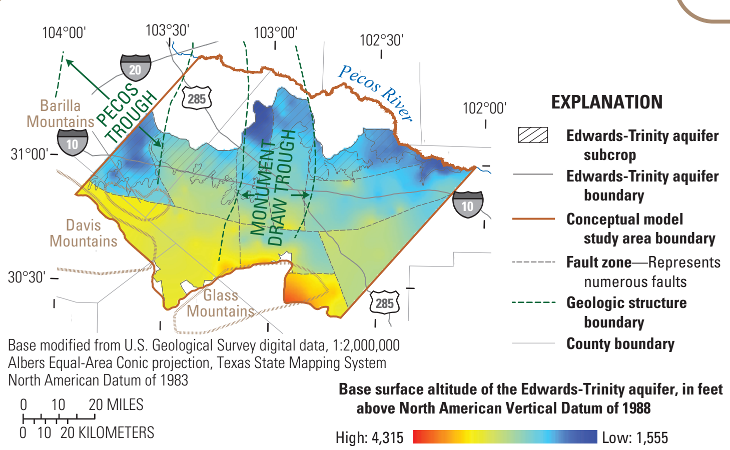


Figure 2. Base surface altitude of the Edwards-Trinity aquifer in the Pecos County region, Texas (modified from Bumgarner and others, 2012, fig. 13).

U.S. Geological Survey gage at Santa Rosa Spring near Grandfalls, Texas.

U.S. Geological Survey pump hoist truck and water-quality trailer.

Geochemistry

Analysis of the geochemical and isotopic samples, from the study, provided insights into the chemical characteristics of water from different sources and different aquifers. Chemical characteristics of water from different sources were used to qualitatively evaluate aquifer interaction, groundwater-flow paths, water-rock interaction, and mixing of water from different sources and to identify likely source waters and geochemical endmembers (distinct water types).

Geochemical and isotopic results indicate that groundwater in the system likely is dominated by mineralized, regional groundwater flow that probably recharged during the cooler, wetter climates of the Pleistocene with variable contributions of more recent, local recharge. The mixing of water from multiple sources combined with water-rock interaction with various rock types, including siliciclastic, carbonate, evaporite, and igneous rocks, contributed to a groundwater chemistry that was complex and variable between and within aquifers.

Four endmembers were identified to use as part of the qualitative groundwater-flow and mixing analysis. The endmembers represented (1) mineralized groundwater that likely recharged northwest of the study area during the Pleistocene and is flowing through the Edwards-Trinity aquifer along regional groundwater-flow paths; (2) dilute, recent recharge from the Barilla and Davis Mountains with a composition indicative of interaction with igneous rocks; (3) dilute, recent recharge from the Glass Mountains with a composition indicative of interaction with carbonate rocks; and (4) mineralized groundwater that is likely a mixture of recharge under recent and Pleistocene climatic conditions and is flowing through the Edwards-Trinity aquifer along regional groundwater-flow paths east of the Monument Draw Trough. Inverse geochemical modeling (PHREEQC; Parkhurst and Appelo, 1999) was used to simulate the mixing of upgradient Edwards-Trinity aquifer groundwater, recharged in the Barilla, Davis, and Glass Mountains, with Rustler aquifer groundwater to approximate the composition of the groundwater. Geochemical model results indicate that Edwards-Trinity aquifer groundwater in the Leon-Belding and Fort Stockton areas is a mixture of groundwater recharged in the Barilla and Davis Mountains and groundwater that has upwelled from the Rustler aquifer. In the Leon-Belding area, the proportion of Rustler aquifer groundwater in the Edwards-Trinity aquifer increased downgradient from south (0–48.8 percent) to north (87.1–100 percent).

Groundwater-Flow System

Groundwater-level and geochemical data were used in context with the hydrogeologic framework to assess regional groundwater-flow paths, recharge sources, and groundwater mixing and discharge in the study area. Groundwater-level altitudes used to generate the potentiometric-surface map of the Edwards-Trinity aquifer ranged from about 2,300 to about 3,300 ft and generally decreased from southwest to northeast. Regional groundwater flow is from areas of recharge in the south and southwest to the north and northeast. Four principal sources of recharge to the Edwards-Trinity aquifer were identified: (1) regional groundwater flow in the Edwards-Trinity aquifer that originated as recharge northwest of the study area and enters the study area near the western corner; (2) runoff from the Barilla, Davis, and Glass Mountains that percolates through underlying rocks and into the gravels along the slopes of the mountains; (3) return flow from irrigation; and (4) upwelling from deeper aquifers. Although some of the groundwater appears to have recharged under conditions similar to the current climate, the only samples collected from the Edwards-Trinity aquifer that likely recharged during the last 60 years (after the onset of atmospheric nuclear weapon testing) were collected from wells in mountain-front recharge areas and in areas receiving agricultural return flow.

Groundwater generally flows north into the downdip extent of the Edwards-Trinity aquifer or east out of the study area. Regional groundwater flow entering the study area from the northwest naturally discharges from springs or turns northward to flow into the Pecos Trough where it discharges into the Pecos Valley or Dockum aquifers at the downdip extent of the Edwards-Trinity aquifer. Recharge from the Barilla and Davis Mountains also predominantly flows toward the Pecos Trough and most likely naturally discharges to other aquifers in the groundwater system. Groundwater flow in the Edwards-Trinity aquifer in the Monument Draw Trough originated as recharge in the Glass Mountains, agricultural return flow, or upwelling groundwater from lower units. Edwards-Trinity aquifer groundwater generally flows north and northeast in the Monument Draw Trough and naturally discharges from springs or to other aquifers in the groundwater system at the downdip extent. Groundwater in the eastern part of the study area likely originated in the Glass Mountains, generally flows northeast, and flows out of the study area to the east or naturally discharges from springs to other aquifers in the groundwater system at the downdip extent or to the Pecos River.

Water-quality sampling by the U.S. Geological Survey, San Solomon Spring, Texas.

Groundwater-Flow Simulation

The modular finite-difference code USGS MODFLOW-2005 (Harbaugh, 2005) was used to develop equations governing three-dimensional groundwater flow. The model has five layers representing the Pecos Valley aquifer (alluvial layer), the Edwards part of the Edwards-Trinity aquifer (Edwards layer), the Trinity part of the Edwards-Trinity aquifer (Trinity layer), the Dockum aquifer (Dockum layer), and the Rustler aquifer (Rustler layer). The calibration period of the simulation extends from 1940 to 2010 for a total of 70 years and 144 stress periods, each one approximately 6 months in length. The hydrologic boundaries of the model include specified flux (areal recharge, pumping, and no-flow), specified heads (Rustler aquifer), and head-dependent flux (general-head and river boundaries). Each boundary was included to represent a specific aspect of the groundwater-flow system. The measured potentiometric surface for 1980–2010 (fig. 4) and the simulated potentiometric surface for 2010 of the Edwards-Trinity aquifer generally are in agreement.

Groundwater pumping in the model represents public supply, manufacturing, mining, power generation (industrial), and irrigation, with irrigation being the largest water-use category. Groundwater-pumping data were compiled from multiple sources to develop a pumping record for 1940–2010. Site-specific pumping data were used when available, though much of the record for irrigation pumping contained only aggregated amounts of withdrawals by county, aquifer, and year. Wells were assigned a model layer if the screen interval of the well was contained within the top and bottom of a given model layer (fig. 5).

Hydraulic properties in the model were assigned as discrete zones (large areas possessing the same property value) and as distributed properties by using pilot points (Doherty, 2005). The value of each pilot point, as well as other discrete zone parameters, was adjusted through manual and automated methods to achieve a best fit to measured values of hydraulic head and spring flow.

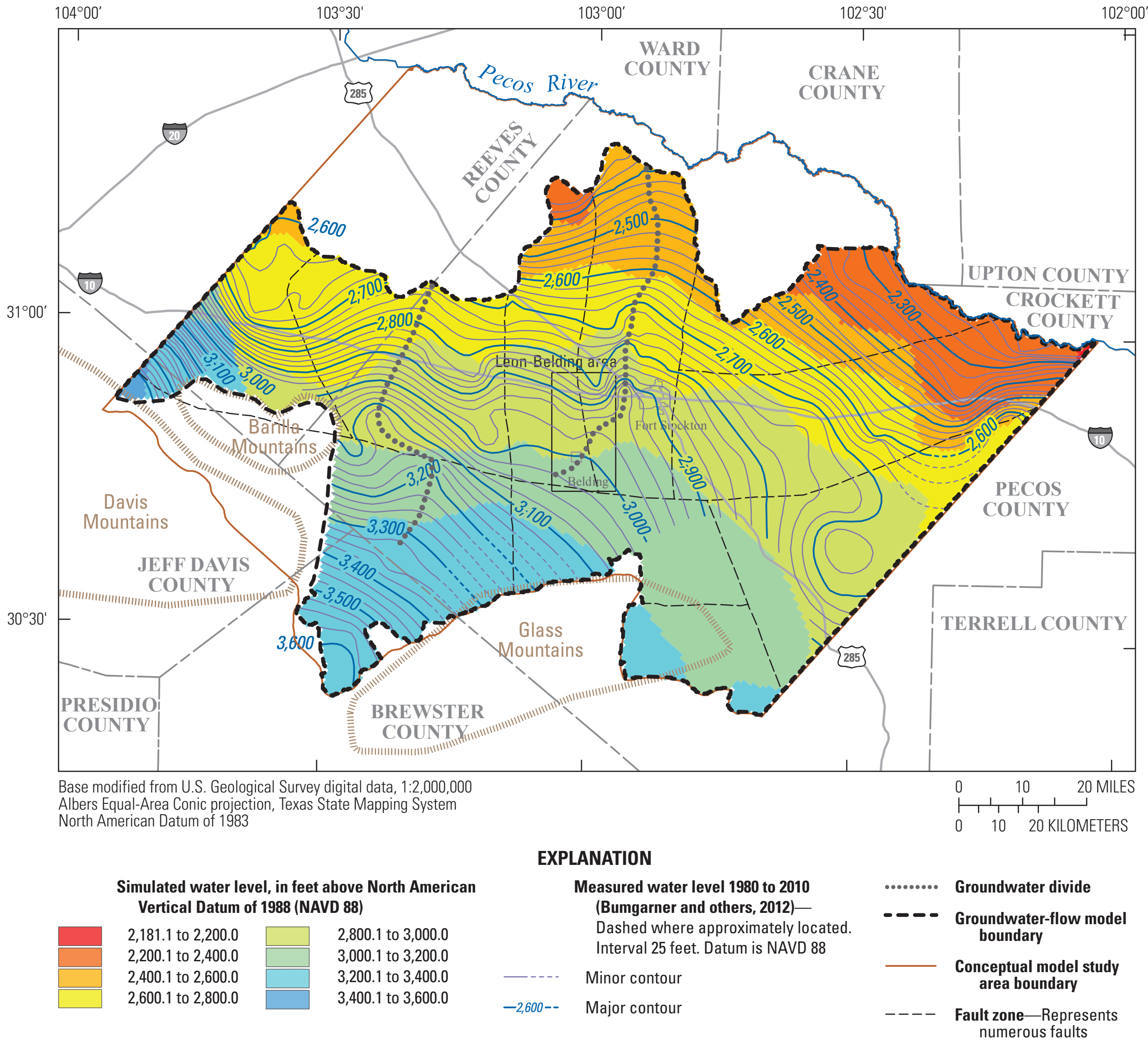


Figure 4. Measured potentiometric surface (1980–2010) and simulated groundwater-level altitudes for the Edwards-Trinity aquifer in the model area of the Pecos County region, Texas, 2010 (modified from Clark and others, 2014, fig. 12).

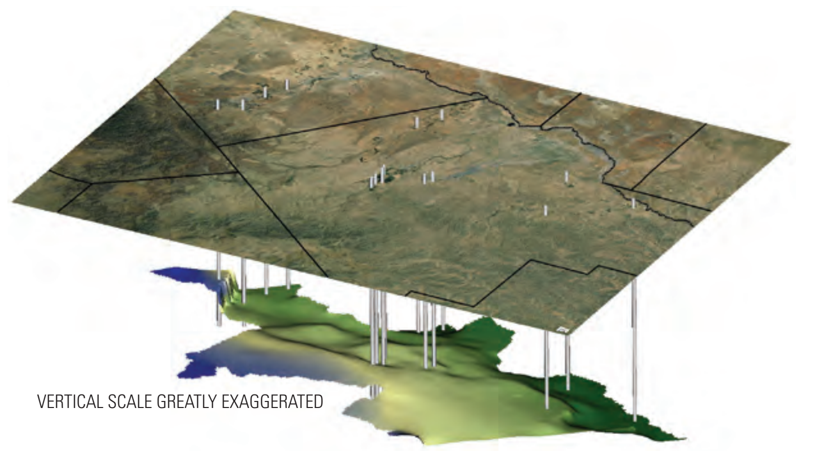


Figure 5. Oblique view of the Pecos County region, Texas, with selected wells extending into the simulated water table of the Edwards-Trinity aquifer (vertically exaggerated) (modified from Clark and others, 2014).

U.S. Geological Survey pump hoist truck deploying pump in windmill well for aquifer testing and electromagnetic flowmeter logging.

Development of Groundwater-Pumping Scenarios

The model was used to simulate groundwater levels resulting from prolonged pumping to evaluate the sustainability of recent (2008) and projected water use. Each of three scenarios is a continuation of the 70-year calibration period and simulates a 30-year period from 2010 to 2040. In scenario 1, recent (2008) irrigation and non-irrigation pumping rates are extended for each year of the 30-year simulation period. Scenario 2 evaluates the effects of 2008 pumping rates applied as continuous, year-round maximum permitted groundwater-pumping rates in the Leon-Belding area for the 30-year simulation period. Scenario 3 evaluates the effects of periodic increases in pumping rates over the 30-year simulation period. For each scenario, the change in groundwater level from 2010 to 2040 was extracted from the model for comparison with regard to effects of changes in pumping. The 30-year period is discretized into sixty 6-month stress periods generally representing seasonality of irrigation water demand.

Projected groundwater-level changes in and around the Fort Stockton area indicate little if any change from current conditions, indicating that the groundwater system is near equilibrium with respect to recent (2008) pumping stress. Projected groundwater-level declines (from 15.0 to 31.0 ft) occurred in localized areas by the end of the scenario in the Leon-Belding area. Results of scenario 1 indicate relatively stable water levels ranging from -5.0 to 5.0 ft throughout most of the model area during the 30-year simulation using pumping amounts as specified for the year 2008. In scenario 2, the maximum projected groundwater-level declines in the Leon-Belding irrigation area were approximately 31.3 ft in small isolated areas, which are depicted as water-level changes ranging from 25.0 to 32.0 in. The remaining area and magnitude of groundwater-level decline are almost identical to that of scenario 1. Results of scenario 3 (fig. 6) indicate that the maximum projected groundwater-level decline in the Leon-Belding area was greater than either scenario 1 or 2 at approximately 34.5 ft, and the extent of the decline is larger in area (about 17 percent increase) than that of scenario 2. Additionally, the area of projected groundwater-level declines in the eastern part of the model area increased as compared to scenario 2. The lack of differences in the remaining areas associated with the results of scenarios 2 and 3 might be attributed to the low magnitude of pumping in 2008 and the relatively small total increase in water use of about 15 percent over the 30-year period, which together produce small increases in pumping amounts.

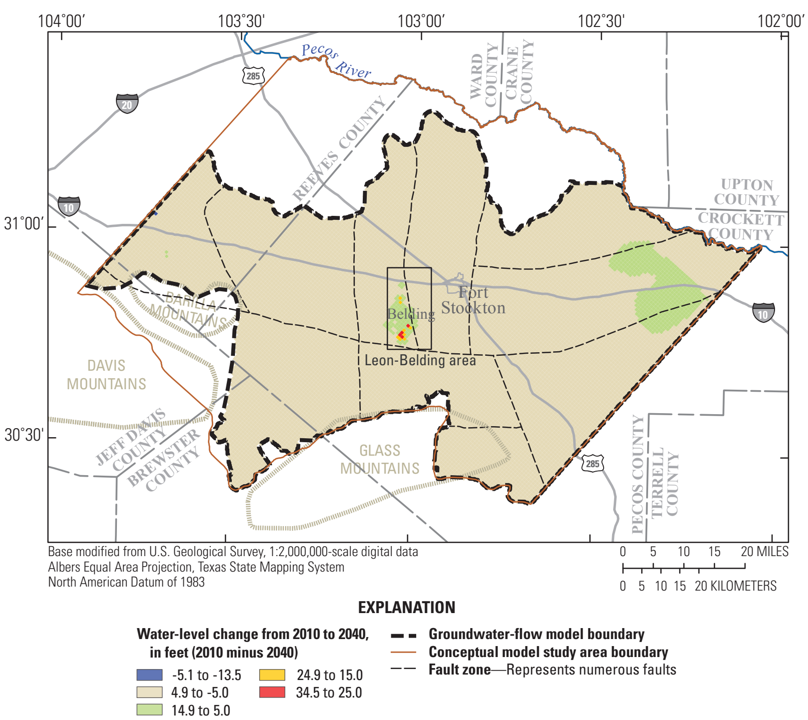
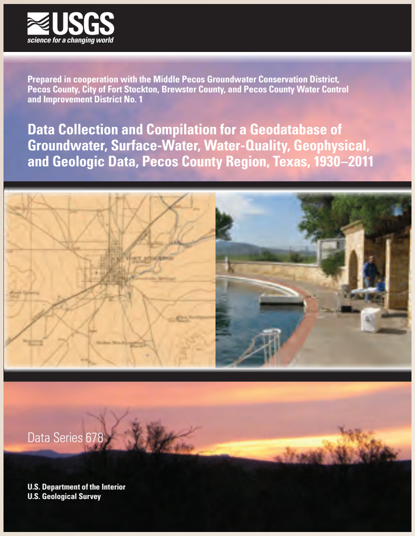
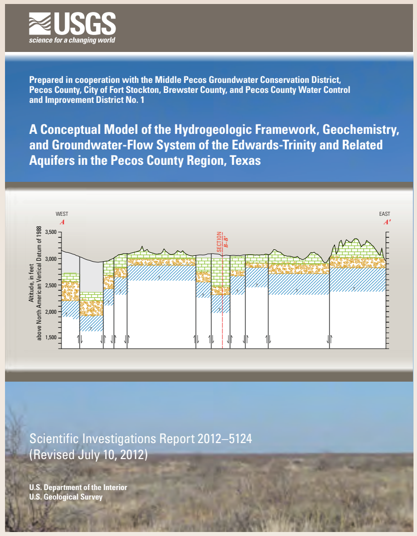


Figure 6. Groundwater-level difference for the Edwards-Trinity aquifer in the model area of the Pecos County region, Texas, from 2010 to 2040 for groundwater-pumping scenario 3 (modified from Clark and others, 2014, fig. 20).

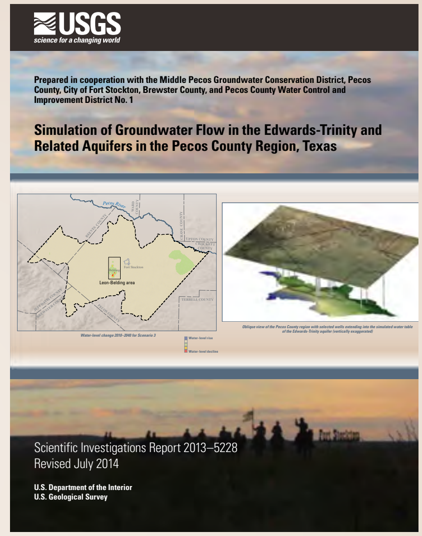
This fact sheet is based on the following USGS reports:



Pearson, D.K., Bumgarner, J.R., Houston, N.A., Stanton, G.P., Teeple, A.P., and Thomas, J.V., 2012, Data collection and compilation for a geodatabase of groundwater, surface-water, water-quality, geophysical, and geologic data, Pecos County region, Texas, 1930–2011: U.S. Geological Survey Data Series 678, 67 p., http://pubs.usgs.gov/ds/678/.



Bumgarner, J.R., Stanton, G.P., Teeple, A.P., Thomas, J.V., Houston, N.A., Payne, J.D., and Musgrove, MaryLynn, 2012, A conceptual model of the hydrogeologic framework, geochemistry, and groundwater-flow system of the Edwards-Trinity and related aquifers in the Pecos County region, Texas: U.S. Geological Survey Scientific Investigations Report 2012–5124, 74 p., http://pubs.usgs.gov/sir/2012/5124/.



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Publishing support provided by
Lafayette and Rolla Publishing Service Centers

ISSN 2327-6916 (print)
ISSN 2327-6932 (online)
http://dx.doi.org/10.3133/fs20143025