Prepared in cooperation with the City of Albuquerque Public Works Department

Simulated Effects of Projected Ground-Water Withdrawals by the City of Albuquerque, 2004-40, for Reduced Water Use Per Person

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Introduction

In the Middle Rio Grande Basin (MRGB) of central New Mexico (fig. 1), ground water currently (2004) is the almost exclusive source of water for municipal and domestic supply to the approximately 690,000 residents of the basin (Bartolino and Cole, 2002). The largest user of ground water in the basin is the City of Albuquerque (COA), which during the 1990's pumped nearly three-quarters of the estimated 150,000 to 160,000 acre-feet of ground water withdrawn annually from the basin (McAda and Barroll, 2002; City of Albuquerque files). From 2000 to 2003 (fig. 2), the COA withdrew 107,000 to 114,000 acre-feet of ground water annually from about 90 deep supply wells that obtain water from sediments of the Santa Fe Group aquifer system.

Because of large withdrawals of ground water from the MRGB, annual outflow from the aquifer system is greater than annual inflow to the aquifer system, thus reducing the quantity of water stored within the aquifer (Bartolino and Cole, 2002; McAda and Barroll, 2002). This reduction of water in storage is reflected in water-level declines that have exceeded 120 feet in parts of the aquifer system (Bexfield and Anderholm, 2002). Large water-level declines can result in a number of regional-scale problems, including increased drilling and pumping costs, subsidence (sinking) of the land surface, deterioration of the quality of available ground water, and decreased surface-water availability. Water-level declines have already resulted in decreased flow in the Rio Grande (McAda and Barroll, 2002).

Recognition by the COA that continued use of ground water to meet all municipal water demand is not sustainable and may result in regional-scale problems led the city to devise a new water-resources strategy in the middle to late 1990's. In addition to water-recycling projects and encouragement of conservation by users, the water-resources strategy calls for the direct use of surface water to meet most municipal demand. The COA owns rights to about 71,000 acre-feet of water in the Rio Grande (City of Albuquerque, 2003), including water that is diverted from streams in the Colorado River Basin to the Rio Grande Basin through the San Juan-Chama Transmountain Diversion Project. The COA plans to begin diverting water directly from the Rio Grande for municipal supply in 2006. Limited ground-water withdrawals will be used to supplement water supplies primarily during periods of large demand or drought.

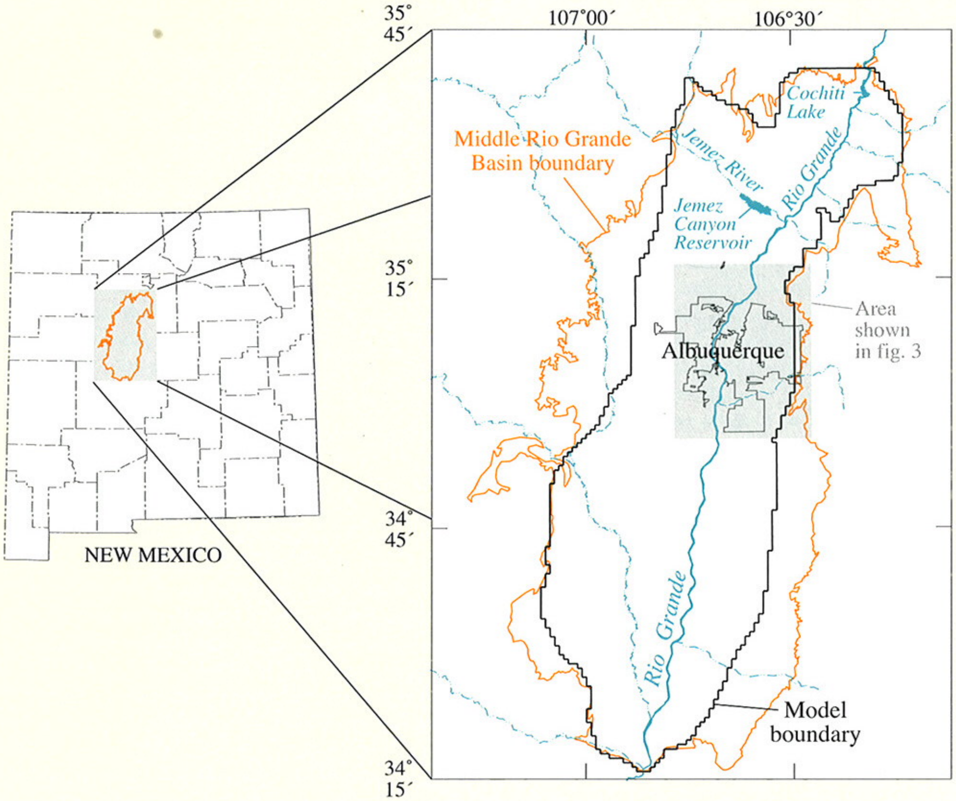

Figure 1. Location map of the Middle Rio Grande Basin.

When the COA begins using surface water instead of ground water as its primary source of municipal supply, substantial changes will occur in the river-aquifer system of the MRGB. In particular, water levels in the aquifer system will change, as will the quantity of water stored in the aquifer system and the quantity of water that leaks into the aquifer system from the river system. Estimates of these changes are important to the design of long-term water-management strategies that will benefit the regional hydrologic system and water users. Ground-water-flow models are particularly useful for making these kinds of estimates, as demonstrated in previous simulations by Bexfield and McAda (2003) of the effects of ground-water management scenarios on the river-aquifer system of the MRGB. This report describes the results of a model simulation performed by the U.S. Geological Survey (USGS), in cooperation with the COA Public Works Department, to investigate the effects of projected ground-water withdrawals by the COA for 2004-40 on the river-aquifer system, assuming future water use per person is reduced.

Ground-Water-Flow Models

A ground-water-flow model, which typically is created using computer software, is a mathematical representation of a particular ground-water-flow system. Aspects of the ground-water-flow system that are represented include the quantity and distribution of recharge to the system, the quantity and distribution of discharge from the system, the aquifer properties that affect the velocity and direction of water moving through the system, and the storage of water in the system. A ground-water-flow model is perhaps the best means available to integrate large amounts of geohydrologic information and simulate the complex operation of a ground-water-flow system and its response to stresses (such as ground-water withdrawals); therefore, a ground-water-flow model is an extremely useful tool for managing ground-water resources.

A ground-water-flow model typically incorporates the best available knowledge of an aquifer system and usually is calibrated and tested to ensure that it can reasonably reproduce historical observations of water levels, streamflow, and other aspects of the aquifer system. Inherent in every ground-water-flow model, however, are uncertainties about some aspects of the ground-water system; these

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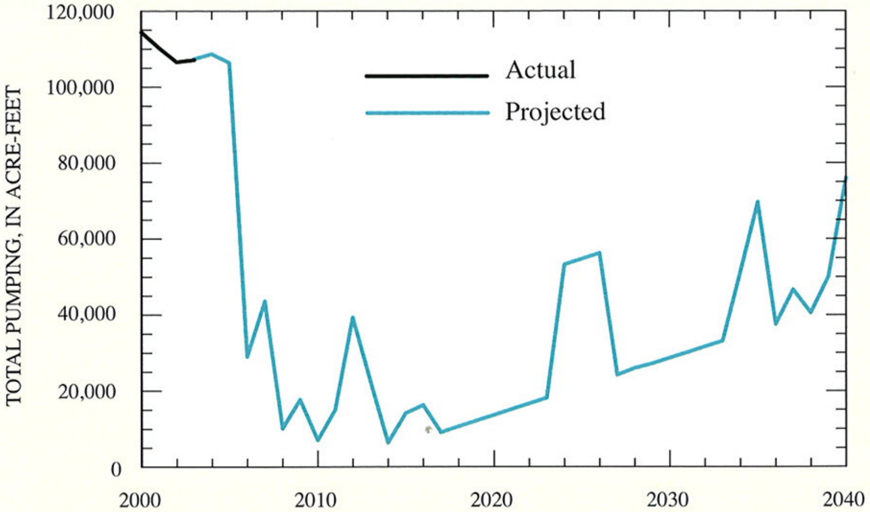

Figure 2. Actual and projected annual City of Albuquerque ground-water withdrawals assigned for the low-use simulation using the McAda and Barroll (2002) model, 2000 to 2040.

uncertainties must be taken into account when evaluating model results.

The McAda and Barroll Model

The ground-water-flow model recently developed by the USGS in cooperation with the New Mexico Office of the State Engineer and the COA (McAda and Barroll, 2002) was used to estimate the effects of a particular COA water-management scenario of the river-aquifer system of the MRGB. Bexfield and McAda (2003) previously used this model to predict the effects of other COA water-management scenarios on the system. The McAda and Barroll model and the methods used to modify the model to estimate future effects of COA ground-water withdrawals are described only briefly here; the reader is referred to McAda and Barroll (2002) and Bexfield and McAda (2003) for additional detail.

The McAda and Barroll model of the MRGB (fig. 1) simulates ground-water flow in the Santa Fe Group aquifer system using the three-dimensional, finite-difference, ground-water-flow model code MODFLOW-2000 (Harbaugh and others, 2000). The aquifer system, which consists mostly of valley and basin-fill sediments, is represented in the model by nine layers extending as much as 9,000 feet below the National Geodetic Vertical Datum of 1929. The horizontal grid contains 156 rows and 80 columns, each equally spaced 3,281 feet (1 kilometer) apart. The grid is oriented north-south to align with important geohydrologic features of the basin. The horizontal hydraulic conductivity (ability of the sediments to transmit water) in the north-south direction of the model ranges from 0.05 to 60 feet per day. This horizontal hydraulic conductivity in the north-south direction is as much as 5 times greater than the horizontal hydraulic conductivity in the east-west direction and as much as 750 times greater than the vertical hydraulic conductivity. Layers 5-9 are represented as continuously under confined conditions, whereas layers 1-4 are allowed to convert from confined to unconfined conditions if water levels drop below the top of the layer.

The McAda and Barroll model simulates predevelopment steady-state conditions and historical transient conditions from 1900 to March 2000 in 1 steady-state and 52 historical stress periods. Average annual conditions are simulated prior to 1990, and seasonal (irrigation and non-irrigation season) conditions are simulated from 1990 to March 2000. Recharge to and discharge from the aquifer system are modeled either as specified-flux boundaries (inflows and outflows are specified and are independent of water levels in the aquifer) or head-dependent flux boundaries (inflows and outflows depend on water levels in the aquifer). Mountain-front, tributary, and subsurface recharge; canal, crop-irrigation, and septic-field seepage; and ground-water withdrawals are simulated as specified-flux boundaries. The Rio Grande, riverside drains, interior drains, Jemez River, Jemez Canyon Reservoir, Cochiti Lake, and areas of riparian evapotranspiration are simulated as head-dependent flux boundaries. Mountain-front, tributary, and subsurface recharge from adjacent ground-water basins are specified to be constant throughout the simulation period, whereas other fluxes vary from stress period to stress period on the basis of historical data.

The McAda and Barroll model was calibrated to measured water levels and water-budget components. The model provided good agreement with predevelopment water levels and the direction and magnitude of water-level changes over time. Although the model cannot provide detailed information about the effects of ground-water withdrawals on flows in the Rio Grande, good agreement was obtained between model results and quantitative information about baseflow and seepage loss along the river system.

One acre-foot is the quantity of water needed to cover 1 acre to a depth of 1 foot and equals about 325,829 gallons.

Design of the Model Simulation

The model simulation for which results are presented in this report was designed in the same way as the simulations presented by Bexfield and McAda (2003). In particular, the McAda and Barroll model was modified slightly by adding two COA municipal-supply wells that had recently begun operation and by allowing layer 5 to convert from confined to unconfined conditions. The model-simulation period was then extended through mid-March 2040 using seasonal stress periods. Many of the parameters used for the most recent (1999-2000) stress periods of the McAda and Barroll model were duplicated without modification through 2040. These parameters included those for mountain-front recharge, tributary recharge, underflow, seepage from crop irrigation, seepage from septic fields, drain conditions, and evapotranspiration conditions. With the exception of COA withdrawals, the most recent data available in the McAda and Barroll model for ground-water withdrawals also were used without modification for each year from 2000 through 2040.

Similar to simulation III of Bexfield and McAda (2003), the "low-use" simulation, for which results are presented in this report, uses projections of future COA ground-water withdrawals that assume surface water is available to meet much of the total water demand starting in 2006, thereafter resulting in decreased ground-water use (fig. 2). These ground-water withdrawal projections provided by Greg Gates (CH2M Hill, written commun., 2004), consultant to the COA, differ from those of simulation III by Bexfield and McAda (2003) in that they represent ground-water withdrawals projected to occur if the COA's water-conservation program is successful in reducing average water use to 150 gallons per person per day, as opposed to the 175 gallons per person per day used in Bexfield and McAda's (2003) simulation III. Also, these projections begin in 2004 rather than 2001 because actual COA ground-water withdrawals were available for 2001-03 at the time the low-use simulation was performed.

As with the projections of future COA ground-water withdrawals used by Bexfield and McAda (2003), the projections used in the low-use simulation incorporate not only the effects of population growth and conservation, but also of potential weather cycles that could affect the availability of surface water for COA supply (resulting in the large variability in ground-water use shown in fig. 2). Conditions in the Rio Grande for the model simulation presented in this report were varied annually to match the projected weather cycles in the same manner as described in Bexfield and

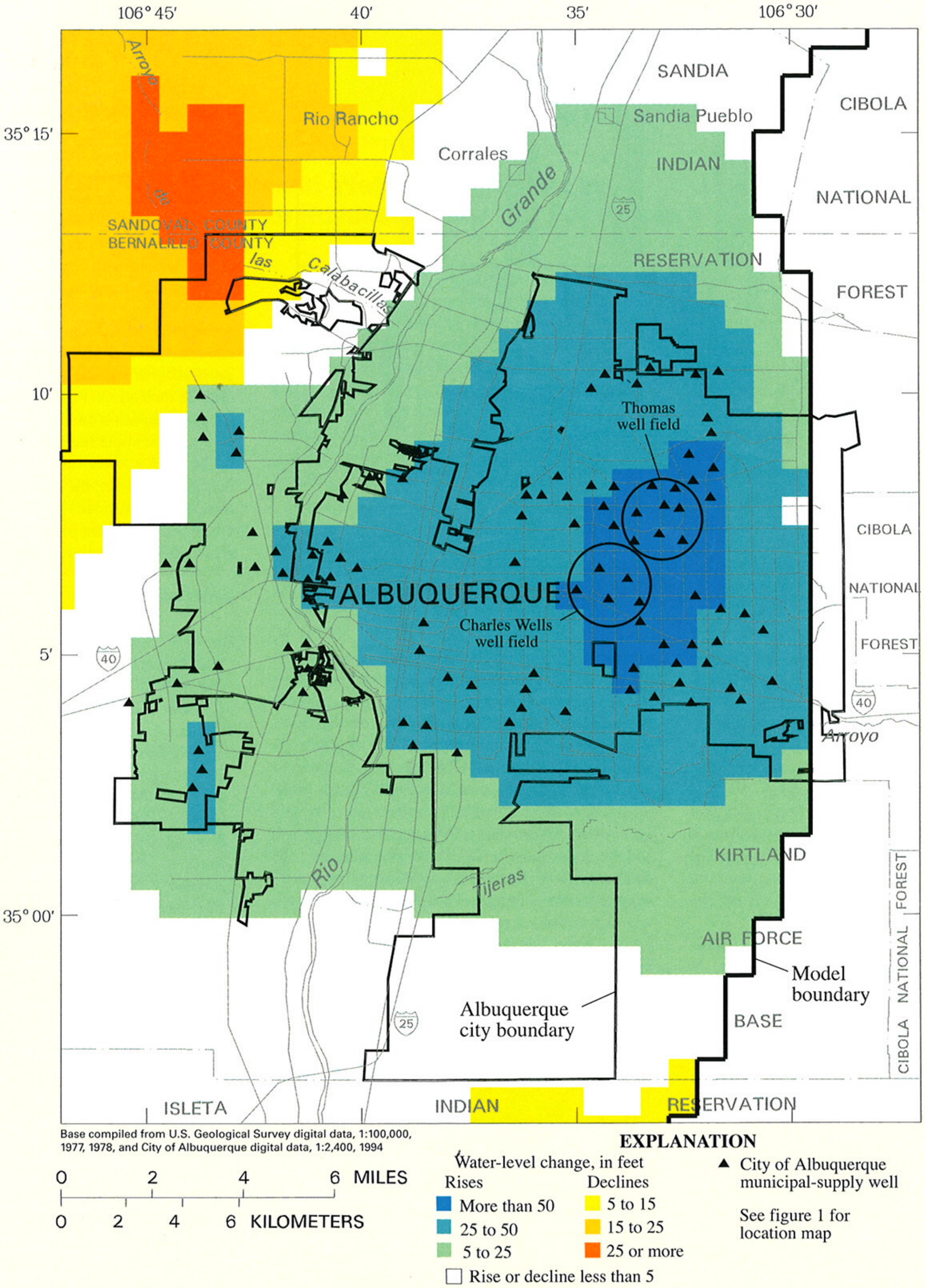

Figure 3. Simulated water-level change in the production zone (model layer 5) in the Albuquerque area between 2000 and 2040.

McAda (2003). The distribution of the total simulated ground-water withdrawal among COA wells during each year of the model simulation was the same as the actual distribution used by the COA in 2000.

Simulated Effects on Water Levels

Water-level changes in the low-use simulation were largest in the Albuquerque area (fig. 3). This is the area of largest historical ground-water withdrawal and the area where future changes in ground-water management were simulated in the model. Water-level changes in layer 5 of the model, which at its bottom is 800 feet below the Rio Grande and is between about 380 and 630 feet thick, depending on location within the model, are shown in figure 3. Layer 5 is referred to as the production zone because it corresponds with the depth range from which ground-water withdrawals are largest in the area. The response to changes in stress can most quickly be observed in this zone.

Water levels in the production zone are simulated to decline in some parts of the Albuquerque area between 2000 and 2040 and to rise in others (fig. 3). By 2040, water levels are simulated to have declined by as much as 35 feet in parts of the area where municipal-water suppliers other than the COA were simulated as continuing to withdraw ground water at year-2000 rates. In contrast, water levels are simulated to have risen by as much as 58 feet by 2040 across broad areas within and bordering the COA. Most of the simulated water-level rise is east of the Rio Grande, particularly in the area of the Charles Wells and Thomas well fields (fig. 3), where some of the largest water-level declines had previously occurred (Bexfield and Anderholm,

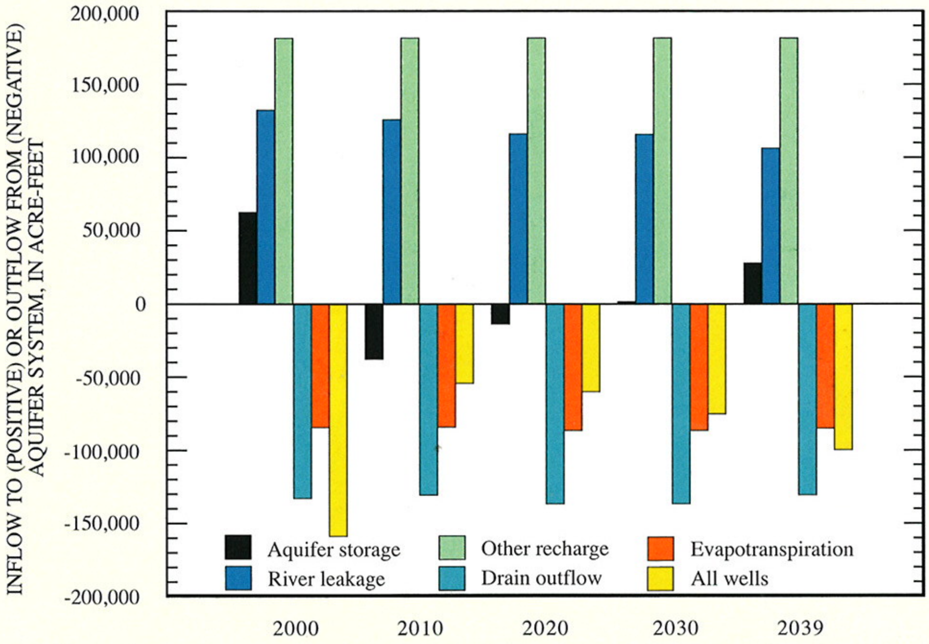

Figure 4. Simulated water budget for the aquifer system of the Middle Rio Grande Basin during selected years of the model. Years start on March 16 of the year shown on the graph and end on March 15 of the following year.

2002). Because the projections of future COA ground-water withdrawals in the low-use simulation are smaller than those used in simulation III of Bexfield and McAda (2003) (150 rather than 175 gallons per person per day), simulated water-level rises in the production zone between 2000 and 2040 commonly are about 25 feet larger in the area of the Charles Wells and Thomas well fields for the low-use simulation described in this report than for simulation III.

Simulated Effects on the Water Budget

All inflows to and outflows from the aquifer system are components of the water budget for the aquifer system. In the water budget of the McAda and Barroll model, changes in aquifer storage are considered to be inflows to or outflows from the aquifer system. Thus, aquifer storage is treated much like the river system, which can either leak to the aquifer system or receive discharge from the aquifer system. (See the box next to fig. 4 for additional information on the treatment of aquifer storage.) Therefore, the water budget of the model specifies that the combination of all inflows must equal the combination of all outflows. As discussed in the section "The McAda and Barroll Model," the simulated quantities of water that enter or leave the aquifer system through certain components of the water budget are not defined as specified fluxes to the model and can vary from year to year, depending on conditions within the aquifer system. For the McAda and Barroll model, the major water-budget components that can vary in this manner are aquifer storage, river leakage, drain outflow, and evapotranspiration (fig. 4).

Aquifer storage is the water-budget component that varies most widely as COA ground-water withdrawals change throughout the model (fig. 4). In 2000 (when ground-water withdrawals are relatively large compared to projected withdrawals in subsequent years), the inflow of water from storage to the ground-water-flow system is strongly positive, which represents removal of water from aquifer storage and corresponds with an overall decline in water levels. In contrast, the much smaller withdrawal of ground water by the COA (and, consequently, from the MRGB as a whole) in 2010 and 2020 compared with 2000 (fig. 2) results in outflow of water from the ground-water-flow system into aquifer storage and the consequent replenishment of storage and overall rise in water levels. Most of the storage recovery occurs at the water table, where pore spaces refill with water. In 2030, ground-water withdrawals by the COA have increased to a point where the overall effect on the system is a decline in aquifer storage and ground-water levels, though by a very small quantity. During 2039, ground-water withdrawals are projected to remove about 30,000 acre-feet of water from storage.

The overall quantity of water simulated to leak into the aquifer system from the Rio Grande also varies over time in the model. River leakage is shown to continuously decrease over the years shown in figure 4, which likely results from the overall rise in water levels in the aquifer system and the associated decrease in hydraulic gradients directed away from the Rio Grande (Bexfield and McAda, 2003). Even in 2039, when the storage value indicates declining water levels in some areas, hydraulic gradients near the river remain sufficiently small to induce less leakage from the river than in previous years. Changes in aquifer water levels over time also have some effects on the quantity of water leaving the aquifer system through drains and evapotranspiration in the inner valley of the Rio Grande, but these effects are relatively minor (fig. 4).

Summary

A model simulation using the McAda and Barroll ground-water-flow model for the MRGB indicates that decreased ground-water withdrawals by the COA starting in 2006 will result in increased aquifer storage, water-level rises across large areas, and decreased infiltration of surface water from the Rio Grande through 2040. Although the model used for the simulation cannot provide detailed information about the effects of implementation of the COA's water-resources strategy on flows in the Rio Grande, the model does provide quantitative estimates of the beneficial consequences of the plan for the overall MRGB river-aquifer system through 2040.

A NOTE ON AQUIFER STORAGE

With respect to the water budget of the ground-water-flow model, a positive value for aquifer storage represents water that is removed from storage and is available for withdrawal by wells. A negative value indicates addition of water to (replenishment of) aquifer storage. Therefore, regional water-level rise would be associated with negative values of aquifer storage in the water budget.

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