AN ANALYSIS OF PROPOSED PUMPAGE EFFECTS ON THE UPPER AQUIFER OF THE MESILLA VALLEY, NEW MEXICO

by

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ABSTRACT

The city of El Paso has currently applied to the State Engineer of New Mexico for 265 groundwater well permits in the Mesilla Bolson of southern New Mexico. Well pumpages were simulated for a 100-year time span using MODFLOW, a computer-based groundwater model.

Model results indicate that approximately 82,000 Acre-feet/year (AFY) of additional net surface water leakance is due to the pumpage of the additional El Paso wells by the end of the simulation. Some river reaches attain a constant leakance level for the last 30 to 40 years of the simulation. Increased aquifer storage loss amounts to approximately 140,000 AFY by the end of the simulation period.

Average drawdown will increase by 0.5, 6.5, and 10.0 feet for the northern, central, and southern upper aquifers, respectively, lowering the water table level below some irrigation drains.

CHAPTER 1

INTRODUCTION

The study area is located in southcentral New Mexico within the Rio Grande rift system. The rift system originates in southern Colorado and fans out southward into New Mexico and across the border in the Mexican State of Chihuahua.

The Rio Grande enters the northern study area through a narrow pass between the Robledo and Dona Ana mountains to the west and east, respectively. Leasburg Dam approximates the northern boundary of the study area between these two mountain ranges. The southernmost extent of the study area is the New Mexico-Mexico border which includes a small portion of Chihuahua. The Franklin and Organ mountains extend southward to form the eastern boundary of the study area. The western boundary is formed by a series of hills and mountain ranges which include the West Potrillo and East Potrillo mountains, Aden Hills, Sleeping Lady Hills, Rough and Ready Hill, and part of the Sierra de las Uvas Mountains (Wilson et al., 1981). The Rio Grande exits the study area in the south at El Paso del Norte, commonly known as 'the narrows', and the pass from which the city of El Paso derived its name.

The purpose of this study is to quantify the effects of various pumping scenarios on the Mesilla Valley, New Mexico using the McDonald and Harbaugh (1984) MODFLOW groundwater flow model. These effects will be quantified, analysed and discussed in relation to current methods of granting well permits by the State Engineer of New Mexico. Estimates of future pumping were considered with and without the proposed 265 wells of El Paso currently applied for to the State Engineer of New Mexico. The wells would be completed on the West Mesa of the study area. The area is known to have an inter-connection of the groundwater and the surface water flows of the Rio Grande, irrigation canals, and irrigation drains (New Mexico State Engineers Office, 1980).

The hydrologic surface water system consists of the river, irrigation drains, and canals and which are confined in extent to the Mesilla Valley. An upper or alluvial aquifer is confined in areal extent to the Mesilla Valley as well. Irrigation is essentially confined to the alluvium of the upper aquifer in Mesilla Valley of the Mesilla Bolson. Underlying the alluvial aquifer is a semi-confining zone which allows surface water to penetrate through the upper aquifer into the underlying lower or Santa Fe aquifer (Wilson et al., 1981). Surface water leakance occurs through the river, drain, and canal beds into the upper aquifer and is a function of hydraulic head, bed conductances, and the magnitude of well pumpages, hydraulic head changes, and hydraulic bed conductance in the upper and lower aquifers. Irrigation is responsible for an estimated 62.5 percent of present aquifer recharge, surface water 30 percent. and the remainder from mountain runoff (Peterson et al., 1984).

Due to the hydraulic inter-connection of the stream-aquifer system, increased pumping causes an increase in the surface water contribution to the underlying aquifers. This is consistent with the longstanding policy of the State Engineer which requires that the net depletion of surface water due to groundwater pumpage be offset with the dedication of surface water rights (Reynolds et al., 1967). The surface water contribution to the aquifer may take the form of increased leakance through the river and canals bed themselves, or more indirectly in the form of lost flow to irrigation drains.

Increased pumping also causes increased drawdown. Drawdown is important since drains have historically been 3 feet below the upper aquifer water table for at least the last 40 years (Maddock et al., 1987). A drawdown of over 3 feet could then cause the cessation of drain flows in portions of the Mesilla Valley. Drains provide a means of flushing excess salts from the soil profile while simply draining excess water away. Therefore, the loss of drain flow amounts to lost return flow to the Rio Grande. The actual flow in the Rio Grande is a combination of reservoir releases, return flows from irrigation, treated effluent, and return flows from ephemeral streams (Peterson, 1984).

The effects of pumpage in terms of net loss to the surface water system were considered as well as the changes in drawdown and head for the northern, central, and southern portions of the Mesilla Valley. Contour plots were made of drawdown and surface water loss to visualize the areal extent of the effects on each portion of the upper aquifer from the beginning to the end of the model simulation, while plots of the drawdown and surface water loss through time illustrate the overall impact of pumping on each portion of the valley over the model simulation.

The surface water system is intricately tied to pumping in the basin. Current policy requires a dedication of offset rights to the State Engineer in an amount sufficient to offset groundwater pumpage effects in the Rio Grande Basin. In the past, well permits have been granted with conditions attached which provide for maintaining surface water flows and dedication of offset rights (e.g., the Buckman and City of Albuquerque permits). The conditional permits allow the State Engineer an ongoing jurisdiction of offset requirements and conjunctive management of the stream-aquifer system in the Mesilla Bolson. The Mesilla Valley is in the Lower Rio Grande Basin, and the hydrological characteristics are similar to the Rio Grande Basin immediately to the north (Wilson et al., 1987), so these same concepts may be applied equally as well to the Lower Rio Grande Basin. Therefore, the net surface water depletion will be quantified in terms of model results and related to the current guidelines and conditions the State Engineer of New Mexico uses as a base to grant well permits in the Rio Grande Basin.

CHAPTER 2

TOPOGRAPHY, CLIMATE AND GEOLOGY

Study Area and Topography

The Mesilla Bolson extends through southcentral New Mexico, southward into western Texas, and approximately 50 miles into northern Mexico (Figure 1).

Faults bounding the mountain ranges in the eastern and parts of the western study area tend to show surficial expression as sharp topographical gradients (Figure 1). The Franklin and Organ mountains show abrupt topographical relief in the same areas where Seager and Morgan (1979) have mapped normal faults. In fact, most of the sharp topographical relief is associated with normal faulting. For example, along the southern Robledo and Dona Ana mountains near the Rio Grande River, abrupt topographical relief marks the boundary between two fault blocks (Seager and Morgan, 1979). Even the East Potrillo Mountains in the western study area are bounded on the eastern side (the side of most abrupt relief) by a normal fault.

In general, the topography of the lower elevation in the Mesilla Bolson converges on the Mesilla Valley. The alluvial deposits of the Organ and Franklin mountains form a steeper gradient towards the Mesilla Valley than the broad, gently-sloping basin fill deposits of the West Mesa. Kilborne, Hunts, and Phillips Hole are large depressions thought to be associated with volcanic explosions on the West Mesa (King et al., 1971). There is an absence of volcanic ejecta associated with Phillips Hole (King et al., 1971) and also two other

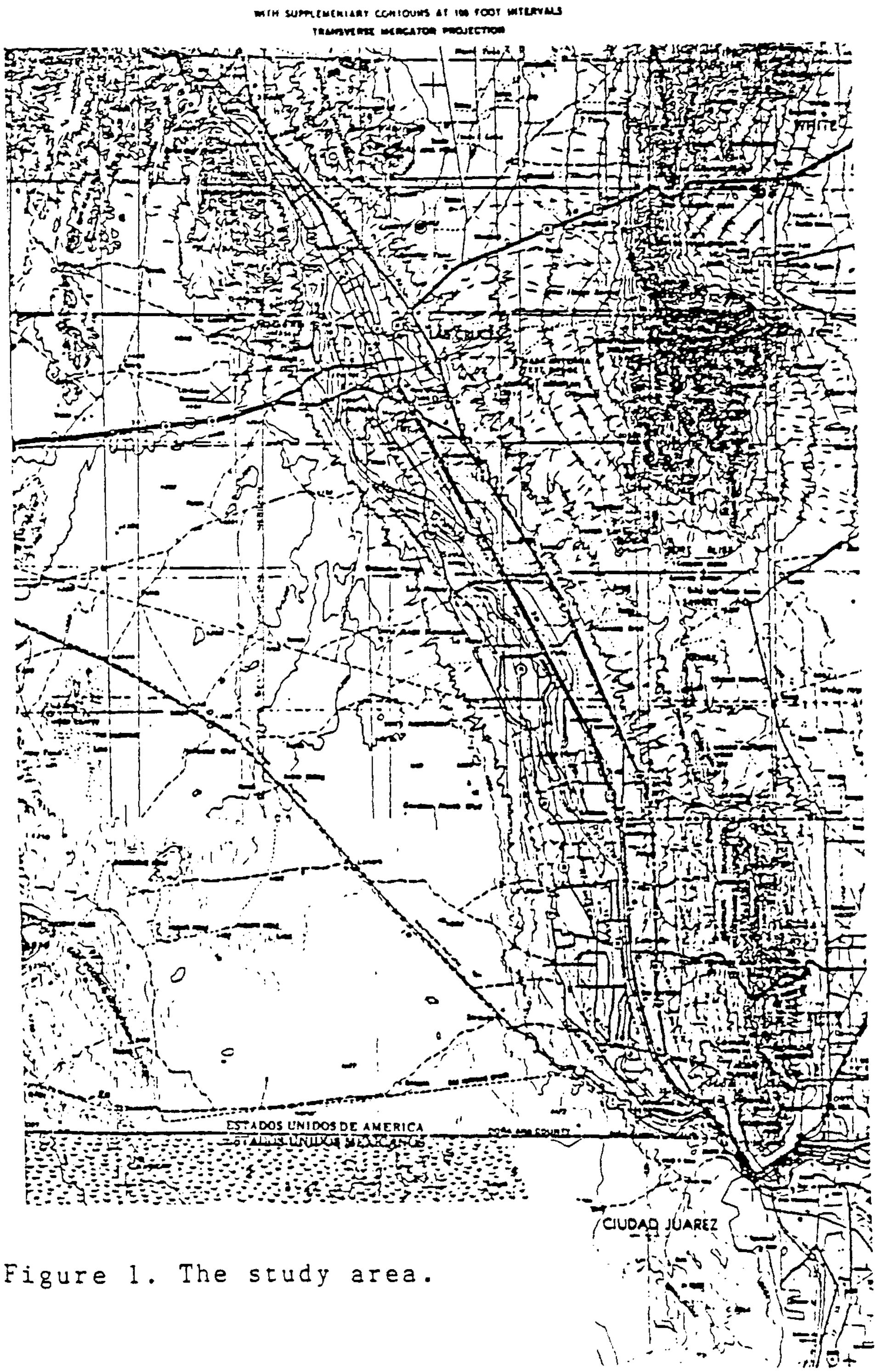

Figure 1. The study area.

larger depressions, one just south of Hunts Hole and the other to the northeast. The absence of volcanic debris may suggest that these depressions are fault controlled, e.g., a result of subsidence on the down side of the normal faults which surround the area.

Climate

The Mesilla Valley area has an arid climate characterized by generally small but variable annual precipitation, large annual temperature ranges, and low relative humidity (Houghton, 1972). Climatic conditions are similar throughout the lower elevations in the study area. The higher elevations receive more precipitation and have proportionally more temperate climates.

About one-half of the total annual precipitation (mainly in the form of rainfall) falls from July to October. Rainfall during these months is predominately from brief, intense thunderstorms (Wilson et al., 1981). A record rainfall of 6 inches occurred on August 29, 1935. Extended periods of storm activity are uncommon in the study area.

The average annual precipitation for a 111-year period recorded in the Las Cruces area and at New Mexico State University is 8.39 inches. This record is the longest record available in the area of the Mesilla Valley (Wilson, 1981).

The monthly average of mean daily temperature in degrees Fahrenheit at New Mexico State University for the period 1941 to 1970 is summarized as follows (U.S. Department of Commerce, 1973):

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
41.7	46.0	51.3	60.0	68.0	76.9	80.0	78.1	71.7	61.2	48.9	42.4

Annual
60.5

The desert areas normally receive more than 80 percent of the possible sunshine (King et al., 1971).

Winds are strongest during March and April (averaging 7.3 to 7.6 mph, respectively), and dust storms are common during the spring months in the desert areas. Humidities in the desert area are typically low. Near New Mexico State University, humidities range from less than 30 percent in the spring and early summer afternoons to 60 percent in the early morning hours. The average humidity for the year is less than 50 percent (King et al., 1971). In general, there are two types of climates in the study area. The climate of the basin area is relatively arid, while the climate over the highest mountain, the Organ and Franklin ranges, tends to be semi-arid.

Geology

The Mesilla Bolson is one of a series of depressions formed by the Rio Grande rift system. The rift system is characterized by extensional deformation and intrusion of calc-alkaline and mafic magma (Chapin and Seager, 1975). Rifting began approximately 30 m.y. ago coincident with the onset of volcanism. Although the rift is a volcanically-starved system compared to other intra-cratonic rifts, the few eruptive sequences signal important events.

The majority of flows were calc-alkaline until a volcanic lull from approximately 20 to 15 m.y. ago. Most of the rift volcanism and extensional deformation has occurred since approximately 15 m.y. ago (Riecker, personnel communication, 1985). Since that time, volcanism has been primarily basaltic. The change from calc-alkaline to basaltic extrusions may suggest the maturing of a passive rift system. The evolution of a passive rift fits the Rio Grande rift system well: rifting, doming, and volcanism (Gardner, personnel communication, 1985).

The Mesilla Bolson is constricted on the north by a narrow pass between the Robledo Mountains on the west and the Don Ana Mountains to the east. A series of small mountain ranges form the eastern boundary of the Basin. A series of small mountain ranges form the northwestern boundary, while the West Potrillo Mountains bound the majority of the western basin. The West Mesa is a broad, nearly unbroken plain in the western basin which extends from near Las Cruces southward into Mexico.

Several horst and graben structures cut the bedrock and basin fill with maximum vertical displacements as large as a few thousand feet. A horst block which lies several hundred feet below land surface effectively forms a structural divide between the Mesilla Bolson and the Jornada Del Muerto Basin to the north (Peterson et al., 1984). The Robledo and Fitzgerald faults form a structural low in the central Mesilla Bolson filled by at least 2,000 feet of sediment. Peterson et al. (1984) suggest that the basin fill where these two faults converge may be greater than 6,000 feet. Oblique fault systems (with respect to the basin) in the western area suggest a counterclockwise structural rotation of the basin.

In summary, the basin has experienced extensional deformation, subsidence, and rotation, the majority of extensional deformation and volcanism occurring in the last 15 m.y.

Deep-seated Precambrian and Tertiary igneous and intrusive bodies of granitic to porphyritic texture make up the cores of the Dona Ana, Organ, and Franklin mountains. The Precambrian intrusives are ultimately associated with complexes of metamorphic rock (King et al., 1971). Paleozoic limestones, dolomites, shales, and sandstones make up the bulk of bedrock in the Robledo and Franklin Mountains. Tertiary volcanics and thick sequences of clastic sedimentary rocks form the major bedrock units of the Dona Ana and southern Organ mountains and the smaller northwestern hills in the basin.

Quaternary olivine basalt flows cover an area of at least 350 square miles in the West Potrillo Mountains. The volcanic field includes approximately 85 cinder cones (Hawley and Kottlowski, 1969a). Several smaller volcanic fields are scattered between the Potrillo Mountains and the Mesilla Valley. The older basalts intertongue with the upper Santa Fe Group. Volcanic explosion features near the western edge of the Mesilla Bolson are delineated as closed depressions. Kilbourne, Hunts, and Phillips Hole are all thought to be explosion features located just east of the East Potrillo Mountains. However, Phillips Hole seems to show no evidence for a volcanic origin (King et al, 1971).

The Santa Fe Group in the West Mesa area overlies Tertiary volcanic and associated rocks of early Oligocene to Miocene age and underlies the Quaternary deposits that postdate the beginning of the Rio Grande Valley entrenchment in the middle Pleistocene (Hawley et al., 1969b). The Santa Fe Group consists of alluvial, fluvial, playa, and lacustrine deposits made up of clay, silt, gravels, caliche, and volcanic ash. Thicknesses of approximately 3,800 ft have been documented on the West Mesa (Myers and Orr, 1985). Near the Robledo, Organ, and Franklin mountains, the gravely alluvial fan facies predominates. The fluvial facies predominates in the western basin and wedges out against the East Potrillo Mountains and the Aden-Sleeping Lady Hills to the west and northwest, respectively. The Quaternary valley fill which overlies the Santa Fe Group generally grades upward from very gravelly at the base to sandy at the top and rarely exceeds 80 ft in thickness. The valley fill is also referred to as river alluvium.

CHAPTER 3

HYDROLOGY

Hydrologic Literature Review and Derivation of Model Parameters

Various authors have described the hydrologic characteristics of the Mesilla Bolson and surrounding area. King et al. (1971) described the water-bearing characteristics of the valley fill relating the geology of the study area to the geohydrology. Wilson et al. (1981) also discussed the geology, groundwater movement, dissolved solids in groundwater, surface-groundwater relationships, and the use of water resources in the study area. Peterson et al. (1984) devised a representative quasi-three-dimensional flow of the aquifer using a water budget with groundwater recharge and discharge values. Myers and Orr (1981) presented a study of the geohydrology, aquifer characteristics, direction of groundwater flow, and groundwater chemistry of the region. Published data from the USGS Mesilla Bolson investigation by Nickerson (1986) and Myers and Orr (1985) were also obtained.

The Model Grid

The model grid is shown in Figure 2 overlain on a map of the study area. Grid spacing is proportionally closer in the area of the Mesilla Valley where river and drain leakance and areas of commercial, municipal, and agricultural pumpage put the greatest stress on the system. A mainframe graphics package was used to contour values of river and drain leakance and drawdown data in the upper aquifer to visualize the areas which are affected the greatest by future pumping

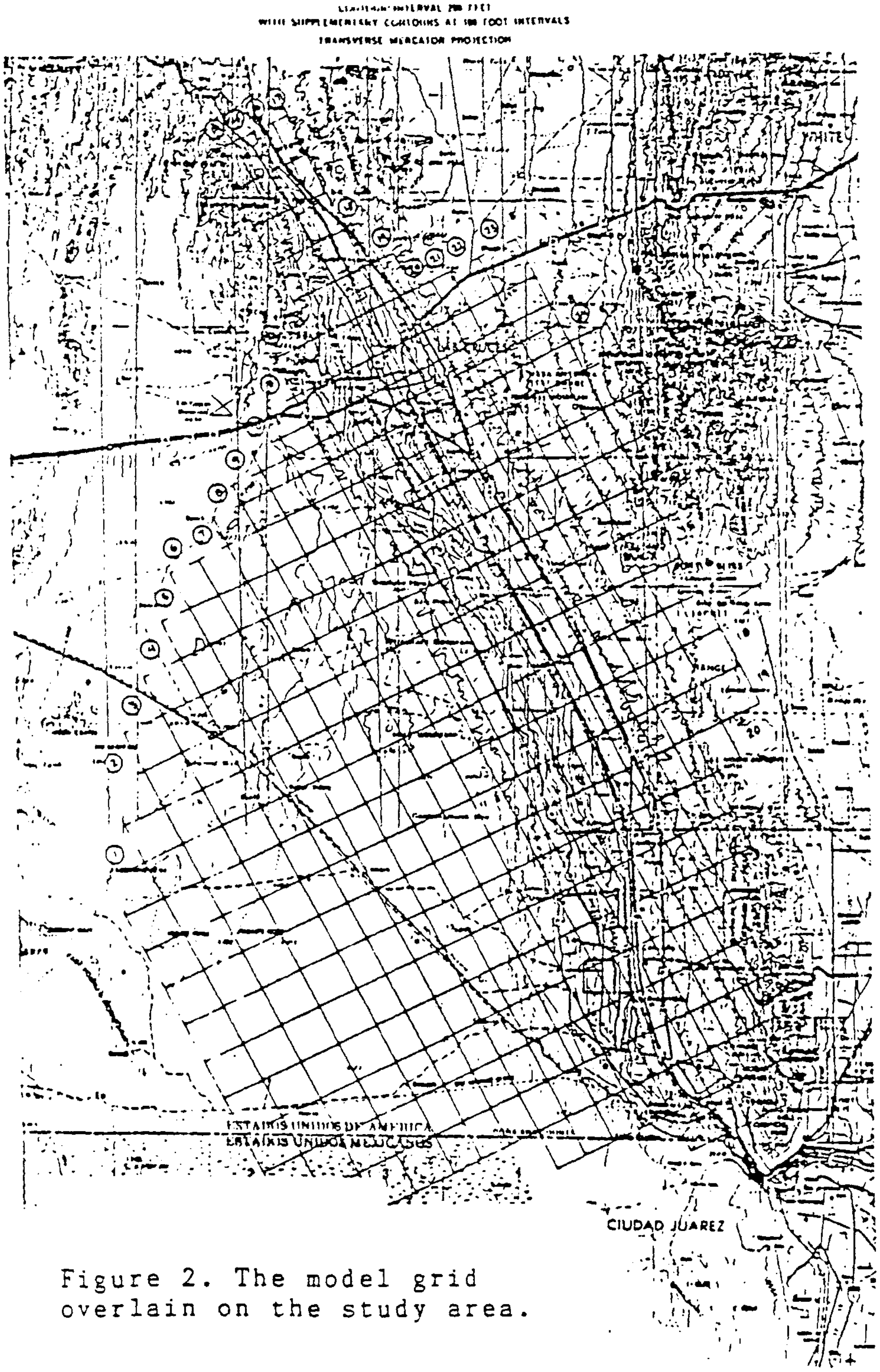

Figure 2. The model grid overlain on the study area.

scenarios. The model grid is shown overlain on the boundary of the contour plot in Figure 3. The model grid was divided into three sections so that river and drain leakance totals and average head and drawdowns were determined for each time step in the model simulation. The three sections in Figure 3 presently isolate areas of relatively intense pumpage. Section 1 contains the areas of Las Cruces and New Mexico State University. Section 2 is mainly an agricultural community with sparsely-spaced small towns. Section 3 contains the Texas-New Mexico border area and also many small towns in El Paso County, Texas along with the Santa Teresa well field of New Mexico.

Groundwater

The alluvial aquifer is unconfined and has an average thickness of approximately 80 feet. The specific yield used in the MODFLOW simulation is based on reports by Updegraff and Gelhar (1977) and Peterson et al. (1984). The hydraulic conductivity of the alluvial aquifer ranges from 60 feet/day near the boundaries of the Mesilla Valley to 200 feet/day under the Rio Grande (Figure 4). The alluvium is underlain by the Santa Fe Group. The storage coefficient of 0.001 for the Santa Fe Group used in the MODFLOW model is based upon Wilson et al. (1981) and Gates et al. (1984). Transmissivity of the Santa Fe Aquifer is variable and is best described by the contour plot in Figure 5. Wilson (1981) has shown that the West Mesa and the Mesilla Valley alluvium is hydraulically connected. Peterson et al. (1984) estimated vertical flow from the alluvium to the underlying Santa Fe to be about 61,000 Acre-feet/year (AFY).

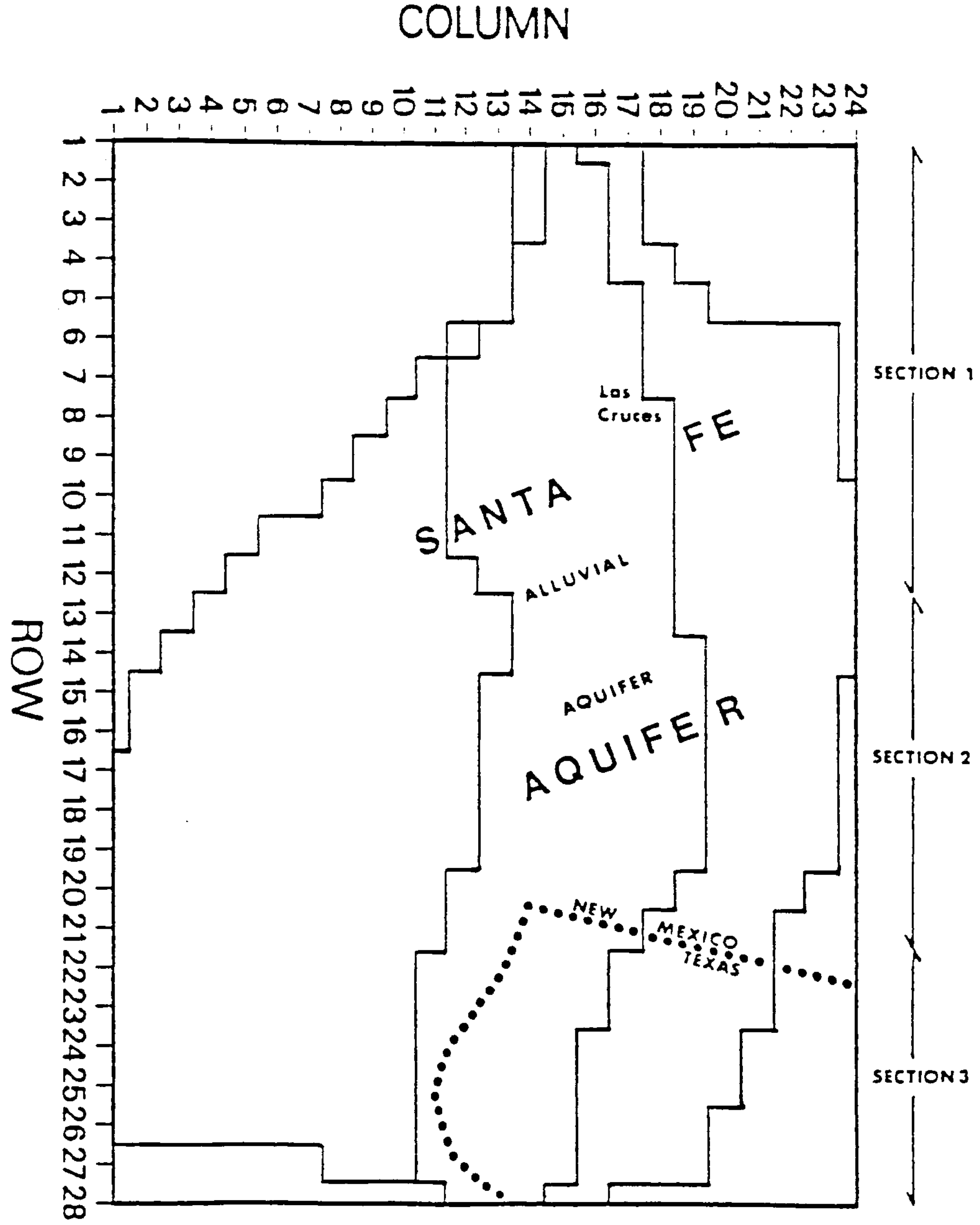

Figure 3. The model grid overlain on the contour plot boundaries. The Santa Fe aquifer encompasses the entire grid while the alluvial or upper aquifer comprises the central portion. Also shown are the division of the upper aquifer into sections 1, 2, and 3 for analysis purposes. Locations of Las Cruces and the Texas-New Mexico border area are approximate.

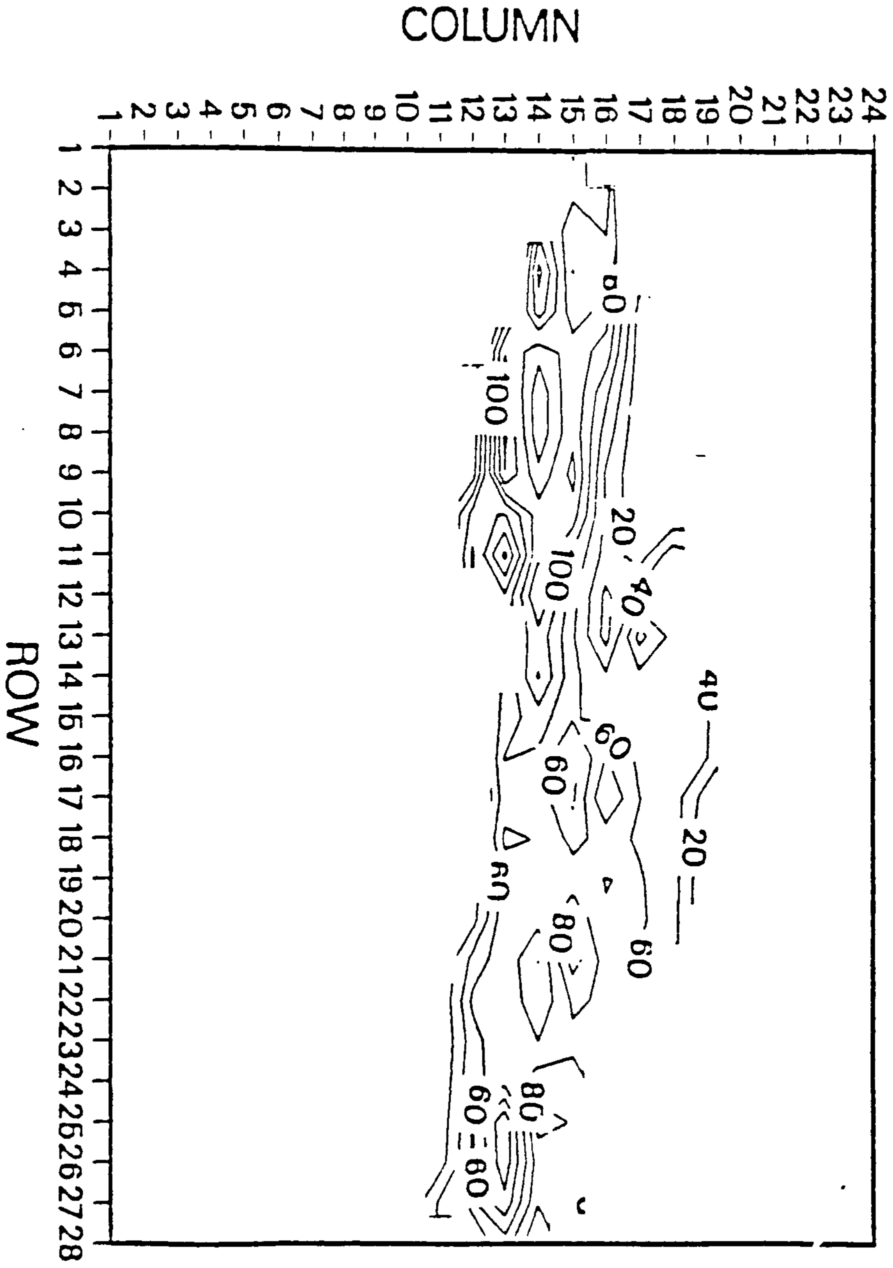

Figure 4. Hydraulic conductivity (feet/day) contour plot of the upper aquifer. Contour interval is 20 feet/day.

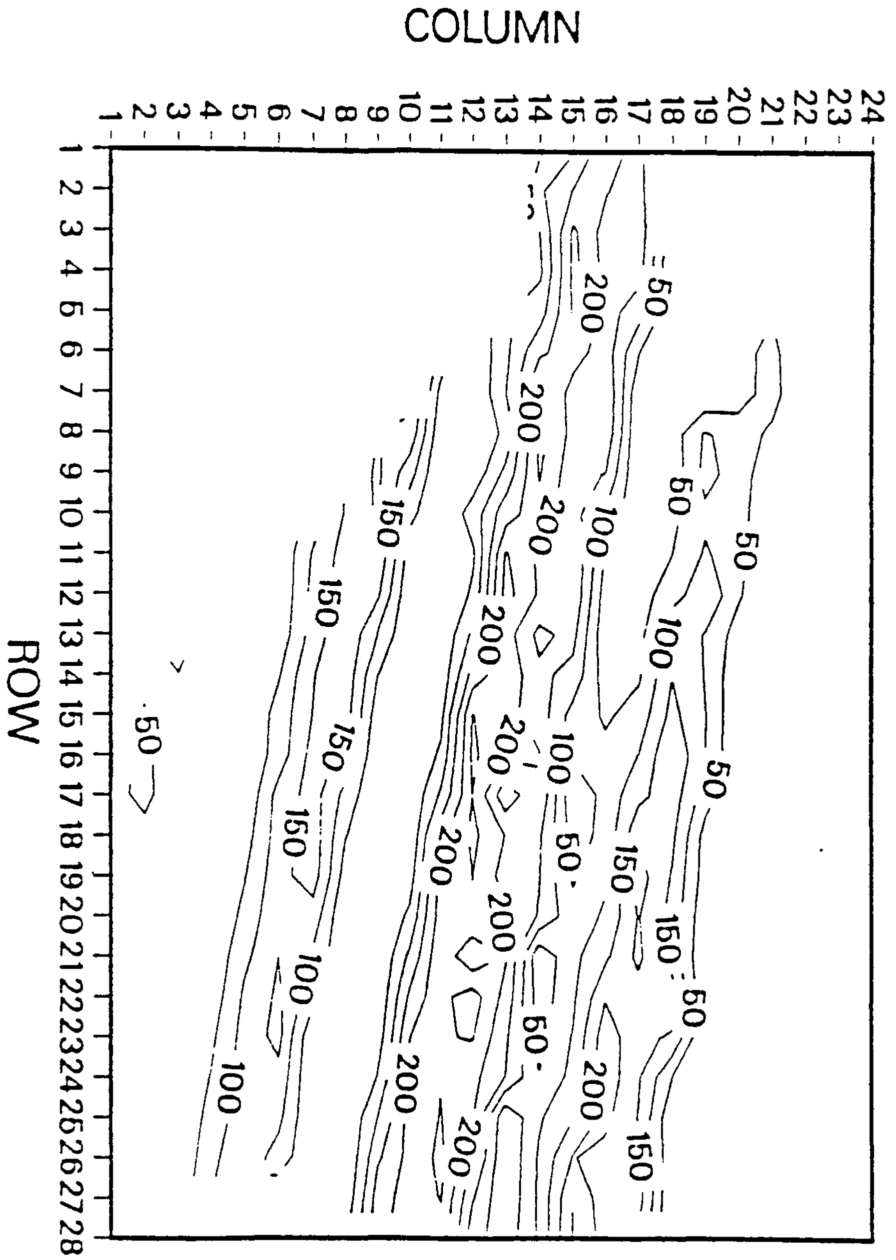

Figure 5. Transmissivity (ft^2/day) contour plot of Santa Fe or lower aquifer. Contours represent hundreds of ft^2/day. Contour interval is 5000 ft^2/day.

Recharge sources include surface water diversions for irrigation, seepage from canals and reaches of the Rio Grande, runoff from mountain areas, and precipitation. Peterson et al. (1984) estimated that total annual recharge is approximately 386,500 acre-feet (AF), 62.5 percent of which comes from irrigation, 30 percent from stream losses, and the majority of the remainder from mountain runoff.

Peterson et al. (1984) estimated present withdrawal of the groundwater system as 386,700 AFY. Evapotranspiration is approximately 43 percent of the total, groundwater pumpage 31.8 percent, drainflow discharge about 25 percent, and the remainder is accounted for by mountain recharge.

Surface Water

Elephant Butte Reservoir serves as a storage reservoir for a hydroelectric power plant at the reservoir outlet. Caballo Reservoir is below Elephant Butte and serves as a storage mechanism for water which is released in proportion to demand downstream. Stored water is released during the irrigation season and diverted into canals for irrigation of approximately 90,640 acres in the agricultural districts of the Rincon and Mesilla valleys in New Mexico and 69,010 acres in Texas and approximately 20,000 acres in Mexico. The limit of irrigable acreage in the EBID remains 90,640 acres, but the actual physical irrigated acreage can change annually. Water is diverted on the east side of the Rio Grande at Leasburg Dam in the Leasburg Canal for distribution in the eastern Mesilla Valley. The Mesilla Diversion Dam diverts water to the eastern and western Mesilla Valley. Annual historical data for stream flow and canal diversions are summarized for the years 1951 to 1986 in Table A-1 (Appendix A). Canal diversions tend to be highly variable due to variable releases from Caballo Reservoir. The river flow at El Paso is essentially a combination of reservoir releases, return flow to canals, return flow of sewage effluent, and ephemeral tributaries.

Excess water and dissolved salts are removed from irrigated farmland in the Mesilla Valley by 12 drains which intercept the shallow groundwater which is subsequently discharged into the Rio Grande. The principal drains include Selden, Leasburg, Picacho, Mesilla, Del Rio, Chamberino, La Mesa, East, Anthony, Nemexas, West, and Montoya. The average total flow of the drains from 1951 to 1986 is 43,002 AFY (Maddock et al., 1987). Table A-2 in Appendix A contains the historical drain flows in the Mesilla Valley.

Water Demand

Surface water is allocated to district landowners in the Rincon and Mesilla valleys by the Elephant Butte Irrigation District (EBID). EBID allocates surface water based on ownership of land with water rights appurtenant to the land. EBID also owns the rights to groundwater wells but, since 1980, the five active EBID wells have been capped, and no groundwater has been allocated to EBID water users from groundwater sources. The major reason EBID originally obtained groundwater rights was to ensure adequate supply to irrigators in times of drought.

Supplemental private irrigation pumping records are virtually non-existent. Due to the lack of pumping data, the Blaney-Hanson method was used to estimate consumptive water use, thereby providing an estimate of the amount of water needed to augment surface water deliveries. The method uses crop type, mean monthly temperature, monthly precipitation, and monthly percentage of daylight hours to estimate consumptive crop water use. The New Mexico State University Agricultural Experiment Station (1968) calculated consumptive use requirements for crops in the Mesilla Valley. Annual crop production was furnished by the U.S. Bureau of Reclamation (1987) and EBID.

The total estimated pumping for irrigation is given by Maddock et al. (1987) as 110,650 AFY. The total indicates that a small portion of land (5,500 acres) in the EBID is irrigated exclusively by groundwater. Data on the distribution of irrigation pumpage for the upper and lower aquifer were simply unavailable as was the spatial distribution of pumpage in the Mesilla Valley. The irrigated pumpage is assumed to be divided as 60 percent from the alluvium and 40 percent from the Santa Fe Group. The distribution of irrigation pumpage was assumed to be uniform over the Mesilla Valley.

Supplemental irrigation pumpage of the El Paso Water Improvement District No. 1 within the southern study area is estimated as 8,300 AFY based on acreage reported by Esslinger (1987). Municipal pumpage from the Canutillo well field in the Mesilla Bolson for El Paso averages approximately 20,000 AFY (Hickerson, 1981). The Santa Teresa well field serves commercial and municipal customers and currently averages about 2,000 AFY (Hernandez, 1987). Leyendecker (personal communication to Thomas Maddock III, 1987) gives the current demand by Las Cruces for municipal and industrial purposes as approximately 15,000 AFY. New Mexico State University is estimated as 1,970 AFY. Hernandez et al. (1987) estimated municipal and commercial pumpage in the study area outside of Las Cruces, Santa Teresa, and New Mexico State University as 3,700 AFY. Table 1 summarizes the preceding estimates of pumpage.

Table 1. Summary of pumpage estimates used in the MODFLOW groundwater model (after Maddock et al., 1987)

	Acre-Feet/Year
New Mexico Primary and Supplemental Irrigation Pumping	110,600
Texas Supplemental Irrigation Pumping	8,300
Las Cruces	15,000
Santa Teresa	2,000
Canutillo Well Field	20,000
Dona Aña Municipal, Industrial, Commercial	3,700
New Mexico State University	1,970

Future pumping estimates were developed by Maddock et al. (1987) and are listed in Table A-3 (Appendix A). All model input data for all scenarios simulated are listed on 5.25-inch floppy diskettes included in the pockets of this thesis.

CHAPTER 4

THE GROUNDWATER FLOW MODEL

The McDonald-Harbaugh model (MODFLOW) was implemented to simulate the effects of variable pumping scenarios on river-canal (river) and drain leakance and drawdown and head data on the upper aquifer alluvium. The main purpose of this thesis is to quantify the location, amount, and timing of the surface water leakance and pumpage effects to the upper aquifer for varying pumping scenarios. Three pumping scenarios were considered: (1) future pumping of the Mesilla Bolson, (2) future pumping of the Mesilla Bolson in addition to proposed El Paso pumpage, and (3) future pumping of the Mesilla Bolson in addition to 50 percent of the proposed El Paso pumpage.

The McDonald-Harbaugh MODFLOW model (1984) simulates three-dimensional flow using a parameter set of transmissivity, hydraulic conductivity, storativity and conductance, and in this case, irregular boundaries and non-homogenous boundary conditions. As the MODFLOW name indicates, the model consists of several separate modules or subroutines to simulate river and drain flow, well pumpage, and evapotranspiration. MODFLOW is capable of solving linear equations by two methods: the Strongly Implicit Procedure (SIP) and Slice-Successive Over-relaxation (SSOR).

The governing partial differential equation of groundwater flow (Todd, 1980; Freeze and Cherry, 1979) used in MODFLOW is well known among the hydrologic community as:

$$\frac{\partial}{\partial x} \quad (K_{xx}(\hat{x},z) \frac{\partial}{\partial x} (\hat{x},z,t))$$

$$+ \frac{\partial}{\partial y} (K_{yy}(\hat{x},z) \frac{\partial h}{\partial y} \quad (\hat{x},z,t) \frac{\partial}{\partial z} \quad (K_{zz}(\hat{x},z) \frac{\partial h}{\partial z} \hat{x},z,t)) \tag{1}$$

$$= S_p(\hat{x},z) \frac{\partial h}{\partial t} (\hat{x},z,t) + Q(\hat{x},z,t)$$

where

$h(\hat{x},z,t)$ = hydraulic head at time t at location $(\hat{x},z)$,

$\hat{x}$ = (x,y), the location of x and y coordinates,

$K_{xx}(\hat{x},z)$
$K_{yy}(\hat{x},z)$ = hydraulic conductivity in the x, y and z
$K_{zz}(\hat{x},z)$ principal coordinate directions, respectively, at point $\hat{x}$,

$S_p(\hat{x},z)$ = specific storage at point $(\hat{x},z)$ and

$Q(\hat{x},z,t)$ = source term at point $(\hat{x},z)$ at time t.

The x, y, and z axes are assumed to be aligned with the principal directions which eliminate all K_{ij} terms for all $i \neq j$. The x and y are assumed horizontal, and the z is assumed vertical.

The Model Specific to the Study Area

The grid for the study area is overlain on the map of the study area shown in Figure 2. The grid contains 446 active block-centered flow cells. The upper aquifer alluvium consists of 151 nodes with the same block-centered flow configuration as the Santa Fe Group below. The upper aquifer alluvium is generally agreed to be separated from the lower Santa Fe Group by a semi-permeable confining zone (Wilson et al., 1981), thereby simulating a quasi-three-dimensional flow regime. Each of the two layers simulated require using a set of parameters such as hydraulic conductivity, (K) transmissivity (T), and storativity (S). The two layers are hydraulically connected through the semi-permeable confining layer by a vertical leakance term K_z/b, where K_z is the vertical conductivity and b is the thickness. The semi-permeable confining zone was assumed to have negligible horizontal flow and storativity, while the two aquifer layers are assumed to have horizontal flow only.

The upper aquifer alluvium is essentially confined in areal extent to the Mesilla Valley and where it is classified as an unconfined aquifer. The following equation of Bredehoeft and Pinder (1970) is applicable to the unconfined aquifer of the alluvium:

$$\frac{\partial}{\partial x} \left(K_{xx}(\hat{x})h_1(x,t) \frac{\partial h_1}{\partial x} (\hat{x},t)\right) \frac{\partial}{\partial y} \left(K_{yy}(\hat{x})h_1(\hat{x},t) \frac{\partial h_1}{\partial x} (\hat{x},t)\right)$$

$$= S_y (\hat{x}) \frac{\partial h}{\partial t} (\hat{x},t) + W_1(\hat{x},t) - \frac{k_z}{L} (h_1(\hat{x},t) - h_2(\hat{x},t) \qquad (2)$$

where

$h_1(\hat{x},t)$ = the hydraulic head in the upper aquifer alluvium, and $h_2(\hat{x},t)$ is the hydraulic head in the Santa Fe Group,

$K_{xx}(\hat{x})$ and $K_{yy}(\hat{x})$ = the $\hat{x}$ and y hydraulic conductivity, respectively, vertically averaged over the initial saturated thickness of the alluvial aquifer,

$S_y(\hat{x})$ = the specific yield and $W_1(\hat{x},t)$ are the sources, sinks or volumetric flux of recharge of withdrawals per unit area of the alluvial aquifer.

Equation 2 above is based on the Dupuit assumptions and a free surface boundary condition. The Dupuit assumptions are as follows: (1) $h(\hat{x},z) = h(x,y) = z$ on the free surface or, in other words, for small inclinations of the surface flow lines are horizontal and, (2) dh/dx and dh/dy are constant with depth, or the change in head in the horizontal direction will remain constant. Assuming that the hydraulic head gradients in the x and y (horizontal) are small, the free surface boundary condition becomes:

$$S_y(\hat{x})dh/dz = -K_{zz}(\hat{x})dh/dz$$

where the terms are defined in Equation 2 above.

The groundwater flow equation applied to the Santa Fe Group aquifer is based on a confined aquifer and takes the form of the following equation:

$$\frac{\partial}{\partial x}\left(T_{xx}(\hat{x})\,\frac{\partial h_z}{\partial x}(\hat{x},t)\right) + \frac{\partial}{\partial y}\left(T_{yy}(\hat{x})\,\frac{\partial h}{\partial y}(\hat{x},t)\right)$$

$$= S_c(\hat{x})\,\frac{\partial h}{\partial t} + W_2(\hat{x},t) + \frac{K_z}{L}\left(h_1(\hat{x},t) - h_2(\hat{x},t)\right) \tag{3}$$

where

$T_{xx}(\hat{x})$ and $T_{yy}(\hat{x})$ = transmissivity in the x and y direction, respectively, isotropic conditions were assumed so that $T_{xx}(\hat{x}) = T_{yy}(\hat{x})$.

$S_c(\hat{x})$ = storage coefficient,

$W_2(\hat{x})$ = source, sink or volumetric fluxes of recharge or withdrawals per unit area of the Santa Fe Aquifer.

Model Parameters

The upper aquifer parameters used in the model are hydraulic conductivity and specific yield. These parameters are used along with a storage coefficient for the Santa Fe Group. The leakance parameter (L) is expressed for the confining zone as follows:

$$L = K_z/b$$

Parameter estimates for the initial steady-state calibration were based on estimates from Wilson et al. (1981), Gates et al. (1984), Conover (1954), Updegraff and Gelhar (1977), and Peterson et al. (1984).

Figure 3 contains the distribution of the hydraulic conductivity for the upper aquifer which ranges from 60 to 200 ft/day adjacent to and under the Rio Grande. The specific yield used in the simulation was 0.21.

Wilson et al. (1981) described significant thicknesses of clay and other fine-grained semi-permeable material bounding the top of the Santa Fe. Therefore, the Santa Fe aquifer is currently believed to be, and was taken as, a confined aquifer in the simulation. The transmissivity of the Santa Fe aquifer is variable, and spatial estimates in the study area were taken from Wilson et al. (1981) and Peterson et al. (1984). A storage coefficient of 0.001 was used for the Santa Fe based on Wilson et al. (1981) estimates. In some cases of heavy pumpage of the lower Santa Fe aquifer, the upper aquifer was essentially pumped dry. In this case, the lower aquifer becomes unconfined, and the equation governing flow becomes Equation 2. A storage coefficient of 0.21 is assigned in this case.

The hydraulic conductivities and thickness of the confining layer have been investigated by Wilson and White (1981). These authors indicated a range of hydraulic conductivity of 26 ft/day in the northern Mesilla Valley and 58 ft/day in the northcentral valley.

Surface Water Parameters

The river is divided into reaches, each one of which is in a single cell. River leakage is defined between each river reach and the model cell containing that reach. The governing equation for leakance is as follows:

$$Q_{RIV} = C_{RIV}(H_{RIV} - h_i)$$

where

Q_{RIV} = leakance through the reach of the riverbed,

H_{RIV} = river stage,

h_i = head on the aquifer side of the riverbed, and

$C_{RIV} = \frac{K_b L_R W}{M}$, the conductance of the riverbed.

where

K = the hydraulic conductivity of the river bed,

L = length of the reach,

W = the width of the river, and

M = thickness of the river.

When the water level drops below the bottom of the river bed, the head on the aquifer side of the riverbed is equal to the elevation of the bottom of the riverbed (R_{BOT}). In this case, the equation becomes:

$$Q_{RIV} = C_{RIV}(H_{RIV} - R_{BOT})$$

Each of the 64 drain nodes requires specification of the elevation of the drain and the drain bed conductance. Drain elevations are approximately 5 to 6 feet below the stages in the river. All of the drain nodes are located within the Mesilla Valley.

Remaining Modules and Parameters

The evapotranspiration (ET) is expressed in terms of flow into the aquifer as:

$Q = 0$ when $h < \text{Exel}$

$Q = \text{EVTR}(h - \text{EXEL})/\text{EXPD}$ when $\text{SURF} \geq h \geq \text{EXEL}$

$Q = \text{EVTR}$ when $h > \text{SURF}$

where

Q = the ET rate,

h = the head in the aquifer,

EXEL = the extinction elevation,

SURF = the ET surface elevation,

EXDP = the extinction depth, and

EVTR = the maximum ET rate.

The word 'extinction' used in the context of ET simply means the cessation of ET. Values of ET from Peterson et al. (1984) were used in the simulation. The ET rates were assumed to be constant with a value of 562 ft^2/day. The extinction depth was also assumed constant at 15.00 ft with the ET surface approximating the land surface.

Virtually all irrigation in the study area occurs on the alluvium. A portion of the irrigation water contributes to the upper aquifer recharge. Peterson et al. (1984) used an alluvium recharge rate of 0.0037 ft/day which was used in the model simulation.

Model Runs and Calibration

Steady State

A steady-state model run (scenario 1) was done to calibrate the model according to existing hydraulic head using the pumpage totals discussed previously. A 60 percent ratio of irrigation pumpage was assumed to be pumped from the upper aquifer and the remainder from the Santa Fe Group. Ninety percent of the Canutillo pumpage is assumed to come from the Santa Fe and 10 percent from the alluvium. All pumpage from Las Cruces, Dona Ana County, and New Mexico State University for municipal, industrial, and commercial purposes was assumed to be from the Santa Fe aquifer.

Hydrographs by Maddock et al. (1987) indicate the mean annual water levels of the groundwater in the alluvial aquifer show no net trend over the last 40 years. Nickerson (1986) and Wilson et al. (1981) also indicated no annual trends over time. While it is true that the upper aquifer water levels may vary in wet and dry years, in general, the average levels will remain constant over a period of years.

The initial hydraulic head data used in the simulation were based on Wilson et al. (1981) and King et al. (1981). For the first simulation used, the heads on the boundary of the Santa Fe were set to a constant value, and the model results were compared to published maps of hydraulic head by Wilson et al. (1981) and King et al. 1971. The model parameters were adjusted until an acceptable fit to the published head values was obtained. The second model run replaced the constant head values with general head boundary cells to produce the constant fluxes.

Transient Model Run

A general head boundary consists of a source of water outside of the study area which supplies water to a cell at a rate proportional to the head difference between the source and the cell. The transient solution runs replace the general boundary conditions by flux boundaries calculated by the General-Head Boundary package of MODFLOW. By creating an artificially-high elevation for the boundary source head, H_b, of 10^7, the rate at which water is supplied a cell is given as:

$$H_b = C(H_b - h_i)$$

where

$$C = \frac{Q}{H_b}, \text{ and}$$

Q = flux derived from the steady-state solution.

The pumping projections listed in Table A-3 (Appendix A) assume that the future pumpage is derived exclusively from the Santa Fe aquifer. Three different pumping scenarios were developed to simulate 100 years of stress at 10-year intervals. Scenario 2 includes pumpage increases only from those wells which have currently been granted permits in the Mesilla Bolson. Scenario 3 includes scenario 2 in addition to the pumpage of all proposed El Paso wells. Scenario 4 includes scenario 2 but with only 50 percent of the proposed pumpage of El Paso.

CHAPTER 5

HEAD AND DRAWDOWN

Similar to the leakance data, contour plots were constructed to visualize the locations of greatest impact due to future pumping. The study area was also divided into three sections to facilitate illustration of the magnitude of pumpage impacts in terms of drawdown and head data in the form of two-dimensional curve plots. Figure 3 illustrates the divison of the study area into the northern, central, and southern portions of the Mesilla Valley.

The hydraulic head and drawdown response of the stream-aquifer system to increases in pumpage is in keeping with the supposed good hydraulic connection the Rio Grande has with the upper and lower aquifers in the Mesilla Bolson (Peterson et al., 1984; Wilson, 1981; New Mexico State Engineers Office, 1987).

Head and drawdown data are particularly critical for agriculture in the Mesilla Valley. If increased pumpage lowers the upper aquifer water table beyond the lower level of the drains, salinity of the aquifer can be expected to increase due to the buildup of previously-flushed salts. The water table in the shallow alluvial aquifer fluctuates in response to the application of irrigation water. Generally, the water table fluctuates about 2 feet during the irrigation season, rising and falling in accordance primarily with the amount of irrigation water applied. The average depth to the water table in the Mesilla Valley is presently about 9 feet. A decline of about 3 feet in the average water table depth will cause a cessation in drains in portions of the Mesilla Valley.

In dry years, agricultural pumpage can be expected to increase, and surface water allocation can be expected to decrease; therefore, drawdown of the upper aquifer may increase significantly from the values given at the end of the simulation. For instance, in the drought period of the 1950's, surface water supply was reduced to 0.25 Acre-feet/acre of crop land compared to the present allocation of 3.00 Acre-feet/acre (U.S. Bureau of Reclamation, 1988). Another important point to consider is that the application of proportionally more of this higher salinity groundwater could adversely affect crop yields depending on the magnitude of salinity increase, the relative salt tolerance of each crop and the length of time the crops are exposed to saline influences (Ayers and Westcot, 1985).

Average two-dimensional graphs were developed for sections 1, 2, and 3 to demonstrate the areas of significantly increased drawdowns due to proposed scenario 3 pumpage. The major areas of stress in terms of decreasing head and increasing drawdown data occur in sections 2 and 3.

Head and drawdown data are virtually identical in behavior and relative magnitude; therefore, drawdown will be discussed although the two-dimensional curves for head are also plotted. While the two-dimensional curves show average drawdown, they effectively illustrate the sections which are affected the most by scenario 3 pumping as the following discussion indicates.

Drawdown

The contour plot for upper aquifer section 1 drawdown data for present-day effects (Figure 6) illustrates areas of relatively intense agricultural and municipal pumpage near the Las Cruces area and southward along the areas of the Texas-New Mexico border towns and the Santa Teresa well field just west of the border. Figure 6 represents the first stress period (10 years) of the model simulation. The results for the first stress period remain the same in all scenarios since the proposed pumpage of scenario 3 does not begin until the second stress period (i.e., the 20th year of simulation). Increases in the magnitude of drawdowns in these same areas are evident at the end of the model simulation for scenario 2 (Figure 7). The northern Mesilla Valley has relatively high conductivities and seems to respond to pumpages in the central and southern valley. The area around Las Cruces (rows 7 through 10) increases in both areal extent and magnitude roughly reaching a localized maximum of 10 feet. The most significant drawdown change for scenario 2 occurs just south of the Las Cruces area and along the Texas-New Mexico border region where model simulations indicate local maximum drawdowns of approximately 70 feet. Areas of high hydraulic conductivity (Figure 4) seem to coincide with areas of relatively high drawdowns (Figure 7), suggesting the influence of conductivity on the drawdown distribution. The areal distribution of drawdown due to scenario 2 at the end of the model simulation also extends toward the area of the Santa Teresa well field (rows 23 through 26, columns 8 through 11) at the end of the model simulation.

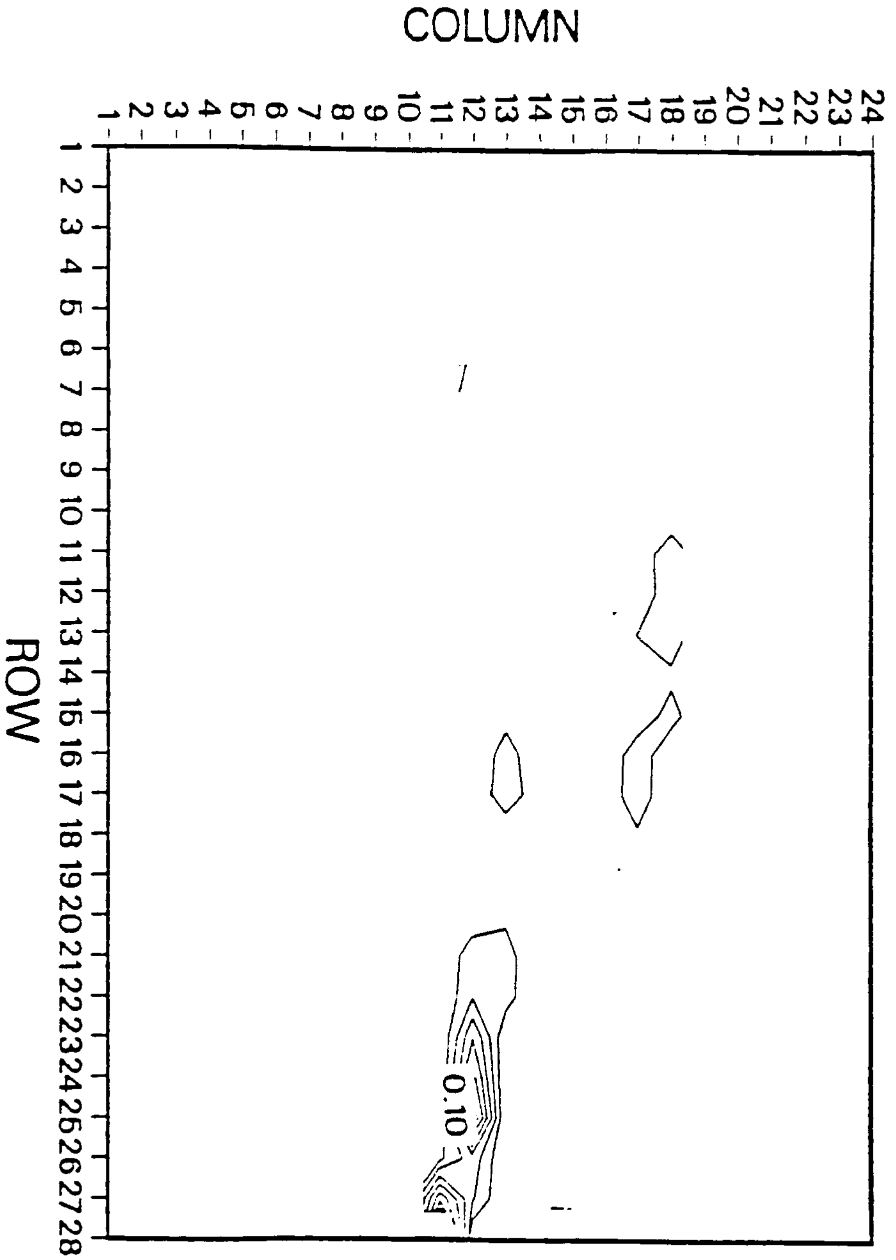

Figure 6. Upper aquifer drawdown contour plot at the end of stress period 1. Contour interval is 0.1 feet. Stress period one is similar for all scenarios since the additional pumping of scenarios 3 and 4 does not start until the second stress period.

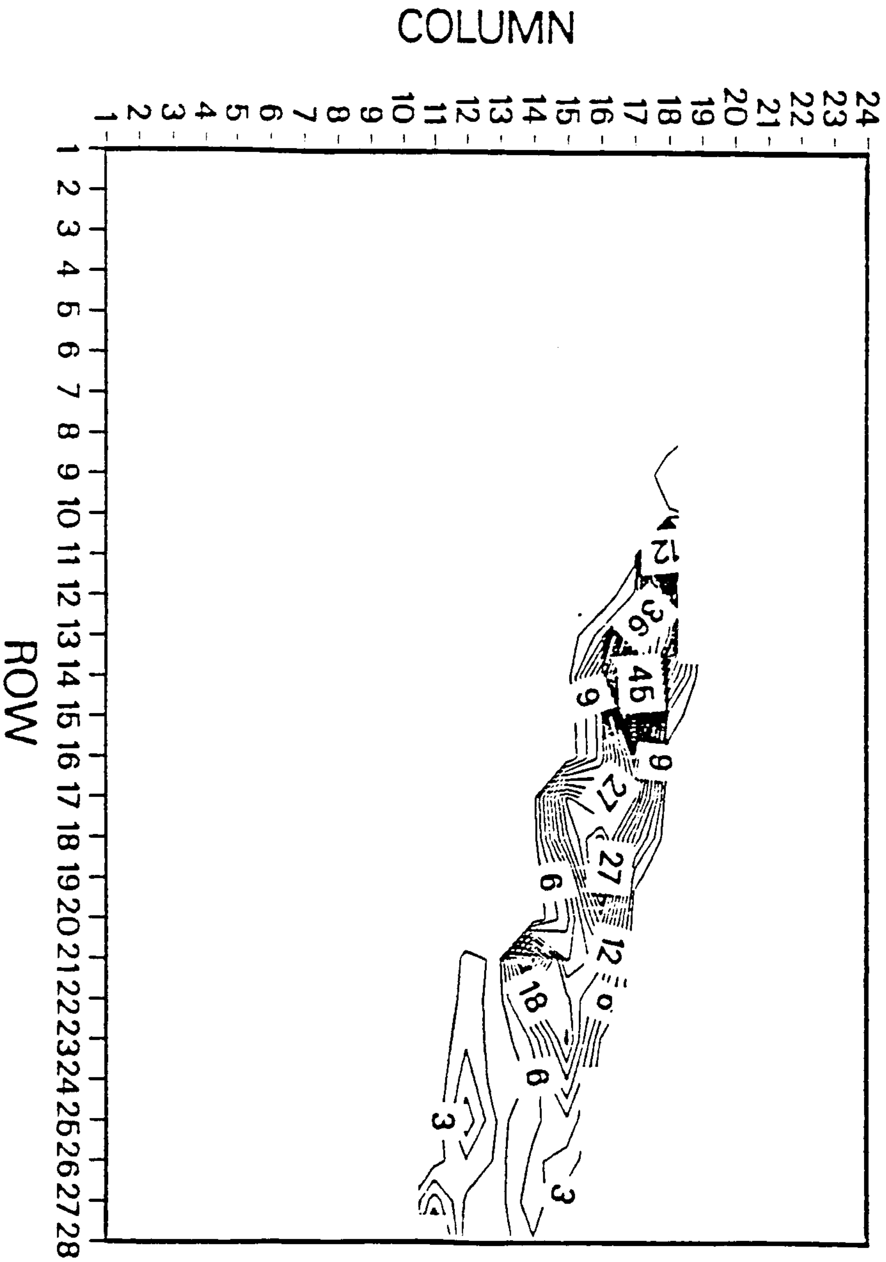

Figure 7. Upper aquifer drawdown contour plot for scenario 2 at the end of simulation. Contour interval is 3.0 feet.

The effects of scenario 3 become apparent when comparing the contour plots of scenario 2 (Figure 7) to those of scenario 3 (Figure 8). The most striking effects of scenario 3 are the increase in areal extent and magnitude of upper aquifer drawdown in the northern (rows 1 through 11, columns 12 through 15), central (rows 13 through 16, columns 12 through 19), and southern (rows 20 through 28, columns 11 through 14) regions of the valley. Figure 9 illustrates the potential effects from the pumpage of scenario 4.

The most concentrated area of drawdown highs for scenario 3 occurs in the Mesilla Valley region of Texas, although parts of the southern upper aquifer (i.e., rows 22 through 24, column 11) adjacent to the Santa Teresa well field, New Mexico are pumped dry; this does not occur in scenario 2 simulation.

The central Mesilla Valley experiences the greatest increase in drawdowns which were virtually nonexistent or quite small (less than 3 feet) in considering only the scenario 2 simulation. Proposed El Paso pumping increases drawdown in the area of the towns of Santo Tomas, Mesquite, and Vado, New Mexico by a maximum of approximately 25 feet in the upper aquifer.

The region near Las Cruces (rows 1 through 9, columns 12 through 16) experiences increased drawdown due to scenario 3 in an area where virtually no drawdown occurs in the simulation of scenario 2.

Two-dimensional plots of average drawdowns for sections 1, 2, and 3 are shown in Figures 10 through 12, while the corresponding head plots are contained in Figures 13 through 15. The two-dimensional average drawdown plot for section 1 (Figure 10) shows little difference

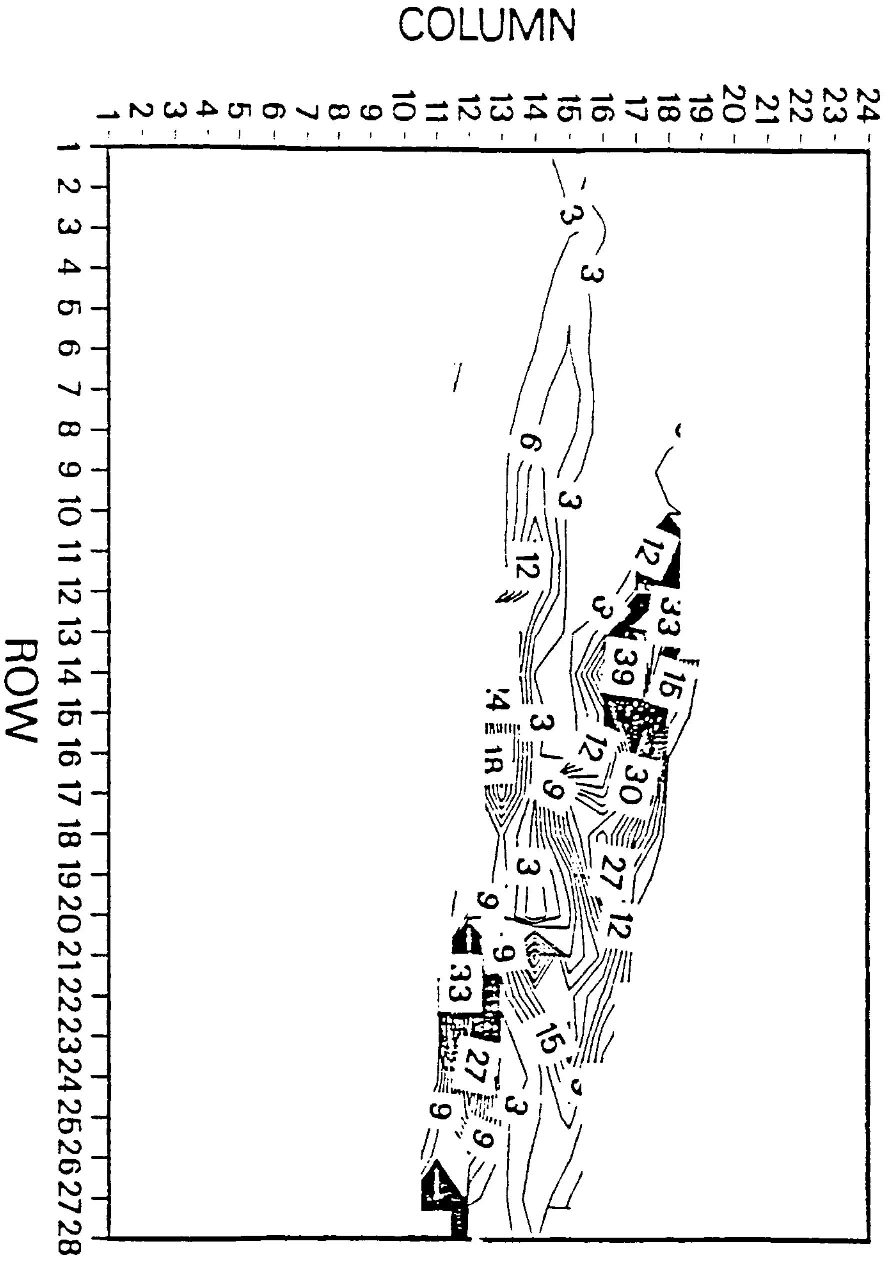

Figure 8. Upper aquifer drawdown contour plot for scenario 3 at the end of simulation. Contour interval is 3.0 feet.

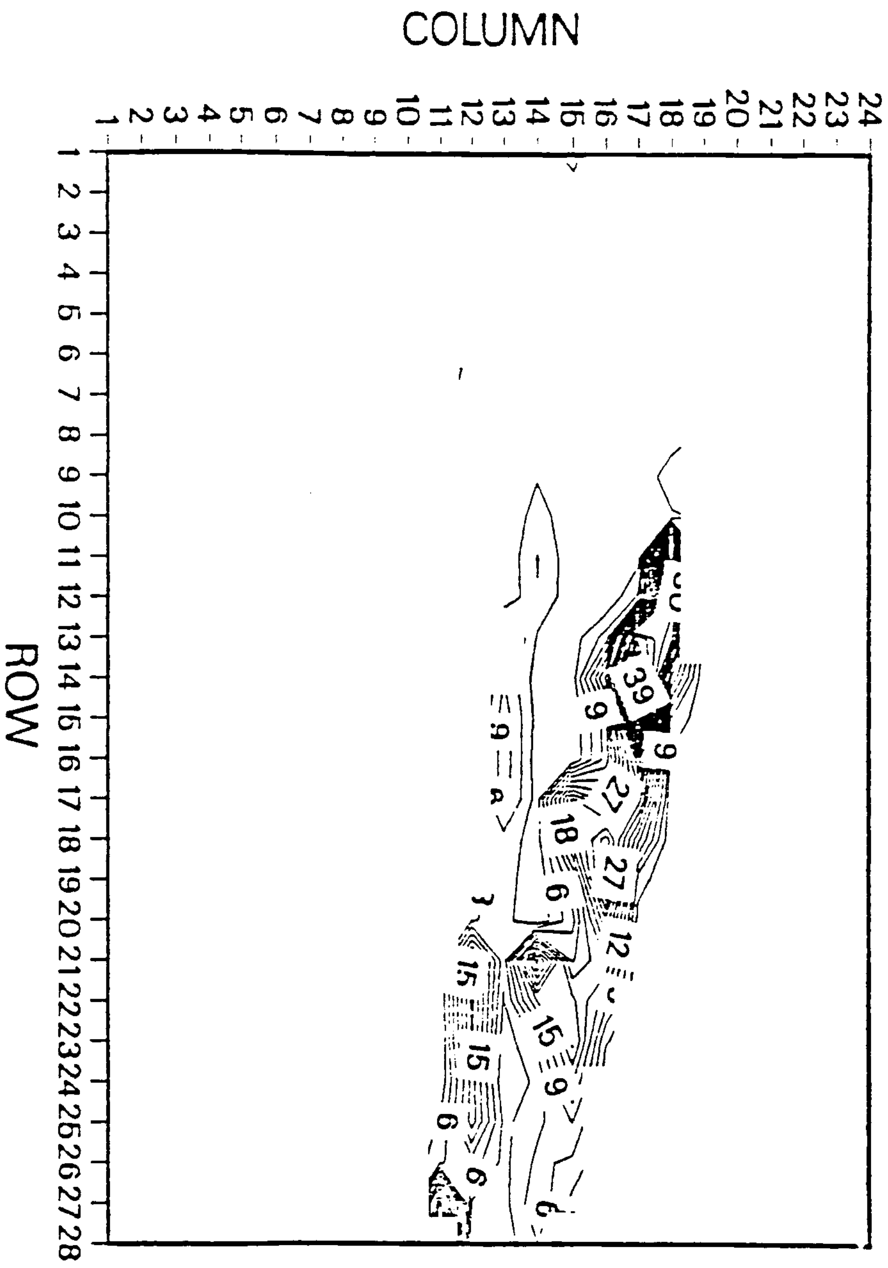

Figure 9. Upper aquifer drawdown contour plot for scenario 4 at the end of simulation. Contour interval is 3.0 feet.

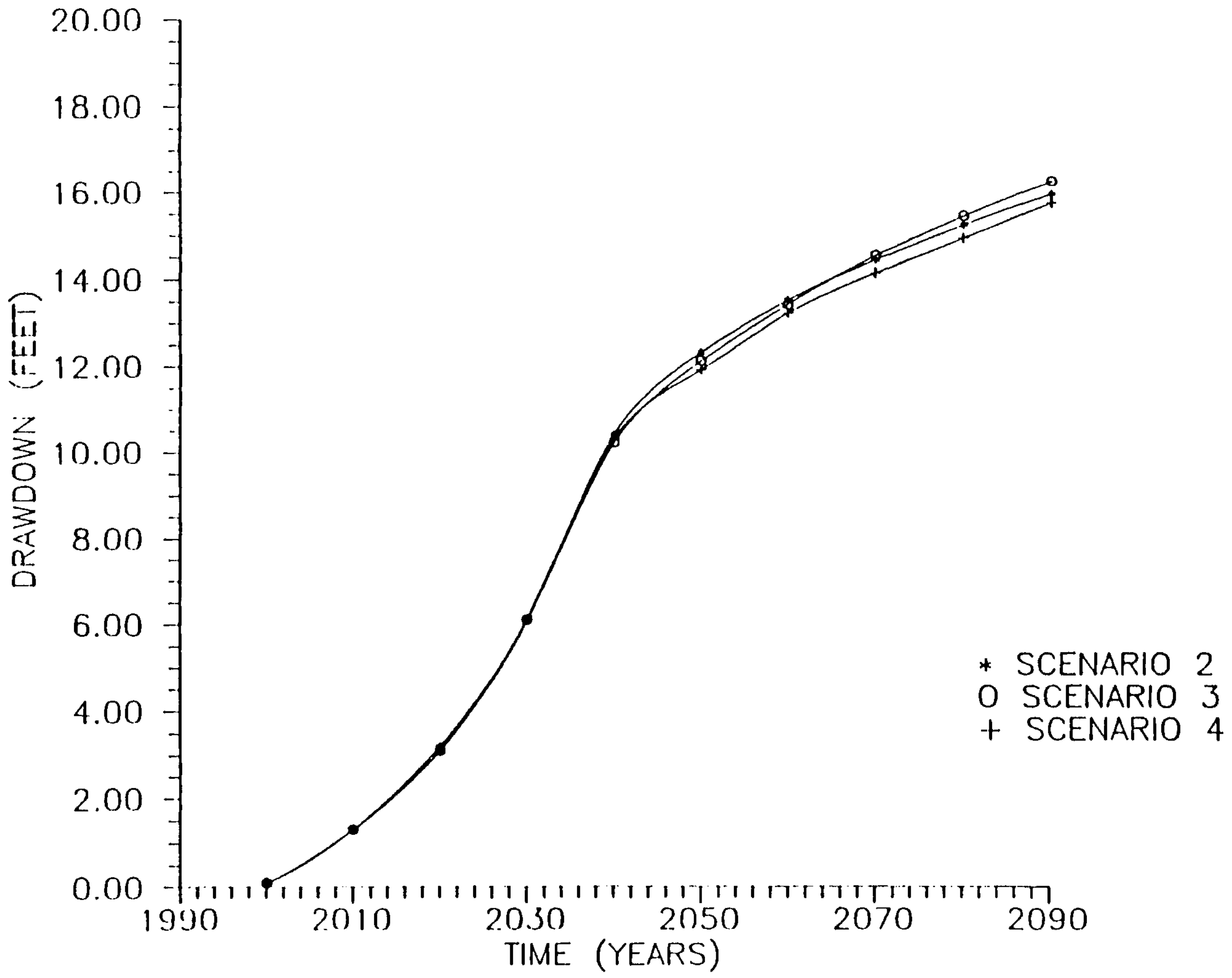

Figure 10. Average drawdown in the upper aquifer through time for scenarios 2, 3 and 4 in section 1.

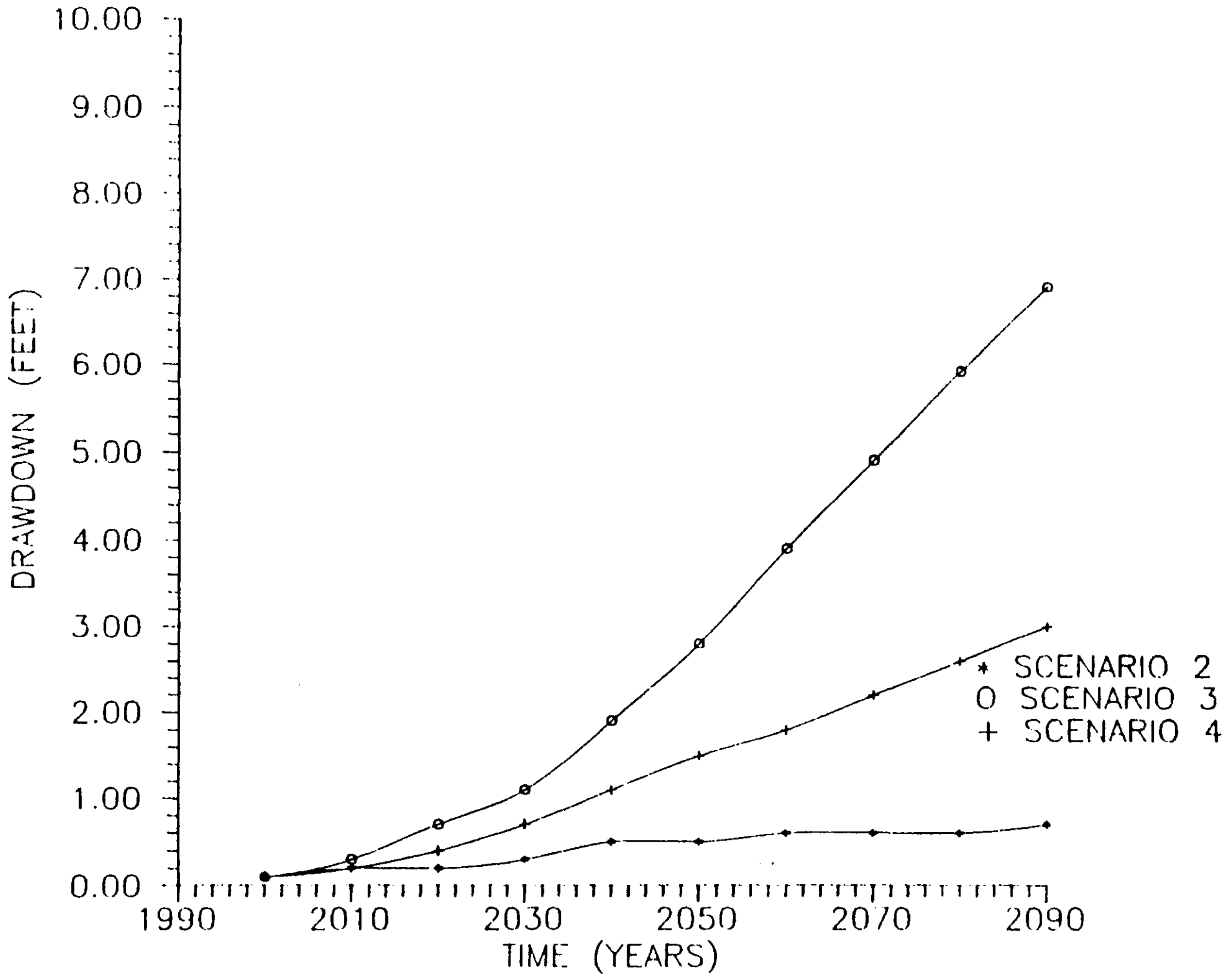

Figure 11. Average drawdown in the upper aquifer through time for scenarios 2, 3 and 4 in section 2.

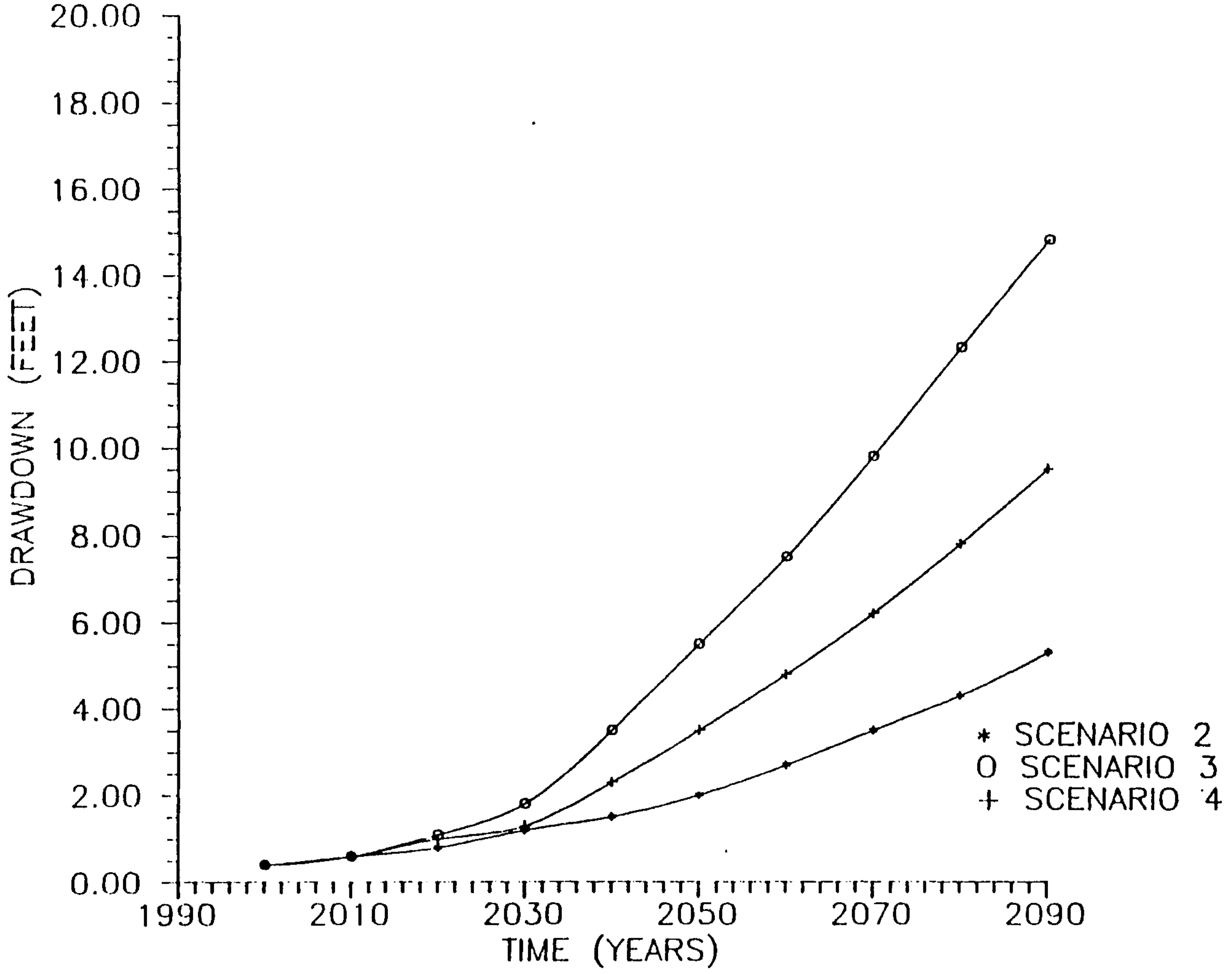

Figure 12. Average drawdown in the upper aquifer through time for scenarios 2, 3 and 4 in section 3.

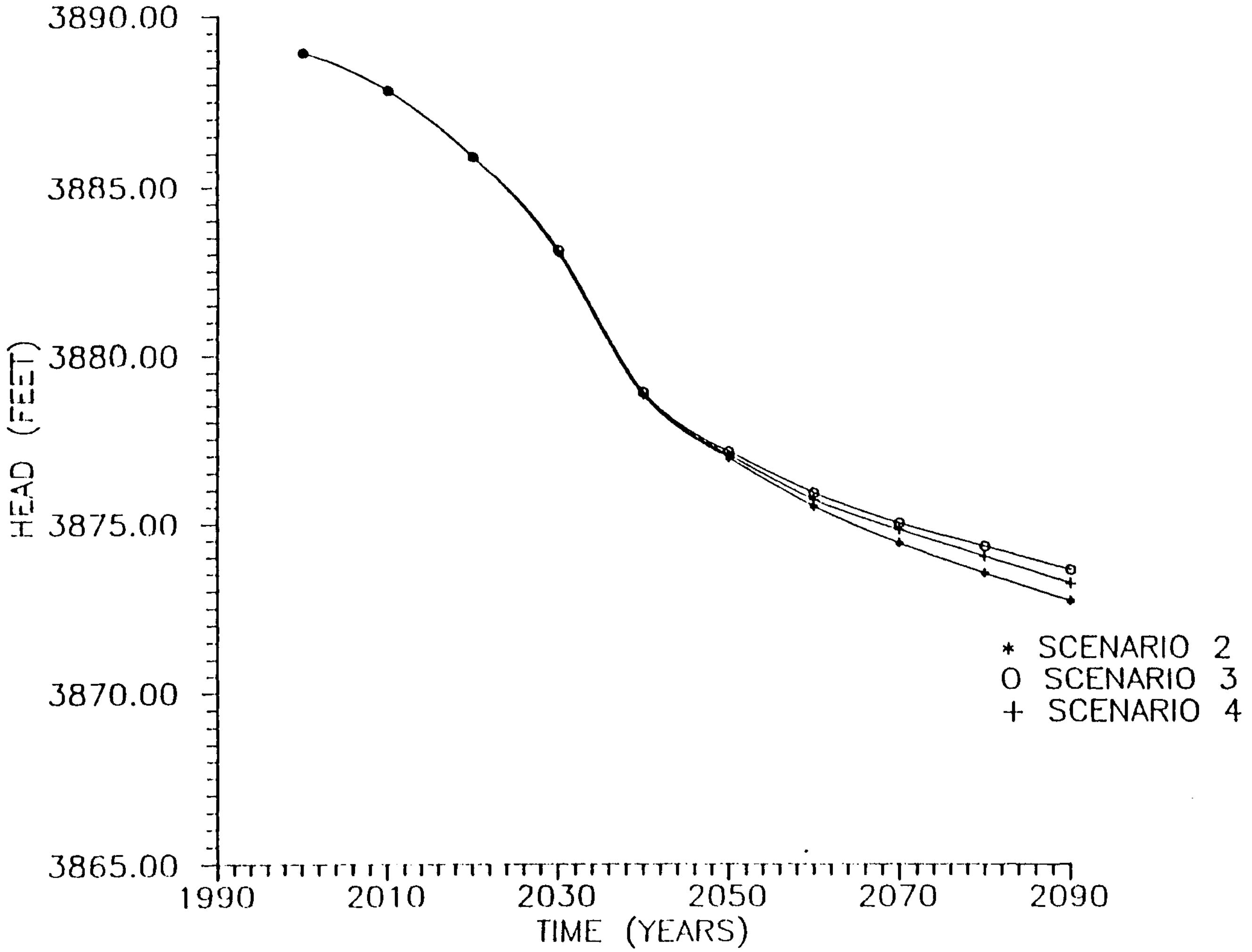

Figure 13. Average head in the upper aquifer through time for scenarios 2, 3 and 4 in section 1.

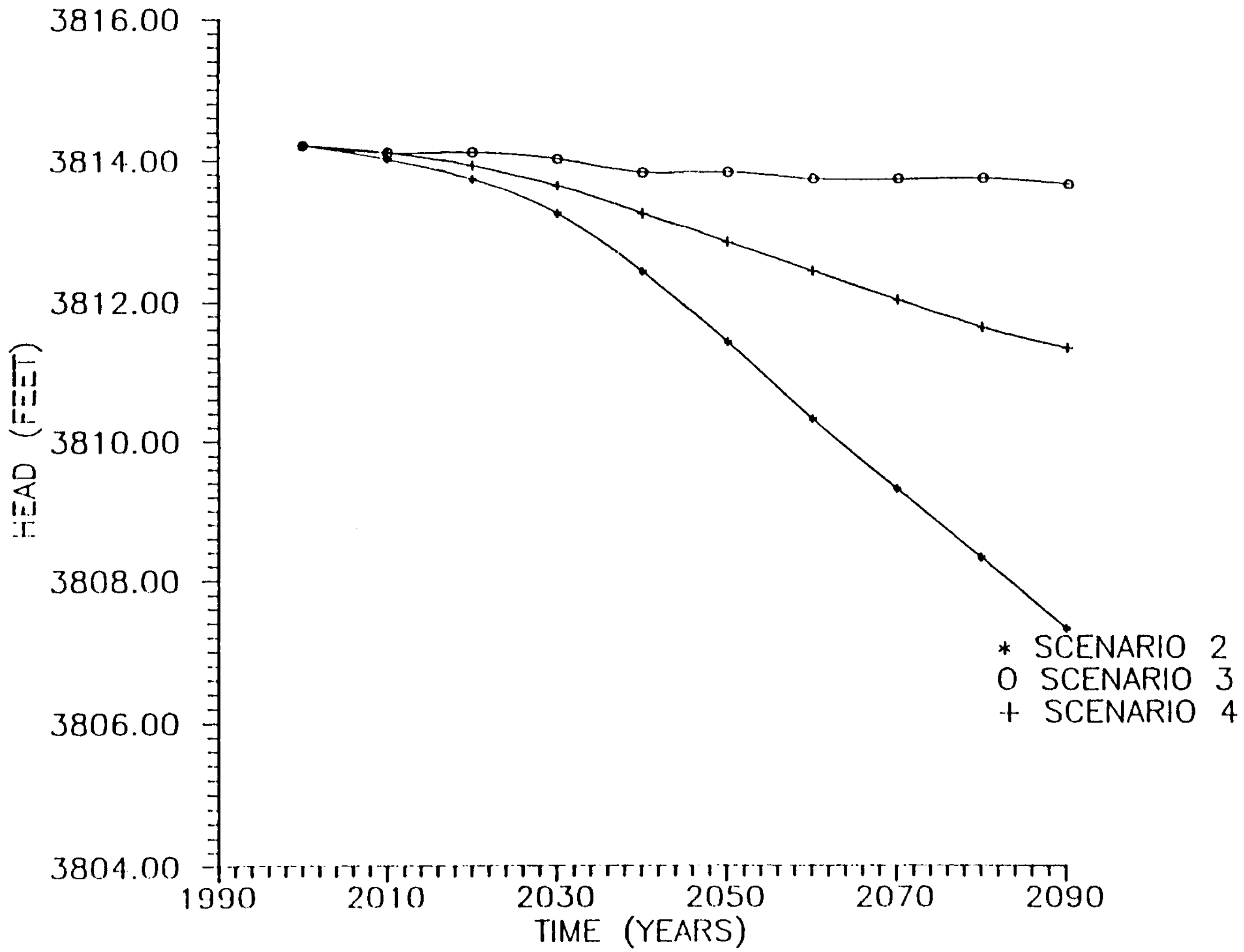

Figure 14. Average head in the upper aquifer through time for scenarios 2, 3 and 4 in section 2.

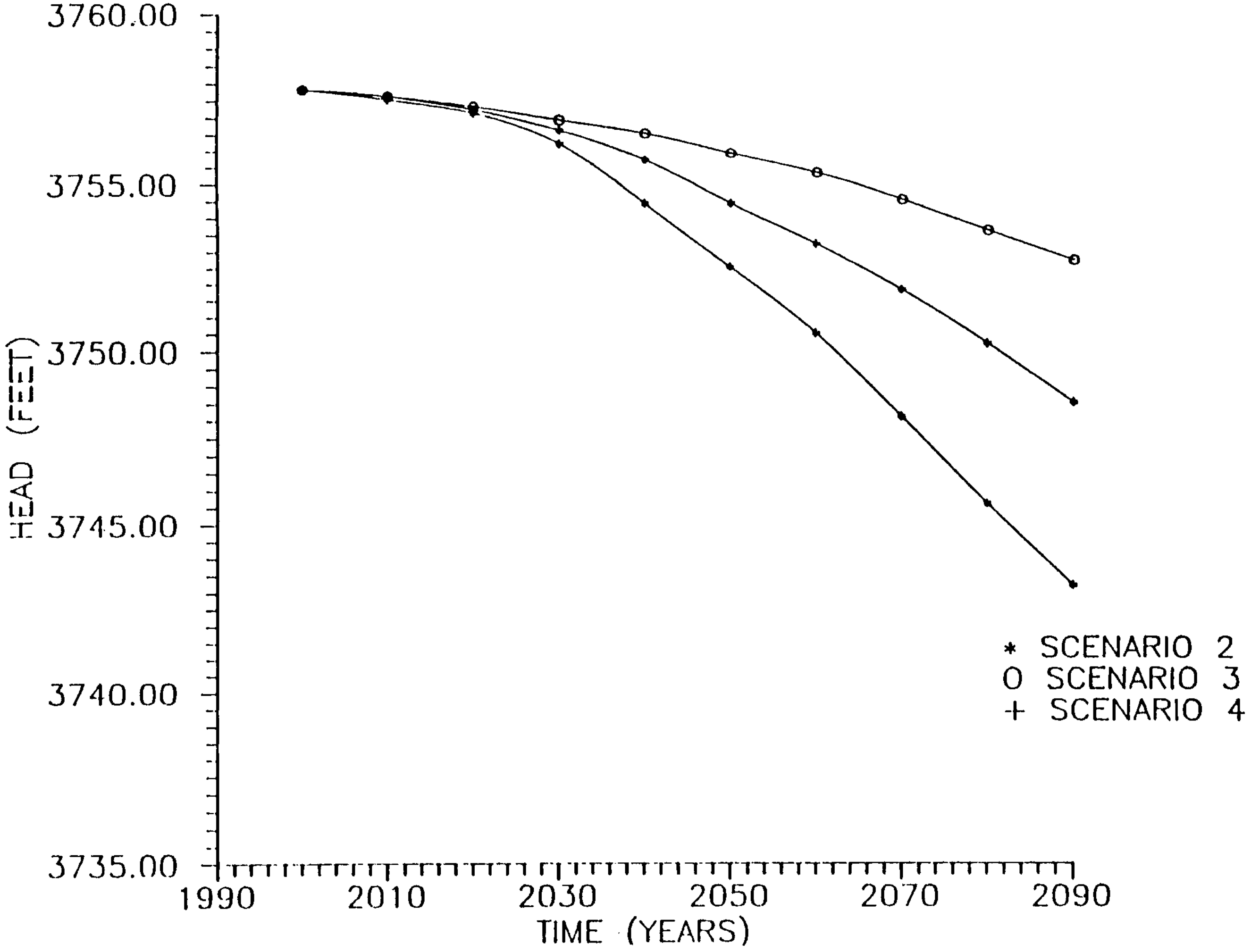

Figure 15. Average head in the upper aquifer through time for scenarios 2, 3 and 4 in section 3.

in average drawdown between scenarios 2 and 3. However, section 1 is in an area of relatively high hydraulic conductivity, and any stress applied to the system seems to be propagated almost instantly as the curves of Figure 10 suggest. Although the average drawdown does not differ markedly for scenarios 2 and 3, the increase in areal extent of drawdown becomes apparent when comparing the contour plots of Figures 7 and 8. Even localized drawdown increases of 3 feet are significant, since the average level of the upper aquifer water table is approximately 3 feet above the level of drains in the Mesilla Valley (Maddock et al., 1987).

Figure 11 shows the average drawdown effects for scenario 3 pumpage on the central Mesilla Valley. While drawdown would remain on the average less than a foot for scenario 2, scenario 3 pumping would increase drawdown by an average of approximately 6 feet. As the contour plot of Figure 8 illustrates, drawdowns in section 2 increase significantly throughout the central portion of the Mesilla Valley. The largest average drawdown occurs in the southernmost portion of section 3. An increase in average drawdown of 10 feet at the end of the model simulation can be attributed to the increased pumpage of scenario 3. The area of heaviest drawdown can be seen in the southern section of the Mesilla Valley near the towns and agricultural districts of the Texas-New Mexico border.

CHAPTER 6

SURFACE WATER LEAKANCE

Introduction

An advanced mainframe graphics package was used to contour leakance data which made the handling of large volumes of data somewhat less arduous. For the purposes of analysis, the model grid for the upper aquifer of the Mesilla Valley was superimposed over the study area and divided into three sections similar to the plots of drawdown and head data. The divisions of the grid into sections were devised to isolate current areas of intense pumping and to illustrate the magnitude and timing of the effects of varying future groundwater pumping.

Future pumping in the Mesilla Bolson (scenario 2) alone was compared to the effects of future Mesilla Bolson pumping in addition to the proposed future pumping of El Paso (scenario 3). Scenario 4 is equivalent to scenario 3 but with only 50 percent of proposed El Paso pumpage included. Scenario 4 is essentially included as a check of the two extremes of scenarios 2 and 3. The contour plots of the first stress period for all scenarios will remain the same since pumping remains constant through the first stress period in all model simulations. Section 1 contains the well fields of Las Cruces and New Mexico State University. Presently, section 2 contains mainly agricultural land and is the area of the least major stress due to pumping in New Mexico. Sections 2 and 3 contain the Texas-New Mexico border towns and agricultural district and is adjacent to a major portion of the proposed El Paso well field. Contour plots of river and drain leakance and drawdown data were constructed to illustrate the spatial distribution of pumpage effects due to scenarios 2, 3, and 4. Two-dimensional leakance plots over time of each separate section serve to demonstrate the temporal effects of scenario 3 on the upper, central, and southern sections of the Mesilla Valley relative to those of scenario 2. To facilitate contouring, the units of the contour lines are the same as the two-dimensional plots: hundreds of acre-feet per year. The two-dimensional plots represent leakance through each simulation period, while the contour plots represent the leakance at the end of the specified simulation period.

Throughout this thesis, it must be kept in mind that the stage of the river is assumed to remain constant in the MODFLOW groundwater model simulation. However, with continued pumping, the river stage can be expected to fall by an amount proportional to the magnitude of pumpage. Essentially, the model assumes a 'best case' scenario which may underestimate such things as the timing of the cessation of drain flows in some areas, and in times of drought (low river flows), the river stage may fall even further and faster than under normal flow conditions.

The Mesilla Bolson is an enclosed river basin. The finer sediment of the southern Mesilla Valley tends to have a lower conductivity than the coarser sediments of the upper basin (Peterson et al., 1984). Contour plots of the leakance data for the drains and rivers over time indicate the areas of maximum flux occur in the middle and southern portion of the Mesilla Valley, although the northern area also shows the effects of scenario 3 pumpage as the following discussion points out.

Rivers

The Rio Grande is considered a losing river (Peterson et al., 1986) in the majority of the study area south of Las Cruces (i.e., one in which the leakance from the river is into the underlying alluvium). The leakance of the river is constrained mainly by the conductance of the river bed for a given amount of pumpage. Therefore, even though pumping may increase stress on the system, river leakance may reach a maximum level.

Currently, the highest areas of leakance (Figure 16) coincide with the more intense areas of pumpage such as around the Las Cruces area (rows 5 through 11 of the model grid) in the northern valley and in the areas around the border-towns (row 18s through 28) in the southern Texas-New Mexico region.

In simulating scenario 2, the Las Cruces area seems to have only a slight increase in river leakance at the end of the modeling period (Figure 17). The largest change in areal extent and magnitude for the leakance of scenario 2 occurs in the border town area which coincides with the southern well fields such as Canutillo, Texas and Santa Teresa, New Mexico. In addition, the leakance of scenario 2 in the central-valley (rows 11 through 18) remains relatively constant in magnitude and areal distribution through the end of the model simulation, as a comparison of Figure 16 and Figure 17 shows.

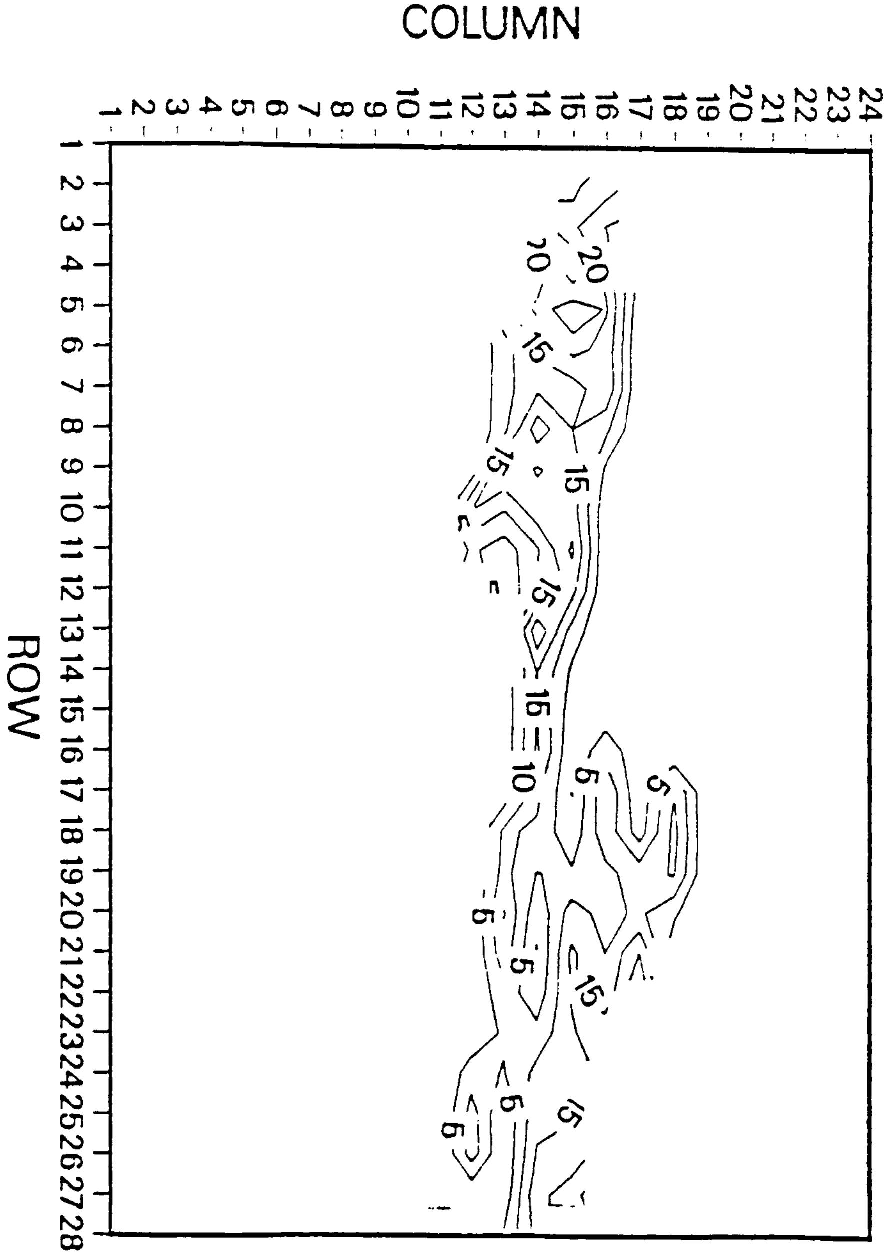

Figure 16. River leakance contour plot at the end of the first stress period. Values are in hundreds of Acre-feet/year. Contour interval is 5.0.

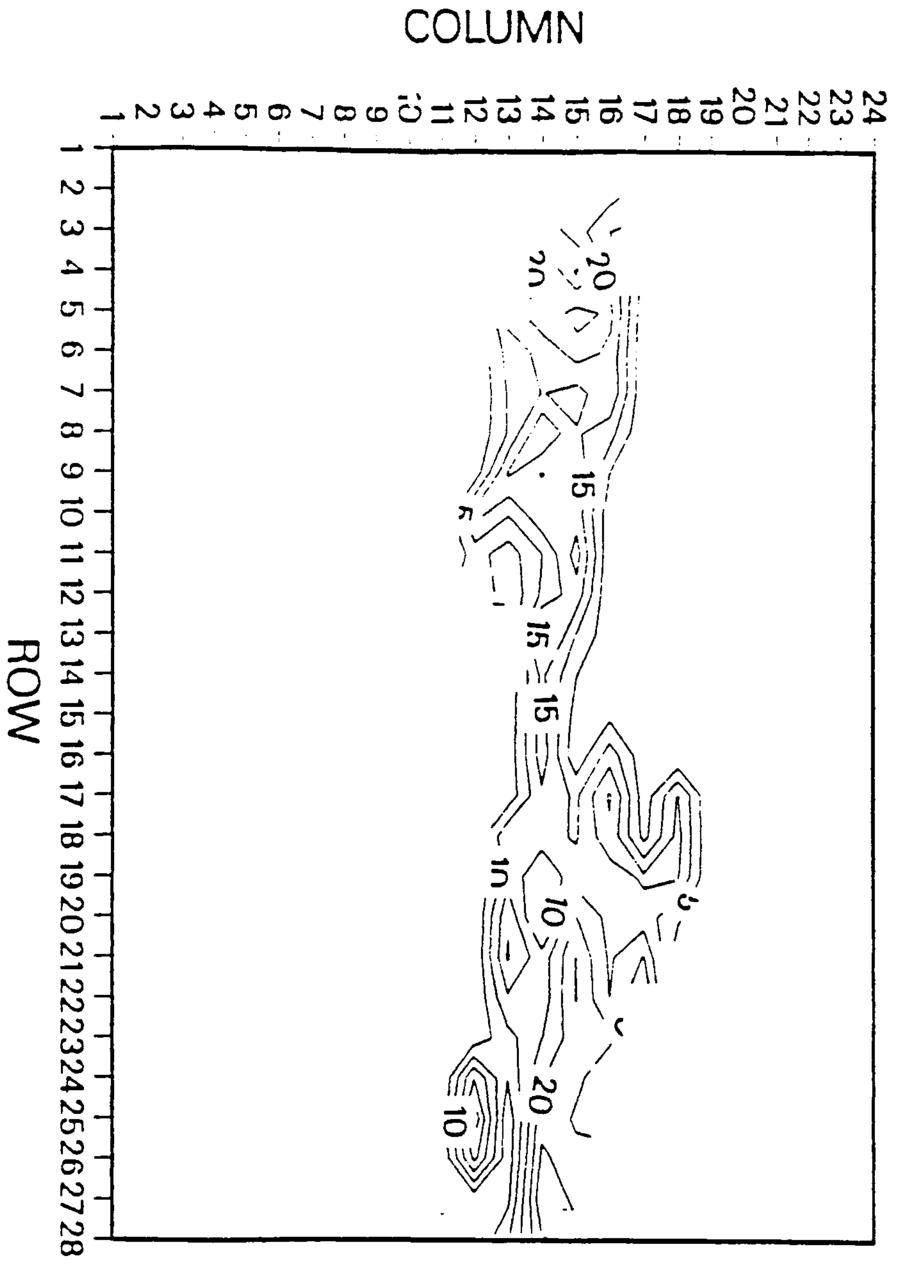

Figure 17. River leakance contour plot for scenario 2 at the end of simulation. Values are in hundreds of Acre-feet/year. Contour interval is 5.0.

Scenario 3 essentially magnifies the effects of the southern border town area, doubling the leakance in one instance of the area just west of Anthony, New Mexico (Figure 18, row 20, columns 12 through 14). In addition, scenario 3 seems to approximately double the leakance immediately north of Las Cruces (rows 2 through 6, columns 14 through 16). The leakance in the central Mesilla Valley (rows 9 through 16) would also be significantly increased with new areas of leakance highs developing, particularly adjacent to the proposed well field of scenario 3 (rows 8 through 18), and near Las Cruces. Figure 19 illustrates the effects of scenario 4 as compared to scenarios 2 and 3.

Table 2 contains the distribution of the additional proposed scenario 3 pumpage in acre-feet/year divided among sections 1, 2, and 3. The pumping for each section remains constant over each 10-year simulation period.

Table 2. Distribution of Proposed Scenario 3 Pumping Over Time For Sections 1, 2, and 3 in Acre-feet/Year.

Year	Section 1	Section 2	Section 3
1990	0.0	0.0	0.0
2000	0.0	35188.0	0.0
2010	0.0	72228.0	926.0
2020	0.0	111119.9	1852.0
2030	926.0	127787.9	25002.0
2040	5737.4	167348.2	25002.0
2050	5737.4	167348.2	25002.0
2060	5737.4	167348.2	72673.8
2070	5737.4	167348.2	72673.8
2080	5737.4	167348.2	72673.8

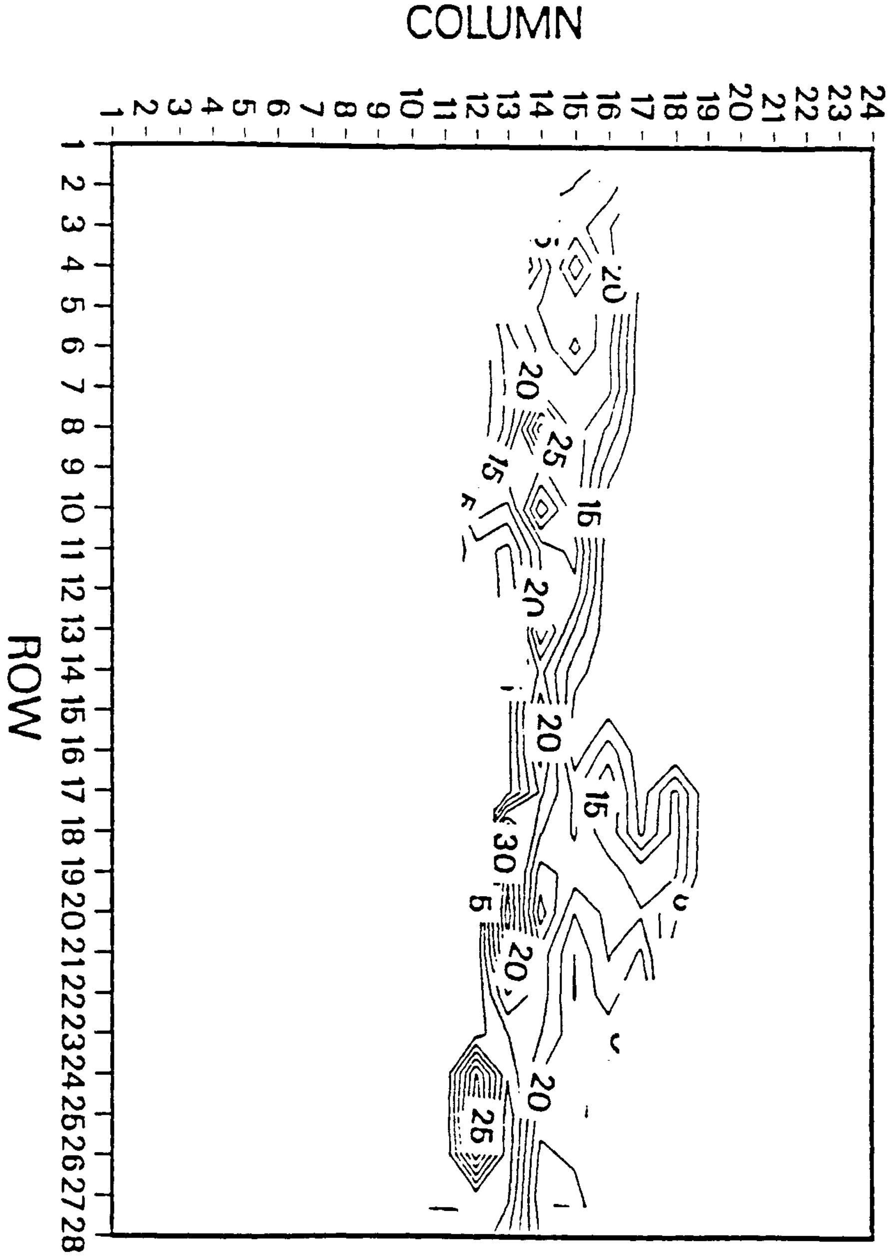

Figure 18. River leakance contour plot for scenario 3 at the end of simulation. Values are in hundreds of Acre-feet/year. Contour interval is 5.0.

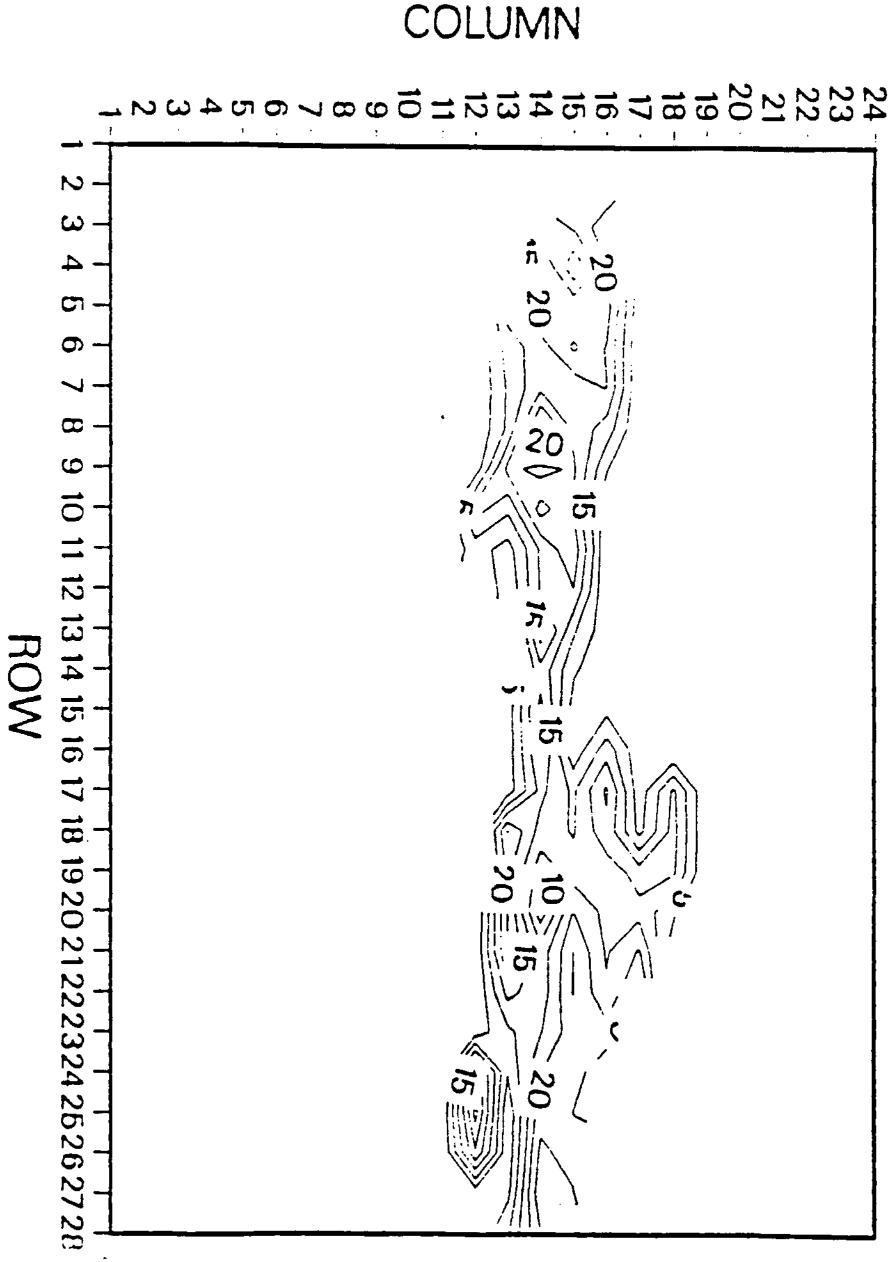

Figure 19. River leakance contour plot for scenario 4 at the end of simulation. Values are in hundreds of Acre-feet/year. Contour interval is 5.0.

The river leakance curves of section 1 diverge slightly after the year 2020 (Figure 20), while pumping does not begin until the year 2030. The beginning of the leakance curve divergence before the initiation of pumping in section 1 suggests a delayed influence on the leakance of section 1 due to section 2 pumpage which starts in the year 2000. When section 1 pumpage actually begins, the divergence of the leakance curves begins to increase significantly. The two leakance curves of scenarios 2 and 3 continue to diverge until the end of the simulation when a maximum difference of about 5,000 AFY is attained.

The river leakance curves in section 2 diverge almost immediately upon initiation of El Paso pumping (year 2000) and reach a maximum difference of 19,500 AFY at the end of the model simulation (Figure 21). The leakance curves for scenario 2, section 1 (Figure 20) seem to have a slight 'dip' just after the year 2080, which again may demonstrate the delayed response of proposed scenario 3 wells pumping in section 2. Leakance for section 3 (Figure 22) does not show any trends toward a decreasing gradient at the end of the model simulation possibly because the largest change in magnitude of scenario 3 pumpage occurs in the year 2060 directly west of section 3 (rows 21 through 25, columns 1 through 4). The upper aquifer surface water leakance system may not have had enough time to adjust to the pumpage affects and simply may not be capable of fully adjusting to such a large increase in pumpage due to maximum leakance constraints of the conductance of the river bed. Actually, some river cells are already at a constant leakance rate (e.g., cells 17,14 and 18,14) for the last 30 to 40 years

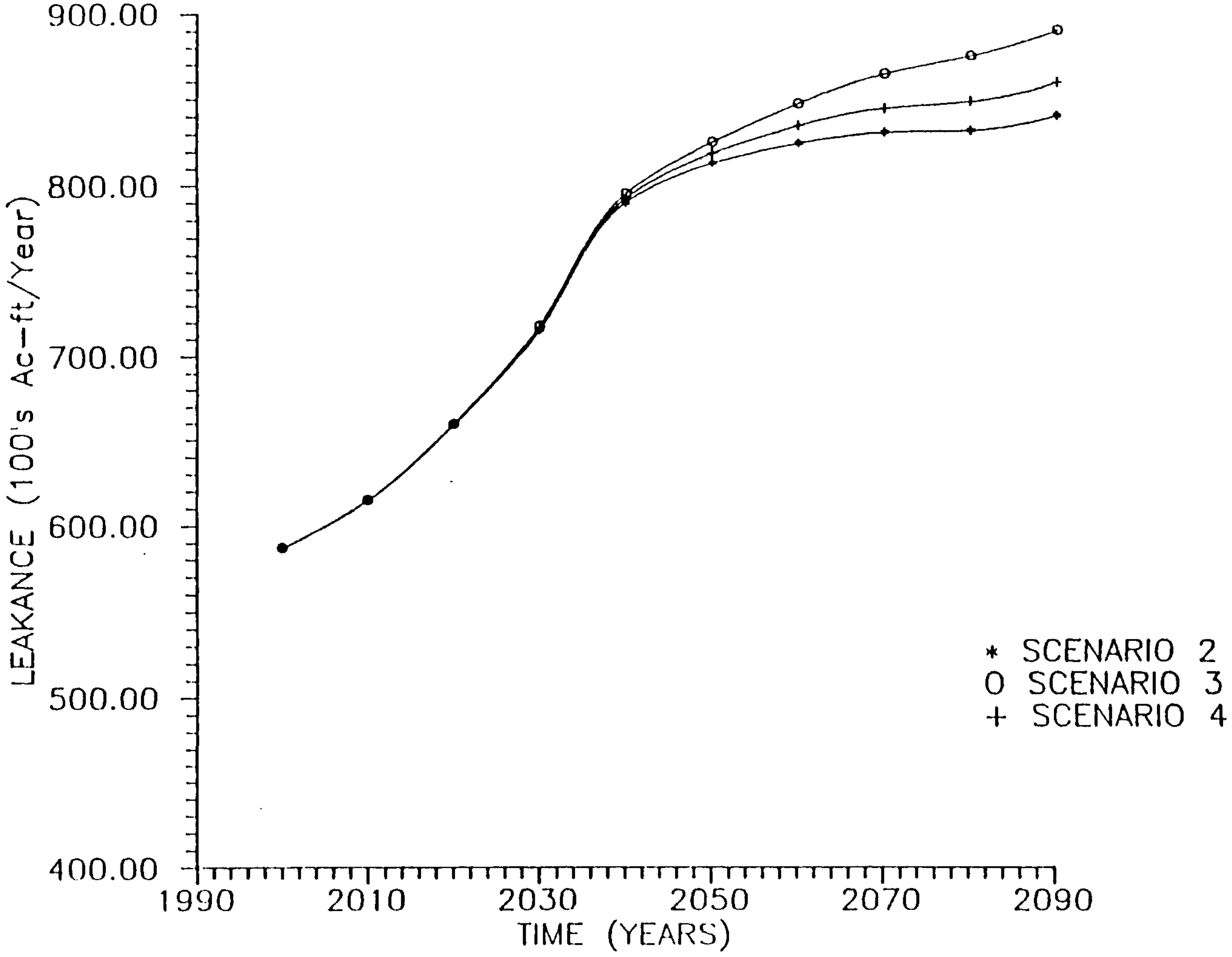

Figure 20. River leakance through time for scenarios 2, 3 and 4 in section 1.

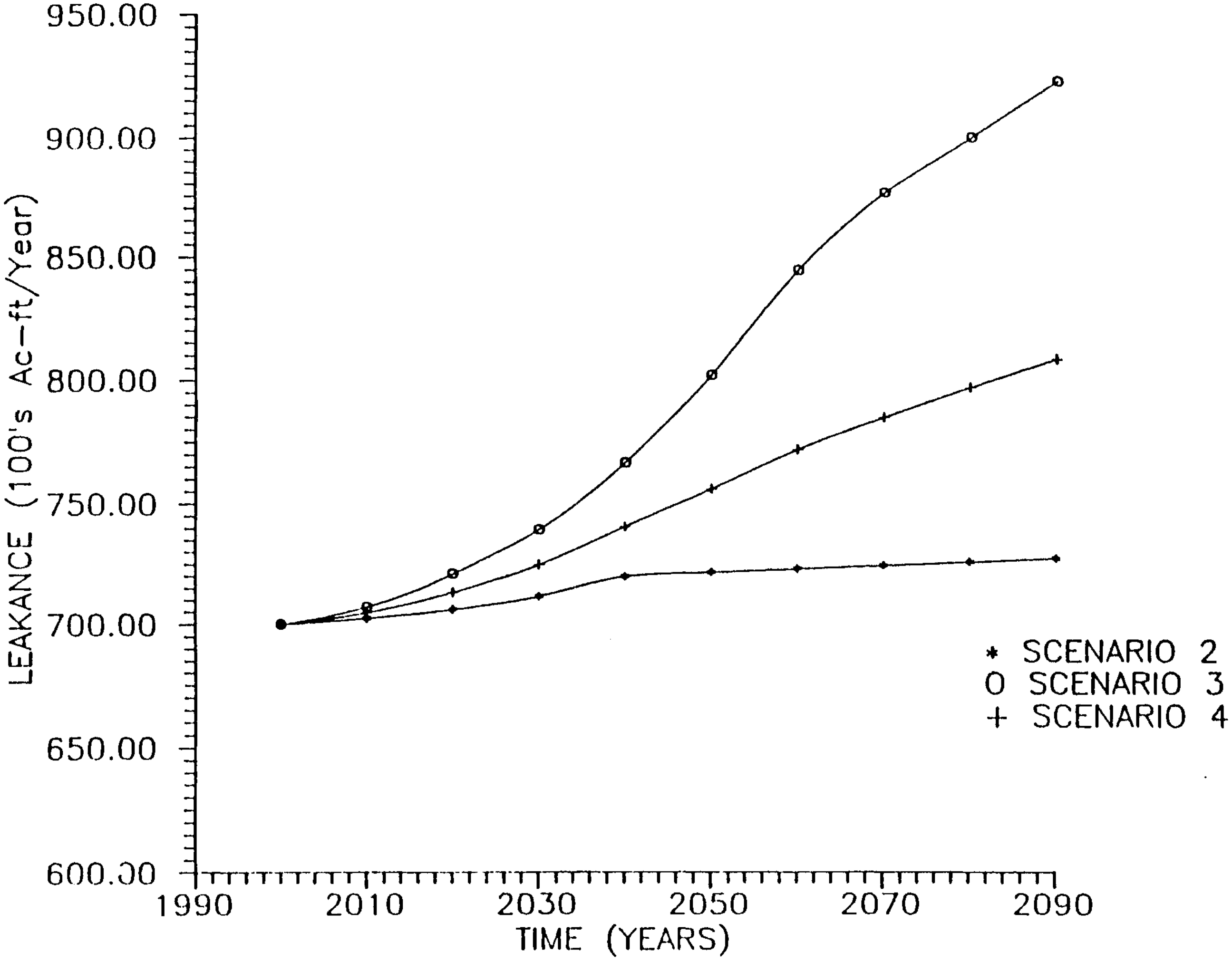

Figure 21. River leakance through time for scenarios 2, 3 and 4 in section 2.

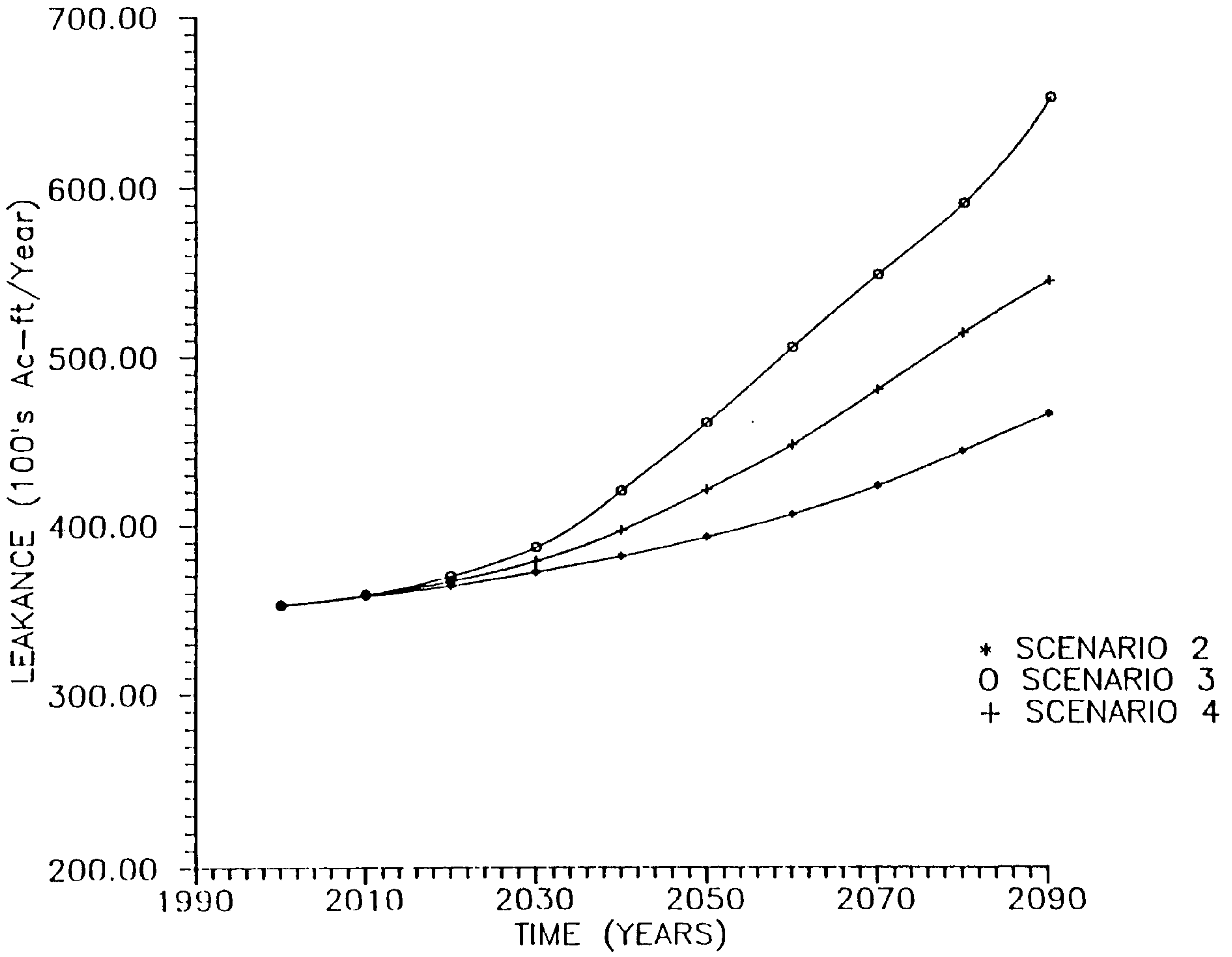

Figure 22. River leakance through time for scenarios 2, 3 and 4 in section 3.

of simulation. The maximum difference reached between the scenario 2 and 3 curves of section 3 is approximately 19,000 AFY.

Drains

The function of the drains in the Mesilla Valley is important for two reasons: they flush the salts from the agricultural soil profile and provide a means of draining excess water from the profile in an agricultural region where the upper aquifer water table is quite shallow (~ 9.0 ft). Present reports (Peterson et al., 1984; Wilson, 1981) consider the flow in the drains to be derived primarily from the shallow groundwater table in the upper aquifer. Maddock et al. (1987) developed a regression equation (correlation coefficient: -0.93) for the flow of the drains as follows:

$$F = -30.8D + 370$$

where

F = flow in the drains in thousands of acre-feet per year, and

D = average depth to the water table in feet below land surface.

The above equation indicates that the drains will cease to flow when the water table declines to a mean depth of approximately 12 feet. The average depth to the water is presently approximately 9 feet. In other words, a decline of about 3 feet in the average water table level could result in the cessation of drain flow in portions of the Mesilla Valley.

Negative values of the drain leakance indicate a flux of groundwater into the drains from the upper aquifer alluvium in the MODFLOW model. Intensive groundwater pumpage should then increase river leakance and decrease drain leakance.

Assuming that irrigation acreage has remained relatively constant in the last 10 years (New Mexico Agricultural Statistics, 1986 and 1982), the contour plot in Figure 23 should be representative of the drain flux occurring presently. The particularly heavy flux of the drains in the northern section (row 7, column 16) indicates areas of relatively heavily irrigated acreage around the Las Cruces area. The southern section (section 3), which straddles the New Mexico and Texas border, shows the heaviest concentration of flow in the drains, also indicating an irrigated agricultural region. Figure 24 illustrates the effects of scenario 2 at the end of the simulation period.

Scenario 3 seems to significantly decrease drain flows throughout the Mesilla Valley due to the lowering of the upper aquifer water table with increasing pumpage. Even the portion of the basin above the northernmost extent of scenario 3 pumpage (near the Las Cruces area) shows drain flow to be reduced by a factor of 4 in the most extreme localized case (Figure 25). The central and southern areas of the Mesilla Valley adjacent to scenario 3 pumpage (rows 11 through 28) are affected to a similar degree, although the decrease in drain flux occurs over a much larger areal extent and therefore has a larger overall magnitude than scenario 2 pumpage.

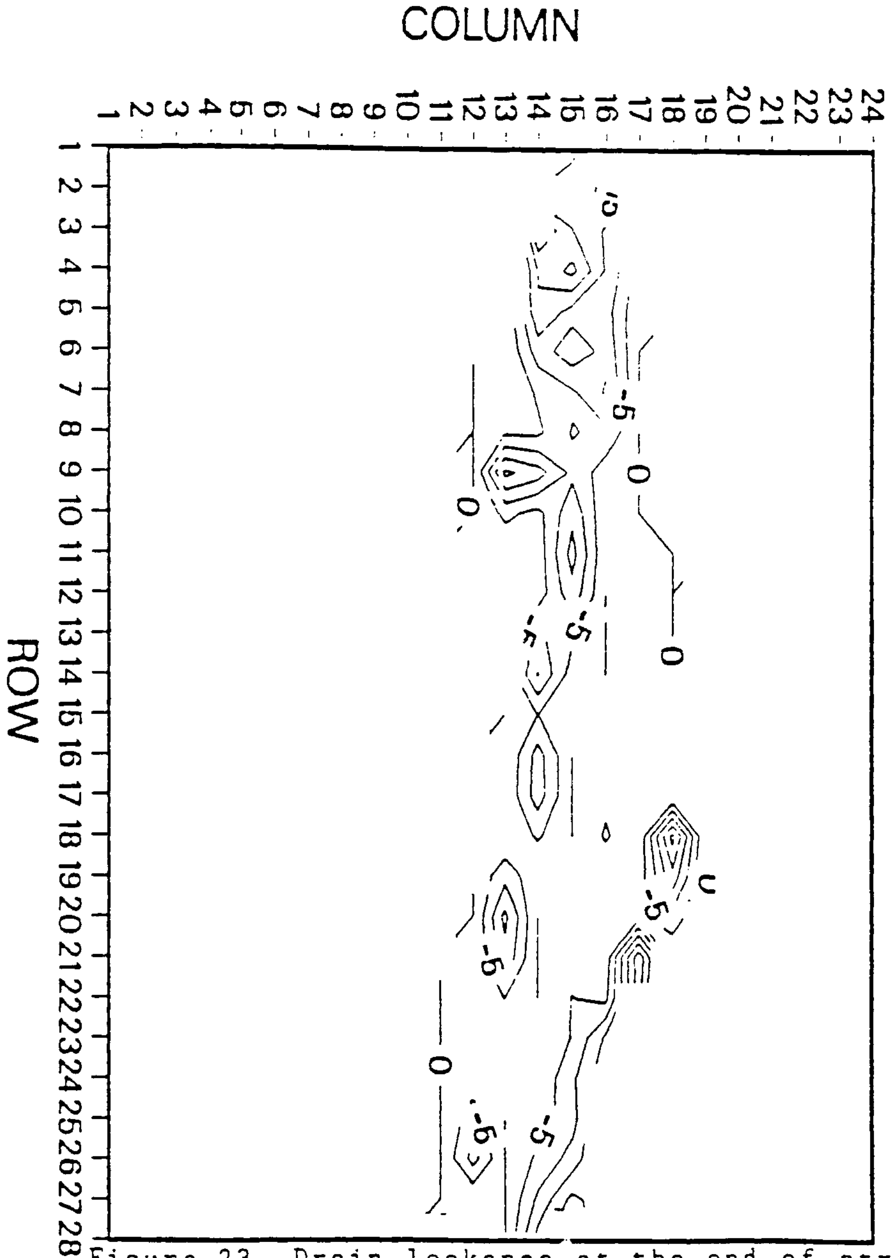

Figure 23. Drain leakance at the end of stress period 1. Values are in hundreds of Acre-feet/year. Note the negative values of drain leakance which denote a flux of water into the drains from the upper aquifer water table. Lowering the water table decreases drain flux. Contour interval is -5.0 verses the plots of drain leakance at the end of simulation which are 1.0 to facilitate reasonable spacing of contour lines.

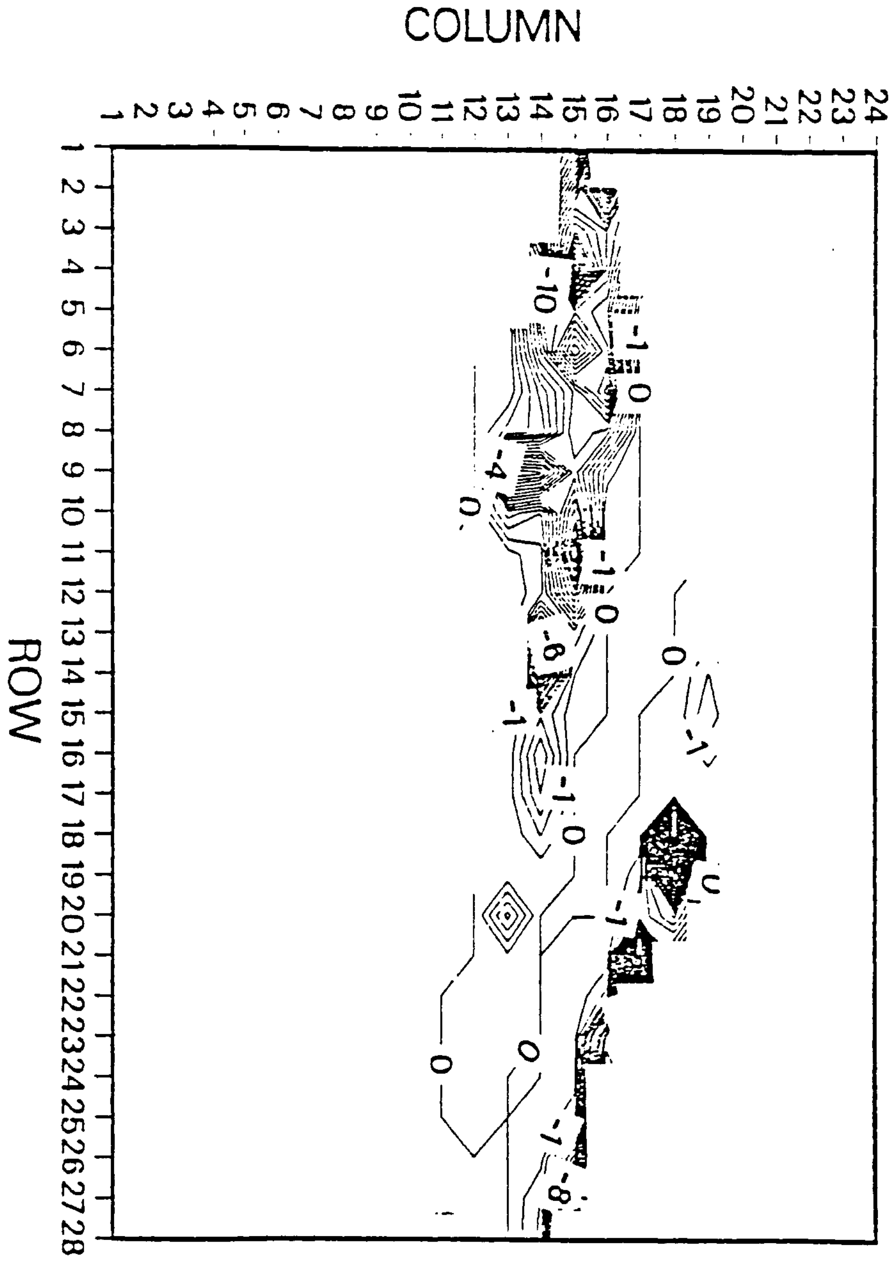

Figure 24. Drain leakance contour plot for scenario 2 at the end of simulation. Values are in hundreds of Acre-feet/year. Contour interval is -1.0.

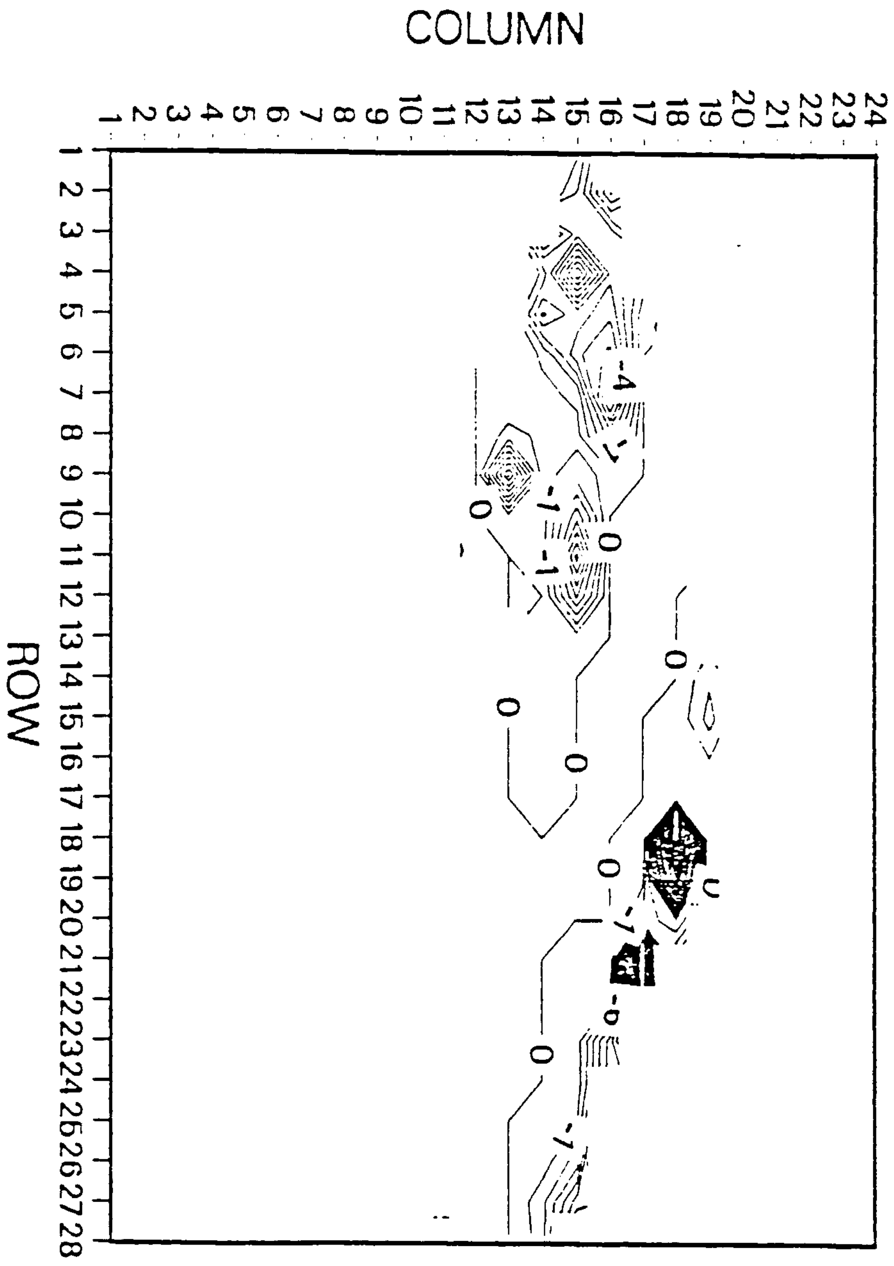

Figure 25. Drain leakance contour plot for scenario 3 at the end of simulation. Values are in hundreds of Acre-feet/year. Contour interval is -1.0.

Perhaps the most significant decrease in drain flux occurs in the central Mesilla Valley. Flux becomes nearly zero acre feet per year for scenario 3 which would otherwise be non-zero in the same case for scenario 2 (e.g., rows 10 through 16 in Figure 24). Although effects to agriculture may not be immediate, long-term absence of the flushing action which the drains provide could lead to decreased crop yields due to salinity increases, especially in areas with salt-sensitive perennial crops such as pecans (Ayers and Westcot, 1985). Figure 26 shows the effects of scenario 4 pumpage on the upper alluvial aquifer.

In addition to the contour plots, two-dimensional plots of drain leakance were developed to determine the timing and total magnitude of the leakance with increasing pumpage in each of the three separate sections.

The leakance curves for scenarios 2 and 3 of section 1 (Figure 27) show similar patterns of drain flow response until the year 2040, when flows diverge continually until 2090 (the end of the simulation period). The drain flow response is similar to the river leakance curves in that the initiation of pumpage in section 2 (the year 2000) seems to cause a delayed decrease in drain flows before the beginning of pumpage in section 2 (the year 2030). The relatively high conductivity of the northern end of the river basin (Peterson et al., 1984) seems to make the upper aquifer sediments quite sensitive to proposed El Paso pumping perturbations in the southern half of the West Mesa. The drain leakance curve for scenario 2, section 1 seems to increase only very slightly at the end of the model simulation, reaching a

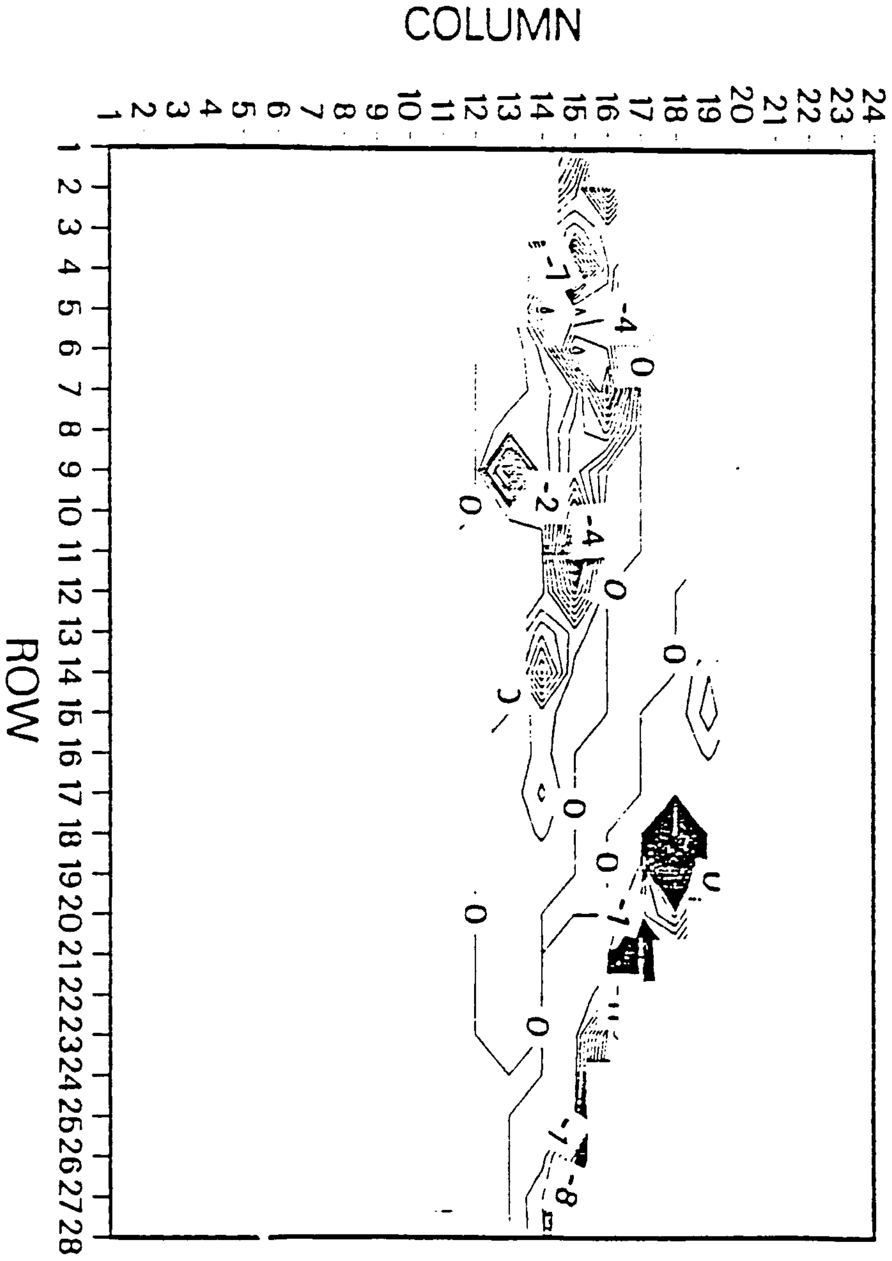

Figure 26. Drain leakance contour plot for scenario 4 at the end of simulation. Values are in hundreds of Acre-feet/year. Contour interval is -1.0.

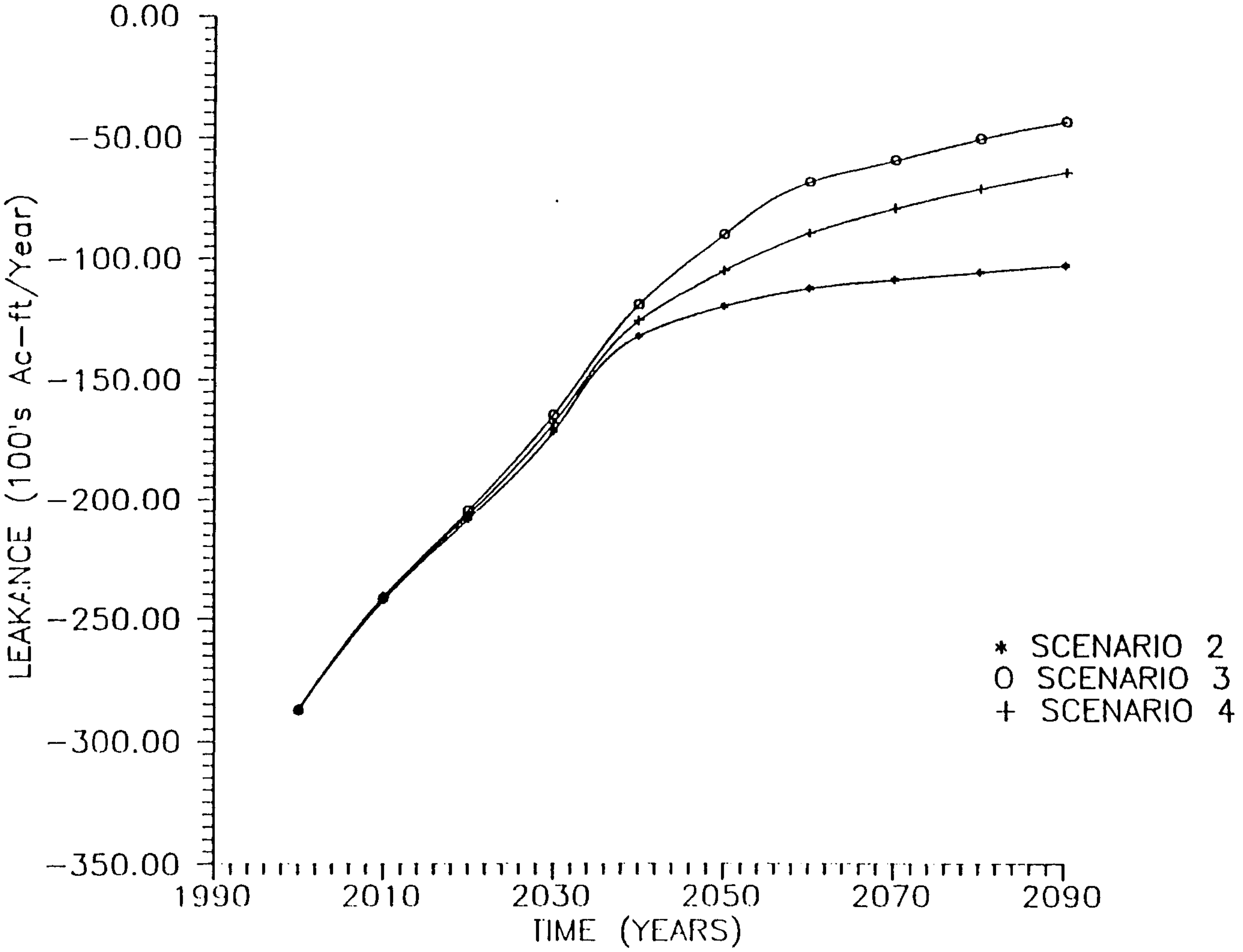

Figure 27. Drain leakance through time for scenarios 2, 3 and 4 for section 1.

maximum value of about 12,500 AFY. The scenario 3 drain leakance curve for the same section diverges sharply from the scenario 2 curve in the years 2040 to 2060, when all proposed scenario 3 wells are pumping at capacity. After this time period, divergence of the curves begins to decrease, indicating a slower rate of leakance.

Continual steepening gradients of any particular leakance curves suggests that the system has a potential for a higher flux rate and that the potential exists for further leakance. However, the maximum leakance may be eventually constrained by the conductance of the river and canal beds in the simulation.

The drain leakance curves of section 1 diverge the slowest and have the lowest gradient of the three sets of leakance curves for sections 1, 2, and 3 at the end of the model simulation. The decreasing gradients of these curves may indicate that the northern portion of the valley will be affected less than the central and lower sections of the Mesilla Valley, which have sharply diverging curves (Figures 12 and 13).

Drain flow is reduced in section 1 from just over 10,500 Acre-feet/year (AFY) to slightly less than 4,500 AFY in 2090 for scenarios 2 and 3, respectively. The net drain flow reduction amounta to approximately 6,000 AFY at the end of the simulation. Reducing the flow by half reduces the ability of the drains to carry a salt load ro the end of the proposed pumping plan of scenario 3 versus the same period for scenario 2 pumpage (Maddock et al., 1987).

Perhaps the most pronounced effects on the drain flows occurs in section 2 (Figure 28). Almost immediately, the effects of scenario

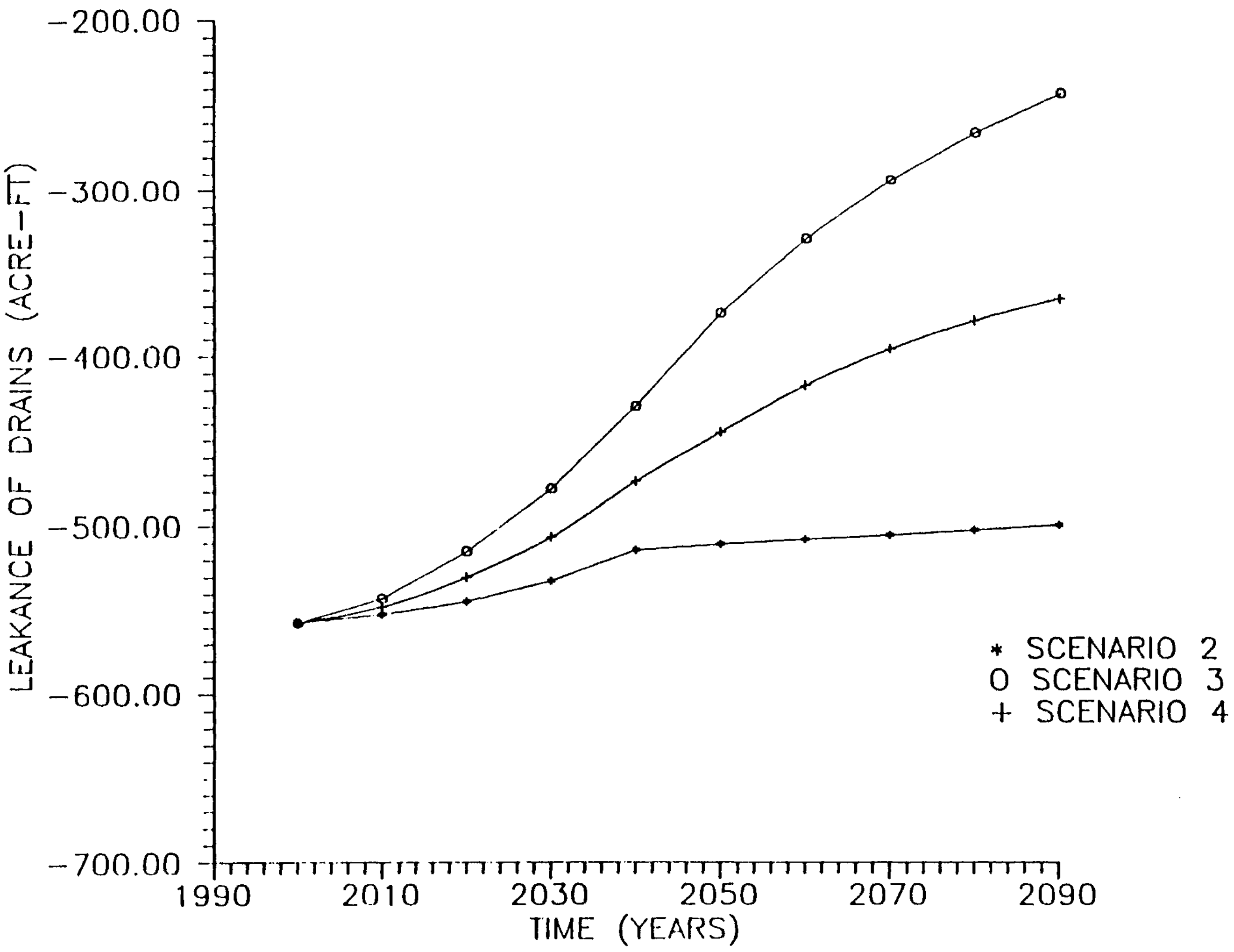

Figure 28. Drain leakance through time for scenarios 2, 3 and 4 for section 2.

3 propagates in the form of reduced drain flows just after pumping begins in the year 2000. Drain flows for scenario 2 seem to decrease only slightly from about 52,000 AFY to 50,000 AFY in the period 2040 to 2090. In contrast, flow decreases from 40,000 AFY to 25,000 AFY in the same time span for scenario 2 pumpage. The impact on section 2 is particularly intense because it is in an area of relatively high hydraulic conductivity in addition to being adjacent to the northern half of the proposed El Paso well field. The gradient of the drain leakance curve for section 2, scenario 3 seems to continually diverge, and the curves show no signs of leveling out or approaching a stable equilibrium value. Therefore, the drain leakance in section 2 may decrease significantly from the values given at the end of the model simulation. The drain flow in section 2 is reduced in scenario 3 by a maximum over that of scenario 2 by 25,500 AFY.

Section 3 is adjacent to the southern portion of the proposed El Paso well field, but as Figure 29 shows, the impact of future scenario 3 pumpage (Table 2) is not as pronounced as in section 2. Although the drain system responds almost immediately to future pumping, flows gradually diverge to a maximum difference of 7,000 AFY between scenarios 2 and 3 at the end of the simulation. The maximum gradients of drain leakance curves for the pumping scenarios occur in the period 2020 to 2060, after which the drain flows of both scenarios seem to nearly parallel one another. Scenario 3 pumping is at full capacity in the year 2060 of the model simulation when the curves begin to nearly parallel one another. The near parallel curves seem to indicate that pumpage for either of the future scenarios seems to have

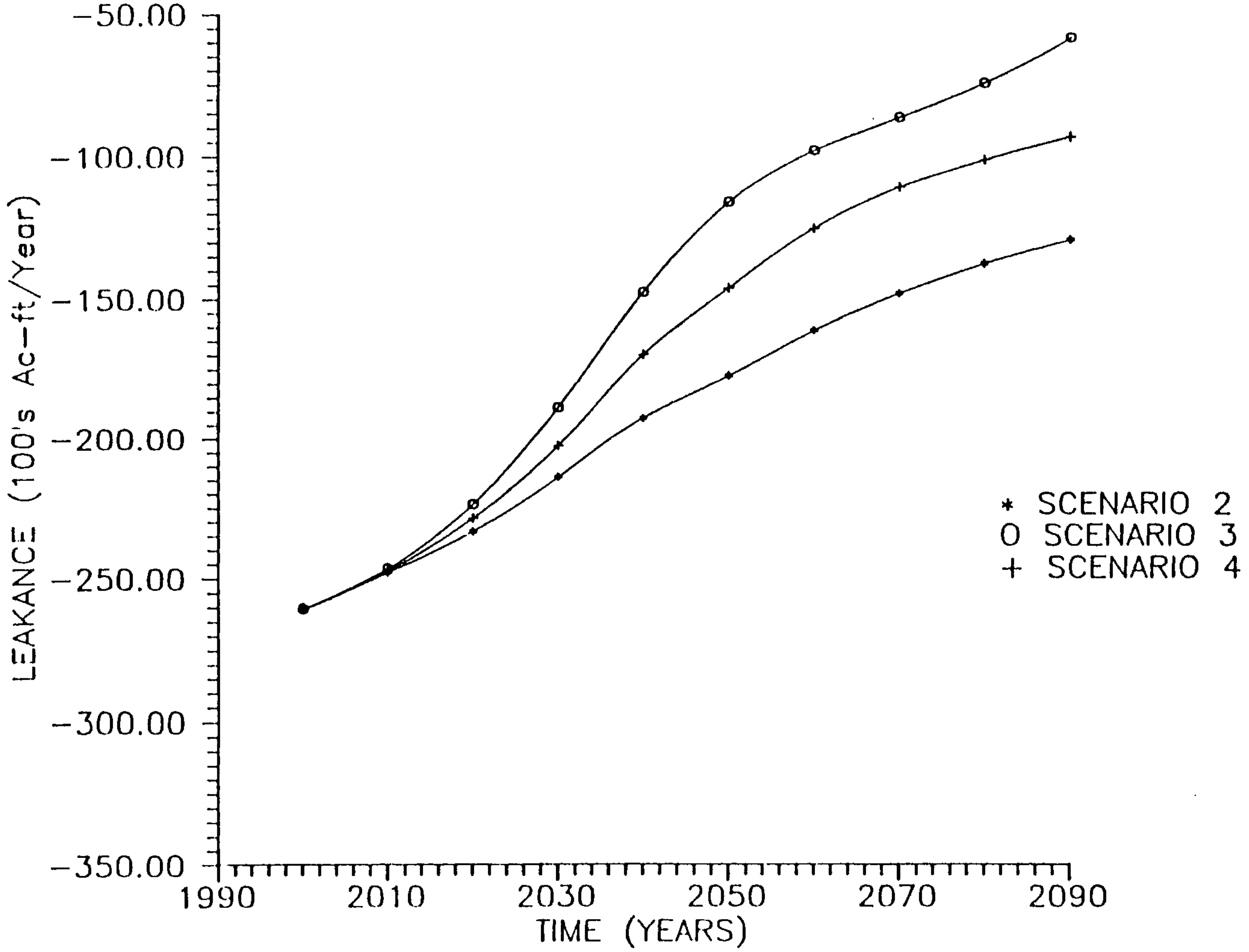

Figure 29. Drain leakance through time for scenarios 2, 3 and 4 for section 3.

the same rates of influence on the drain flows. even though scenario 3 reaches a greater overall flux rate. The continual increasing and relatively steep gradient of both the drain leakance curves for section 3 suggest that the potential to decrease drain flow will increase beyond the simulation period, which implies that the drain leakance, although a minimum for the models' simulation period, is not at a maximum for the stream-aquifer system.

Summary of River and Drain Leakance

Common effects of both river and drain leakance are apparent from inspection of the leakance contour and two-dimensional plots. The two-dimensional curves of section 1 data indicate a loss of 6,000 AFY in drain flow and about 5,000 AFY in river flow (11,000 AFY total) in comparing scenarios 2 and 3 at the end of the model simulation. Both sets of river and drain leakance curves of section 1 have significantly reduced gradients towards the end of the time simulation. The relatively high conductivity of the upper aquifer in the northern Valley area (Figure 2) seems to make the system quite sensitive to perturbations in the central and lower sections of the Mesilla Valley.

Section 2 river and drain leakance data indicate major river leakance increases and drain flow losses due to scenario 3 pumpage. River leakance for scenario 3 would increase to a maximum of 19,500 AFY over scenario 2, while drain flow would decrease by a total of 25,000 AFY, a total net loss of 45,000 AFY to the stream-aquifer system at the end of the model simulation. The section 2 leakance curves for scenario 3 show steeper gradient trends than those of scenario 2 at the end of the simulation, indicating that the total net loss to the stream-aquifer system would be significantly higher for section 2 if maximum leakance values could be reached. Some of the river cells (e.g., cells 17,14 and 18,14) actually reach a constant value of leakance near the end of the scenario 3 simulation period. The pumping stress of scenario 3 seems to be great enough such that some reaches of the river respond with the greatest possible leakance given the conductance the river bed.

Section 3 river leakance curves versus time exhibit steep gradient trends which reach a maximum difference of 19,000 AFY at the end of the 100-year model simulation. The drain flux leakance curves for section 3 steepen somewhat more gradually than those of the river leakance, which may be due in part to the following explanation. Agricultural and municipal pumpage is quite intense in the area because of the concentration of border towns around the agricultural region. The relatively intense pumpage of the Santa Fe aquifer has the effect of lowering the upper aquifer water table near the bottom level of the drains, thereby reducing the flux from the water table into the drains which, in turn, reduces the potential difference in magnitude of the drain leakance curves for scenarios 2 and 3. The maximum difference for scenarios 2 and 3 for section 3 at the end of the simulation reaches 7,000 AFY. The total of 26,000 AFY for section 3 represents both increases in river leakance and losses to drain flow.

Adding the totals for all the sections, the net surface water loss for the entire stream-aquifer system for the Mesilla Valley due to the proposed increase of scenario 3 pumpage amounts to approximately

82,000 AFY by the end of the model simulation, with the potential existing for a greater amount should more of the river reaches attain a constant leakance level. The total pumpage attributed to scenario 3 pumpage at the end of the simulation period is approximately 246,000 AFY, which means that about 33% of this total can be accounted for by the leakance of the river and drains.

Results from the simulation indicate approximately 30,800 AFY coming from storage in scenario 2 and 169,700 AFY for scenario 3 from the end of the first stress period to the end of the simulation. This amounts to an increase of about 140,000 AFY of aquifer storage depletion due to scenario 3 pumpage over scenario 2. Thus, a large portion of the aquifer storage is capable of being depleted at a relatively rapid rate with the pumpage of scenario 3 versus that of scenario 2.

The 82,000 AFY lost to the river and drain system represents approximately 30 percent of the average river flow (282,159 AFY) at El Paso Station 08364000 (Maddock et al., 1987). The 82,000 AFY net surface water loss actually exceeds the river surface flow in the drought years 1955, 1956, and 1964 when flows were 67,089, 57,481, and 64,307 AFY, respectively (U.S. Bureau of Reclamation, 1987).

CHAPTER 7

FACTORS INFLUENCING CONSERVATION
OFFSET POLICY DECISIONS

A replacement of a resource used or lost with that of similar or equal value constitutes an offset. Some of the common examples simply involve restoring or replacing a natural resource to the pre-use state for the sustenance of that resource. For example, offsets are common in the timber industry in the form of reforestation. Industries responsible for environmental contamination are often responsible for the restoration of the environment to the original state.

The Lower Rio Grande Basin has long been known to have an inter-connected stream aquifer system (New Mexico State Engineers Office, 1980). Therefore, conjunctive management of the stream aquifer system requires the replacement of surface water to offset the effects of groundwater pumpage. The New Mexico State Engineer controls the development of surface and groundwater as a single interrelated resource through conjunctive management. Offsets have served as a tool of management for at least 20 years. Perhaps the earliest comprehensive indepth case of this involves the City of Albuquerque versus Reynolds (71 N.M. 428). The management approach itself dates back approximately 30 years and has been confirmed by the New Mexico Supreme Court which concluded that not only is conjunctive management an acceptable concept in stream-connected basins, it is also essential [City of Albuquerque versus Reynolds (71 N.M. 428)].

Reynolds et al. (1967) may provide the most effective explanation of offsets applied to the depletion of surface water flows due to groundwater pumpage in the Rio Grande Basin. The term offset describes the action taken such that there is no net increase in surface water loss or no net decrease in surface water flow. An example of these actions is retirement of irrigation water rights. However, both return flows and water rights retirement are often considered offsets (Wilson et al., 1987). Return flows from municipal users are approximately 40 to 50 percent of groundwater pumpage (Wilson et al., 1987; Reynolds et al., 1967). Ultimately, the groundwater user must retire surface water rights equal to the consumptive use of groundwater.

Reynolds et al. (1967) provide that the State Engineer shall permit the drilling of well and withdrawals of groundwater on the condition that the effects of those withdrawals on the flow of the Rio Grande at each point in time are offset by the retirement of existing surface water rights to the use of the surface waters of the Rio Grande. In the conditions put forth by the State Engineer on the granting of groundwater well permits to Albuquerque, offsets could be accomplished with any water available to the City of Albuquerque from any source. Albuquerque was allowed to lease San Juan-Chama Project water to offset the effects of the cities' groundwater pumpage on the surface water flows of the Rio Grande.

Conditions attached to the well permits granted to Buckman and the City of Albuquerque state that when new appropriation of the groundwater in the Basin is permitted, the effects of the new pumping on the river must be calculated, and return flows should be metered

(State Engineer files RG-960 through 963 and RG-2015 et al.). The amount and timing of offset required are usually determined by the State Engineer with a groundwater model developed by the staff of the State Engineers Office (Wilson et al., 1987). Due to hydrological variabilities and pumping proximities to river water, the timing of the offset requirements may vary from permit to permit.

The surface water supply of the Rio Grande has long been fully appropriated. The Rio Grande Compact fundamental objective was the maintenance of the status quo with respect to the amount of consumptive use of water within each state (Reynolds et al., 1967). Therefore, offsets become important in the sense of not only conservation but maintaining an inter-state compact.

International aspects also dictate conservation efforts. The Mexican Treaty of 1906 guarantees that the United States will deliver 60,000 AFY to Mexico with the provision that both nations will share in times of drought. The treaty is a result of both negotiations and a promise by Mexico to drop all claims for damages that resulted during water shortages in Texas and the southern part of New Mexico during the late 19th century. What seems to be a simple case of surface water conservation suddenly begins to have both national and international implications in water law and policy.

Offsets are more than just preserving the river or 'keeping the river whole'. Offsets can be used as a tool of public welfare as the guidelines of the New Mexico State Engineers for granting permits suggest. Since the study area is classified as an inter-connected stream basin (State Engineers Office, 1980), the granting of well permits is intricately tied to preserving surface water flow.

The granting of well applications is based on a set of guidelines set forth by the State Engineer of New Mexico. The State Engineer has the power to grant a well permit if the withdrawal of groundwater will not impair existing rights, is not contrary to conservation of water in the state, and is not detrimental to the public welfare of the state. In addition, the State Engineer will consider without being limited to the following factors: (1) the supply of water available to the State of New Mexico, (2) water demands in the State of New Mexico, (3) potential water shortages in the State of New Mexico, (4) whether the water that is subject to the application permits could be feasibly transported to alleviate water shortages in the State of New Mexico, (5) supply and sources of water available to the applicant in the state where the applicant intends to use the water, and (6) the demands placed on the applicant's supply in the state where the applicant intends to use the water [(N.M. Stat. 72-12B-1)].

The majority of surface water in the Mesilla Valley has historically been used for irrigation. Offsets indirectly protect the agricultural community by assuring surface water flows which essentially ensures that all appropriators will receive the requested surface water allotment. A substantial portion of the valley is devoted to agriculture which constitutes a major portion of the chosen lifestyle in the area. Therefore, impinging on the agricultural community could infringe on the public welfare of the area. In addition, should pumping affect surface water allocations of junior appropriators, existing rights would be impaired. Permanent decreases in surface water allotment would create a heavier stress on supplemental irrigation pumpage, thereby increasing the rate of depletion of aquifer storage which in effect could decrease the supply of water available to the State of New Mexico. In this case, a sort of chain reaction could potentially develop, violating more and more of the State Engineers guidelines as the reaction proceeds to an undesirable equilibrium.

Another public welfare question is the preservation of water quality. Water quality would be expected to deteriorate with the lowering and/or cessation of drain flows in the valley (Shosted, 1987). If irrigation continued, the excess salts would eventually filter down to the lower aquifer and potentially affect water used for industrial, but more importantly, municipal purposes.

Conditions and Policy Towards Past Permits

Essentially, the State Engineers guidelines for the granting of well permits are intricately tied to offset policy due to the hydraulic inter-connection of the Basin. Therefore, a policy of the granting of well permits should be conditional on the dedication of offset rights rather than an absolute unqualified permit to pump. Certainly, past experience has shown this to be true. In the granting of well permits to the City of Albuquerque, the State Engineer attached several conditions on the applications (State Engineer files RG-960 through

963). The Buckman permits (State Engineer file RG-20516 et al.) also had similar conditional well permits.

The conditions for the Albuquerque permits demonstrate how conjunctive management is necessary in a temporal sense. The conditions related to conjunctive stream-aquifer management which follow are important in the sense that they protect the right of the State Engineer to continuously govern offset policy. For example, in Condition No. 3, the State Engineer retains ongoing jurisdiction with respect to offsets to control surface water loss. In the present context, ongoing jurisdiction is certainly reasonable given that computer models (i.e., methods of offset estimation) may become obsolete with the rapidly advancing technology in a matter of years. For instance, analogue groundwater models once widely used in the 1950's and 60's are now rarely used. If the offsets are not provided, Condition No. 4 of the Albuquerque permits indicates that the State Engineer shall retain the right to terminate certain well pumpages to ensure that withdrawals will not result in the impairment of existing rights.

Condition No. 5 states that the City of Albuquerque is entitled to offset the effects of groundwater withdrawals with any water available to the City of Albuquerque from any source. In summary, the conditions give the State Engineer and the applicant flexibility as to the manner, timing, and source of the offsets.

The Buckman permit (State Engineer file RG-20516) was treated similar to the City of Albuquerque with respect to the offsets. The State Engineer retained ongoing jurisdiction for offsets, the procurement of offsets was guaranteed to the State Engineer, and metering and reporting of pumping and offset releases were required as well as offset locations. The water rights to offset pumpage were dedicated prior to pumping, while the need to actually retire the rights could be delayed (Wilson et al., 1987) depending on the temporal effects on surface water loss calculated by the State Engineer.

There is one basic problem in applying past history to the proposed pumpage of El Paso, and that is simply the magnitude of pumpage with respect to the groundwater basin of the Mesilla Bolson. Certainly, one could intuitively see if current groundwater loss is in approximate equilibrium with recharge estimates (Peterson, 1984) of about 387,000 AFY, an eventual additional pumpage of 246,000 AFY by El Paso will have a substantial effect on the Basin. What these effects mean in terms of surface water leakance and drawdown effects can be estimated by the computer model. The effects on the people of the Mesilla Bolson is a more subjective concept. The effects on the economy, lifestyles, livelihoods, and the simple well-being of the population are left largely to be considered by the State Engineer of New Mexico (Bradley, 1988). These are delicate issues which become weighty with increasing pressure by out-of-state appropriators to gain access to a groundwater supply in New Mexico.

Therefore, the granting of permits would seem to have a sequence of three steps: (1) determine the hydrological effects on the given basin, (2) determine if the hydrological effects are feasible given hydrological and legal constraints, and (3) grant the permits with a set of conditional constraints to ensure ongoing jurisdiction over hydrological and legal constraints.

At this point, it becomes necessary to view the hydrological effects in terms of the model results to determine a set of potential conditions related to the granting of well permits.

Surface Water Loss and Drawdown from Model Results

The importance of offsets becomes apparent when considering the model results. One outstanding feature which the river/drain and drawdown/head curve plots convey is the hydraulic inter-connection of the stream-aquifer system. As the pumpage increases, the curves diverge in proportion to the intensity and amount of pumpage.

By and large, the major areas of river and drain flow loss due to scenario 3 are in the central and southern Mesilla Valley. Figures 20 through 22 illustrate that the greatest impact of scenario 3 pumpage on river leakance is in the central (section 2) and southern (section 3) Mesilla Valley. The magnitudes of the differences in drain leakances in Figures 27 through 29 also indicate a similar result on drain flows in the same regions of the valley. The ultimate net surface water leakance seems to be limited by the conductance of the river and drain beds.

The Mesilla Bolson is managed as a stream-connected basin. Presently, the installation and pumping of groundwater wells is dependent on the replacement of surface waters of the Rio Grande in an amount sufficient to offset pumpage effects on river leakance. However, the upper limit of leakance is bounded by the conductance in the drain and river beds, and some river cells in scenario 3 have attained a maximum leakance rate. For example, cells (row, column) 17,14 and 18,14 reach a constant leakance level for the last 30 to 40 years of the simulation. Table 3 summarizes the river and drain depletions for scenarios 2 and 3 in sections 1, 2, and 3 which correspond to the northern, central, and southern portions of the Mesilla Valley, respectively.

Table 3. Summary of New Mexico and El Paso pumping effects after 100 years of simulation. All values are in acre-feet/year. Negative values indicate a leakance into the drains from the upper aquifer.

Section	Scenario 2 Leakance		Scenario 3 Leakance	
	River	Drain	River	Drain
1	84,000	-10,500	89,000	-4,500
2	72,500	-50,500	92,000	-25,000
3	46,000	-13,000	65,000	-6,000
Totals	202,500	-74,000	246,000	-35,000

The net surface water loss listed in Table 3 is the river plus the drain leakance. Scenario 2 has a net surface water loss of 128,500 AFY, while scenario 3 has a net loss of 210,500 AFY at the end of the simulation.

The net loss of surface water flow in terms of reduced drain flows and increased river leakance due to the additional pumpage of scenario 3 amounts to approximately 82,000 AFY at the end of the model simulation. The total loss in surface water flow exclusively in New Mexico which includes river and drains amounts to approximately 56,000 AFY. The remaining 26,000 AFY loss occurs near and around the Texas-New Mexico border area.

The purpose of maintaining a stream-aquifer equilibrium becomes a question of how much groundwater is the river capable of contributing and will it be sufficient to replace groundwater pumpage. Surface water replaced above and beyond the maximum river leakance will simply flow downstream, benefiting none of the intended parties. Simply put, upper bounds on river leakance rates may limit the effectiveness of offsets.

Storage contributes approximately 140,000 AFY to scenario 3 pumpage over that of scenario 2 during the simulation. Peterson et al. (1984) estimated annual recharge to be approximately 386,500 AFY, of which 62.5 percent is from irrigation, 30 percent from river losses, and the majority of the remainder from mountain recharge. Peterson et al. (1984) also estimated present loss to the groundwater system in the Mesilla Bolson as 386,700 AFY. The aquifer system seems to be in approximate equilibrium with the present pumpage. Again, the MODFLOW model assumes a constant river stage which could become substantially lower during and after scenario 3 pumpage. If the stage is lowered (e.g., during a drought), the expected rate of storage depletion should increase since the same pumping stress would be applied to a smaller amount of surface water and river bed area and therefore, river leakance. In addition, upper aquifer drawdowns would occur at a more rapid rate than the model would indicate.

The net loss to aquifer storage due to scenario 3 could also occur considerably sooner due to lost irrigation recharge, should agriculture cease in areas where the eventual salt buildup would reduce crop yields beyond the point of profitability. The lowering of the upper aquifer water table would lower potential drain flow, thereby permitting an increase in the soil salinity and reducing recharge. Presently, the level of the upper aquifer water table is approximately 3 feet above the level of the drains (Maddock et al., 1987). Drawdowns below drain levels have the potential to increase the soil salt load (Shosted, 1988) due to the absence of a flushing mechanism. Table 4 summarizes the average drawdowns for the northern (section 1), central (section 2), and southern (section 3) portions of the Mesilla Valley. The large average values for section 1 reflect the locations of Las Cruces and New Mexico State University, both of which create a localized heavy pumping stress on the northern Mesilla Valley.

Table 4. Average drawdown for sections 1, 2, and 3 in the upper aquifer. Values are in feet.

Section	Scenario 2 Drawdown	Scenario 3 Drawdown
1	15.5	16.0
2	0.5	7.0
3	5.0	15.0

Lowering of the upper aquifer table may then (a) impair existing rights by increasing localized lift costs, and (b) impose upon the public welfare due to possible long-term damage to cropland and decreased water quality. In fact, to offset scenario 3 pumpage effects with irrigation rights, by the end of the model simulation, over 40,000 acres of cropland with appurtenant water rights would need to be purchased. This assumes the New Mexico State Engineer office estimate of 1.93 AFY consumptive surface water use per acre of irrigated cropland.

A comparison of Tables 3 and 4 illustrates the magnitude of the scenario 3 pumpage effects over those of scenario 2 to the central and southern Mesilla Valley at the end of the simulation. River leakance will increase by 19,500 AFY in the central Mesilla Valley and by 19,000 AFY in the southern Mesilla Valley. Average drawdown will increase by 6.5 feet and 10.0 feet in the central and southern Mesilla Valley, respectively. Even the northern section of the Mesilla Valley will be affected, although not to the extremes of the central and southern regions. The drawdown comparisons are done on an average basis, and localized areas may have substantially more or less depending on proximity to well fields, hydraulic conductivities, and pumping rates.

Full-scale pumpage of scenario 3 causes enough surface water leakance to exceed the flow of the Rio Grande at El Paso in periods of drought. For instance, in the years 1955, 1956, and 1964, river flows were below 70,000 AFY, while net surface water loss due to scenario 3 is 82,000 AFY. Care must be taken to ensure adequate river flow in times of drought to satisfy the international obligation (Mexican

Treaty of 1906) which guarantees Mexico a flow of 60,000 AFY at all times near Ciudad Juarez. During periods of low flow and continued pumpage, the river stage can be expected to drop significantly faster in comparison with years of normal flow due to increased use of groundwater for irrigation in the absence of surface water.

Model Results In Relation to Conditional Well Permits

Given that the El Paso applications are found to be within the guidelines of the State Engineer, at least four conditions for the El Paso well permits become apparent when considering the effects of the model results. The magnitude of the proposed El Paso pumpage essentially seems to require the same conditions which are consistent with past offset policy in the conjunctive management of the Basin. The following suggested conditions are as consistent as possible with the current conservation policies as well as the management of the Mesilla Bolson as a conjunctive stream-aquifer system.

Condition 1 would allow the permits to be granted on a yearly basis in an amount for which depletions can be offset. Rights to surface water would also dictate the maximum amount of annual pumping if dedicated offset rights did not completely cover stream depletions. If upper limits of leakance on the Rio Grande were reached, this would implicitly limit the amount of allowed depletion of the groundwater permits. This condition could also be used to put an upper bound on pumping to limit the effects on irrigation drain flows. In the event offsets are not provided, this will ensure that valid existing rights are not violated which is similar to Condition No. 4

placed on the Albuquerque permits. The types of graphs of the river leakance in Figures 20 through 23 and drain leakance (Figures 27 though 29) would provide an estimate of the potential surface water contribution over time. These types of estimates would allow the amount of current offsets to be related to future demand on the system ensuring that surface water supply will meet future demands.

Conditions 2 would allow the right to offset depletions to surface water flows with any water available to El Paso, provided the water is of the same or better than existing river standards. This would provide at least some flexibility in the source of the offsets to the applicant which is in keeping with the provision of Condition No. 5 of the Albuquerque permits.

Condition 3 would determine the feasibility of obtaining surface water rights for offset purposes prior to pumping. The State Engineer would retain the right to revoke all or a portion of the permits if sufficient quantities of surface water become unavailable or are simply not available. In addition, in times of drought, surface water offsets would need to be guaranteed or, in the absence of sufficient surface water, a portion of the pumpage would need to be proportionally reduced. This would limit the damage to senior appropriators and international obligations in time of heavy stress imposed on the aquifer.

Condition 4 would allow the State Engineer ongoing determination as to the location and timing of the offsets just as in the granting of the City of Albuquerque and the Buckman permits. Certainly, credit could be given in the form of return flows as was granted in previous permits. Return flows could potentially return 40 to 50 percent of the pumpage total. Figures 20 through 29 illustrate both the areal and temporal distribution of the overall surface water leakance. In this case, the location of the offsets would need to begin north of Las Cruces and extend southward through the entire Mesilla Bolson. The largest portion of the offsets would need to be in the central and southern areas of the Mesilla Valley adjacent to the area of heaviest pumpage of El Paso amounting to approximately 40,000 AFY by the end of the 100-year simulation period for a return flow rate of 50 percent.

The variable geology which is systematically intertwined with the hydrology in the Mesilla Bolson requires an ongoing jurisdiction by the State Engineer. Ongoing jurisdiction would adjust for the effects of unexpected encounters with variable hydrology, and also allows the adaptations of state-of-the-art groundwater modeling methods and the use of new hydrological data which become available over a period of years. Therefore, it seems that the granting of well permits in the Mesilla Bolson cannot be absolute, rather it must be conditional. Although conditional permits are not compatible with the requirements of a municipality due to a unequivocable per capita baseline supply, it seems to be the only alternative which is consistent with the past conditions attached to applications granted by the State Engineer.

Conclusions

The El Paso permits were denied by the State Engineer of New Mexico on December 23, 1987 based on the '40-year rule' in which the

State Engineer found El Paso had enough of a water supply to meet its needs 40 years from the original date of the application. However, litigation will no doubt not stop there (Bradley, 1988). The model results quantify what is intuitively obvious: heavy pumping in the Mesilla Bolson creates heavy stress on the surface water system. Conditional well permits are an essential element of offset policy and should be implemented as a ongoing control by the State Engineer in the conjunctive management of the Mesilla Bolson.

The effects of scenario 3 pumpage also reach into the southern Mesilla Valley of Texas. It would then seem to be of mutual interest to both states to cooperate in the decision conditional inter-state water transfers, although a lengthy court battle is eminent (Bradley, 1988). The long-term integrity of agriculture in the Mesilla Valley both in Texas and New Mexico is threatened; therefore, both states stand to be adversely affected in the long run due to scenario 3 pumpage.

It seems that the conductance of the river and canal beds may limit the leakance rates. After maximum leakance rates are attained, a considerable amount of water will come from aquifer storage. The additional surface water from the offsets would simply flow downstream, benefiting the downstream users without accomplishing the purpose of the offsets. Offset policy would prevent this from happening since the State Engineer could retain ongoing jurisdiction over well permits and the authority to limit pumpages over time.

The Mesilla Bolson seems to be in equilibrium with present day pumpage (Peterson, 1984). Any future pumping by New Mexico or Texas may commence mining of the aquifer storage and subsequently start the 'beginning of the end' in terms of the life of the aquifer. Offset policies can at least prolong the aquifer life by requiring a replace ment of potentially lost aquifer storage.

The central and southern portions of the Mesilla Valley would feel the brunt of the additional pumpage of scenario 3. Drawdowns would increase close to the levels of the drains deteriorating the existing irrigation water quality and could potentially threaten agriculture. If the drains remain dry, increased salinity would eventually reach the lower aquifer which is the main source of the municipal water supply in the valley. The model simulation assumes a constant river stage. In effect, it can be thought of as keeping the river at a constant stage by the replacement of surface waters (i.e., offsets). Then it becomes that obvious offsets have no effect on keeping the drain flows whole with large increases in pumpage. In this case, the interest of public welfare and conservation simply dictates refusing well permits beyond a specified amount which begins to affect the drain flow.

Conditions attached to future well permits in the Mesilla Bolson seem to be the best viable alternative New Mexico would have to guarantee ongoing compliance with the guidelines set forth by the New Mexico State Engineer in the event any future well permits are to be granted in the Mesilla Bolson to in-state as well as out-of-state appropriators. Offsets serve as a tool for conjunctive management of the Mesilla Bolson which provides for resource conservation and the public welfare of the people of New Mexico.

APPENDIX A

DATA FOR MODEL INPUT

TABLE A-1
HISTORICAL STREAMFLOW AND CANAL DIVERSIONS IN THE LOWER RIO GRANDE BASIN
1951-86

(all units in acre-feet)

Calendar Year	Releases From Caballo Reservoir (Station 08362500)	Diversion Into Leasburg Canal	Diversion Into East Side and West Side Canals	Rio Grande at El Paso, Texas (Station 08364000)
1951	469,450	100,350	177,341	252,000
1952	543,975	100,943	188,940	283,680
1953	528,628	100,664	195,190	264,500
1954	244,165	50,509	127,401	93,725
1955	219,157	35,509	103,854	67,089
1956	246,140	35,340	111,800	57,481
1957	397,103	63,540	168,902	139,571
1958	737,125	162,954	237,107	392,863
1959	687,144	162,450	237,959	385,810
1960	705,162	155,772	403,507	378,260
1961	561,697	125,173	211,529	300,690
1962	651,941	147,965	245,347	376,116
1963	517,172	136,562	223,033	263,711
1964	206,085	78,194	100,161	64,307
1965	505,598	79,884	150,710	202,392
1966	610,341	124,145	201,338	308,782
1967	456,517	122,903	238,093	232,744
1968	505,691	149,711	232,583	264,408
1969	667,669	169,205	276,919	365,407
1970	661,125	165,008	262,166	360,719
1971	498,375	131,808	213,184	244,156
1972	260,911	86,666	128,705	133,568
1973	617,461	121,636	243,035	301,789
1974	640,843	142,709	261,104	382,953
1975	580,617	124,701	254,025	360,959
1976	679,676	146,199	290,711	402,835
1977	416,496	84,158	148,700	214,553
1978	356,167	51,909	101,977	156,024
1979	568,687	101,420	203,177	312,594
1980	658,686	140,908	245,343	353,983
1981	608,166	114,567	228,146	333,329
1982	643,962	122,363	246,726	326,642
1983	648,386	127,686	254,791	331,955
1984	633,153	124,423	240,427	359,361
1985	677,397	126,664	246,032	359,917
1986	1,396,165	164,896	295,353	528,857
Mean	555,750	116,097	213,763	282,159
Standard Deviation	208,406	37,406	64,119	110,490

TABLE A-2
HISTORICAL FLOW IN PRINCIPAL DRAINS IN THE MESILLA VALLEY
1951-86
(all units in acre-feet)

Calendar Year	Picacho	Del Rio	La Mesa	East	Nemexas	West	Montova[1]	Total
1951	4,630	47,380	14,740	11,770	12,020	25,350	43.760	126.750
1952	3,430	38,510	8,230	8.270	10,240	16,950	26.940	87.380
1953	3,060	35,660	6,760	8.360	9,370	14,760	30.920	86.010
1954	650	17,890	720	3.100	2,380	3,700	10.200	32.730
1955	110	4,290	0	684	695	1,080	4.420	9.650
1956	0	1,000	0	301	490	824	3,210	4.560
1957	67	3,528	0	88	908	1,006	4.300	8.071
1958	1.620	31,470	10.660	3.120	3.740	3.630	15.660	64.524
1959	5,150	46,190	17,700	13,510	12,180	15,250	35,810	125.320
1960	5,620	49.530	16,150	13.700	15,660	22,190	50.500	144.790
1961	4,320	44.210	12.730	11.560	13,200	19,580	38.700	116.490
1962	4,770	51,930	17,380	15.150	14,980	24.150	44.680	143.340
1963	3.910	39,480	11,180	13,780	11,370	15,370	32.670	106.594
1964	522	10,458	933	3,458	2,284	3.207	8.393	24.200
1965	25	13.107	138	3,929	1,345	2,495	7,199	24.446
1966	1,633	29.544	11,872	11.863	5,585	9,572	20.624	75.320
1967	0	24,006	7,087	8.432	3,750	10.657	20.527	56.185
1968	1,864	27,430	9.934	10,049	8,637	13,741	27,930	77.586
1969	3,188	39,036	14.837	11.195	13.433	22.395	40.360	111.009
1970	4.691	45,491	20,967	15,100	15,020	25.103	46.037	134.509
1971	2.734	30,123	11.080	8.663	8.315	16,853	30.401	83.062
1972	1.344	20.297	4,773	3.935	2,835	4.018	13.276	43.625
1973	2,705	23.622	9,394	8.702	6,383	9.620	20.216	64.886
1974	3,805	30.645	15.160	13.354	12.283	19,142	35.384	98.348
1975	3,602	37,229	20.316	13.270	13.378	24.840	40.565	114.982
1976	3,995	36,420	22.018	15.545	13.319	26.295	40.374	118.352
1977	2,743	25,830	10,124	8.044	7.192	14.680	25.194	72.667
1978	2,344	7,379	3,228	2.750	3,020	3.234	7,424	23.125
1979	2.282	24,503	19,050	11,819	6.023	16,916	26.516	84.170
1980	1,691	31,181	22.509	14,205	11.061	24,456	38,997	108.583
1981	1,898	33,106	23.760	15.564	10,932	27.321	45.507	119.835
1982	2,512	34,920	23.054	16.047	12,020	25.296	44.504	121.037
1983	3.365	39,484	22.558	16.979	13.278	27.300	45,203	127.589
1984	NM*	41,061	20.536	16.961	13.583	24.973	46.605	125.163
1985	NM*	40.692	19.268	18.696	NM*	NM*	45.350	124.006
1986	NM*	55,737	20.137	24.791	NM*	NM*	48.241	148.906
Mean	2.553	30.899	12.471	10.465	8.556	15.469	29.627	87.161
Standard Deviation	1,640	14,131	7,756	5.823	4,902	9.677	15.010	43.002

*NM = not measured

[1] Includes Nemexas and West

TABLE A-8

SUMMARY OF FUTURE PUMPING FORECASTS

(1,000 acre-feet/year)

	1991- 2000	2001- 2010	2011- 2020	2021- 2030	2031- 2040	2041- 2050	2051- 2060	2061- 2070	2071- 2080	2081- 2090
New Mexico Irrigation	110.6	110.6	110.6	110.6	110.6	110.6	110.6	110.6	110.6	110.6
Texas Irrigation	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
Las Cruces	15.0	23.2	31.4	39.7	47.9[1]	47.9[1]	47.9[1]	47.9[1]	47.9[1]	47.9[1]
Santa Teresa	8.9	15.7	22.6	29.5	36.3	43.2	50.0	56.9	63.8	70.6[2]
Canutillo	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Dona Ana Cty.	4.5	7.1	11.0	17.5	27.8[3]	27.8[3]	27.8[3]	27.8[3]	27.8[3]	27.8[3]
New Mexico State University	2.0	10.0	18.1	26.1	34.2[4]	34.2[4]	34.2[4]	34.2[4]	34.2[4]	34.2[4]
Subtotal	169.3	194.9	222.0	251.7	285.1	292.0	298.8	305.7	312.6	319.4
El Paso	0	35.2	73.2	113.0	153.7	192.6	246.0	246.0	246.0	246.0
Total	169.3	230.1	295.2	364.7	438.8	484.6	544.8	551.7	558.6	565.4

[1] Personal communication, Jerry Leyendecker, Utilities Engineer for City of Las Cruces, to Leo Eisel and Thomas Maddock, December 4, 1987.

[2] Based on 62 percent of Santa Teresa applications being utilized. 62 percent is based on estimated percentage of Dona Ana County applications being utilized.

[3] Based on data in Hernandez, et al. 1987.

[4] Personal communication, Bob Creel, December 7, 1987.

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