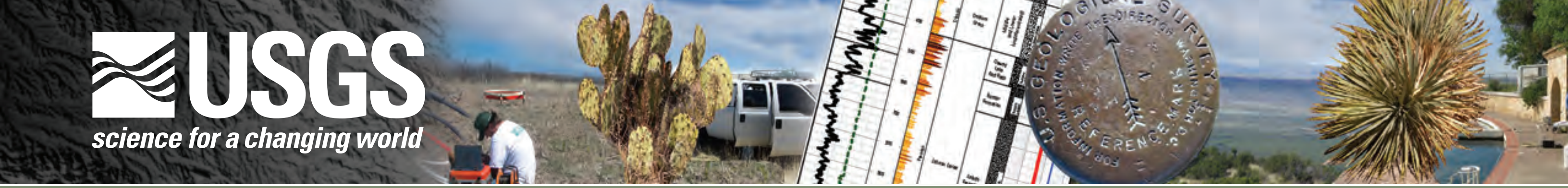


Prepared in cooperation with Middle Pecos Groundwater Conservation District, Pecos County, City of Fort Stockton, Brewster County, and Pecos County Water Control and Improvement District No. 1

Simulation of Groundwater Flow

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

Introduction

The Edwards-Trinity aquifer, a major aquifer in the Pecos County region of western Texas, is a vital groundwater resource for agricultural, industrial, and public supply uses (Barker and Ardis, 1992; Freese and Nichols, Inc., and LBG-Guyton, Inc., written commun., 2010). Resource managers would like to better 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 that end, 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 comprehensive, integrated analysis of available hydrogeologic data to develop a groundwater-flow model of the Edwards-Trinity and related aquifers in parts of Brewster, Jeff Davis, Pecos, and Reeves Counties (fig. 1). The model incorporates conceptual information provided by Bumgarner and others (2012) and data collected and compiled by Pearson and others (2012). Following calibration, the model was used to evaluate the sustainability of recent (2008) and projected water-use demands on groundwater resources in the study area.

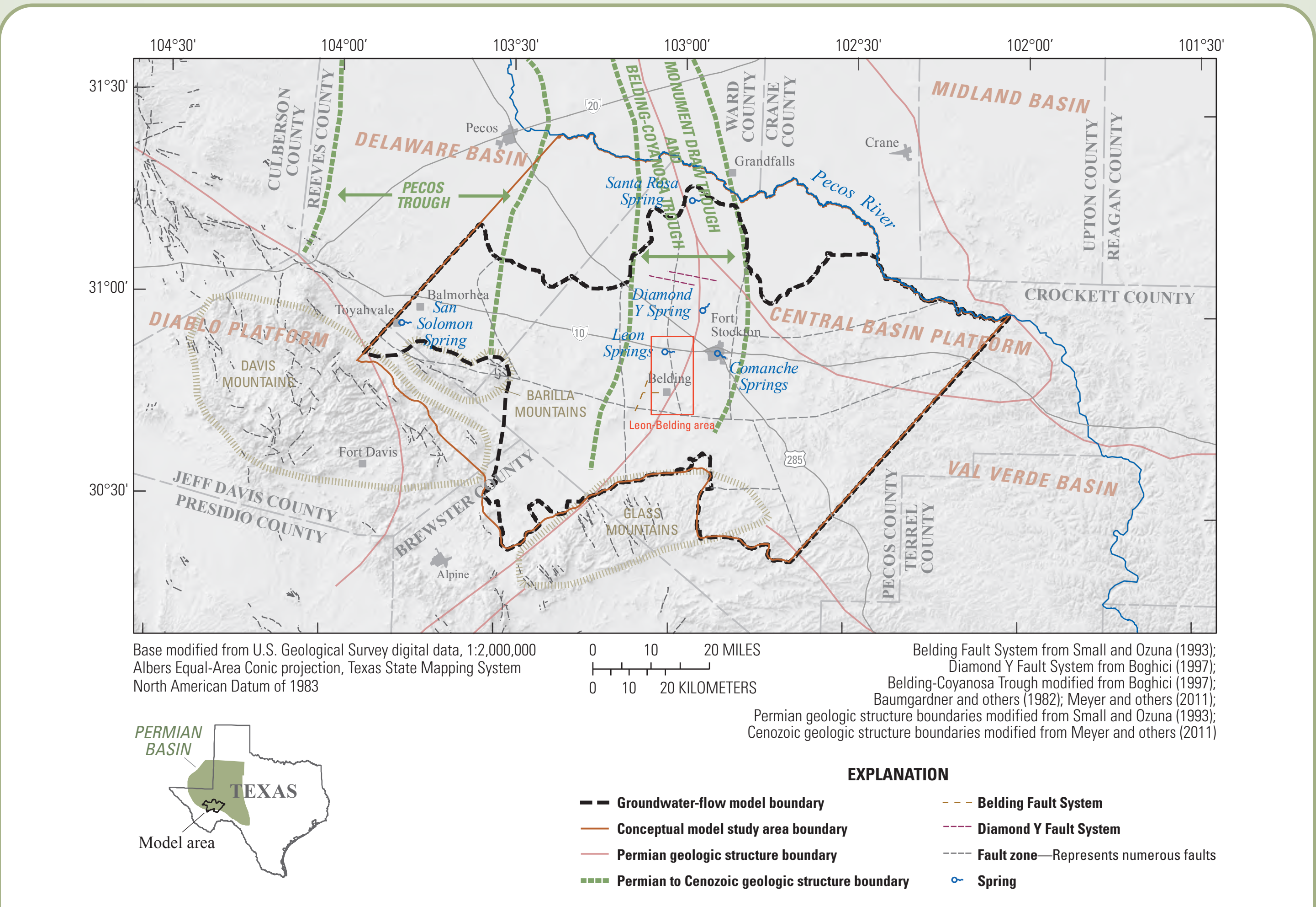


Figure 1. Location and general geological structural features of the model area in the Pecos County region, Texas (modified from Clark and others, 2014, fig. 1).

Description of the Model Area

The model area includes the saturated areas of the Edwards-Trinity aquifer and covers about 3,400 square miles of the Pecos County region of Texas. The southwestern and southern boundaries of the model area are rimmed by the Barilla and Davis Mountains in northeastern Jeff Davis County and southwestern Reeves County and the Glass Mountains in northeastern Brewster County and southern Pecos County. The northeastern boundary of the model area is the Pecos River.

Hydrogeologic Framework

The geologic setting contributed to the formation of two major and four minor aquifers in the model area. In addition to the Edwards-Trinity aquifer, the other major aquifer in the Pecos County region is the Pecos Valley aquifer. In the northern part of the model area, the Pecos Valley aquifer unconformably overlies the Edwards-Trinity aquifer. Minor aquifers include the Igneous, Dockum, Rustler, and Capitan Reef aquifers. Additional details about the geologic and hydrogeologic setting, as well as the hydrogeologic framework of the model area, can be found in Bumgarner and others (2012).

Groundwater-Flow System

The Edwards-Trinity aquifer in the model area is dominated by mineralized, regional groundwater that most likely recharged during the Pleistocene with variable contributions of more recent, local recharge. Groundwater generally flows northward into the downdip extent of the Edwards-Trinity aquifer or eastward out of the model area. Regional groundwater flow entering the model area from the northwest naturally discharges from springs or flows northward into the Pecos Trough where it discharges into the Pecos Valley or Dockum aquifers at the downdip extent of the Edwards-Trinity aquifer. Additional details about the groundwater geochemistry and the conceptual groundwater flow in the model area are available in Bumgarner and others (2012).

Groundwater-Flow Model Construction

The groundwater-flow system is represented in the model by a set of grid cells, and within each individual cell the hydraulic properties are the same. The transient model simulates 70 years (1940–2010) of system response to stress by using 144 stress periods. Stress period 1 is a steady-state stress period, used to establish equilibrium conditions, while the remaining stress periods are each 6 months in length, representing irrigation (April through September) and non-irrigation (October through March) intra-annual variability.

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 hydrologic boundaries of the model include specified flux (areal recharge, pumping, and no-flow), specified groundwater levels (also referred to as "hydraulic heads," or simply "heads") for the 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.

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

Recharge

Because precipitation is relatively low and evapotranspiration is relatively high (Anaya and Jones, 2009), very little net recharge was expected over much of the model area. The Edwards-Trinity aquifer in the model area was dominated by mineralized, regional groundwater that most likely recharged during the Pleistocene with variable contributions of recent, local recharge. Net areal recharge in the model primarily occurred as mountain-front recharge at the Barilla, Davis, and Glass Mountains. The width of the mountain-front recharge zone was assumed to be approximately 5 miles along the base of the mountains at an initial rate of 2.0 inches per year (in/yr) on the basis of higher estimates of recharge for the Edwards-Trinity aquifer (Long, 1958; Rees and Buckner, 1980) and was further adjusted through model calibration. Additional recharge may be introduced through irrigation return flow (Bumgarner and others, 2012). Recharge was specified as 0.2 in/yr in irrigated areas to represent irrigation return flow on the basis of low but detectable concentrations of nutrients and pesticides (Bumgarner and others, 2012).

Discharge

Multiple springs exist within the model area, though few discharge records are available to aid model calibration. Sufficient discharge data were available for Comanche Springs, however, and these data were used to specify boundary conditions, as well as to calibrate the model. Monthly discharge measurements from Comanche Springs within each 6-month stress period were averaged to represent measured flow. Groundwater-pumping estimates 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. All pumping totals were aggregated to annual amounts and assigned to the appropriate stress period of the model. 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. If a well was screened in multiple aquifers, the well was assigned to multiple model layers, and pumping amounts were distributed to each layer.

Boundaries

General-head boundaries, which represent horizontal flow into or out of the model area, were placed along the western, northwestern, north, and southeastern perimeters of the model area in layer 3 (Trinity layer). To address the likely upwelling from the Rustler aquifer in some areas of the model area, time-variant constant heads were specified in the active cells of model layer 5 to represent groundwater levels in the Rustler aquifer as represented in the Groundwater Availability Model (GAM) of Anaya and Jones (2009). The MODFLOW-2005 River Package (Harbaugh, 2005) was used to represent the Pecos River on the northeastern side of the model area. The southwestern perimeter of the model area and the base of the Rustler aquifer are represented as no-flow boundaries. While faulting is recognized as typically occurring in fault zones, delineated fault zones were represented as horizontal flow barriers in the groundwater-flow model by using the Horizontal Flow Barrier Package of MODFLOW-2005 (Harbaugh, 2005), which simulates reduced conductance between individual pairs of cells.

Model Calibration Results

Simulated hydraulic heads were compared to observed hydraulic heads (2,860 groundwater-level altitude measurements made at 288 wells) in the Edwards-Trinity aquifer. Simulated hydraulic heads were generally in good agreement with observed hydraulic head values, with 1,684 (59 percent) simulated values within 25 ft of the observed value. The average root mean square error value of hydraulic head for the Edwards-Trinity aquifer for all stress periods was 34.2 ft, which was approximately 4 percent of the average total measured changes in groundwater-level altitudes (groundwater levels). Simulated spring flow representing Comanche Springs generally reproduces the measured spring flow. Results from the calibrated model are in agreement with the geochemical modeling analyses, which indicate that groundwater in the Edwards-Trinity aquifer in the Leon-Belding and Fort Stockton areas is a mixture of recharge from the Barilla and Davis Mountains and groundwater that has upwelled from the Rustler aquifer. Graphs depicting residuals for the Pecos County region model and the relation between simulated and measured hydraulic heads for the Pecos County region model are provided in figures 2 and 3, respectively.

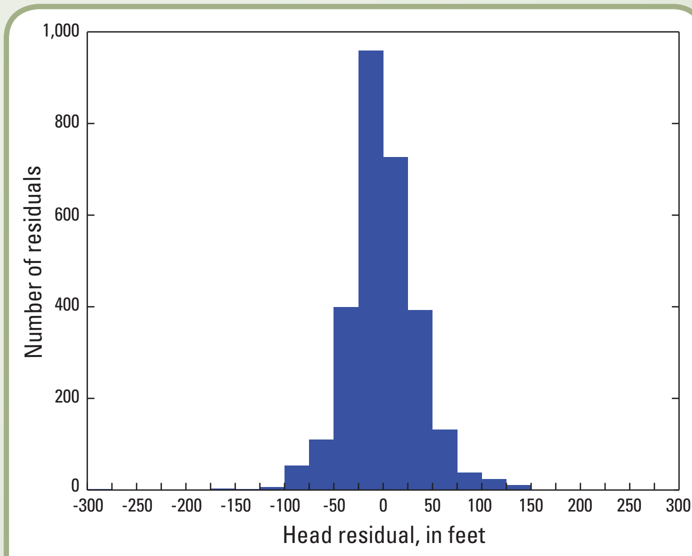


Figure 2. Residuals for the Pecos County region model, Texas (modified from Clark and others, 2014, fig. 14).

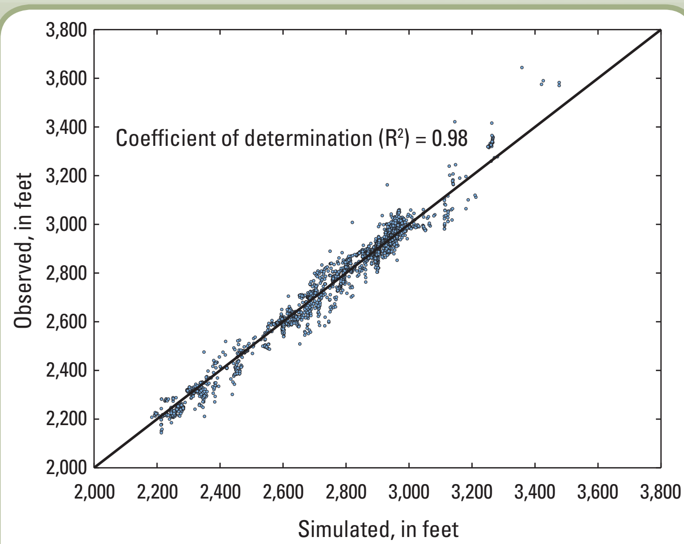


Figure 3. Relation between simulated and measured hydraulic heads for the Pecos County region model, Texas (modified from Clark and others, 2014, fig. 15).

Model Limitations

An understanding of model limitations is essential to effectively use groundwater-flow and hydraulic-head simulation results (Reilly and Harbaugh, 2004). The accuracy of a groundwater model is limited by simplification of complexities within the groundwater-flow system (conceptual model), space and time discretization effects, assumptions made in the formulation of the governing flow equations, and simplifications of representations of boundary conditions and discretization and representation of climate. The Pecos County region model provides a relatively good fit to measured groundwater levels in the Leon-Belding and Fort Stockton areas and to spring flow from Comanche Springs. The Pecos County region model provides a relatively good fit to measured groundwater levels in the Leon-Belding and Fort Stockton areas and to spring flow from Comanche Springs (fig. 4). One of the findings, however, was that simulated spring flow is highly contingent on the

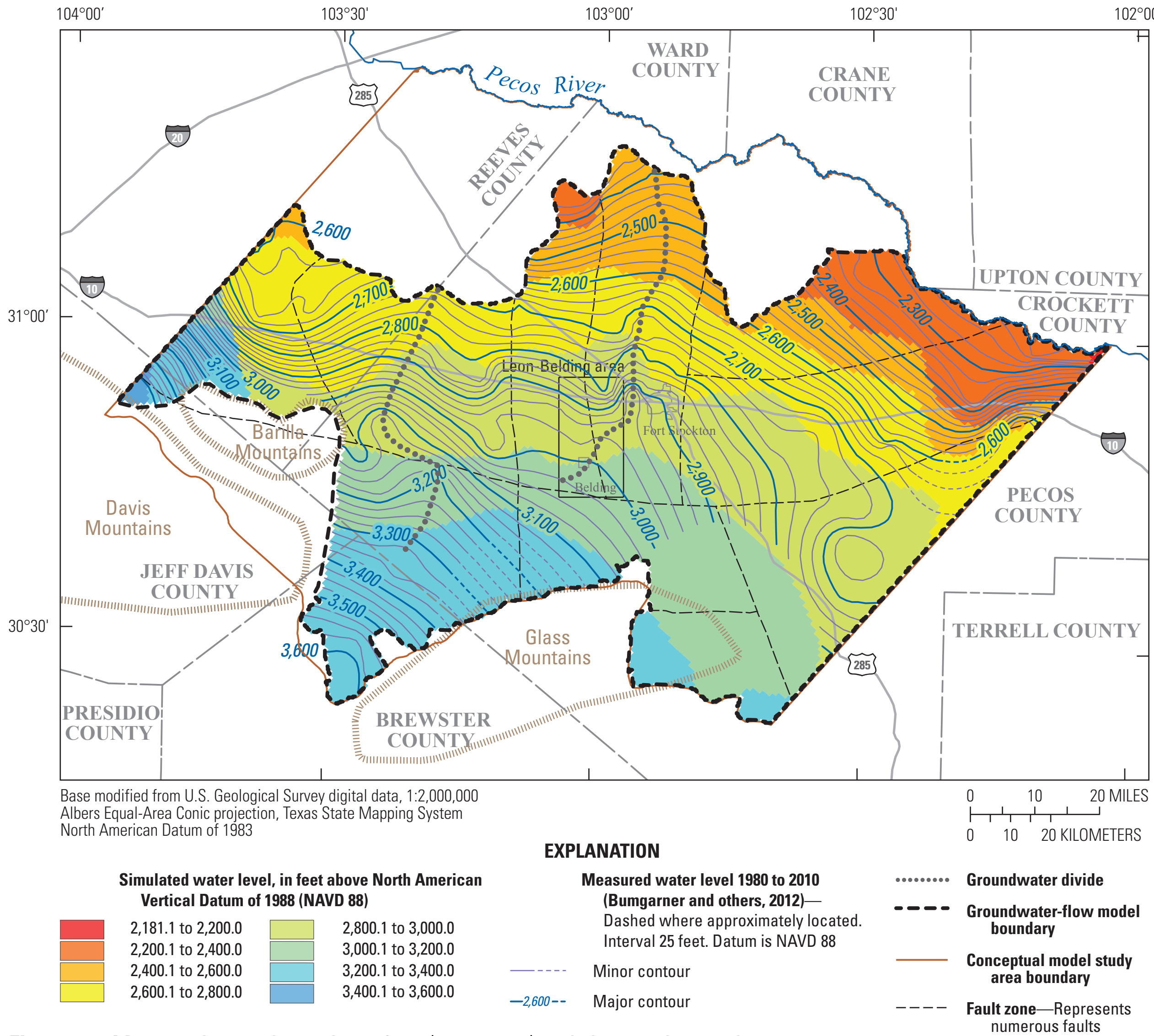


Figure 4. Measured potentiometric surface (1980–2010) and simulated groundwater-level altitudes for the Edwards-Trinity aquifer in the model area of the Pecos County region, Texas, 2010 (modified from Clark and others, 2014, fig. 12).

Pecos County region, Texas.

transient nature of the underlying specified head boundary conditions in model layer 5 (Rustler layer), which indicates the importance of adequately understanding and characterizing the entire groundwater system.

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. 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 (fig. 5). The 30-year period is discretized into sixty 6-month stress periods generally representing seasonality of irrigation water demand.

Scenario 1

Scenario 1 extends recent (2008) irrigation and non-irrigation pumping rates for each year of the 30-year simulation period from 2010 to 2040. Return flow recharge from irrigation is included in scenario 1. Scenario 1 provides a measure of the sustainability to the 2008 water usage and also provides a baseline scenario for comparison against additional scenarios. 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.

Scenario 2

Scenario 2 evaluates the effects of extended recent (2008) pumping rates as assigned in scenario 1, in addition to year-round maximum permitted groundwater-pumping rates (about 42 Mgal/d) in the Leon-Belding area for the 30-year simulation period. Return flow recharge from irrigation is not included in scenario 2. Results of scenario 2 are similar in water-level decline and extent from those of scenario 1. The extent of the projected groundwater-level decline in the range of 5–15 ft in the Leon-Belding irrigation area expanded slightly (about 2 percent increase) from that of scenario 1. 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.

Scenario 3

Scenario 3 evaluates the effects of periodic increases in pumping rates over the 30-year simulation period by using the same 6-month irrigation and non-irrigation stress periods as in scenarios 1 and 2; however, for this scenario, groundwater use is predicted to increase approximately 16 percent by 2040 because of the projected population growth for Pecos County (Texas Water Development Board, 2013). Based on this projected groundwater-use increase, simulated pumping for all wells was increased by 5 percent every 10 years to account for an approximate 15-percent increase by the end of the 30-year simulation period. Return flow recharge from irrigation is not included in scenario 3. Projected groundwater-level declines resulting from scenario 3 are depicted in figure 5 (results from all three scenarios are depicted in Clark and others, 2014). Results of scenario 3 are similar to those of scenario 2 in terms of the areas of groundwater-level decline. 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.

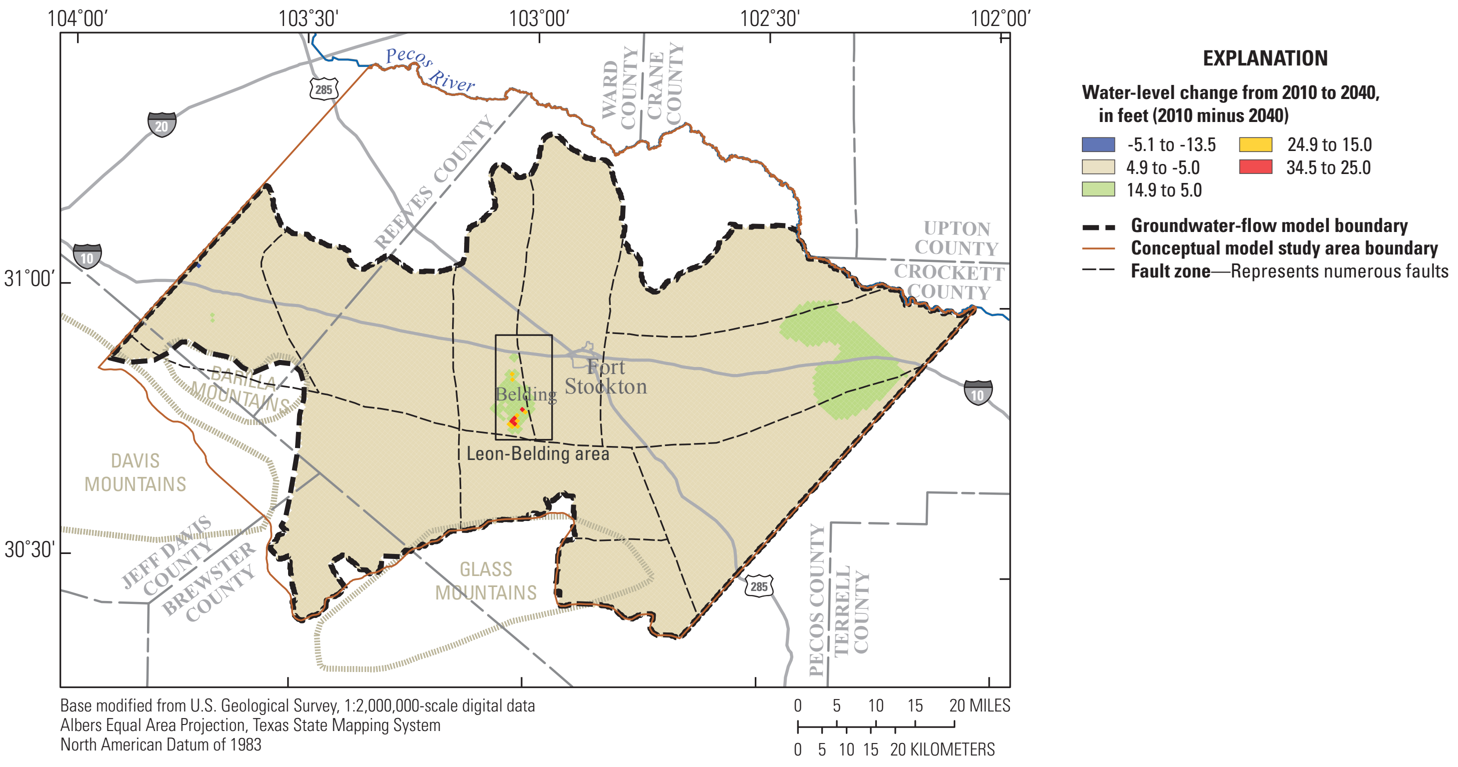
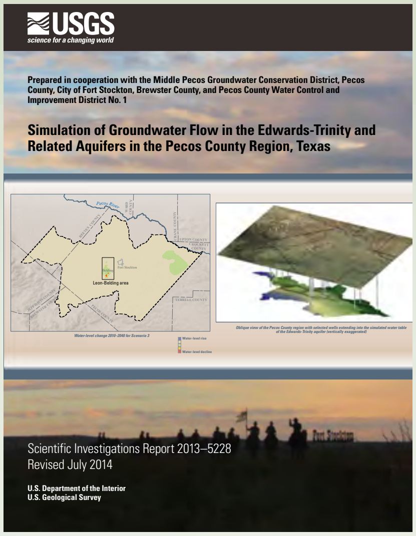


Figure 5. Simulated groundwater-level difference for the Edwards-Trinity aquifer in the model area of the Pecos County region, Texas, from 2010 to 2040 for groundwater-pumping scenario 3 (modified from Clark and others, 2014, fig. 20).

This fact sheet is based on the following USGS report:

Clark, B.R., Bumgarner, J.R., Houston, N.A., and Foster, A.L., 2014, Simulation of groundwater flow in the Edwards-Trinity and related aquifers in the Pecos County region, Texas: U.S. Geological Survey Scientific Investigations Report 2013–5228, 56 p., http://dx.doi.org/10.3133/sir20135228. (Revised July 2014).



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