SIMULATION OF GROUNDWATER FLOW
TO ASSESS THE EFFECTS OF
GROUNDWATER PUMPING AND CANAL LINING
IN THE MESILLA BASIN OF
DOÑA ANA COUNTY, NEW MEXICO AND EL PASO COUNTY, TEXAS

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Statement By Author

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Abstract

In March 1991, after a decade of litigation over a proposal to pump water from within the state of New Mexico for transportation across state lines into Texas, a Settlement Agreement between the State of New Mexico and the City of El Paso, Texas was negotiated. From this agreement came the expressed desire for a computerized groundwater model capable of simulating interaction between the ground and surface water systems of the Mesilla Basin.

The hydrologic repercussions of future pumping withdrawals and proposed irrigation canal lining were of particular concern to the parties of the Settlement Agreement. To meet these concerns, an existing and calibrated groundwater flow model was used to evaluate how these two activities will affect flows in the Rio Grande, flows in the irrigation drain system, water levels in the groundwater system, and water quality in both the surface and groundwater systems.

The study involves 98 separate computer simulations: 7 altering future pumping rates, 2 altering canal lining, 5 manipulating the application of diverted surface water to farmlands, and 84 evaluating model sensitivity to selected input parameters.

In addition to a detailed presentation of simulation results, this report briefly discusses the physical features of the basin and provides some historical background on water use in the study area. A special chapter is dedicated to discussions concerning surface water capture concepts and factors which influence ground and surface water quality in the basin.

Executive Summary

This study, which is part of a settlement over the rights to water resources in the Mesilla Basin, uses a groundwater model to estimate how pumping in the basin affects the hydrologic regime.

In April 1981 the New Mexico State Engineer denied the City of El Paso, Texas application for well permits. This set off a decade of litigation between the City of El Paso and the state of New Mexico over El Paso's right to pump water from the Mesilla Basin in New Mexico. In March 1991 the City of El Paso and the State of New Mexico negotiated a Settlement Agreement stating that "...both parties work together to study, identify and address common concerns." (El Paso Water Suit Settlement Agreement, 1991). The various parties making up this settlement are referred to as the Joint Commission.

The Joint Commission wanted a transient model capable of simulating the ground and surface water system's response to (1) lining a portion of the Rio Grande canal system, and to (2) pumping changes in the study area. Hamilton and Maddock (1993) revised a USGS groundwater model to meet the Commission's request. They performed two simulations of the flow system: a steady state simulation of the 1915 flow system, and a 76 year (1915 to 1990) transient simulation. The transient simulation was calibrated to observed surface water flows and groundwater elevations.

This study uses the Hamilton/Maddock model to illustrate the effects of pumping withdrawals and canal lining on the hydrologic regime of the Mesilla Basin. The scope of work calls for:

- The evaluation of the effects of existing and expected groundwater withdrawals within the Mesilla Basin, with particular attention given to groundwater withdrawals from the Canutillo wellfield and from the Las Cruces area,
- The evaluation of the effects of lining major portions of the existing canal system to create a surface water conveyance facility, and
- A sensitivity analysis of the model's output with respect to uncertain input parameters.

The scope of work also called for an estimate, if possible, of the minimum amount of irrigation water required to keep salts mobile in the system. Since the groundwater model used in this study is incapable of determining this, an alternative analysis was performed on the effects of altering the amount of Rio Grande water applied to basin farmlands.

The Mesilla Valley, which lies within the Mesilla Basin, contains a complex surface water system consisting of the Rio Grande and an irrigation system with canals, laterals, and drains. Flows in this surface water system are controlled through releases from Elephant Butte and Caballo Reservoirs, which are located approximately 60 and 40 miles upstream, respectively, of the northern boundary of the basin. This system of reservoirs, canals and drains is the Rio Grande Project.

Primary sources of recharge to the Mesilla Basin groundwater system include canal leakage, Rio Grande leakage, infiltration of applied irrigation, mountain front recharge, underflow at canyons, and direct infiltration of precipitation. Based on simulation results, Project water accounts for approximately 97% of groundwater system recharge. Primary sources of discharge from the groundwater system include pumping for both agricultural and non-agricultural purposes, drain seepage, evapotranspiration from both agricultural and non-agricultural land, and underflow at canyons.

Of primary interest in the pumping analysis is (1) the quantity of water drawn from the river by pumping wells, (2) the effects of pumping on aquifer storage, and (3) the effects of pumping on drain flows.

Items (1) and (2) are related to capture: the reduction of system discharge, or the increase of system recharge, or a combination of both, so as to supply a pumping well with necessary water. In a system where surface water is fully appropriated, as in the Rio Grande system, capture is of critical concern to surface water appropriators.

Items (2) and (3) are related to the water quality of subsurface system. The existing drain system controls the water table so that excess irrigation water can flush concentrated salts out of the soil profile, through the shallow groundwater system, and into the drains. Reducing storage (synonymous to lowering groundwater levels) leads to decreased drain flows. When drain flows decrease, less salt is conveyed from irrigated areas, and more is concentrated in the groundwater system and soil profile.

Agricultural practices in the Mesilla Valley result in elevated Rio Grande salinity during the non-irrigation season and down-gradient degradation of water quality. To remedy this it is proposed that the majority of Rio Grande flow be conveyed in a lined conveyance canal. This strategy aims to reduce canal and river conveyance losses and preserve water quality. The reduction of Rio Grande leakage and canal leakage, however, is expected to result in reduced drain discharge. As long as agriculture continues in the valley, drain flows are an important component of the hydrologic system because they convey dissolved solids away from the soil profile, and reduce the mixing of shallow saline waters with deeper high water quality.

To quantify the effects of a given stress on the system, model simulations *with* and *without* the stress of interest are compared. All boundary conditions, except those involving the stress of interest, are held constant. Boundary conditions that remain constant in the predictive simulations, such as evapotranspiration from agricultural land, infiltration of precipitation, application of irrigation diversions to farmland, groundwater withdrawals for municipal and industrial purposes, recharge from septic systems, Rio Grande leakage, canal leakage, drain system seepage, and evapotranspiration from non-irrigated lands, are meant to represent average annual conditions.

Climate in the Mesilla Basin is described by low but variable annual precipitation, large annual temperature ranges, and low relative humidity. The high variability of climate from year to year poses some difficulty in quantifying average conditions. When selecting a time series of data from which to derive an annual average, the time period should be as long as possible to capture long-term variabilities that may exist. In addition, the data must be homogenous. Any event that permanently alters the characteristic being analyzed represents a break in data series. Non-homogeneity of data tends to shorten otherwise long time-series.

A review of the hydrologic history of the Mesilla Basin was conducted to find a representative time period from which to base average annual flows. Almost all recharge (97%) in the Mesilla Basin comes from the Rio Grande in the form of surface water leakage and applied irrigation. Since fluctuations in Rio Grande flow will have a profound impact on the groundwater system, the history of Rio Grande water supply was considered.

Engineering Science (1991) shows that annual releases from Elephant Butte reservoir declined during the 1950's from a previous average of 808,900 acre-ft, to a new average of 606,700 acre-ft. The post 1950's flow is 183,000 acre-ft less than the 790,000 acre-ft anticipated during compact negotiations (Engineering Science, 1991). Flows were reduced by increased groundwater withdrawals and other unaccounted for diversions upstream of Elephant Butte Reservoir. Based on this information all boundary conditions used in the predictive simulation, with the exception of pumping fluxes, were assigned the 1958 to 1990 historical simulation average.

Using current water supply conditions and new storage and conservation procedures, Engineering Science (1991) recommends normal project releases between 600,000 and 650,000 acre-ft annually (828 to 897 cfs). In the predictive simulations an annual Rio Grande Discharge of 602,500 acre-ft is assigned at Leasburg Dam. Estimates show this equivalent to an annual release of 630,500 acre-ft from Caballo reservoir.

Pumping Scenarios

In order to simulate non-irrigation pumping withdrawals, the model area is divided into 5 zones, each of which is assigned a separate growth rate. Municipal and industrial pumping and return rates used from 1977 to 1991 in the historical simulation were averaged and used to represent current pumping conditions. Increasing or removing pumping in specified zones is simulated by increasing the extraction rate of all wells within the zone or by setting all extraction rates in the zone to zero. Population growth and water demand studies for the City of Las Cruces and for Doña Ana County, New Mexico were used to estimate future increases in pumping.

The effects of pumping on the hydrologic regime are illustrated with 7 simulations that vary the magnitude of pumping in specified areas. These 7 simulations are identical except for differences in pumping rates, sewage return flows to the river, and simulated leach field returns. All simulations are run 40 years into the future. The 7 scenarios are as follows:

- Constant Basin Wide - Pumping throughout the model is held constant at current rates.
- Increased Basin Wide - All pumping in the model is increased by the growth rate associated with each pumping zone.
- Removed Basin Wide - All pumping in the model is removed at the start of the simulation.
- Increased Canutillo Pumping - Canutillo wellfield pumping is increased 2.81% annually; all other pumping in the model is held constant.
- Removed Canutillo Pumping - Canutillo wellfield pumping is removed at the start of the simulation; all other pumping in the model is held constant.
- Increased Las Cruces Pumping - Las Cruces area pumping is increased 2.81% annually; all other pumping in the model is held constant.
- Removed Las Cruces Pumping - Las Cruces area pumping is removed at the start of the simulation; all other pumping in the model is held constant

The runs are structured to bracket the extremes of the possibilities at hand. The upper bound extreme is the increase of pumping to accommodate all increased water demand. The lower bound extreme is the immediate removal of the pumping in question. Between these upper and lower bounds is another scenario of interest, the holding of pumping constant at current rates.

Selected system components are recorded as the simulations progress. The effect of pumping or canal lining on the hydrologic regime is based on the behavior of the selected components. The system components this analysis focuses on are:

- Water table elevation,
- Aquifer storage,
- Deep aquifer piezometric head,
- Rio Grande discharge at the Narrows,

- Rio Grande and canal transmission losses, and
- Irrigation system drain flows.

The proximity of pumping to the Rio Grande influences the timing of surface water capture; it also affects the quantity of water drawn from storage when new pumping is introduced or existing pumping is increased. The further new pumping is from the source of capture, the more storage depletion required before capture is complete. In the Mesilla Valley the majority of pumping occurs in the Las Cruces area and in the Canutillo/Anthony area. The Canutillo wellfield is much closer to the Rio Grande than the bulk of Las Cruces pumping. On the east side of the Rio Grande there is little pumping between Anthony and Mesilla; on the west side, there is no pumping north of Canutillo.

Basin Wide pumping scenarios show that after 40 years of increasing *all* pumping within the model at expected rates...

- Storage is reduced by about 625,000 acre-ft,
- Rio Grande flows at the Narrows drop by 59 cfs, an 11.5% flow reduction, and
- 183 cfs is pumped Basin Wide, with about 87 cfs (48%) coming from captured surface water sources.

When all pumping within the model is held at current rates, no changes in Rio Grande discharge is simulated.

Simulations manipulating Canutillo wellfield pumping indicate that pumping from the wellfield draws roughly 15% of its water from storage, 70% from surface water sources, and 15% from salvaged evapotranspiration. If held constant, Canutillo pumping withdraws 510,000 acre-ft of water over 40 years; if increased (at an expected rate of 2.81% annually), it withdraws about 933,000 acre-ft.

Simulations indicate that Las Cruces area pumping draws roughly 24% of its water from storage, 44% from surface water sources, and 32% from salvaged evapotranspiration. If held constant, Las Cruces area pumping withdraws 649,000 acre-ft of water over 40 years; if increased (at an expected rate of 2.81% annually), it withdraws about 1,187,000 acre-ft of water. Because 95% of the surface water captured by Las Cruces pumping is returned to the River as sewage return flow, Las Cruces pumping is shown to have no net effect on Rio Grande discharge at the Narrows.

In the southern region of the model, the East/Anthony and West/Nemexas drain systems are affected by Canutillo pumping. If pumping in the Canutillo wellfield is increased, these drains will experience depleted discharge, but are not threatened to dry up. If pumping across the river in the Santa Teresa is also increased, additional flow reductions will result.

In the northern region of the model, the Picacho, Leasburg, Mesilla and Del Rio drains are affected by Las Cruces area pumping. If pumping in the Las Cruces area is increased, the Mesilla and Picacho drains will dry up. The Del Rio and Leasburg drains show distinct flow reductions, but are not simulated to dry up.

Surface Water Scenarios

Two simulations were conducted to analyze the effects of canal lining on the hydrologic regime. The two runs represent...

- The lining of all canals in the system (to quantify the effects of canal leakage on the hydrologic regime), and
- The creation of a lined conveyance facility.

The surface water alternative plan recommended by Engineering Science calls for leaving 50 cfs in the Rio Grande and diverting all other project releases into a lined conveyance channel. Water from the lined canal is delivered to all agricultural, municipal and industrial surface water appropriators in the Rincon and Mesilla Valleys. In the Mesilla Valley the water is conveyed on the east side of the river in the Leasburg and Picacho canals until it passes underneath the river at the Picacho flume. From there the conveyance facility remains on the west side of the river for the remainder of its course through the valley.

Based on average annual Project flows in the Held Constant simulation, total system seepage losses are simulated to be 175,000 acre-ft per year (242 cfs). 1/3 of that comes from the Rio Grande, and 2/3 comes from the irrigation delivery system. Drain flows returning to the Rio Grande are simulated to be 110,000 acre-ft per year (153 cfs). Simulation results where *all* canals are lined indicate that...

- Water savings, as measured in Rio Grande at the Narrows, will amount to about 30,000 acre-ft per year (≈ 42 cfs), an 8% flow increase.
- Drain flows system wide will be reduced from 153 cfs to 78 cfs (a 49% reduction), indicating that canal leakage accounts for approximately half of all drain flows.
- The Selden, Picacho, Leasburg, and Mesilla drains of the Las Cruces area will dry up. All other drains in the system will experience flow reductions of at least 40%.

Simulation results representing the recommended surface water alternative indicate that...

- Water savings, as measured in Rio Grande at the Narrows, will amount to about 18,000 acre-ft per year (≈ 25 cfs), a 5% flow increase.
- Drain flows are reduced from 153 cfs to 99 cfs (a 35% reduction).
- The Selden, Picacho, and Leasburg drains will dry up. All other drains experience flow reductions of at least 40%. On the east side of the river, south of the Picacho flume, drain flow depletions are less as one travels

south. On the west side of the river drain flow depletions are relatively uniform along the length of the valley.

Irrigation Efficiency

The scope of work calls for an estimate, if possible, of the minimum amount of irrigation required to keep salts mobile in the system. Due to the inability of the model to accomplish this, an alternative analysis was performed evaluating the hydrologic effects of altering irrigation efficiency: the ratio of water consumed by a crop in proportion to the amount applied to it. Under the assumption that salts are flushed from the soil after each irrigation, the *total dissolved solids* (TDS) of excess irrigation water increases with increasing irrigation efficiency. While in theory an irrigation efficiency of 100% is ideal, in practice it is not possible. Excess water must be regularly flushed through the soil profile to prevent the accumulation of salts, which can render the land unfit for cultivation.

While an estimate of the minimum amount of water required to keep salts mobile in the system is not possible with the current model, the effect of irrigation efficiency on the hydrologic regime is. Six simulations with different irrigation efficiencies were analyzed. The results show that...

- Decreasing irrigation efficiency increases drain flows and replenishes storage at the cost of reduced water supply. Increasing irrigation efficiency has the opposite effect; it increases water supply at the cost of lower drain flows and reduced storage.
- Once the system equilibrates to *any* new *increase* in recharge rates, 78% of the increased recharge is discharged to the surface water system, 20% is consumed by evapotranspiration, and about 2% replenishes storage reserves. The percentages are the same when recharge is *decreased*,

except that discharges to the surface water system is reduced, evapotranspiration rates drop, and storage reserves are depleted.

- Almost all flow changes at the Narrows from changes in irrigation efficiency are attributable to changes in evapotranspiration rates.
- As less water is applied the land to increase irrigation efficiency and save water, less water is being flushed through the system. This implies that one or both of two processes is occurring: salts are being left behind in the groundwater system, and/or drain return flows have elevated TDS concentrations.

Sensitivity Analysis

A sensitivity analysis was performed to assess model sensitivity to selected input parameters. The analysis consists of 84 separate simulations altering transmissivity, vertical conductance, specific yield, evapotranspiration parameters, Rio Grande bed conductance, canal bed conductance, and drain bed conductance. Sensitivity under different states of stress were determined by testing the selected parameters with the Held Constant Basin Wide simulation and the Increased Basin Wide simulation. The analysis illustrates the following:

- Water supply, as measured in the Rio Grande at the Narrows, is insensitive to all the parameters tested.
- Aquifer storage is most sensitive to changes in layer 1 horizontal conductivity and deep aquifer transmissivities. Storage is moderately sensitive to vertical conductance, river bed conductance, drain bed conductance, and canal bed conductance. It is relatively insensitive to specific yield and the evapotranspiration parameters evaluated.
- Transmission losses from canals and the Rio Grande are sensitive to all the parameters evaluated except vertical conductance, specific yield and evapotranspiration.

- Drain flows are very sensitive to all the parameters evaluated except vertical conductance and specific yield. They are moderately sensitive to the evapotranspiration extinction depth.

1. Introduction

This study is part of a settlement to a dispute between several parties over the rights to water resources in the Mesilla Basin of Doña Ana county, New Mexico and El Paso county, Texas.

In New Mexico surface water resources are exploited under the doctrine of prior appropriations. Water rights under this doctrine are dependent upon (1) beneficial use of the water, and (2) the date when the water was first put to use. "First in time, first in right" dictates how water is rationed in times of shortage. The sooner a right is claimed, the higher the time priority, and the more senior the right. To claim and maintain a water right, an appropriator must continuously put the water to beneficial use.

In the mid-1800's, when the doctrine of prior appropriations was evolving, water used for agriculture, industry and mining came solely from rivers. As time passed, two things happened: (1) all available surface water supplies became appropriated, and (2) advances in technology allowed for the exploitation of a previously untapped water source: groundwater.

Before modern hydrology matured to its present state of sophistication, ground and surface water resources were viewed more or less as separate and disconnected systems, and relatively little consideration was given to interaction between the two. As time progressed into the twentieth century, however, groundwater pumping steadily increased and river flows slowly declined in many regions of the West. The indication that pumping wells were depleting streamflows led to a greater focus on interactions between ground and surface water systems and to the eventual acknowledgment that ground and surface water systems were, in many cases, interdependent. A good deal of the knowledge gained about these interactions came from water rights disputes where quantification of ground and surface water interaction was the pivotal issue.

This study uses a groundwater model to estimate how pumping and canal lining in the Mesilla Basin affects the hydrologic regime. It is part of a settlement over the disputed rights to water resources in the Mesilla Basin. The following paragraphs outline the events leading to the current study.[1]

Background

In April 1981 the New Mexico State Engineer denied the City of El Paso, Texas application for well permits based on the New Mexico Embargo Act, which forbade out-of-state transfer of groundwater. El Paso appealed this decision on the grounds that the Embargo Act was in violation of the U.S. Constitution's Commerce clause. Their appeal was upheld through decisions by the Supreme Court and the U.S. District Court (Hamilton and Maddock, 1993).

The New Mexico legislature repealed the embargo statute and enacted a new statute allowing the export of groundwater only if the "applicants withdrawal and transportation of water for use outside the state would not impair existing water rights, is not contrary to the conservation of water within the state, and is not otherwise detrimental to the public welfare of the citizens of New Mexico" (Harris et al., 1990). The legislature also codified into law an existing State Engineer Regulation requiring that "municipalities, counties, state universities and public utilities...shall be allowed a water use planning period not to exceed forty years..." (Harris et al., 1990). The purpose of this regulation was to prevent water speculation. The New Mexico State Engineer denied El Paso well permits based

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[1] A more detailed chronology is presented by Hamilton and Maddock (1993).

on this "40 Year Rule." El Paso appealed the State Engineer's denial, but the appeal was denied in three separate courts.

With the appeal still pending in the New Mexico state Court, the parties to the litigation began settlement discussions. In March 1991 the City of El Paso and the State of New Mexico negotiated a Settlement Agreement stating that "...both parties work together to study, identify and address common concerns." (El Paso Water Suit Settlement Agreement, 1991). The various parties making up this settlement are referred to as the Joint Commission.

A modeling effort was initiated to address "both parties concerns." (El Paso Water Suit Settlement Agreement, 1991) The Joint Commission desired a transient model capable of simulating the effects on ground and surface water systems by...

- Pumping withdrawals, and
- The lining of selected canal sections.

In response to this request, Hamilton and Maddock (1993) revised an existing USGS MODFLOW model to fulfill the desires of the Joint Commission. Their work included the simulation of 1915 steady state flow, and the calibration of a 76 year historical simulation (1915 to 1990) to observed flows and water levels. Hamilton and Maddock's work provided the Joint Commission with a model to evaluate the hydrologic system of the Mesilla Basin under alternative scenarios of development.

Scope of Work

This study, using the Hamilton/Maddock model, runs a series of scenarios to illustrate the effects of pumping withdrawals and canal lining on the hydrologic regime. The scope of work is as follows:

Using the existing representation of the unlined canal system, evaluate the effects[2] of groundwater withdrawals...

1) For the entire Mesilla Basin,
2) At the Canutillo wellfield, and
3) In the Las Cruces area.
4) Using a revised representation of the canal system, evaluate the effects of lining major portions of the existing canal system to create a surface water conveyance facility, and
5) Perform a sensitivity analysis of the model's output with respect to uncertain input parameters.
6) If possible, estimate the minimum amount of applied irrigation required to keep salts mobile in the system.

Item 6 in the above Scope of Work was requested by a member of the Elephant Butte Irrigation District and cannot be fulfilled with the current model for a number reasons which are discussed in Section 4.7. While an estimate of the minimum amount of water required to keep salts mobile in the system is not provided in this report, an analysis of the effects of changing irrigation efficiency is presented. The analysis illustrates how the hydrologic regime is affected when the amount of surface water applied to valley farmland is altered.

Report Organization

This report is intended to provide sufficient background information so as to stand by itself. A wealth of published information is available concerning the water resources of

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[2] The "effects" of each scenario refers to (1) flow changes in the surface water system, and to (2) storage, flow and water quality changes in the groundwater system.

the Mesilla Basin. Five reports, in particular, are referred to frequently by this author. A brief summary of these reports is provided below in **Description of Previous Studies**[3].

The geology and hydrology of the basin is briefly presented in Chapter 2. Chapter 3 covers two concepts imperative to understanding this report's analysis: (1) the physics of surface water capture by groundwater pumping, and (2) processes controlling water quality in the basin.

Chapter 4 covers the simulation of groundwater flow and is the bulk of the report. The boundary conditions used in predictive simulations are meant to represent average annual conditions. The determination of these conditions in the context of the region's climate and historical farming practices is outlined. This is followed by a description of the model scenarios and a presentation of the results. Finally, results of the sensitivity analysis are presented.

Chapter 5 lists the references used in the report. The Appendices present summaries of simulation input and output data, and are referred to in the main body of the report.

Description of Previous Studies

In 1987 Wright Water Engineers and Thomas Maddock, III prepared a report for the Elephant Butte Irrigation District (EBID) and Doña Ana County, New Mexico. The study analyzed the hydrology of existing EBID systems, and created a finite difference model of the basin flow system to simulate the effects of proposed El Paso well fields on the region's hydrology. In particular, the study included...

- A review of technical reports and documents that pertain to the hydrology and hydrogeology of the Lower Rio Grande Basin,

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[3] A more complete summary of previous studies is provided by Hamilton and Maddock (1993).

- Determination and quantification of the relationship between drain flows and shallow ground water levels, and
- Determination if there was a salinity problem, and what its causes were.

A 1990 report by Frenzel, Kaehler, and Anderholm studies the groundwater hydrology and geochemistry of the Mesilla Basin as part of the USGS Southwest Alluvial Basins Regional Aquifer-system Analysis program. A finite-difference groundwater model was used to simulate system flow from 1915 to 1975. The primary purpose of the model was to test the validity of the conceptualized groundwater flow system. Despite the fact that "...the model matched measured hydraulic heads, drain discharges and river depletions reasonably well with a few exceptions", the authors felt that its usefulness as a predictive tool was limited by non-uniqueness. This original five layer model simulated ...

- Groundwater interaction with the Rio Grande and the irrigation drains,
- Evapotranspiration from irrigated and non-irrigated lands,
- Infiltration of irrigation water applied to farmland,
- Groundwater withdrawals for irrigation and non-irrigation purposes,
- Mountain front recharge, and
- River underflow through the canyons entering and leaving the basin.

In 1992 Frenzel published a supplement to the 1990 report. This report describes changes made to the 1990 model and looks at the effects of pumping on Rio Grande flows. Revisions to the original model included...

- A 10 year extension (from 1975 to 1985) of the original 60 year transient simulation,
- Modifications to represent new geological interpretations, including adjustment of basin-fill thickness, removal of layer 5, and changes in the

methodology used to determine transmissivity and vertical conductance values, and

- Estimation of agricultural evapotranspiration based on reported acreages of individual crops rather than on assumed crop-types and estimated winter crop evapotranspiration.

In this report Frenzel concludes that, with the new modifications, the "...model is a reasonable tool for projection."

In 1991 Engineering Science presented a study evaluating surface water supply alternatives for El Paso and southern New Mexico. The study looks at the Rio Grande as a water supply source for municipalities and industry below Elephant Butte Reservoir. In particular, it investigated changes in Rio Grande water supply and changes in Rio Grande Project operation, and it proposed four surface water supply alternatives for El Paso[4]. It also recommended a groundwater modeling study to determine the hydrologic impacts of the recommended plans.

In 1993 Engineering Science and Boyle Engineering jointly prepared a study to evaluate and quantify surface water supply alternatives, the main goal being to meet the future needs of El Paso, Las Cruces, and other users in southern New Mexico. The study looks at the conversion of Project water to municipal use, and the reduction of waste incurred through canal seepage, reservoir evaporation, and delivery system operation. The report notes that water savings calculations in this study are "...only rough estimates. They are accurate enough to support the conclusions and recommendations but should be better quantified in subsequent work."

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[4] The surface water supply alternatives suggested in this report are similar to those made in a later study prepared jointly by Engineering Science and Boyle Engineering Corporation.

Final modifications to the USGS groundwater model were completed and presented by Hamilton and Maddock (1993). The main goal of their work was to improve model representation of ground and surface water interaction. The scope of work included...

- A review of the literature,
- Developing a transient model capable of simulating the groundwater system under alternative scenarios of development (changes in pumping, the lining of canals, etc.),
- Modifying the USGS Streamflow-Routing package (Prudic, 1989) and incorporating it into the model to simulate shallow groundwater interaction with canals, drains and the river,
- Performing a steady state run simulating the 1915 flow system,
- Updating the USGS model of the Mesilla basin by extending the transient simulation from 1986 to 1990, and
- Performing a sensitivity analysis to determine the data needs for upgrading and improving modeling and management activities.

The Stream Routing (or Prudic) package tracks flows in streams that interact with groundwater systems. In particular it...

- Calculates the stage (or free water surface elevation) in the river, canals and drains[5],
- Quantifies aquifer-stream discharge,[6]
- Allows for diversions from streams (splitting streams) and for the joining of two tributaries,

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[5] Based on the Manning formula, an assumed rectangular channel cross-section, and a specified flow.

[6] Based on the model derived head in the aquifer, the stream conductance term (which represents the conductivity of the alluvium connecting the stream with the underlying aquifer), and the calculated stream stage.

- Limits stream to aquifer seepage to the amount of water available in the stream,

The package was modified by Hamilton to ...

- Simulate the continuous removal of farm water along a canal's length, and
- Specify diversions from the river and canals as either a percentage of the flow in the contributing river/canal, or as an explicit value.

Hamilton and Maddock's 1915 to 1990 transient simulation is referred to in this report as the *historical transient simulation.*

2. Geology And Hydrology Of The Study Area

This section briefly discusses the geology and hydrology of the Mesilla Basin. For a more complete discussion, the reader is referred to Frenzel and Kaehler (1990). Frenzel and Kaehler (1990), Frenzel (1992), and Wright Water Engineers and Maddock (1987) all offer good discussion on a variety of matters concerning the groundwater flow system. Reports by Engineering Science (1991), and Boyle Engineering and Engineering Science (1993) discuss the surface water system extensively.

Figure 2-1 is a map of the Upper Rio Grande Basin from its head waters in Colorado to the north, to the Narrows at El Paso, Texas in the south. This figure offers a regional view of the entire Upper Basin and illustrates the location of major towns and cities, state boundaries, reservoirs and river gages.

Figure 2-2 shows the key features of the Rio Grande Project. This figure includes a regional map illustrating the location of the Rio Grande and Project facilities from Albuquerque, New Mexico to El Paso, Texas. Also presented are two local maps showing (1) Elephant Butte Reservoir and the Rincon Valley and (2) the stretch of river from Leasburg Dam in the Mesilla Valley to Fort Quitman, Texas (about 60 miles south of El Paso).

Figure 2-3 outlines the area specifically modeled in this study. The majority of the Mesilla Basin lies within Doña Ana County, New Mexico, although parts of the basin lie within El Paso County, Texas and the State of Chihuahua, Mexico. The Mesilla Basin is the southernmost of a series of basins along the Rio Grande in New Mexico (Frenzel and Kaehler, 1990).

Physical Features

The Mesilla basin is bounded by the East and West Potrillo mountains to the southwest, the Robledo mountains to the northwest, the Doña Ana and Organ Mountains to the northeast, and the Franklin Mountains to the southeast (Figure 2-1). The Rio Grande enters the basin from the north, through Selden Canyon, between the Robledo and Doña Ana Mountains. It exits the basin to the south through El Paso Narrows between the Franklin Mountains and the Sierra de Christo Rey. The broad region west of the Rio Grande is called the West Mesa (or La Mesa). The Rio Grande has incised into the Mesa and formed the Mesilla Valley, a long narrow valley (approximately 50 miles long by 5 miles wide) covering approximately 110,000 acres. The valley is distinguished by cliffs up to 400 feet in height that were formed by the incision of the Rio Grande into the Mesa (Frenzel and Kaehler, 1990). The Mesilla Basin and the Mesilla Valley, as referred to in this report, are *not* interchangeable terms. The Mesilla Valley lies *within* the Mesilla Basin, and is primarily a surficial feature, consisting essentially of the historical Rio Grande flood plain and its thin layer of alluvium (see Figure 2-3).

Climate

The Mesilla Basin has an arid climate described by low but variable annual precipitation, large annual temperature ranges, and low relative humidity (Houghton, 1972). About half of the total annual precipitation occurs between July and October (Wilson et al., 1981). The 111 year average annual precipitation is 8.39 inches (Wilson et al., 1981).

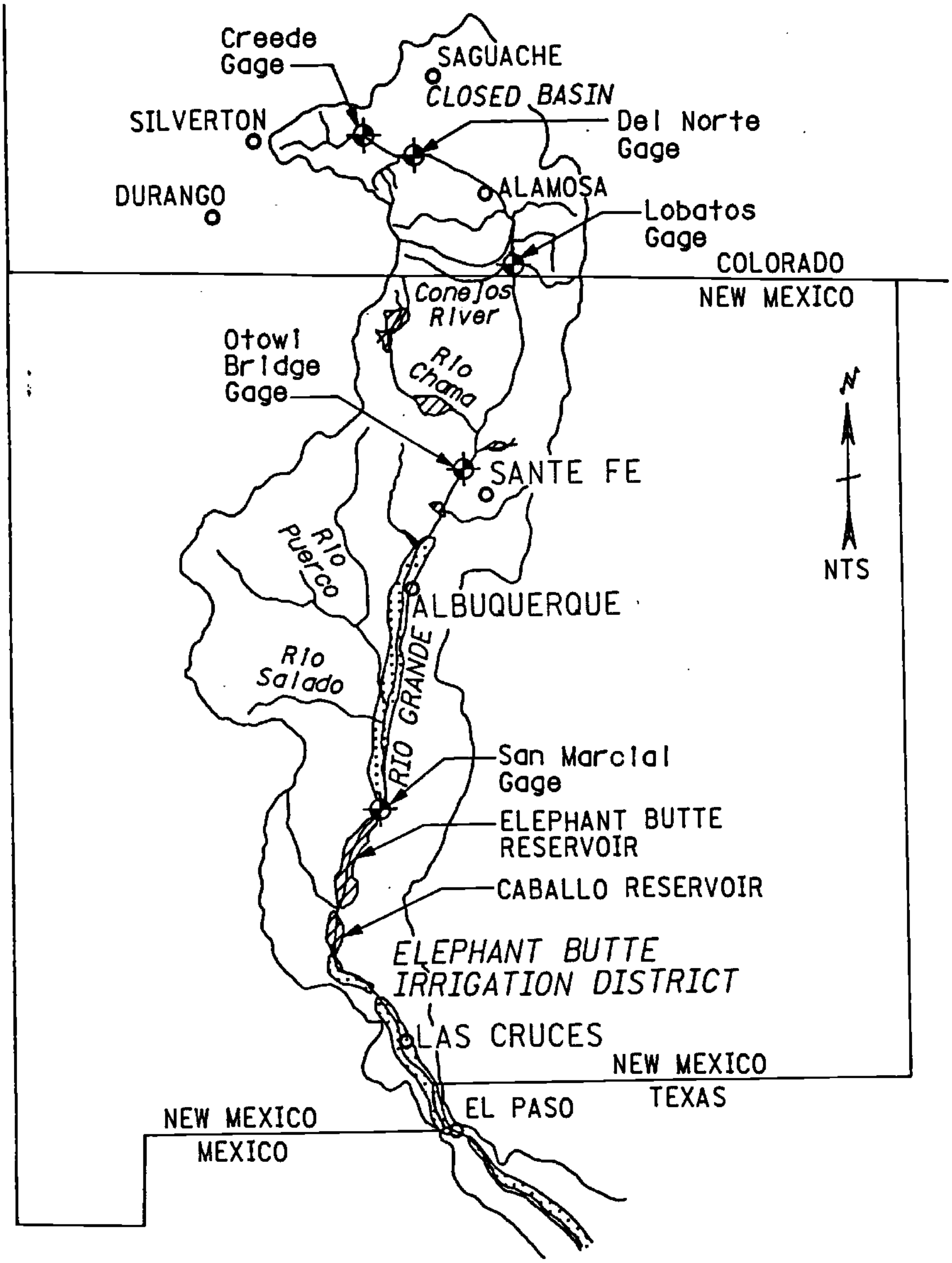

Figure 2-1: Map detailing the Upper Rio Grande Basin (Engineering Science, 1991)

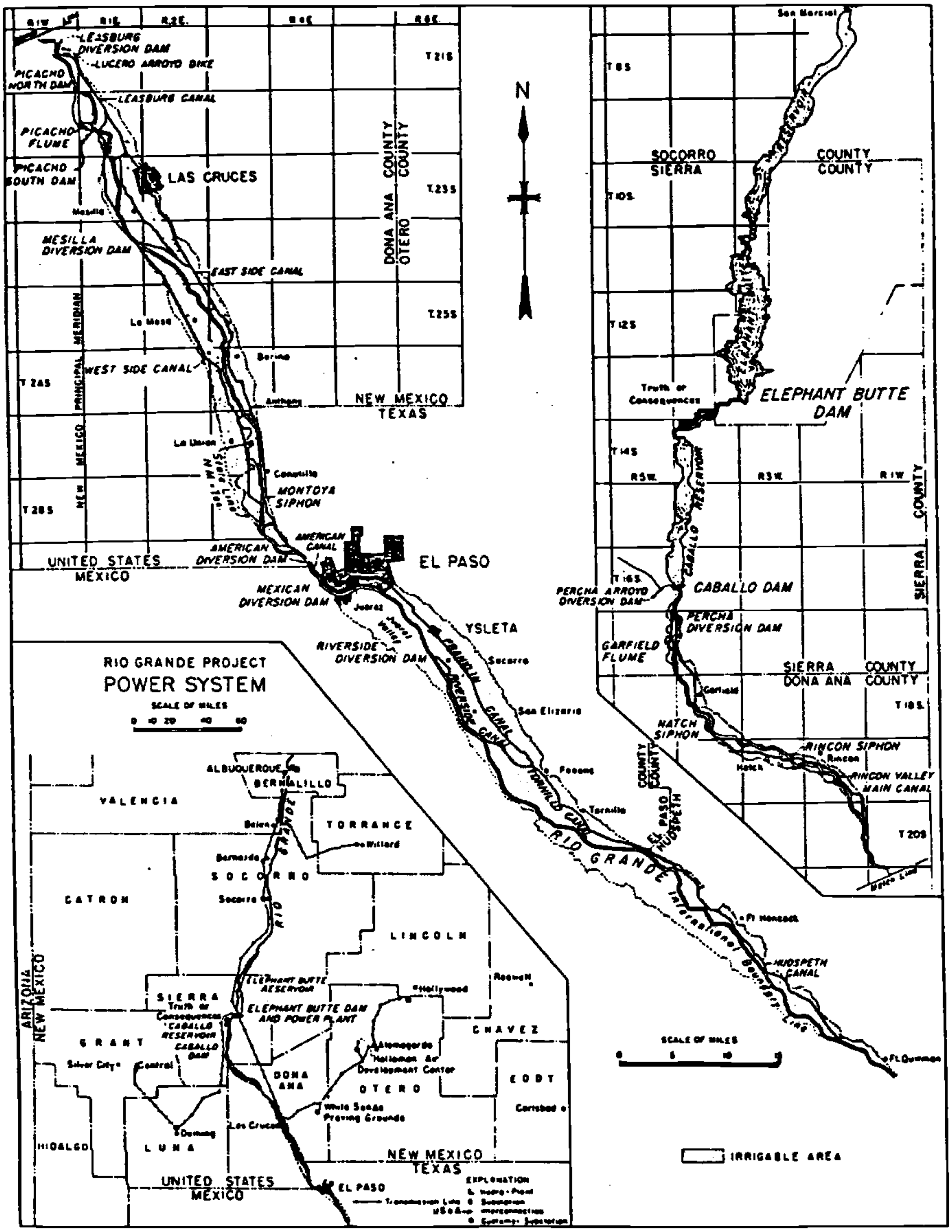

Figure 2-2: Map detailing the Rio Grande Project (Engineering Science, 1991)

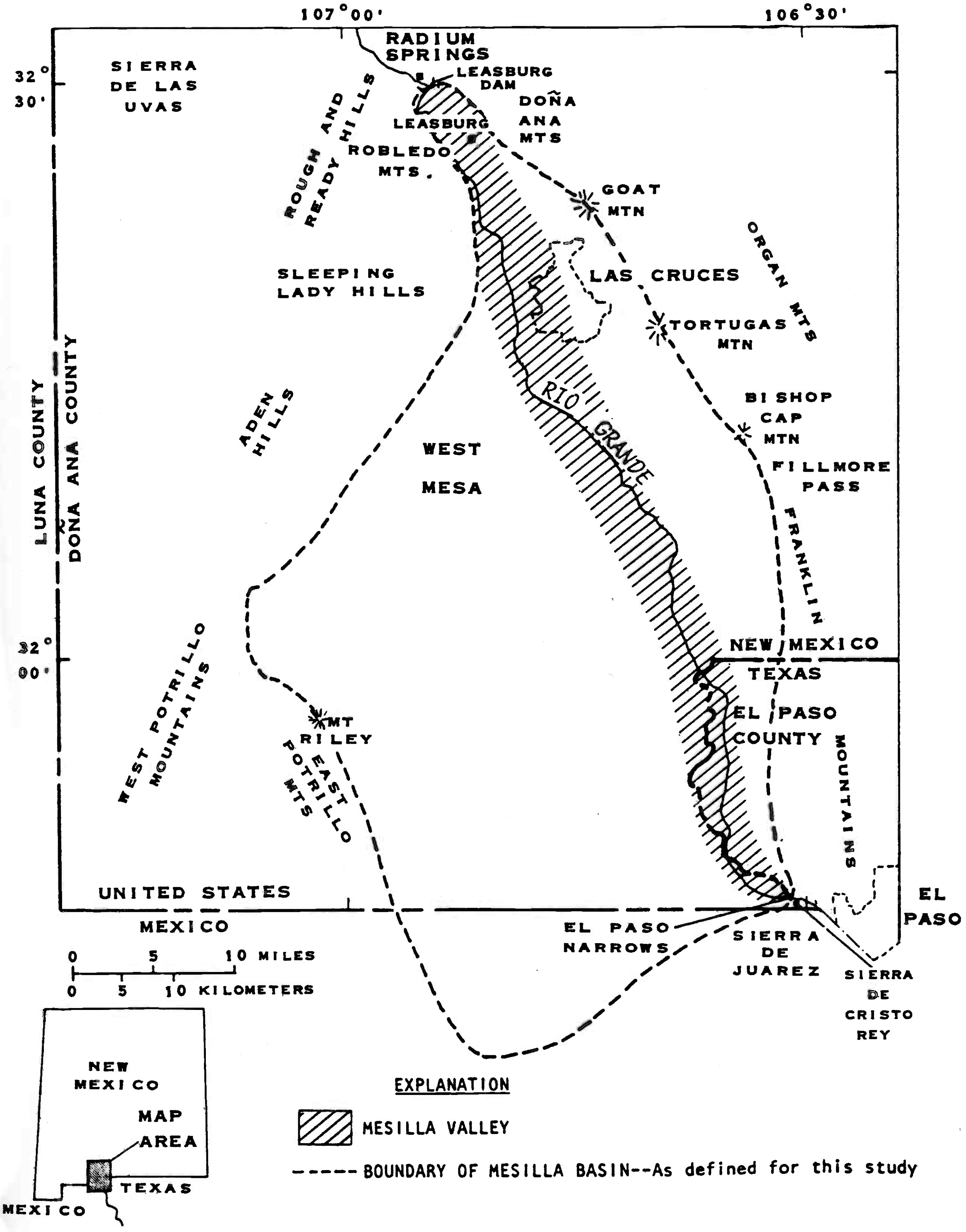

Figure 2-3: Map detailing the Mesilla Basin study area (Frenzel and Kaehler, 1990)

Groundwater System

The lateral extent and depth of the groundwater flow system is defined by relatively low permeability bedrock consisting of igneous-intrusive and metamorphic rocks, Paleozoic and Mesozoic sedimentary rocks, and lower Tertiary sedimentary and volcanic rocks (Frenzel and Kaehler, 1990). The zone of permeability contrast marked by the bedrock-alluvium interface forms the boundary of the groundwater flow system. Basin-fill deposits, which consist of a shallow layer of flood-plain alluvium and the Santa Fe formation, form a three dimensional groundwater flow system.

Primary sources of recharge to and discharge from the groundwater system are listed below.

- Runoff from the mountains surrounding the basin recharges the groundwater system along the mountain fronts. At the mountain fronts slopes begin to flatten, and the alluvium becomes thick enough to absorb runoff. This is termed Mountain Front Recharge, and is simulated to be about 18 cfs (Frenzel and Kaehler, 1990).
- Water enters the groundwater flow system at Selden Canyon as underflow, and similarly leaves the system at Fillmore Pass[1] and El Paso Narrows.
- Water recharges the groundwater system from Rio Grande and canal leakage, and discharges the system as drain seepage.
- Water is withdrawn from the floodplain alluvium, primarily for agricultural purposes, and from the Santa Fe formation, primarily for municipal and industrial purposes.
- Water is recharged through the application of diverted surface water to valley farmland.
- Water is discharged through evapotranspiration from vegetation.

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[1] Fillmore Pass is located between the Franklin and Organ Mountains.

- While the majority of precipitation evaporates or occurs as runoff, the remainder either infiltrates directly into the saturated zone (in areas where the depth to groundwater is small) or serves to reduce evapotranspiration. The combination of these two processes is termed *effective precipitation.*

Total annual recharge is estimated by Peterson et al (1984) to be 386,500 acre-ft, 62.5% of which comes from irrigation, 30 percent from stream loss, and the remainder from mountain front recharge (Peterson et al., 1984).[2]

Groundwater flow is generally away from the valley above Las Cruces, and towards the valley in the southern part of the basin. The groundwater flow system has typically been divided into three zones of distinct stratigraphic characteristics.

- The shallow zone is unconfined. It is composed of flood plain alluvial deposits and the upper part of the Santa Fe group, and consists primarily of gravels and coarse sands (Hamilton and Maddock, 1993). On the average it is about 80 feet thick (Wright Water Engineers and Maddock, 1987).
- The middle zone is the intermediate Santa Fe group, which consists of alternating beds of coarse grained sand, silty clay, and gravel. The sand deposits tend to have lenses of silty clay (Hamilton and Maddock, 1993).
- The deep zone, composed entirely of lower Santa Fe group deposits, is characterized by uniform fine to medium grain size sand with some silt and clay (Hamilton and Maddock, 1993).

Surface Water System

The Mesilla Valley is host to a complex surface water system consisting of the Rio Grande and an irrigation system containing 141 miles of canals, 462 miles of laterals, and 457 miles of drains (Boyle Engineering and Engineering Science, 1993). There are two

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[2] In predictive simulations the average annual recharge to the model from these sources was simulated to be 363,200 acre-ft per year, with 81% coming from irrigation practices (canal leakage and excess irrigation), 16% coming from Rio Grande losses, and the remainder from mountain from recharge.

irrigation districts in the Basin: The Elephant Butte Irrigation District (EBID) and the El Paso Water Improvement District # 1 (EPWID). According to the Rio Grande Compact, the EBID serves 90,640 acres and EPWID serves 69,010 acres (Boyle Engineering and Engineering Science, 1993). The actual acres served by each district varies slightly from year to year. Based on these acreages, the Compact states that the EBID is entitled to 56.77% of project releases, and EPWID is entitled to 43.23%.

Project water is stored in Elephant Butte Reservoir and downstream in Caballo Reservoir (see Figure 2-2). Irrigation releases from Caballo Reservoir are replaced by releases from Elephant Butte Reservoir. Water in the Rio Grande flows from Caballo Reservoir through the Rincon Valley to Selden canyon and into the Mesilla Basin. The EBID serves approximately 16,260 acres of land in the Rincon Valley.

There are three diversion dams which divert water from the river for use on agricultural lands:

- Percha Diversion Dam serves 16,260 acres in the Rincon Valley.
- Leasburg Diversion Dam serves 31,600 acres in the Mesilla Valley.
- Mesilla Diversion Dam serves 53,650 acres in the Mesilla Valley (Boyle Engineering and Engineering Science, 1993).

Water is diverted from the Rio Grande at these dams and delivered to farms, where it is applied to the fields for the cultivation of crops. Applied irrigation which is not evaporated or transpired by crops infiltrates into the shallow groundwater system. Some of this water recharges the deeper aquifer, but most of it flows towards nearest downgradient drain and returns to the Rio Grande.

During years of ample water supply, the majority of irrigation water used by farmers is diverted from the Rio Grande. It is estimated that about 1/3 of this replenishes the groundwater system (Blaney and Hanson, 1965). In times of water shortage, farmers turn to groundwater pumping to make up the difference. Increased pumping during times of drought leads to valley wide drawdown of the water table, but groundwater levels rebound once normal surface water supplies return (Frenzel and Kaehler, 1990).

The existing system depends largely on the Rio Grande channel to convey irrigation water to points of diversion. There are currently proposals to change this practice and convey the majority of water in a lined conveyance facility.

3. Important Concepts

This chapter is provided to insure that the reader is familiar with some important technical concepts applicable to this analysis. Readers familiar with 1) capture, and 2) the processes that dictate drain flow and groundwater salinization in the Mesilla Valley may wish to skip this chapter.

3.1 Capture

In 1940 C.V. Theis stated that,

> "Under natural conditions...previous to development by wells, aquifers are in a state of approximate dynamic equilibrium. Discharge by wells is thus a new discharge superimposed upon a previously stable system, and it must be balanced by an increase in the recharge of the aquifer, or by a decrease in the old natural discharge, or by a loss of storage of the aquifer, or by a combination of these."

Theis was referring to capture: adjustments in the rate of recharge and/or discharge in response to pumping an aquifer. The depletion of surface water flows due to pumping in the Mesilla Valley is a primary focus of this study. In order to insure that the reader has a clear understanding of the important concepts pertaining to this, the mechanics of capture are discussed.

The Mathematics of Capture

Groundwater basins under virgin conditions are usually assumed to be in a state of equilibrium. When recharge into a groundwater system is equal to the discharge from it, the system is said to be in steady state. Since inputs and outputs to the system are balanced, there is no change in storage. Mathematically this is represented as:

$$R - D = 0 \tag{3-1}$$

where R is the virgin rate of recharge, and D is the virgin rate of discharge.

When a stress, such as pumping, is imposed on a system in steady state, equation 3-1 becomes:

$$(R + \Delta R) - (D + \Delta D) - Q + \frac{dS}{dt} = 0 \tag{3-2}$$

where ΔR and ΔD are the mean *changes* in recharge and discharge, Q is the pumping rate, and dS/dt is the rate of change of storage in the system. Since it is assumed that the virgin rates of recharge and discharge sum to zero (Equation 3-1), Equation 3-2 can be rearranged and expressed as:

$$Q = \Delta R - \Delta D + \frac{dS}{dt} \qquad \text{(3-3)}^{1}$$

where $\Delta R - \Delta D$ is the rate of capture. This equation states that water pumped from an aquifer will be equal to the capture rate plus the change in storage. Phrased differently, it says that storage change in the system equals the deficit between the pumping rate and the capture rate.

Once the pumped system reaches steady state, storage change becomes zero. Equation 3-3 then becomes:

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[1] The sign convention for storage change is not immediately intuitive. A *decrease* in aquifer storage corresponds to a *positive* dS/dt. This is because water is being removed from storage and put into the flow system; it represents a gain to the flow system.

$$Q = \Delta R - \Delta D \qquad (3\text{-}4)$$

This equation states that when a pumped groundwater system is in equilibrium, the amount of groundwater withdrawal is offset by the sum of decreased system discharge and increased system recharge. In a newly pumped system, some change in the virgin rate of discharge and/or recharge is required for the system to reach steady state.

Reaching Equilibrium

Achieving an equilibrium is important in the context of water planning. As long as the system is in steady state, storage and flows are not changing, and the water source is reliable. If a newly pumped system has not reached steady state, however, at least some storage is being depleted to supply the pumped water. If pumping withdrawals are substantial, the future reliability of the water source may be in question.

Determination of when and if a system can reach equilibrium, and what the state of the system will be, is of primary importance in water planning. Equilibrium will never be reached if the potential capture within the system is less than the amount of water being pumped. In such a situation, the deficit between capture and withdrawal is the rate at which water is being "mined".

In many settings, the dynamics of the groundwater system is such that extended periods of time are required before equilibrium can be achieved. Time delays in groundwater systems are much greater that those of a surface water systems. Surface water system response times are usually thought of in terms of minutes, hours or days. Groundwater response times are viewed in the time frame of days, months, years, or even decades. In many circumstances groundwater system response is so slow that the depletion of storage reserves may continue beyond any practical planning period.

An Intuitive Approach

To help the reader see the concepts of capture more intuitively, a qualitative approach is presented here using analogies and examples to illustrate the mechanics of capture.

Imagine a trampoline of infinite extent and covered uniformly with a single layer of marbles. At some point on the plane defined by this imaginary trampoline is a hole through which marbles are to be pulled through. In order to induce the marbles to roll towards the hole, the trampoline must be pulled down at the hole, causing a conical depression extending outwards from the hole. All marbles lying within this conical depression will roll towards and into the hole.

This trampoline analogy illustrates the dynamics of an expanding cone of depression. The perfectly flat trampoline represents a water table of infinite extent in a static system with no water movement. Just as it is necessary to pull the trampoline down to induce the marbles to roll into the hole, it is also necessary to draw down the water table to induce water to flow into a well. In an aquifer with no source of capture, the cone of depression will continue to expand in order to induce additional water to flow to the well. Figure 3-1 illustrates an expanding cone of depression in a water table aquifer.

Consider the elasticity of the trampoline material, and the difference between the behavior a stiff canvas and a very soft and pliable rubber. The stiff canvas will resist being deformed, producing a broad and shallow conical depression. The soft rubber, on the other hand, will deform easily, producing a deep and narrow conical depression. In order to induce the same amount of marbles to flow to the hole from each imaginary trampoline, the rubber trampoline will have to be pulled down much further than the canvas trampoline.

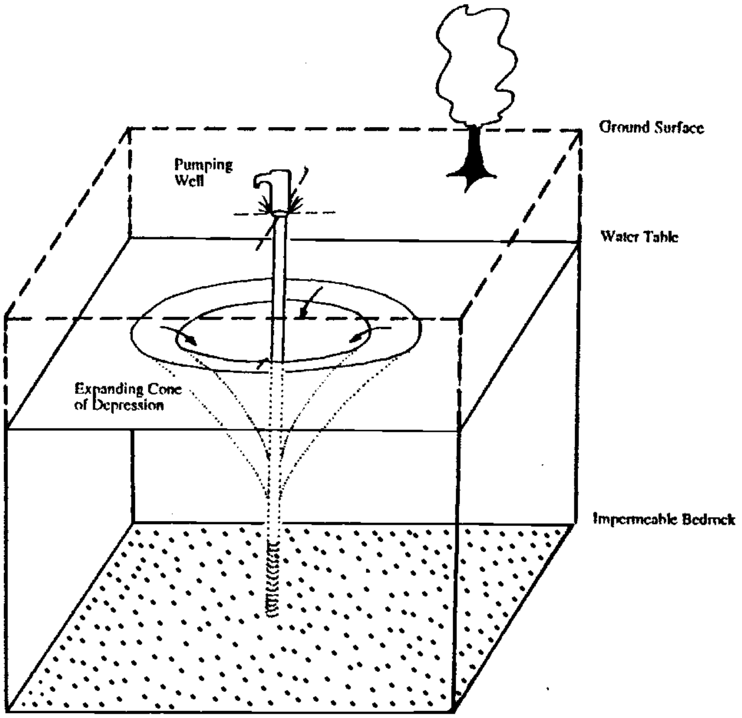

Figure 3-1: An expanding cone of depression (Sobczak, 1994)

The trampoline material is analogous to the aquifer material. Transmissive aquifers (such as those composed of coarse sands and gravels) are represented by the stiff canvas material. Aquifers which are not abundantly transmissive (such as those containing clays and silts) are represented by the pliable rubber material. Given the same pumping rates, transmissive aquifers will have much shallower and broader cones of depression than those composed of less transmissive materials. Conical depressions in highly transmissive aquifers tend, therefore, to reach more laterally *outward* while in less transmissive aquifers they tend to reach more vertically *downward.*

In the imaginary trampoline analogy, loss of storage is represented by the volume bounded above by the original surface of the undisturbed trampoline and below by the conically depressed surface of the stressed trampoline. The further the trampoline must be drawn down, the greater the storage loss.

In any pumped system, water is always drawn from storage during the initial stages of pumping. This is because the cone of depression has not had time to expand and intercept sources of recharge and discharge. Once the rate of capture equals that of pumpage, expansion of the cone of depression ceases and the system has achieved a new equilibrium.

Note that the further wells are placed from the source of capture, the longer it takes the stressed system to reach a new equilibrium, and the greater the storage depletion. This is because a larger cone of depression is required to intercept the potential source of capture. Note also that in less transmissive aquifers the cone of depression is less expansive and deeper for the same pumping rate, implying longer time periods to reach equilibrium, and greater storage loss.

To illustrate the timing of capture, replace the imaginary trampoline with an island situated in a fresh water lake. The island is composed of alluvial sediments, is bounded beneath by bedrock, and is recharged uniformly from above from rainfall (Figure 3-2A). The system is in steady state; rainfall recharging the aquifer is balanced by the outflow from the aquifer into the lake.

A well is introduced at the center of the island and pumped at a constant rate, causing a cone of depression to expand outward from the well. Figures 3-2B through 3-2D show the cone of depression as it expands towards the periphery of the island. The slope of the water table at the aquifer-lake interface is an indicator of the relative discharge to or from the aquifer. The steeper the slope is *toward* the lake, the greater is the discharge *into* the lake; conversely, the steeper the slope is *away* from the lake, the greater is the discharge

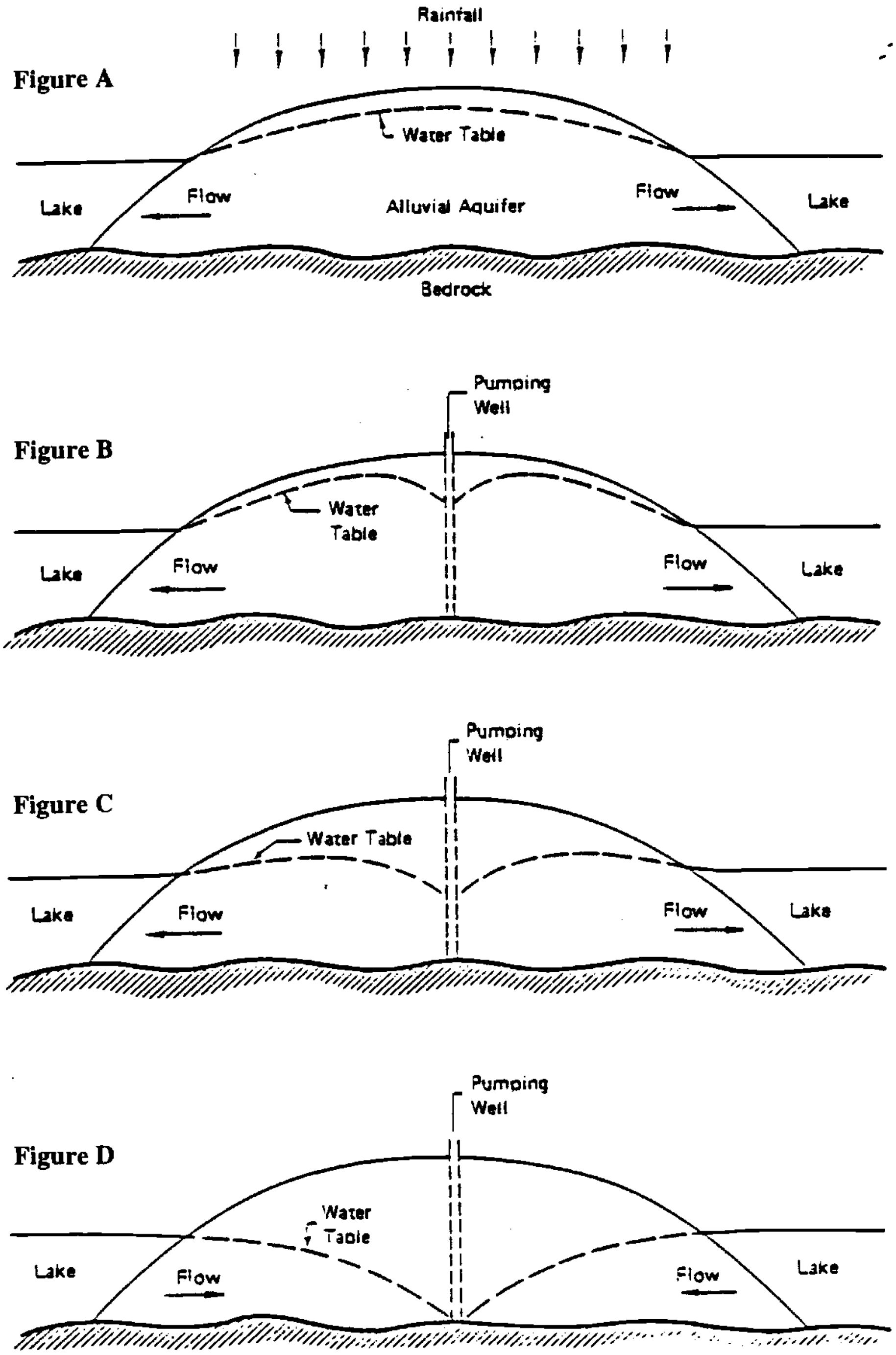

Figure 3-2: Capture of water from an island on a fresh water lake (Bredehoeft et al., 1982).

out of the lake (and into the aquifer). A level water table equal to the elevation of the lake indicates zero flow between the lake and aquifer. Figure B shows how, initially, water is drawn mainly from storage, and only a small amount is captured. Only rain falling within the small cone of depression is captured by the well; this portion of the rainfall no longer discharges to the lake, and is termed *interception* capture because it is intercepted prior to discharge from the groundwater system.

As the cone of depression becomes deeper and wider, less water is discharged to the lake. This is shown in Figure C by a shallower gradient at the island-lake interface. Figure D illustrates the new steady state. Drawdown of the water table has stabilized, and discharge is now *from* the lake *to* the aquifer. Capture has now balanced the pumping withdrawals. If recharge were exactly equal to pumping, the water table would be perfectly level at the lake-aquifer interface, and transfer of water across this interface would be zero. Instead, however, discharge to the lake was actually reversed from its virgin condition, indicating that recharging rainfall alone was unable to supply all the water necessary at the well screen.

The island example has two sources of capture: infiltrating rainfall and infiltrating lake water. The interception of the rainfall leads to reduced discharge from the groundwater system; infiltration from the lake is a source of increased recharge. The fact that water is being drawn from the lake implies rainfall alone is unable to supply all the water pumped by the well.

In the Mesilla Basin, as in most cases, capture occurs as a combination of three processes (Figure 3-3):

- Interception of groundwater flow prior to reaching a discharge point,
- Increased infiltration from a surface water source, and

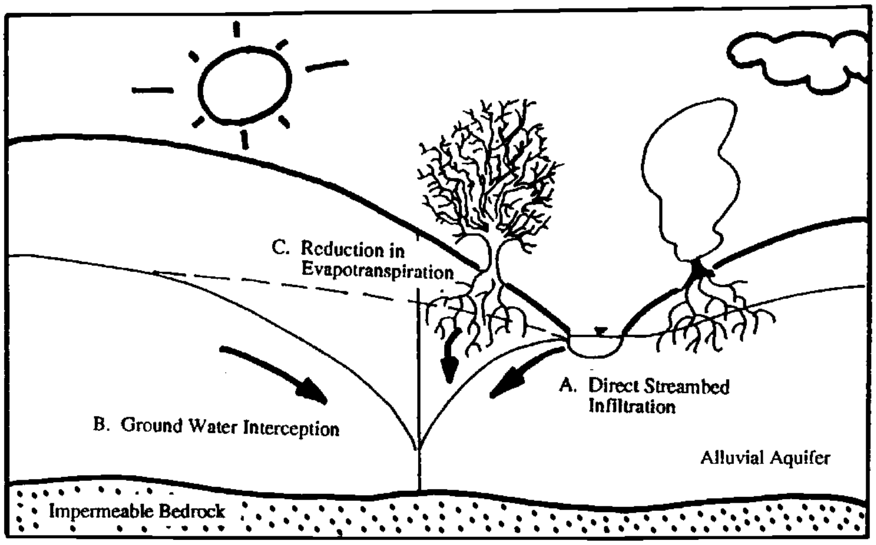

Figure 3-3: Modes of capture (Sobczak, 1994)

- Decreased evapotranspiration due to lowering groundwater levels.

A stabilized cone of depression is often incorrectly assumed to indicate that stream depletion is not occurring. Under this condition, the system has reached a new equilibrium, and storage is no longer being depleted. As illustrated by Equation 3-4, a pumped system that is in steady state has already reduced discharge and/or increased recharge to the system.

Summary

This section has illustrated the following points:

- Capture in a groundwater system is the reduction of system discharge, or the increase of system recharge, or a combination of both, so as to supply a pumping well with necessary water.
- Storage will always be reduced to some extent in order for capture to occur.
- Equilibrium, or steady state, occurs when change in storage becomes zero.

- There is a time delay between when the pumping begins, and when the system reaches a new equilibrium. Storage reserves are reduced during this period.
- The required time to reach equilibrium may be very extended, encompassing periods of years or even decades.
- If potential capture is insufficient to meet pumping demands, steady state will never be reached.
- The further the well is from the source of capture, the longer it will take for capture to occur, and the greater the storage depletion will be.
- All other things being equal, pumping from a less conductive medium results in longer time periods to reach equilibrium and greater storage loss.
- A pumped well can capture water through three processes: 1) it may intercept recharge, thereby reducing discharge from the system, 2) it may increase surface system losses, thereby increasing recharge, or 3) it may reduce evapotranspiration.
- A stable cone of depression *does not* indicate the absence of capture.

3.2 Drain Performance and Water Quality

The effect of pumping and canal lining on drain flows in the Mesilla Valley is one focus of this study. Drain flows are an essential component of the irrigation system. A brief history of how the drain network came to be, and how it controls subsurface salinization is presented.

Drain History

After the construction of Elephant Butte Reservoir irrigation practices changed and led to a rise in water levels. Riley (1991) notes that "so much farmland was being irrigated with as much as 7 acre-ft as reported in 1919 that the groundwater table rose to a point where in many places it was the same as the ground surface." Conover (1954) notes that after the construction of the dam, clear water (water with little suspended sediment) became available for application to the fields. He suggests that the new and relatively sediment free water supply led to increased infiltration rates and a quick rise in water levels after the first releases from the reservoir (Conover, 1954). Whether brought on by changes in irrigated land, changes in irrigation practices, changes in water sediment content, or a combination of these factors, a rise in water levels was observed after the construction of Elephant Butte Reservoir.

When farmers diverted water from the river, part of it evaporated in transit to the fields, part of it evaporated after application to the land, part was transpired by crops, and the remaining *excess irrigation* infiltrated into the shallow groundwater system. As the water table rose evaporation and transpiration increased; in addition, there was no natural flushing of the shallow zone. These factors led to an increase in shallow groundwater salinity (Frenzel and Kaehler, 1990), caused waterlogging, and led to the abandonment of many productive farmlands (Conover, 1954).

To rectify the problem, an open drain system designed to control the water table elevation was constructed in the 1920's (Frenzel and Kaehler, 1990). Since then farmers have used excess irrigation water to leach deposited salts out of the soil profile. Once excess irrigation reaches the saturated zone, low vertical conductivity relative to horizontal conductivity results in the lateral transport of dissolved solids to the nearest down gradient drain.

Drain Mechanics

The premise that shallow saline groundwater tends to move laterally rather horizontally is supported by observed differences in water quality with depth below the land surface. Shallow wells completed in the alluvium (up to 80 feet below the ground surface) tend produce water with a TDS greater than 1,000 *parts per million* (ppm), while water drawn below the alluvium tends to be of much better quality; in the range of 500 to 700 ppm of TDS (Conover, 1954). It is believed that increased downward gradients from excess irrigation and deep aquifer pumping has accelerated the vertical mixing of lower quality shallow water with higher quality deep water (Frenzel and Kaehler, 1990).

Regarding the vertical migration of more saline shallow aquifer water, Wilson and others (1981) state that

> "The general trend of decreasing dissolved-solids concentrations with depth in shallower Mesilla Valley sediments may be attributed, in part, to the effects of surface irrigation practices and evapotranspiration. As part of the applied water evaporates or is transpired by plants, the dissolved solids in the water are concentrated. This more saline water is recharged into the shallow groundwater system. Low vertical permeabilities resulting from interbedded clays probably retard vertical mixing, contributing to water-quality differences with depth. Local conditions such as the distribution of clay in flood-plain alluvium or the proximity to linear or point source recharge or discharge areas (the river, canals, drains, and wells) also affect the distribution of water quality with depth."

Current farming practice is to irrigate fields to supply the necessary water for both maximum crop yield and the flushing of salts through the system. Removal of salts is important since high concentrations in the soil profile and shallow groundwater adversely affects crop yields (Frenzel and Kaehler, 1990).

Local flow conditions dictate the rate at which saline water is conveyed from a field. Fields lying directly between two drains will probably be near a shallow groundwater divide, where horizontal flow is relatively slow in comparison to that near the drains.

Because of evapotranspiration, regions where shallow groundwater flow is slow will have higher TDS than regions where the flow is faster (Frenzel and Kaehler, 1990).

Annual flows of the principle drains in the Mesilla Valley are variable from year to year; a variability that is well correlated with releases from Caballo reservoir (Wright Water Engineers and Maddock, 1987). Mean total drain flow for the principle drains in the Mesilla Valley (the Picacho, Del Rio, La Mesa, East, Nemexas, West, and Montoya drains — see Figure 4-19 for a schematic of the surface water system) for the period of 1951-1986 was approximately 87,000 acre-ft/year[2]. Annual discharge from the Selden, Leasburg, Mesilla and Anthony drains is small, while discharge from the remaining drains is substantial (Wright Water Engineers and Maddock, 1987).

During an extended drought in the 1950's drain flows suddenly decreased due to a reduced water supply and increased groundwater pumping. When the drought was over drain flows rebounded, but not to pre-drought flow rates. From 1960 to 1987 there does not appear to be a trend in drain flows, either increasing or decreasing (Wright Water Engineers and Maddock, 1987).

A regression analysis by Wright Water Engineers and Maddock (1987) using data obtained from 39 Bureau of Reclamation wells showed a strong correlation between the average depth to groundwater and drain discharge. This regression demonstrates that drains in the Mesilla valley will cease flowing when the water table drops to 12 feet below the land surface. Based on this finding, and the observation that the mean annual depth to water was 9 feet, the report predicts that a 3 foot decline in water levels from historic depths will result in the drying up of the drains.

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[2] Model results show the mean total flow for all represented drains to be about 110,000 acre-ft per year.

Another regression, presented in the same report and also using Bureau of Reclamation data, displayed a strong correlation between water levels and drain salt loadings. Due to insufficient long-term data, however, this analysis did not suggest an increasing or decreasing trend in TDS or chloride.

Wright Water Engineers and Maddock (1987) conclude that during periods of drought, when groundwater levels drop and drain flows decrease, less salt is conveyed out of the irrigated areas, and more is left behind in the groundwater system or soil profile.

Water Quality

Water chemistry in the Mesilla Valley is influenced by the infiltration of excess applied irrigation water. Due to the concentration of salts from evaporation and crop transpiration, the quality of excess applied irrigation water is significantly lower than groundwater in non-irrigated areas (Frenzel and Kaehler, 1990).

Irrigation efficiency is the percentage of water applied to a crop that is lost to evapotranspiration. An irrigation efficiency of 100% implies that all applied water is either lost to evaporation or transpired by plants, and that excess irrigation is zero. Anderholm (Frenzel and Kaehler, 1990) estimates the concentrations of dissolved ions in excess irrigation water based on the assumptions that 1) salts are flushed from the soil after each irrigation, and 2) that no dissolved solids are taken up by the plants (Table 3-1)[3]. These estimates illustrate that TDS concentrations increase with increasing irrigation efficiency. A change in efficiency from 40% to 80% fosters a threefold increase in excess irrigation salinity; an efficiency of 50% yields excess irrigation concentrations twice that of the source water. Irrigation efficiencies for a farm near San Acacia, New Mexico were

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[3] Calculations are based on the measured TDS of water below Elephant Butte Dam on May 14, 1980 - 274 ppm.

62% in 1978 and 49% in 1979 (Gelhar and others, 1980). Irrigation efficiencies in the Mesilla Valley are expected to be similar to this, with a tendency to be greater than 50% rather than less than 50% (Frenzel and Kaehler, 1990).

Table 3-1: Irrigation Efficiency and Excess Irrigation Water Quality (Frenzel, Kaehler and Anderholm, 1990)

Source Water = 274 ppm TDS	
Irrigation Efficiency	Excess Irrigation TDS (ppm)
0.4	457
0.5	548
0.6	685
0.7	913
0.8	1,361

Downgradient Water Quality Degradation

The water quality of Elephant Butte Reservoir is sufficient for municipal use, with TDS measurements just below the Dam ranging between 350 and 500 ppm. The water quality of Caballo Dam releases range from 400 to 550 ppm, depending on the time of year (see Figures 2-1 to 2-3 for geographic reference). Salinity increases as high as 50 ppm have been noted between Elephant Butte and Caballo Dam during the early and late irrigation seasons. Two possible sources are offered to explain this drop in quality: hot spring inflow in the area, and the contribution of waste water effluent from the City of Truth or Consequences (Boyle Engineering and Engineering Science, 1993).

The influence that irrigation practices have on salinity is evident by down-gradient degradation of water quality. By the time the water reaches El Paso, TDS measurements range between 600 and 800 ppm during the irrigation season, and between 1600 and 1800 ppm during the non-irrigation season winter months. Discharges to the Rio Grande from the southern most drains in the system, the East and Montoya drains, are usually the most saline of all Project return flows - frequently over 2,000 ppm TDS (Boyle Engineering and Engineering Science, 1993). Since the drains are fed by shallow groundwater, the same down-gradient degradation of water quality is observed in the shallow aquifer. A study by Gelhar and McLin (1979), using 1976 data, shows that TDS at the base of the alluvium ranges from 1,000 ppm in the northern part of the valley to more than 8,000 ppm in the southern portion of the valley.

During the winter non-irrigation season high salinity drain flows comprise a larger portion of Rio Grande flow than in the summer irrigation season. The TDS of Rio Grande water directly downstream of Caballo Dam is relatively constant throughout the year (due mainly to the dampening effect of the two reservoirs) while at El Paso substantial variation is observed. The above cited two- to three-fold increase in Rio Grande salinity at El Paso is a good example of this.

Water quality standards assumed necessary for municipal use of project water (Boyle Engineering and Engineering Science, 1993) were 950 ppm for TDS and 275 ppm for hardness. Based on these standards, increases in salinity at El Paso during the winter non-irrigation months imply that the water is unusable for municipal purposes. This is indeed the case. Rio Grande water exceeds the treatable limits of El Paso's water treatment plants, on the average, about five months out of the year (October through February) (Boyle Engineering and Engineering Science, 1993).

Summary

This section presents the conclusions and results of several previous studies concerning the performance of the Mesilla Valley drain system and its influence on surface and subsurface water quality. The key points presented in this section are listed below.

- The existing drain system is used to keep the water table low enough so that excess irrigation water will flush concentrated salts out of the soil profile, through the shallow groundwater system, and into the drains.
- Anisotropy results in the lateral transport of the majority of dissolved solids to drains, and retards the vertical mixing of shallow and deep groundwater. This is evident from the high TDS of shallow alluvium water in comparison to water in the upper Santa Fe Unit. Despite the vertical anisotropy of the system, increased vertical gradients from heavy pumping can accelerate the influx of shallow saline groundwater to the deeper aquifer.
- Due to the effects of evapotranspiration, regions of slow shallow groundwater flow will have higher TDS than regions where the flow is faster.
- An extended drought in the 1950's led to increased groundwater pumping and a permanent reduction in drain discharges. Currently, annual discharge from the Selden, Leasburg, Mesilla and Anthony drains is small in comparison to the other major drains in the system.
- Wright Water Engineers and Maddock (1987) conclude that a 3 foot decline in water levels from their historic depth will result in the drying up of the drains.
- When drain flows decrease, less salt is being conveyed from irrigated areas, and more is concentrated in the groundwater system or left behind in the soil profile.

- The quality of shallow groundwater is much lower in agricultural areas than in non-agricultural areas.
- The TDS of excess irrigation water increases with increasing irrigation efficiency.
- Water quality in the Mesilla Valley decreases as it travels downstream. Evidence of this is found in the quality of the southern most drains in the system, which are usually the most saline of all Project return flows.
- Water quality in the Rio Grande decreases during the non-irrigation season due to low Project releases and the high salinity drain flows comprising a large portion of Rio Grande flow.

4. Simulation of Groundwater Flow

This chapter presents the results of the pumping, canal lining, and irrigation efficiency simulations and the sensitivity analysis. The boundary conditions used by the model are discussed in detail, and the hydrologic history of the basin is presented as it pertains to the selection of an appropriate time period for the calculation of average annual boundary conditions. The structure of all scenarios is discussed in detail prior to their presentation. All figures are located at the end of the chapter.

The simulation of groundwater flow in this study in performed with MODFLOW, the Modular Three-Dimensional Finite-Difference Groundwater Flow Model developed by McDonald and Harbaugh (1988) for the USGS. This model uses the finite difference approach to simulate flow in a three-dimensional groundwater system. The continuous flow system described by the partial differential flow equation is replaced with a set of discrete points in both space and time, and partial derivatives that are approximated from the difference in head values at these points. The result is a set of linear algebraic equations that must be simultaneously solved to obtain the heads at each point in the system. Hamilton and Maddock (1993) discuss the theoretical representation of groundwater flow, describe the structure of MODFLOW, the model grid, the streamflow routing package, and the handling of boundary conditions. Some of this material is covered in detail in this report, while others is only touched upon. The reader will be referred to appropriate sources for information beyond that provided in this report.

4.1 Discretization

A brief description of the spatial discretization of the groundwater model is presented here. If more information is required, the reader is referred to Hamilton and Maddock (1993), Frenzel (1992), and Frenzel and Kaehler (1990).

The model consists of 36 rows, 64 columns, and 4 layers. Grid spacing ranges from 0.5 to 2.0 miles, and is finest in the Rio Grande flood plain and in the vicinity of the Las Cruces and Canutillo pumping areas. The basin fill is represented by 4 layers.

- Layer 1, the base of which is set 200 feet below the 1975 groundwater table, represents the flood-plain alluvium and the upper Santa Fe Group for the entire model. It also represents the shallow middle Santa Fe group in the region below Las Cruces.
- Layer 2 is about 400 feet thick and represents the upper section of the middle Santa Fe Group.
- Layer 3 is about 600 feet thick and represents the lower section of the middle Santa Fe Group.
- Layer 4 ranges from 200 to 1,000 feet in thickness and represents the deep Santa Fe Group (Hamilton and Maddock, 1993).

4.2 Boundary and Initial Conditions

In this section the assignment of average annual boundary conditions is discussed. First is a description of all boundary conditions and how they are used. This is followed by a discussion of the climate driven flow variabilities of the model region, and how they influence the selection of representative average annual boundary conditions. A review of observed and simulated historical flows in the system will be presented, followed by description and justification of average annual boundary condition calculation.

The accuracy to be expected of the discussed boundary condition estimations is discussed in detail in Frenzel and Kaehler (1990, pages 34-42).

What is a Boundary Condition?

To solve the system of equations created by the finite difference approximation of the basin flow system, conditions along the periphery of the model domain must be specified. These are boundary conditions; they insure a unique solution and have a direct impact on the validity of the model's predictions. Inaccurate boundary conditions can result in erroneous simulation results, or inaccurate parameter estimation. Considerable effort was spent in this study to insure that the boundary conditions used in predictive simulations were representative of *average annual conditions.*

Types of Boundary Conditions

There are 3 types of boundary conditions in groundwater modeling. They are...

- Fixed Head (or Dirichlet), where head is assigned on surfaces bounding the model domain,
- Fixed Flux (or Neumann), where flows across surfaces bounding the model domain (boundary fluxes) are assigned, and
- Head Dependent (or Mixed), which is combination of the first two boundary conditions, such as an assigned boundary flux that is dependent upon model derived head.

Boundary conditions are so termed because they specify conditions along the boundary of the model domain. Whether directly or indirectly, boundary conditions control the transfer of water across the model boundary. All cells along the periphery of the model grid must have one of the above boundary conditions specified to it. Despite the implication, boundary conditions are not reserved for boundary cells only; they can be assigned to any cell within the model domain. For example, pumping wells located deep in the aquifer are represented by specifying a flux at interior model cells. The following is a list of the boundary conditions used in the Mesilla Basin groundwater model.

- The No Flow boundary is a special case of the specified flux condition where flux across the model boundary is set to zero. No flow cells correspond to the basin fill-bedrock interface. In this study, the majority of cells along the lateral boundary of the model are assigned the No Flow condition.
- The Fixed Head boundary is specified in order to hold the water table "up" or "down" in specified model cells. Fixed head cells are used in this model at the grid boundary to simulate underflow at Selden Canyon, El Paso Narrows, and Fillmore Pass.
- Specified Flux boundaries are assigned to cells throughout the model to represent a number conditions. They are used...
  - At selected cells in Layer 1, along the grid's lateral boundary, to represent mountain front recharge,
  - To represent the net flow into or out of the groundwater system due to the combined effects of agricultural evapotranspiration and effective precipitation,
  - To represent the application of Rio Grande Project water to farmland,
  - To represent groundwater withdrawals for municipal and industrial purposes, and
  - To represent recharge to the shallow groundwater system from septic systems.
- Head dependent flux boundary conditions are used...
  - To represent groundwater interaction with surface water sources: specifically, the Rio Grande and Project canal and drains, and
  - To simulate evapotranspiration from non-irrigated lands.

Figure 4-1 is a schematic displaying the specified flows into and out of the model.

Climate Variability and Average Annual Conditions

Climate drives the hydrologic system. Regions where precipitation is plentiful are hydrologically different than those where it is scarce. One of the principle and often overlooked differences between arid and temperate zone climates is year to year climate variability. The coefficient of variation for annual precipitation is generally larger in Arizona and western New Mexico than the rest of the United States. This is attributed primarily to the aridity of the region (Sellers, 1960).

In the historical simulation boundary conditions are in a continuous state of change. As a result, it is difficult to assess the hydrologic effects of any one component of the flow system. To illustrate this the reader is referred to Figure 4-2, which displays selected boundary flows and storage change for the historical simulation. From about 1950 to 1958 river discharge and irrigation recharge decline sharply (Figure B) while municipal and industrial pumping increases steadily (Figure C). During this period a distinct decline in aquifer storage is simulated (Figure A). While it can safely be concluded that this decline in storage is due to decreased surface water supply and increased pumping, it is difficult to quantify the storage loss attributable to each separate component.

To most accurately assess the effects of a single boundary condition on the hydrologic regime, it is best to hold all other conditions constant in time, altering only the stress of interest. This isn't possible in the historical simulation, but it is accomplished in the predictive simulations. For example, when looking at the effects of increased pumping, the specified fluxes representing the pumping of interest are increased, while all other boundary conditions are held constant at their annual average. This insures that any simulated changes in the flow system are due to pumping only.

Many of the boundary conditions that remain constant in the predictive simulations actually vary in time. In order for the simulations to be accurate, these boundary conditions should be representative of average annual conditions. The high variability of climate from year to year poses some difficulty in quantifying average conditions.

Highly variable data requires reasonably long time series to insure sample averages are representative of actual average conditions. Shorter periods of record usually won't represent the long-term variabilities that may exist because they don't capture such hydrological extremes as severe drought, catastrophic storms and floods, and prolonged periods of increased precipitation (Haan, 1977).

In the arid southwest, the settlement and subsequent recording of climatic and hydrological data are very recent undertakings in a climatic time frame. Modern records are often too short to reflect long-term climatic trends that fluctuate with periodicities longer than a few decades. In the study of arid land flood frequency, even 30 years of good data will produce widely different estimates (Reich et al., 1990). In order to be representative, data sets derived exclusively from unusually wet or dry periods should be avoided. If average annual conditions were based on the drought decade of the 1950's, the data would yield a flow that is below the true average. Irrigation recharge rates based on this flow would be lower than true rates, and the predicted effects of municipal and industrial pumping would be exaggerated.

When selecting data for average boundary condition estimation, they must be homogeneous in time. When an event within a time series causes a change in the characteristic being averaged, the series is said to be non-homogenous and should be divided and evaluated in two sections — one before the event, and one after. Events causing non-homogeneity can be natural or anthropogenic. Natural events include weather modifications and catastrophic events that permanently alter the hydrologic regime, such as earthquakes, hurricanes, fires and floods. Anthropogenic events include gage relocation, stream diversions, construction of dams, changes in the watershed (e.g. urbanization or deforestation), and stream channel modification.

In summary, there are two constraints in selecting a series of data that will represent average annual conditions:

1) The time period of the series should be as long as possible in order to capture long-term variabilities that may exist.
2) The data must be homogenous. Any event that permanently alters the characteristic being analyzed represents a break in data series.

Historical Analysis

A history of the events affecting the hydrology of the Mesilla Basin is presented here to illustrate the chronology of events leading to the current state of the system. Appendix A provides a detailed mass balance summary for each time step of the historical transient simulation. Appendix B presents the historical transient simulation data used to calculate average annual boundary conditions.

Frenzel and Kaehler (1990) divide the hydrologic history of the Mesilla Basin into five time periods.

1) Prior to 1915 the Mesilla Basin groundwater system was assumed to be in steady state.
2) From 1915 to 1926 the Rio Grande Project began operations, leading to increased irrigated land and the installation of a drainage network.
3) From 1927 to 1940 hydrologic conditions were relatively stable.
4) 1941 to 1975 was marked by periods of drought separated by periods of plentiful supply. A drought in the early 1950's led to the exploitation of

shallow groundwater reserves for irrigation purposes. At the same time, municipal and industrial pumping began to steadily increase.

5) After 1975 deeper wells were drilled for irrigation purposes.

The Rio Grande Compact calls for "enough water entering Elephant Butte Reservoir to sustain a normal release of 790,000 acre-ft per year from Project storage for use on lands in New Mexico downstream of Elephant Butte Reservoir and on lands in Texas and also to comply with the obligations of the Treaty of 1906 for deliveries of water to Mexico" (60,000 acre-ft per year). As will be illustrated below, this release rate was not sustained.

Almost all recharge (97%) in the Mesilla Basin comes from three sources: Rio Grande leakage, canal leakage, and applied irrigation. These three recharge sources are dependent entirely upon Rio Grande water supply. Fluctuations in Rio Grande flow, therefore, will have a profound impact on groundwater recharge and the shallow groundwater system. Because of this, the time period used to represent future average conditions was determined based on the historical flow of the Rio Grande. Figure 4-2B illustrates the high correlation between Rio Grand flow and applied irrigation.

Engineering Science (1991) demonstrates that water use changes in the Rio Grande watershed have altered the water supply. They performed an analysis of flow data from several gaging stations along the Rio Grande to determine when and where these changes occurred. Plots of cumulative Rio Grande flow at selected stations were used to quantify average annual discharge before and after the changes. The plots indicate a drop in the annual water supply between 1925 and 1930, and again in the early 1950's. From 1949 to 1990...

- Average annual flow *into* Elephant Butte Reservoir was 718,900 acre-ft, 227,300 acre-ft less than the 946,200 acre-ft anticipated during compact negotiations, and
- Average annual flow *out of* Elephant Butte Reservoir was 606,700 acre-ft, 183,300 acre-ft less than the 790,000 acre-ft anticipated during compact negotiations (Engineering Science, 1991).

Engineering Science lists three possible reasons for the observed change in water supply: long term climatic change, changes at the gage, and activities due to man. Each of these possibilities was investigated. Long-term climatic change was ruled out because precipitation gaging records showed no long term fluctuations. Changes at the gage, such as changes in gage location, gaging equipment, or channel cross-section were also ruled out; no visual changes occurred at the gages indicating altered flow. In addition, flow changes were recorded simultaneously at different gages. The report concludes that increased groundwater withdrawals and other unaccounted for diversions led to the decrease in Rio Grande flow. Wright Water Engineers and Maddock (1987) also hypothesized that supplemental pumping contributed to reduced flows since the 1950's drought.

A prime example of reduced river flows due to irrigation pumping is found with farmers in the San Luis Valley of Colorado. They began to convert from flood irrigation to center pivot sprinkler systems in the 1950's. The sprinkler systems, which are supplied from wells, irrigate more efficiently, and therefore reduce groundwater return flows to the Rio Grande. Engineering Science (1991) notes that these groundwater withdrawals take appropriable water from the Rio Grande. Unless factored into the gaging stations, as provided by the Rio Grande Compact, no limitations are placed on these withdrawals.

Surface Flows

Interaction between the ground and surface water system is simulated using the streamflow routing (or Prudic) package. A brief description of the methodology employed by the package to quantify stream-aquifer interaction is presented here. Hamilton and Maddock (1993) discuss the package and its implementation into the current model in greater detail.

The Rio Grande and all canals and drains are represented as stream segments with rectangular cross-sections. Each segment is broken down into reaches which correspond to a single model cell. The head in each reach is calculated with Manning's flow equation using the discharge of water entering the reach, the slope and width of the channel, and a Manning's roughness coefficient (or *n* value). The flow of water between the aquifer and the stream reach is calculated using the head difference between the stream and aquifer and a *bed conductance* term. The bed conductance term represents the hydraulic conductivity of the channel bed material multiplied by the length and width of the channel reach and divided by the thickness the channel bed material.

Model representation of the surface water system does not explicitly include all canals, drains and laterals in the valley. Modeled stream segments and reaches are essentially lumped parameters, representing the main canals and drains in the system as well as the laterals extending to the fields and the smaller drains returning from them. Bed conductance terms, therefore, are empirical parameters that are not directly related to the hydraulic conductivity or thickness of the channel bed material they represent.

Wright Water Engineers and Maddock (1987), and Peterson et al. (1984) used vertical hydraulic conductivities ranging from 0.379 to 1.14 ft^2/day to determine river and canal conductances. Hamilton and Maddock (1993) used 0.758 ft^2/day to calculate river and canal conductance in the present model. They back calculated drain bed conductances were back calculated using the average drain flow rate from 1923 to 1950 (1.4 cfs per mile) and the average water table-drain elevation difference (3 feet) for the same time period. This method was adopted from Frenzel and Kaehler (1990), and it effectively forces the drain flows to approach observed values.

All surface flows used in the predictive simulation are the 1958 to 1990 average of historical simulation flows. In the historical simulation, flows were explicitly defined only for the Rio Grande and for the Leasburg, Westside and Eastside canals. All other canal flows[1] were specified as fixed percentages of the contributing segment's flow (Hamilton and Maddock, 1993). Hamilton and Maddock (1993) estimated these percentages based on the acres served by each canal segment (Elephant Butte Irrigation District, computer printout, 1992; El Paso Water Improvement District No. 1, computer printout, 1992).

The Streamflow-Routing Package removes water from each reach of each canal segment to simulate the delivery of water to farms. Hamilton and Maddock determined removal rates based on the acreage served by the canal and its average annual delivery rate (Elephant Butte Irrigation District, computer printout, 1992; El Paso Water Improvement District No. 1, computer printout, 1992).

Annual Rio Grande flow depletion between Leasburg Dam and the Narrows was 222,000 acre-ft from 1930 to 1950, 221,000 acre-ft from 1951 to 1960, and 218,000 acre-ft from 1961 to 1975 (Frenzel and Kaehler, 1990). Engineering Science (1991) shows that annual releases from Elephant Butte reservoir declined during the 1950's from a

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[1] This includes the Picacho, Las Cruces, Mesilla, Three Saints East, Three Saints West, La Union East and La Union West canals.

previous average of 808,900 acre-ft, to a new average of 606,700 acre-ft. Based on these data, depletions have remained relatively constant during the projects history, but have increased as a percentage of Rio Grande flow.

Based on current water supply conditions and new storage and conservation procedures, Engineering Science (1991) recommends normal project releases between 600,000 and 650,000 acre-ft annually (828 to 897 cfs). The average release from Caballo Reservoir between 1951 and 1986 was 606,700 acre-ft per year (837 cfs) (Wright Water Engineers and Maddock, 1987).

Rio Grande flow into the model is specified just above Leasburg Dam; all other specified surface water flows are either diversions into canal segments, or withdrawals from canals that represent farm deliveries. The 1958 to 1990 average of assigned surface water flows in the historical simulation[2] were used to represent average annual conditions in the predictive simulations. This resulted in a simulated flow at Leasburg of 602,500 acre-ft per year (832 cfs).

Flow at Leasburg Dam is lower than releases from Caballo reservoir due to depletions in the Rincon Valley. Rio Grande depletion between Percha and Leasburg Diversion Dams will have an expected annual average of 28,000 acre-ft (38 cfs)[3] based on the assumptions that...

- An average of 3 acre-ft per acre are delivered to farmland in the Rincon Valley[4],
- 16,260 acres are served by the Percha Diversion Dam,

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[2] Historical simulation stress periods 8 through 27.

[3] Calculated Rincon Valley losses are only meant to be an approximation to check the validity of simulated Rio Grande flow in the Mesilla Basin.

[4] This is based on data from Table 6 in Hamilton (1993).

- 57% of water delivered to farmland is consumed by agricultural practices[5]
- There is no major river depletion in the Rincon Valley due to pumping, and
- Transmission loss of Rio Grande water as it flows through the Rincon Valley is returned to the river in the southern end of the valley before the river enters Selden Canyon.

Based on this estimated depletion, an annual Rio Grande discharge of 602,500 acre-ft at Leasburg Dam corresponds to an annual release of 630,500 acre-ft from Caballo reservoir. This discharge rate falls within the range of recommended releases specified by Engineering Science and agrees well with 1951 to 1986 observed historical releases.

All other boundary conditions used in the predictive simulation, with the exception of pumping fluxes, are assigned the 1958 to 1990 historical simulation average. This time period is most representative of what is expected in the next 40 years.

Irrigation Recharge

Applied irrigation is simulated using the recharge package. This package applies the volume of total net diversions uniformly to all model cells representing project irrigated land. Net diversions is the volume of water diverted into canals less the amount of water returned to the river. By implication, this includes canal losses due to seepage, evaporation at the water surface, and evapotranspiration from plants growing along the canals (Frenzel and Kaehler, 1990). Quantification of historical irrigation recharge by Hamilton and Maddock is based on estimates of the percentage of gross diversions delivered to farms (Conover, 1954 and Wilson et al., 1981). In the historical transient

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[5] Simulation results suggest that, of the 237 cfs (171,700 acre-ft) delivered to farmland in an average year, about 101 cfs (73,200 acre-ft) is returned to the river, and the remainder is lost through agricultural practices. Drain return flows are simulated to be 171 cfs (123,900 acre-ft), 70 cfs (50,700 acre-ft) of which is attributable to canal leakage.

simulation, irrigation recharge in the Las Cruces area was turned off after 1940 (Hamilton and Maddock, 1993). The calculated annual average was determined using model specified flows from 1958 to 1990. Since Rio Grande flow and irrigation recharge are strongly correlated, they derive their averages from the same time period.

Excess Irrigation and Supplemental Irrigation Pumping

The net agricultural loss (called the net irrigation flux by Hamilton and Maddock) is a boundary condition applied to cells representing irrigated land in the Mesilla Valley. The flux represents the sum of effective precipitation[6] on agricultural and non-agricultural land, evaporation from canal surfaces, and evapotranspiration from agricultural land. Evapotranspiration from agricultural land was estimated to be 2.2 acre-ft per year. Because effective precipitation is so small in the Mesilla Valley, net agricultural loss is a negative number.

There are currently two sources of water for agriculture in the Mesilla Valley: surface water, which is a source *external* to the basin, and shallow groundwater, which is a source *internal* to the basin.

- When surface water is used, a source of water external to the groundwater system is applied to the fields. That amount of water not consumed by agriculture is recharged. Surface water diversion for agricultural use is, therefore, a net *positive* flux to the groundwater system.
- When groundwater is used for irrigation, it is usually pumped from the shallow aquifer and usually applied to fields near the point of withdrawal. Water that is not consumed by agriculture is returned to the shallow groundwater system — presumably near to where it was removed. The

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[6] Effective precipitation is that part of rainfall that effectively recharges the groundwater system or reduces groundwater discharge.

result is a net *negative* flux from the groundwater system equal to the amount of water consumed by crops.

In times of drought, farmers use groundwater to supplement reduced surface water supplies. This means that the net *positive* flux associated with surface diversions *decreases* while the net *negative* flux associated with supplemental pumping *increases*. The result is a decrease in recharge to the groundwater system.

Excess irrigation recharge in this study is the sum of net agricultural loss and irrigation recharge. Representation of excess irrigation in this manner automatically accounts for supplemental irrigation pumping under the conditions that

- Pumping occurs only from the shallow aquifer,
- Pumped water is not transported far from the point of withdrawal,
- Pumping is uniformly distributed about agricultural lands, and
- The same amount of land is irrigated in drought and non-drought years.

Net agricultural loss increases slightly in years of simulated drought due to decreases in effective precipitation and Project water supply (which leads to reduced irrigation recharge). The net result is a reduction in excess irrigation recharge because the same amount of land is being farmed with less surface water and precipitation.

There are two points to note concerning the assumptions of shallow well pumping and the proximity of irrigation wells to the point of applied water.

- Frenzel and Kaehler (1990) report that some irrigation wells installed after 1975 were completed far below the shallow alluvium. While these wells are not believed to compose a significant amount of supplemental irrigation pumpage, increasing this practice is not representative of the predictive simulations.
- There are cases in the Mesilla Valley where water is pumped by one farmer, sold to another, and transported in the canal network (Riley,

> personal communication, 1994). While this is not consistent with the assumption that pumped irrigation water is not transported far from the point of withdrawal, it is not considered representative of most pumping irrigation practices in the Mesilla Valley.

In February 1948 there was a reported 70 irrigation wells in the Rincon and Mesilla Valleys. During periods of water shortage in the following two decades hundreds of wells were drilled in the Mesilla Valley (Conover, 1954). By 1975 there were reported more than 920 "usable" irrigation wells in the Mesilla Valley alone, most of them about 100 feet deep (Frenzel and Kaehler, 1990). After 1975 a large number of irrigation wells were drilled deeper in order to obtain higher quality water (Wilson and White, 1984). Based on crop evaporation requirements, climatological data, and water delivery data from 1970 to 1986, supplemental irrigation pumpage is estimated to be 185,000 acre-ft per year; that is 164,000 acre-ft for land served by the EBID, and 21,000 acre-ft for Mesilla Valley land not served by the EBID (Wright Water Engineers and Maddock, 1987). Supplemental irrigation pumping is not believed responsible for permanent change of groundwater levels in the study area. Increased pumping during periods of drought draw the water table down, but levels quickly rebound once surface water deliveries are returned to normal (Wright Water Engineers and Maddock, 1987).

Supplemental irrigation pumpage for selected years was estimated by this author based on

- An assumed depth of water applied to fields in the Mesilla Valley,
- Net diversions (acre-ft/year)[7],
- Irrigated acres[7], and
- Effective precipitation on Agricultural Land (acre-ft/year)[7].

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[7] Obtained from Hamilton and Maddock (1993), Tables 7 and 8.

It is estimated that conditions in the Mesilla Valley require the application of between 3 and 5 feet of water per year to produce a good crop (Gary, 1994). A range of possible withdrawals was estimated using the following relationship:

(Irrigation Pumpage) = (Application Rate)*(Irrigated Acres)-(Effective Precipitation)-(Net Diversions)

The results are provided in Table 4-1. Values of zero imply that either no irrigation pumpage occurred, or that the assumed application rate is not realistic. Application rates of 5 feet per year tend to agree best with Wright Water Engineers and Maddock's estimate of supplemental pumping.

Table 4-1: Estimated Irrigation Pumpage (acre-ft\year)

Year	EP (acre-ft)	Net Diversion (acre-ft)	Irrigated Acres (acre-ft)	Assumed Annual Field Application of ...		
				3 feet/year	4 feet\year	5 feet\year
1951	17,495	136,063	84,210	99,072	183,282	267,492
1967	29,150	149,425	70,471	32,838	103,309	173,780
1970	21,415	228,750	75,877	0	53,343	129,220
1971	32,695	150,823	74,293	39,361	113,654	187,947
1980	36,358	175,710	74,687	11,993	86,680	161,367
1984	54,284	185,150	70,481	0	42,490	112,971
1988	46,737	220,295	63,577	0	0	50,854
1989	13,965	159,299	64,711	20,869	85,580	150,291

Evapotranspiration

Evapotranspiration from non-agricultural land usually depends on water table depth. When the water table drops below the root zone suddenly, such as during a drought or when pumping is introduced into the region, evapotranspiration rates are expected to decline. The model determines evapotranspiration based on model derived water table depth below the land surface. Simulated evapotranspiration varies linearly from the maximum evapotranspiration rate when the water table is at the ground surface, to zero at the "extinction depth" (the depth at which evapotranspiration is considered to no longer occur), which is 12 feet in this model (Frenzel and Kaehler, 1990).

Municipal and Industrial Pumping

Estimates of non-agricultural groundwater withdrawals within the Mesilla Basin show that pumping has increased from about 6 cfs in 1950 (Frenzel and Kaehler, 1990) to around 60 cfs in the late 1980's (New Mexico State Engineers Office, 1992).

In the historical simulation non-irrigation groundwater withdrawals were either assigned reported values, or assigned estimated values based on population (Frenzel and Kaehler, 1990). Amount and location of groundwater withdrawal by industrial users, small subdivisions and the city of El Paso were obtained from the files of the USGS in El Paso (Don White, written communication, 1980). Withdrawals by the City of Las Cruces were either estimated or reported. Withdrawals by small towns and villages in Doña Ana County were estimated mainly from population data. Withdrawals by New Mexico State University were estimated by multiplying student population by 46,000 gallons per year (126 gallons per day).

A complete discussion of municipal and industrial pumping representation in the predictive simulations is provided in Section 4.3.

Return Flows

Return flows from domestic, industrial and municipal pumping were modeled as either discharges to the surface water system or recharge from septic systems, or were neglected. Return flows from pumping are handled as follows (Frenzel and Kaehler, 1990):

- Water withdrawn for El Paso is not returned to the Mesilla Basin.

- Surface return flows for Las Cruces pumping was set to 50% of the Las Cruces withdrawal rates. Based on oral communication with city personnel, Frenzel and Kaehler (1990) estimate that about one half of wintertime withdrawals are returned to the Rio Grande as surface discharge.
- Based on data from Sorensen (1977, tables 1 and 2), it is estimated that half of pumped water returns to the groundwater via septic systems in communities without surface disposal systems. Return flows from leach field systems were represented as positive fluxes in model layer 1 (using the well file). Septic returns in the predictive simulations are historical annual averages, and are averaged over the same time period as municipal and industrial withdrawal rates.
- Returns from major industries and subdivisions in the Lower Mesilla Valley were not represented. This water is assumed evaporate from sealed ponds or return to the river in negligible amounts (Frenzel and Kaehler, 1990).

Since return flows are directly related to pumping withdrawals, they vary accordingly with their associated pumping source. Simulations altering Las Cruces and/or Anthony pumping rates alter their respective return flows to the River by the same proportion; leach field return flows change at the same rate as their corresponding pumped sources.

Initial conditions

Starting heads for the predictive simulations were obtained by running a short simulation that allows the model to adjust to the new average annual boundary conditions. Initial heads for this priming simulation are obtained from the termination of the 1915 - 1990 historical transient simulation. The new averaged boundary conditions were incorporated, and the model was run for 2.5 years. Figure 4-3 shows changes in the following flows as the model adjusts to the new boundary conditions:

- Flow out of storage,
- Surface water flows and losses, and
- Evapotranspiration.

4.3 Description of Pumping Scenarios

City of Las Cruces Growth

Population projections were performed for the city of Las Cruces by the New Mexico Environmental Improvement Division. The projections were based on a 1980 Bureau of Business and Economic Research (BBER) report that predicted populations to the year 2005. These population projections were used by Kenneth Needham to compile *The City of Las Cruces 40 Year Water Plan* (November, 1981). The 25 year projections of the BBER report were linearly extrapolated to 2060. Water demand was estimated based on an assumed fixed per-capita consumption rate of 259 gallons per day (gpd).[8]

The planning area, which covers only people living within the city limits of Las Cruces and Mesilla, is expected to grow in population from 47,100 in 1980 to 124,700 in 2030; an annual growth rate of 1.97%. Growth of the planning area is summarized by dividing it into three developmental zones:

- Urbanizing Fringe: the periphery of Las Cruces. In 1980 this zone holds 26.5% of the planning area population - by 2005 it is estimated to be 42.8%. The annual growth rate for this zone is 4.2%.
- Core Area: the older, urbanized area of Las Cruces. In 1980 this zone holds 59.3% of the planning area population - by 2005 it is predicted to be 42.8%. The annual growth rate for this zone is 0.9%.

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[8] This per-capita rate includes commercial and industrial use.

- Outlying Areas: the remainder of the study area, including such communities as Doña Ana and Mesilla. In 1980 this zone holds 14.2% of the planning area population - by 2005 it is still 14.4%. The annual growth rate for this zone is 2.3%.

An unpublished study by the Las Cruces Planning Department (*Master Plan for Water Gas and Sewer*, 1985) predicts a population of 109,000 for the Las Cruces area by 2005 (results presented in Hernandez, 1989). Predicted growth rates in the following Las Cruces areas are as follows:

City	0.57%
East Mesa	4.53%
North Valley	4.63%
South Valley	3.66%
West Valley	4.76%

Similar to the city's 40 year water plan, this study predicts moderate growth in the urbanized area of Las Cruces, and strong growth in the areas immediately surrounding the city center. Growth rates for the Las Cruces region as a whole will fall somewhere between the high rates outside of the urban core area, and the low rates inside the urban core area.

Doña Ana County Growth

The Community 40-Year Water Plan for the County of Doña Ana, New Mexico, 1980-2030 (Hernandez et al., 1989) predicts water requirements for all of Doña Ana County. The study estimates future water demand based on historical population trends and estimated per-capita use. The county is divided up into 8 Community Census Districts (CCD), 4 of which fall within the domain of the model grid. These four districts are as follows:

- The Las Cruces District - covering people living in the Las Cruces area, excluding those within the city limits of Las Cruces and Mesilla.
- The La Mesa District - including La Mesa and the surrounding area. This district is primarily west of the river and south of I-10.
- The La Union District - encompassing the entire area south of I-10 and west of the River, excluding the area covered in the La Mesa District.
- The Anthony District - including Anthony and all other communities between I-10 and the Rio Grande from the New Mexico-Texas state line north to where I-10 bends west and crosses the Rio Grande.

The study excludes 4 communities within these districts on the following grounds:

- The city of Las Cruces, because it forecasts its own future demands,
- The community of Santa Teresa, because it had characteristics that made it significantly different than the other 32 communities in the study (e.g. an industrial park, a golf course, a sod farm, etc.),
- Sunland Park, because it was purchasing water from Santa Teresa and was only recently incorporated, making future predictions difficult, and
- New Mexico State University (NMSU), because it was not characteristic of the small communities in the county.

Some factors that may affect water demand are mentioned in the report.

- Family income is a major factor. Higher family incomes are associated with larger houses, multiple bathrooms, dishwashers, home laundry washers, swimming pools, etc., all of which tend to increase per capita water use.
- Higher incomes are usually associated with a lower number of persons per household.
- Metering of water enforces conservation and leads to decreased water demand.
- Sewer installation tends to increase water demand.

The study assumes that new modern homes will be built, and that per-capita income will grow. Based on these assumptions, projections assume that per capita use will continue increasing into the future by one gallon per person per year beginning in 1985.

The study concludes that by 2030 the population of the county will be approximately 184,000 people, with an estimated water demand of 33,000 acre-ft per year.

Summary of Growth Studies

A summary of the results from the 40 year Las Cruces and Doña Ana County studies are presented in Table 4-2.

Table 4-2: Predicted Population and Water Demand Growth from 1985 to 2030

Community Census District	Population Growth (% per year)	Water Demand Growth (% per year)	Estimated Water Demand (cfs) 1985	Estimated Water Demand (cfs) 2030
Anthony†	4.39	5.09	2.07	19.32
La Mesa and La Union†	2.69	3.13	0.28	1.10
Las Cruces Area†	2.38	3.04	0.97	3.73
Las Cruces‡	2.04	2.79	10.96	37.83

†Based on Hernandez (1989) - covering people outside the city limits of Las Cruces and Mesilla

‡Based on Needham (1981) - covering people inside the city limits of Las Cruces and Mesilla

In the Hernandez study, per-capita consumption of water in the Las Cruces area was estimated to be 141 gpd. This figure is much lower than the 259 gpd cited by Needham. Needham's figure includes commercial and industrial use, while that of Hernandez does not. In order to maintain consistency, the consumption rate of Hernandez was used with Needham's population data to estimate water demand *within* the city limits of Las Cruces and Mesilla. Las Cruces area water demand was determined in the following manner:

1. Estimates of the population within the Cities of Las Cruces and Mesilla were linearly extrapolated to the year 2030 using data from the 1980 BBER.

2. Per capita use of 141.1 gpd is assumed for 1980, and increased 1 gpd per capita per year beginning in 1985. Under this growth scheme, per capita use will be 196.1 gpd in 2030.
3. Water demand within the city limits of Las Cruces and Mesilla was added to demand rates for the population living outside city limits (but within the Las Cruces CCD). The sum represents growth for the entire Las Cruces pumping area.
4. Total system water demand was computed for 1980 and 2030, and the compound annual growth rate was calculated based on the following relationship: $r = \left[\frac{D_{2030}}{D_{1980}}\right]^{1/50} - 1$, where r is the annual growth rate, and D is the demand.

Growth rates for all other zones are drawn directly from the data presented by Hernandez (1989).

Simulated Pumping Scenarios

The pumping estimates the impact of different pumping scenarios on the surrounding hydrologic regime. The runs are structured to bracket the extremes of the possibilities at hand. The upper bound extreme is the increase of pumping to accommodate all increased water demand. The lower bound extreme is the immediate removal of the pumping in question. Another scenario of interest that lies between these upper and lower bounds is the holding of pumping constant at current rates.

Increased pumping withdrawals are simulated using the rates in Table 4-2. Two methodologies could be employed to simulate increased withdrawals. One method is to determine when and where new withdrawals will occur, and how much will be pumped. New wells are added to model, and withdrawals assigned accordingly. The main drawback to this method is that such detailed information concerning the location and pumpage of future wells is difficult, if not impossible, to obtain. A second alternative is to estimate an annual growth rate, and increase the withdrawals of existing wells in the model. As long as undeveloped regions are *not* opened up to new pumping, this method provides an adequate representation of expected pumping growth.

This study employs the second method. The predictive simulations represent a situation where pumping throughout the basin remains in its present relative distribution. Pumping increases are represented in the following manner:

1. All municipal and industrial pumping from 1977 to 1991 in the historical simulation is averaged and used to represent current pumping conditions.
2. Increased pumping in specified zones is simulated by increasing the extraction rate of all wells within the zone.

The model area is divided into 5 zones, each of which is assigned a separate growth rate. The five zones and their assigned growth rates are as follows:

- The Las Cruces Area — all pumping occurring north of column 34 (around mile 32)[9]. The combination of the two Las Cruces area projections (within the city limits, and outside the city limits) predict that water demand will increase at a 2.81% annual rate.
- The Canutillo Wellfield — all pumping designated in the following cells: (21,13), (22-23,11-13), (24,13-17), and (25,15-16). Demand projections for the Canutillo wellfield were not obtained. Since estimated Las Cruces area growth is the lowest in the model, the same rate of 2.81% is used for the Canutillo wellfield. This is considered to be a conservative estimate.
- The Anthony Area — all pumping occurring between (and including) columns 18 and 34 (miles 15 and 32) on the east side of the Rio Grande, except those cells designated as Canutillo pumping cells. Pumping in this

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[9] Note that the columns in the model run perpendicular to the Rio Grande (roughly east-west), and the rows run parallel to it (roughly north-south).

zone is increased 5.09% annually — this is the highest growth rate in the model.

- La Mesa/La Union — all pumping south of column 34 (around mile 32) and west of the Rio Grande, except those cells designated as Canutillo pumping cells. Within this zone are two communities not included in the 1991 Hernandez study: Santa Teresa and Sunland Park. Hernandez notes that Santa Teresa "water consumption will probably fall within the range of the 32 communities studied", and "Sunland Park purchases water from Santa Teresa." Since no data is available concerning the growth of these two communities, pumping growth is assigned the same rate as all other pumping in the La Mesa/La Union zone — 3.13% annually.
- Texas — all cells east of the river and south of column 18, except those cells designated as Canutillo wellfield pumping cells. Demand projections for Texas wells were not obtained. This zone is assigned the same rate as Las Cruces and is considered to be a conservative estimate.

The presented results are from 7 simulations that vary the magnitude of pumping in specified areas. These 7 simulations are identical, except for differences in pumping rates, sewage return flows to the river, and simulated septic returns. All simulations are run 40 years into the future. The 7 scenarios are as follows:

- Constant Valley Wide - Pumping throughout the model is held constant at current rates.
- Increased Valley Wide - All pumping in the model is increased by the growth rate associated with each pumping zone.[10]
- Removed Valley Wide - All pumping in the model is removed at the start of the simulation.

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[10] Pumping is 65.0 cfs valley wide at the start of the simulation, and 182.7 cfs at the end of the 40 year simulation

- Increased Canutillo Pumping - Canutillo wellfield pumping is increased 2.81% annually[11]; all other pumping in the model is held constant.
- Removed Canutillo Pumping - Canutillo wellfield pumping is removed at the start of the simulation; all other pumping in the model is held constant.
- Increased Las Cruces Pumping - Las Cruces area pumping is increased 2.81% annually[12]; all other pumping in the model is held constant.
- Removed Las Cruces Pumping - Las Cruces area pumping is removed at the start of the simulation; all other pumping in the model is held constant

Wright Water Engineers and Maddock used the following discharge rates in their groundwater model to represent groundwater withdrawal in the Mesilla Valley for municipal and industrial purposes:

- Las Cruces Area: 15,000 acre-ft per year (21 cfs)
- Canutillo Area: 20,000 acre-ft per year (28 cfs)
- Santa Teresa Area: 10,000 acre-ft per year (14 cfs)

The current study uses the following withdrawals to estimate annual average conditions:

- Las Cruces Area: 16,200 acre-ft per year
- Canutillo Wellfield: 12,750 acre-ft per year
- La Mesa/La Union: 4,350 acre-ft per year

Table B-5 (Appendix B) presents the pumping discharge rates assigned to the model for each stress period and each pumping zone in the seven scenarios.

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[11] Canutillo pumping is 18.9 cfs at simulation start, and 49.8 cfs at the end of the 40 year simulation

[12] Las Cruces area pumping is 24.0 cfs at simulation start, and 63.3 cfs at the end of the 40 year simulation

4.4 Results From Pumping Scenarios

Simulation results are presented to illustrate the impact of individual pumping areas on the hydrologic regime. In order to quantify how flow is affected, separate system components are recorded as the simulation progresses, and presented in graphical and tabular form. The system components this analysis focuses on are:

- Water table elevation,
- Aquifer storage,
- Deep aquifer piezometric head,
- Rio Grande discharge,
- Rio Grande and canal transmission loss, and
- Irrigation system drain flows.

This study attempts to answer the question: "How much storage loss, river depletion, drain flow reduction, etc. is attributable to the pumping of an individual well or group of wells?" To quantify the amount of water being drawn from surface water sources or from storage by a pumping scheme, the difference between the run *with* and the run *without* the pumping of interest must be determined. This methodology is analogous to weighing an object with a foot scale. If the object is not easily positioned on the scale, the person may weigh themselves first *with* the object in hand, and then *without*. The difference between the two is the weight of the object. In the case of this presentation, weight is replaced by water volume or flow rate, and plots of simulated data will replace the foot scale. The effect of the *presence* of the pumping of interest will always be the difference between the *Removed* line and the *Held Constant/Increased* line (depending on which scenario is being analyzed).

The spread between the *Removed* and the *Held Constant/Increased* lines also indicate sensitivity of the plotted variable to the pumping in question. The greater the spread, the more sensitive is the aquifer storage or surface water flow to the pumping of interest; the closer the lines plot together, the less sensitive it is.

- Lines plotted in dark blue with upward pointed triangles represent removal of the pumping source in question,
- Lines plotted in red with downward pointed triangles represent increasing the pumping of interest, and
- Lines plotted in green with square symbols represent the maintenance of all pumping at current rates.

The Valley Wide scenarios are presented first and in the greatest detail to...

- Insure that the effects of all withdrawals in the valley are taken into account,
- Demonstrate the maximum probable costs of future pumping withdrawals,
- Demonstrate the maximum possible benefit gained by the removal of all pumping,
- Show system behavior in the absence of pumping, and
- Determine the possibility of intersecting drawdown cones, which can accelerate water table drawdown.

Also presented are results from the Canutillo and Las Cruces simulations; these simulations are compared to each other, and to the Valley Wide scenario. A mass balance summary of each pumping scenario is provided in Appendix D.

Figure 4-4 is a plan map showing the extent of the finite difference grid, major landmarks in the model area, and the location of Cross Sections A-A and B-B. Also shown is the location and relative magnitude of all simulated pumping in the valley. Note in particular...

- The large amount of pumping occurring in the Las Cruces area and in the Canutillo/Anthony area,
- The proximity of Canutillo pumping to the Rio Grande in comparison to that of Las Cruces pumping,
- The lack of pumping along the Rio Grande between Anthony and Mesilla, and
- The absence of pumping north of Canutillo, on the west side of the Rio Grande.

Pumping in the region of the Montoya Siphon is referred to as Santa Teresa Pumping because the majority of withdrawals in the area are from the community of Santa Teresa.

4.4.1 Valley Wide Pumping

Figure 4-5A shows simulated water table drawdown after 40 years of increasing all municipal and industrial pumping. Water table drawdown from Las Cruces pumping does not extend west of the Rio Grande. Leakage from the Rio Grande and the irrigation system holds the water table up, preventing expansion of the cone of depression west of the river. Drawdown on the west side of the river in the southern region of the model is due to Santa Teresa Pumping (figures presented later will demonstrate this more clearly).

Change in storage represents the lowering or raising of the water table. Storage change beneath the Mesilla Valley occurs on an annual basis. It increases during the irrigation season, when water is being applied to the fields, and decreases in the winter season as excess irrigation slowly seeps into the drain system. The model in this study does not capture these seasonal fluctuations; it represents changes in average annual flows. Storage changes in the predictive simulations indicate distinct trends, *not* seasonal fluctuations. When looking at model predicted storage change, the reader should keep in mind that 22,000 acre-ft of storage loss corresponds to a uniform, 1 foot decline in the water table throughout the valley.[13] This is mentioned only to provide a frame of reference. In reality, storage loss does not occur uniformly throughout the valley; it is concentrated around areas of heavy pumping and reduced recharge.

In 1987, Wright Water Engineers and Maddock reported that the Lower Rio Grande Basin was not in a "mining" situation. Most studies tend to consider the system in a long-term steady state condition, where head levels may fluctuate in the short-term (5 years), but in the long-term remain relatively constant (Hamilton and Maddock, 1993). Predictive simulations where pumping is held at current rates indicate a continued decline in storage of approximately 137,000 acre-ft over the next 40 years (Figure 4-5B).

Removing all pumping in the model results in about 196,000 acre-ft of storage gain over 40 years; increasing all pumping depletes storage reserves by about 625,000 acre-ft (Figure 4-5B).

Figure 4-5C displays Rio Grande discharge at the Narrows. Since all drains and canals empty into the river upstream of the Narrows, the sum of all canal and drain flow changes are transferred to the Rio Grande and measurable at the Narrows. Increasing pumping valley wide will reduce Rio Grande flows 59 cfs over 40 years, an approximate 11.5% reduction in river flows from current rates. By the end of the simulation, municipal and industrial pumping in the valley is 183 cfs; about 87 cfs of which will come from captured surface water sources. If pumping is held at current rates, consumption of surface water sources will remain at 31 cfs, the current rate of capture.

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[13] Based upon the modeled specific yield of 0.2, and a valley area of 110,000 acres (172 square miles).

Figures 4-6 and 4-7 illustrate drawdown as seen through Cross Sections A-A (west to east through Las Cruces) and B-B (west to east through the Canutillo Wellfield) respectively. In the northern region of the model:

- Water table decline (Section A-A, Layer 1) west of the Rio Grande does not occur.
- At depth (Layer 2), heads begin to drop as the piezometric divide progresses slowly (less than 1 mile in 40 years) to the west.

In the southern region of the model:

- Water table declines are steep and pronounced to the east of the river (Section B-B, Layer 1).
- Pumping in the Santa Teresa area causes some water table drawdown west of the river.
- At depth (Layer 3) noticeable piezometric drawdown extends more than 10 miles west of the river. Deep aquifer drawdown west of the river in the Las Cruces area is not nearly as pronounced.

Frenzel and Kaehler (1990) note the "indistinct cone of depression" in the area of the Canutillo Wellfield on a contour map of January 1976 observed heads in the Mesilla Basin. They point out that this may indicate that "a large part of the water pumped from the Canutillo well field may move vertically towards the production zones from nearby streams and irrigation-return flow from irrigated lands."

Figure 4-8 illustrates where storage change occurs in the Held Constant and Removed Valley Wide simulations. When pumping is held at current rates, further drawdown of the water table occurs only in the immediate vicinity of Las Cruces pumping (Figure 4-8A). No drawdown is observed in the southern region of the model. The majority of water table recovery from the removal of pumping occurs in the Las Cruces area (Figure 4-8B), although some rebound is noted in the Canutillo/Anthony area.

While Rio Grande discharge at the Narrows shows surface water system flow as a whole, it does not show where the changes occur. Figure 4-9A displays Layer 2 drawdown after 40 years of increased pumping, and Figure 4-9B displays stream to aquifer discharge at selected points along the Rio Grande. These figures show a strong correlation between simulated Layer 2 drawdown and increased Rio Grande depletion. At the Picacho Flume and the Mesilla Diversion Dam, which both lie on the 5 foot drawdown contour, increases of about 0.4 cfs per mile in transmission losses are simulated. At Mesilla, which is near the 10 foot drawdown contour, increased transmission loss is more than 1.0 cfs per mile. At La Mesa very little change (0.1 cfs per mile) is simulated, while at the Canutillo Wellfield, losses increase by more than 4 cfs per mile.

Figure 4-10 shows aquifer-stream interaction along the Rio Grande as pumping is increased. This figure demonstrates the following:

- The Rio Grande is primarily a loosing stream as it flows through the Mesilla Valley.
- Increasing Las Cruces area pumping draws additional water from the Rio Grande between the Picacho flume and the Mesilla Diversion Dam. The greatest depletions are in the vicinity of Mesilla.
- Increasing Canutillo pumping draws additional water from about two miles north of Anthony to about 1 mile south of Canutillo.
- Increasing pumping in the Santa Teresa area draws additional water from the river near the Montoya siphon.

Predictive simulation results representing status quo agree well with previous seepage studies.

- Peterson et al. (1984) outline a number of seepage studies, including unpublished gain and loss studies by the New Mexico State University

Civil Engineering Department. All of the studies show the 5 to 6 mile stretch of Rio Grande directly below Leasburg Dam as a gaining stream, with the remainder of the river being a loosing stream as it flows through the Mesilla Valley to the Narrows. They summarize Rio Grande losses in the Mesilla Valley as ranging from 0.27 to 4.8 cfs per mile.

- Two seepage studies on the Rio Grande conducted in February 1974 and January 1975 showed the river having slight gains in the upper part of the Mesilla Valley, and becoming a loosing stream about 6.2 miles north of Las Cruces. The greatest losses were found to occur between what is represented in this report as river mile 14 and the Mesilla dam. Losses in this section were found to range from 1.7 to 4.8 cfs per mile, with an average of 2.5 cfs per mile. River losses were found to be 1.2 cfs per mile just below confluence with the Del Rio Drain (approximately river mile 33), and 1.8 cfs per mile adjacent to the Canutillo well field. (Wilson and others, 1981, p66.)
- A seepage study conducted by the USGS in January 1991 found that the Rio Grande is primarily a gaining stream from Radium Springs, New Mexico to near Picacho, and primarily a loosing stream from Picacho to El Paso, Texas (Hamilton and Maddock, 1993).

The source of pumped water was determined by comparing simulations with and without the pumping of interest. Four sources were considered: storage, stream depletion, reduced evapotranspiration, and changes in flows at fixed head cells. Frenzel and Kaehler (1990, pp 94-99) evaluated the sources of pumped water in the same manner. They note that "...estimates of evapotranspiration may be somewhat inaccurate because head-dependent evapotranspiration tends to make up for errors in the specification of other properties." Flows at fixed head cells were found to be negligible, and were thus ignored.

Predictive simulation results show that during the course of the 40 year *held constant* simulation:

- 1,750,000 acre-ft of water is pumped from the system. About 19% of this comes from storage, 59% from surface water sources, and 22% from reduced evapotranspiration[14].
- Canutillo Wellfield pumping removes about 510,000 acre-ft of water. About 14% of this comes from storage, 76% from surface water sources, and 20% from reduced evapotranspiration.
- Las Cruces area pumping removes about 649,000 acre-ft of water. About 20% of this comes from storage, 45% from surface water sources, and 35% from reduced evapotranspiration.

During the 40 year *increased simulation*:

- 3,333,000 acre-ft of water is pumped from the system. About 25% of this water comes from storage, 57% from surface water sources, and the remaining 18% from reduced evapotranspiration.

4.4.2 Canutillo Pumping

Figures 4-11 through 4-14 present results from the Canutillo Pumping scenario. Comparison of water table drawdown in Figures 4-11A, 4-8A and 4-5A demonstrates the effects of Santa Teresa pumping.

- When both Santa Teresa and Canutillo pumping is increased (Figure 4-5A), appreciable drawdown occurs west of the river.
- When both pumping sources are held constant (Figure 4-8A), there is no significant drawdown west of the river.

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[14] Frenzel and Kaehler (1990) found that depletion of river and drain flow accounted for about 80 percent of pumped water, with the remaining 20 percent being split between storage and salvaged ET.

- When Canutillo pumping *only* is increased (Figure 4-11A) there is no drawdown west of the Rio Grande.

This implies that drawdown west of the river in the Valley Wide simulation is due primarily to Santa Teresa pumping. It is concluded that...

- Holding Santa Teresa pumping constant does *not* cause appreciable drawdown, and
- Increasing Santa Teresa pumping is the dominant cause of drawdown west of the River in the Increased Valley Wide scenario.

Upon removal of Canutillo pumping, storage depletion continues at a slow rate (Figure 4-11B) due to continued Las Cruces pumping. Reduced aquifer storage attributable to increased Canutillo pumping amounts to about 81,000 acre-ft after 40 years. With respect to surface water flows, simulation results show that (Figure 4-12C):

- Increasing Canutillo pumping results in a 25 cfs reduction of river flow after 40 years - this is 4.8% of current flow rates.
- In all, increasing Canutillo pumping results in the capture of more than 36 cfs from surface water sources after 40 years, at which time pumping is 50 cfs. This is a 72% capture rate.
- Current Canutillo pumping captures about 14.5 cfs of surface water flows (an 82% capture rate).

Figures 4-12 and 4-13 demonstrate that Canutillo pumping does not diminish Rio Grande flows more than 3 miles up or down stream of the pumping center. The slight increase in transmission loss near the Montoya Siphon during the first five years of the simulation (Figure 4-12B) is model adjustment to the new average boundary conditions. Santa Teresa and Anthony pumping will result in slightly increased Rio Grande losses when increased; if held constant, no additional losses will occur. When both Canutillo and Santa Teresa pumping are increased, simulated transmission losses after 40 years are

6.3 cfs per mile at Canutillo (Figure 4-9); when only Canutillo pumping is increased, losses are 4.8 cfs per mile (Figure 4-12). The 1.5 cfs per mile difference is attributed to pumping in the Santa Teresa and Anthony areas.

Predictive simulation results show that during the course of the 40 year *increased* simulation 933,000 acre-ft of water is pumped from the Canutillo Wellfield. About 17% of this comes from storage, 69% from surface water sources, and 14% from reduced evapotranspiration.

Table 4-3 displays simulation results of drain and canal flows. Each major canal and drain system is presented. Results are displayed as the percentage *change* in flows since the beginning of the simulation. Positive numbers indicate *increasing* flows; negative numbers indicate *decreasing* flows. The following conclusions are drawn:

- Because the water table is below the invert of the canals, canal flows are unaffected in *any* of the simulations. Leakage from the canals to the aquifer is dependent only on the head in the canal, and is independent of head fluctuations in the aquifer. Further decline of the water table will *not* influence canal losses. Peterson et al. (1984), using U.S. Bureau of Reclamation canal profiles, determined that for nearly all canal sections in the valley in both the irrigation and non-irrigation season, the water table lies several feet below the bottom of the canal.

- Surface water flows are unaffected in regions where pumping is held constant. The only exception to this is the Mesilla drain, which shows a 22% increase in drain flows when pumping is held at current rates. This is because the simulated drain flow is still adjusting to the new boundary conditions. Since flow in the Mesilla drain is so small, very small fluctuations in flow amount to a large percentage change in flow.

- The Picacho, Leasburg, Mesilla and Del Rio drains are influenced only by pumping in the Las Cruces area, as noted by their insensitivity to Canutillo pumping.

- The East/Anthony and West/Nemexas drain systems are influenced only by Canutillo pumping, as noted by their insensitivity to Las Cruces pumping.
- Flows in the Selden and Chamberino/La Union drain systems are insensitive to both Las Cruces and Canutillo pumping.

Table 4-3: Simulated Effects of Pumping on Canal and Drain Flows

		Percentage Change in Canal or Drain Flow						
Name	*Segment Number*	*Held Constant*	*Increased Valley Wide*	*Removed Valley Wide*	*Increased Canutillo*	*Removed Canutillo*	*Increased Las Cruces*	*Removed Las Cruces*
Canals								
Leasburg	*3*	0	0	0	0	0	0	0
Picacho	*4*	0	0	0	0	0	0	0
Las Cruces	*6*	0	-8	8	0	0	-7	8
Mesilla	*8*	0	0	1	0	0	0	1
3 Saints West	*22*	0	-5	5	0	1	-2	3
3 Saints East	*23*	0	-4	4	0	0	-3	3
Combined La Union	*19*	0	-3	4	-1	2	0	0
Drains								
Selden	*9*	0	0	0	0	0	0	1
Picacho	*12*	-2	-99	45	-3	-1	-90	40
Leasburg	*24*	0	-45	15	0	0	-31	13
Mesilla	*27*	-3	-99	483	-4	-2	-99	399
Del Rio	*26*	0	-33	10	0	0	-24	9
Chamberino/La Union	*32*	0	-4	3	-1	1	0	1
East/Anthony	*37*	0	-27	17	-13	9	0	1
West/Nemexas	*44*	0	-25	12	-13	6	0	0

Only one canal seepage study was found by Hamilton and Maddock (1993). This study was performed by the Bureau of Reclamation in November 1923. It found that the Leasburg Canal from Wasteway No. 1 to Elwood (approximately 11.5 miles) experienced losses ranging from 0.7 to 2.2 cfs per mile, with an average of 1.2 cfs per mile. The Held

Constant simulation results show an average annual seepage rate of 2.4 cfs per mile for the Leasburg canal[15].

When displaying the effects of pumping on drain flows, the Valley Wide Pumping results are presented. The Valley Wide results demonstrate the same behavior as the separate Las Cruces and Canutillo simulations, but show greater flow depletions for some drains. Since only the East/Anthony and West/Nemexas drain systems are affected by Canutillo pumping, only their results are presented in this section. Figure 4-14 illustrates the effects of the Valley Wide Pumping simulation on drain flows in the southern portion of the model. The following notations are made:

- Pumping causes no change in drain flows if held constant. When increased, however, distinct flow declines are simulated.

When pumping is increased…

- The East and Anthony drains (just before their confluence) show 37% and 8% flow reductions, respectively.
- The Nemexas and West drains experience 30% and 26% flow reductions, respectively.
- The East/Anthony and West/Nemexas drain systems are not simulated to dry up within the time frame of the simulation.
- For all the drains presented, rapid flow increases are simulated upon the removal of pumping.

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[15] Note that laterals are not explicitly represented in the model. The canals as represented in the model are therefore lumped parameters, representing both the canals, and the laterals coming off of them. Because of this, they would be expected to have higher seepage rates in order to account for leakage occurring from laterals.

4.4.3 Las Cruces Pumping

Figures 4-15 through 4-18 present results from the Las Cruces Pumping scenario. Water table drawdown in the northern section of the model is identical to the Valley Wide simulation (Figures 4-5A and 4-15A), indicating that pumping outside the Las Cruces pumping zone does not influence drawdown in the Las Cruces area.

Upon removal of Las Cruces pumping, storage depletion continues at a slow rate (Figure 4-15B); this is due to continued Canutillo pumping. Storage loss attributable to increased Las Cruces pumping amounts to slightly more than 197,000 acre-ft over 40 years. With respect to surface water flows, simulation results show that (Figure 4-15C) Rio Grande flow at the Narrows is unaffected by Las Cruces pumping. This is because about 41% of the water pumped in the Las Cruces area is simulated to return to the river as sewage discharge. These sewage return flows replace 95% of the surface water captured by Las Cruces pumping wells.

Predictive simulation results show that during the course of the 40 year *increased* simulation 1,187,000 acre-ft of water is pumped from the Las Cruces area. About 28% of this comes from storage, 43% from surface water sources, and 29% from reduced evapotranspiration.

Figures 4-16 and 4-17 show that, in the northern region of the model, deep aquifer drawdown and increased Rio Grande transmission losses are slightly greater in the Valley Wide scenario (Figures 4-9 and 4-10). Drawdown and surface flow depletion in the Las Cruces area appear to be influenced slightly, but not significantly, by pumping increased outside of the Las Cruces pumping zone.

Simulation results show that only the Leasburg, Del Rio, Mesilla and Picacho drains are affected by Las Cruces pumping; the Chamberino/La Mesa drain system is unaffected, as are all other drains found south of this. Figure 4-18 illustrates the effects of the Valley Wide Pumping simulation on drain flows in the northern portion of the model. In particular, this figure illustrates that:

- Pumping held at current rates induces no change in drain flows.
- The Mesilla and Picacho drains are simulated to go dry if Las Cruces pumping is increased.
- Flows in the Leasburg and Del Rio drains decline by 45% and 34%, respectively, from their current rates.
- In all cases, rapid increases in flows are simulated upon the removal of pumping.

4.4.5 Summary of Findings

- The proximity of pumping to the Rio Grande influences the timing of surface water capture; it also affects the quantity of water drawn from storage when new pumping is introduced or existing pumping is increased. As a pumping source is moved away from the river, more storage depletion is required in order to capture leakage from the river.
- When all pumping within the model is held at current rates, storage reserves are reduced by about 137,000 acre-ft over 40 years. The majority of this depletion is in the Las Cruces area, with the remainder occurring in the vicinity of the Canutillo Wellfield. 1,750,000 acre-ft of water is pumped from the system in the course of the 40 year simulation. About 19% of this comes from storage, 59% from surface water sources, and 22% from reduced evapotranspiration
- After 40 years of increasing all pumping within the model…
    - Storage is reduced by about 625,000 acre-ft,

- Rio Grande flow at the Narrows drops 59 cfs, an 11.5% flow reduction, and
- 183 cfs is pumped Valley Wide, with about 87 cfs (48%) of that being captured surface water.

Canutillo pumping…

- When *left at current rates*, withdraws 510,000 acre-ft of water in the course of the 40 year simulation.
    - 14% of this water is from storage,
    - 72% is captured surface water, and
    - 14% is salvaged evapotranspiration.
- When *increased*, withdraws 933,000 acre-ft of water in the course of the 40 year simulation.
    - 17% of this water is from storage,
    - 69% is captured surface water, and
    - 14% is salvaged evapotranspiration.

- After 40 years of increasing pumping at the Canutillo Wellfield only…
    - Storage is reduced by about 218,000 acre-ft,
    - Rio Grande flow at the Narrows drops 25 cfs, a 4.8% flow reduction, and
    - 50 cfs is pumped from the Canutillo wellfield, with about 36 cfs (72%) of that being captured surface water.

Las Cruces pumping…

- When *left at current rates*, withdraws 649,000 acre-ft of water in the course of the 40 year simulation.
    - 20% of this water is from storage,
    - 45% is captured surface water, and

        - 35% is salvaged evapotranspiration.
    - When *increased*, withdraws 1,187,000 acre-ft of water in the course of the 40 year simulation.
        - 28% of this water is from storage,
        - 43% is captured surface water, and
        - 29% is salvaged evapotranspiration.
- About 95% of the surface system loss attributable to Las Cruces pumping is returned to the River as sewage return flow. Because of this, Las Cruces pumping has no net effect on Rio Grande discharge as measured at the Narrows.
- After 40 years of increasing pumping in the Las Cruces area *only*,
    - Storage is reduced by about 334,000 acre-ft,
    - Rio Grande flow at the Narrows remains unchanged (because of sewage return flows), and
    - Capture is effectively non-existent as measured at the Narrows.
- When all pumping is held at current rates, average annual Rio Grande discharge will not change.
- Increasing Canutillo pumping draws additional Rio Grande water from about two miles north of Anthony to about one mile south of Canutillo.
- Increasing Las Cruces area pumping draws additional water from the Rio Grande between the Picacho flume and the Mesilla Diversion Dam.
- Pumping in the Santa Teresa area, if increased, will reduce river flow in the vicinity of the Montoya Siphon, and noticeably draw the water table down.
- The influences of the Las Cruces area and Canutillo Wellfield pumping operations have no significant affect on each other.

- The Rio Grande acts as a barrier to expanding cones of water table depression by holding heads up and preventing drawdown to spread across the river.
- The Rio Grande between the Leasburg Diversion Dam and the Narrows is a loosing stream.
- Leakage from canals is independent of pumping in the valley.
- In the southern region of the model, the East/Anthony and West/Nemexas drain systems are influenced by Canutillo pumping. If pumping in the Canutillo Wellfield is increased, these drains will experience depleted discharge, but are not threatened to dry up. If pumping across the river in the Santa Teresa is also increased, additional flow reductions will result.
- In the northern region of the model, the Picacho, Leasburg, Mesilla and Del Rio drains are influenced by Las Cruces area pumping. If pumping in the Las Cruces area is increased, the Mesilla and Picacho drains will dry up. The Del Rio and Leasburg drains show distinct depletions in flow, but do not threaten to dry up.

4.5 Description of Lining Scenarios

As farm land served by the Rio Grande Project is converted to urban use, associated irrigation water can be transferred to municipal use. Boyle Engineering and Engineering Science propose two plans to aid in the transfer of Project water from agricultural to municipal and industrial use. They propose that the majority of Rio Grande flow be conveyed in a lined conveyance canal. This strategy aims to 1) reduce canal and river conveyance losses, and 2) preserve water quality. In this section, the proposed surface water alternatives are briefly outlined. Model representation of the preferred scenario is discussed, and simulation results presented.

Proposed Surface Water Alternatives

Under the current conditions of the Rio Grande Compact, El Paso is delivered water only during the irrigation season, when deliveries are being made to EPCWID below El Paso. During the winter non-irrigation season drain flows constitute a substantial percentage of Rio Grande flow, and water quality is often too poor to be treated by El Paso water treatment plants. Two alternatives are proposed by Boyle Engineering and Engineering Science (1993) to remedy this.

Alternative 1 calls for a lined conveyance channel from Percha Diversion Dam to American Diversion Dam that transports Project releases for EPCWID and Mexico. EBID releases will continue to be conveyed through the Rio Grande. Alternative 2 also calls for a lined conveyance channel. This canal would be constructed as much as possible in existing EBID canal alignments, and would convey project water for El Paso, Mexico, EBID, Las Cruces, and other southern New Mexico municipalities. Both scenarios...

- Preserve water quality through diversion of project water into a conveyance canal, thereby preventing its mixture with river water degraded by drain return flows, and
- Reduce transmission losses through reduced flows in the Rio Grande and the lining of the main conveyance facility.

Reduction of Rio Grande and canal leakage is expected to result in reduced drain discharge. As long as agriculture continues in the valley, drain flows are an important component of the hydrologic system. The drains convey dissolved solids away from irrigated areas, thereby reducing the contamination of higher quality deep groundwater by lower quality shallow groundwater.

Since it provides municipal water supplies to both El Paso and Las Cruces, Alternative 2 is preferred over Alternative 1. Also, Alternative 2 takes advantage of economy of scale and joint rights of way. Under Alternative 1, water suitable for municipal use would be provided to Texas, but not to New Mexico. Alternative 2 advantages include (Engineering Science, 1991)...

- The provision of improved quality water for the entire Mesilla Valley, for both agricultural and non-agricultural purposes,
- Improved drain flow water quality due to lower salinity water being applied to the land,
- Improved delivery response times (minimizing stress on delicate crops),
- The potential for groundwater pumping reductions, and
- Reduced operations and maintenance costs.

The main disadvantages to the plan are (Engineering Science, 1991)...

- Reduced groundwater recharge,
- Increased salinity of deep and shallow groundwater (due to reduced drain flows),
- Increased salinity of remaining Rio Grande flows (due to a higher percentage of drain flows comprising the Rio Grande main channel flow), and
- Lower Rio Grande flow, which may have adverse environmental impacts.

The historical delivery versus release efficiency rate is less than 50%. With the new lined system, efficiency is expected to exceed 90% (Boyle Engineering and Engineering Science, 1993).

Simulated Lining Scenarios

Two simulations were conducted to analyze the effects of canal lining on the hydrologic regime. The two runs represent…

- The lining of all canals in the system to quantify the effects of canal leakage on the hydrologic regime, and
- The creation of a lined conveyance facility as described by Alternative 2.

These two simulations are identical to the Held Constant Valley Wide simulation except for the changes to the canal system.

The preferred surface water alternative plan leaves 50 cfs in the Rio Grande and diverts all other project releases into a lined conveyance channel. Diverted water is carried through the Rincon Valley and Selden Canyon into the Mesilla Valley. Once in the Mesilla Valley, the water is transported…

- From the Leasburg canal,
- To the Picacho canal,
- To the Westside canal,
- To the La Union Main canal,
- To the La Union East canal,
- To the combined La Union canal, and finally
- To American Diversion Dam.

Canals used in the new conveyance facility will be enlarged and lined. New sections will probably be built to connect the Picacho canal to the Westside canal, and to extend the Combined La Union canal to American Diversion Dam. The Eastside canal would most likely be diverted from the Westside canal, siphoned under the river, and delivered to farmers in existing unlined facilities on the east side of the river (Hutchinson, 1994). The

Leasburg and Mesilla Diversion Dams would become obsolete. At no point between Percha and American Diversion Dams will the conveyed water be returned to the Rio Grande.

In order to simulate the surface water alternative, the irrigation system was altered from its historical configuration. Figure 4-19 is a schematic showing the current canal system representation, and the new conveyance facility representation. Configuration of the drain system was not altered. Bed conductances of all river, canal and drain beds were unaltered from the historical simulation, except for the...

- Leasburg,
- Westside,
- La Union Main,
- La Union East and
- Combined La Union

canals. These canal conductances were set to zero, thereby hydraulically disconnecting them from the groundwater system. In reality, some seepage loss from concrete canals is expected. The USBR's "rule of thumb" for planning studies is estimated to be 0.05 cubic feet per day per square foot of wetted area (Boyle Engineering and Engineering Science, 1993). Based on this seepage rate, losses from the lined conveyance facility are estimated to be about 10,000 acre-ft per year (13.6 cfs)[16]. Simulation results show the new lined conveyance facility reducing transmission losses by about 56,000 acre-ft per year; that includes reduced seepage resulting from canal lining and from reduced Rio Grande flows.

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[16] Wetted area based on a trapezoidal channel 50 feet wide at its base, 70 feet wide at the water surface, 7 feet deep (74.41 feet of wetted perimeter), and 60 miles long.

The implication is that using a conductance of zero to represent lined canals will result in an overestimation of seepage savings by 18%, at the most.[17]

The lined conveyance facility was widened for the predictive simulations, and new Manning coefficients assigned to the appropriate segments. This, however, is simply a matter of aesthetics. Since all lined canals are hydraulically disconnected from the groundwater system, they simply act to transfer water from one section of the model to another. The head in lined canals is not important in these simulations.

4.6 Results From Lining Scenarios

There are several estimates of river and canal leakage in the Mesilla Valley from previous studies.

- Boyle Engineering and Engineering Science (1993) estimate normal year seepage losses for EBID and EPCWID to be 129,000 acre-ft. About 2/3 of these losses are estimated to come from the river, and 1/3 from the canal system.
- Maddock & Wright Water Engineers (1987) and Lee Wilson & Associates (1993) estimate canal seepage losses to be 125,000 acre-ft per year in the Mesilla Valley.
- Maddock estimates that river losses in the Mesilla Valley range from 111,000 acre-ft to 193,000 acre-ft annually (Boyle Engineering and Engineering Science, 1993).

Based on average annual Project flows in the Held Constant simulation, total system seepage losses are simulated to be 175,000 acre-ft per year (242 cfs). 1/3 of that comes

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[17] In reality this percentage will probably be lower, since some of the "lost" canal water will discharge into drains, thereby offsetting the reduced canal returns.

from the Rio Grande, and 2/3 comes from the irrigation delivery system. Drain flows returning to the Rio Grande are simulated to be 110,000 acre-ft per year (152 cfs).

Table 4-4: Simulated Effects of Canal Lining on Drain Flows

			Flow at Time = 40 Years			% Change After 40 Years		
Drain	Segment Number	Flow at Time = 0	Held Constant	All Lined	Conveyance Canal	Held Constant	All Lined	Conveyance Canal
Selden	9	3.4	3.4	0.3	0.0	0	-91	-99
Picacho	12	1.9	1.8	0.0	0.0	-2	-99	-99
Leasburg	24	5.3	5.3	0.0	0.0	0	-99	-99
Mesilla	27	0.5	0.5	0.0	0.2	-3	-99	-61
Del Rio	26	30.9	30.8	15.9	21.1	0	-47	-31
Leasburg/Del Rio/Mesilla	28	48.4	48.3	27.0	36.9	0	-43	-23
Chamberino/La Union	32	13.6	13.6	4.8	4.2	0	-64	-68
East/Anthony	37	21.2	21.0	11.1	18.3	0	-47	-13
West	40	26.3	26.1	16.3	17.3	0	-37	-33
Nemexas	41	32.5	31.9	11.8	17.9	-1	-63	-44
West/Nemexas	44	64.5	63.7	34.5	39.7	0	-45	-37

Figure 4-20 illustrates the predicted effects of the two surface water simulations on drain return flows (Figure A) and Rio Grande flow at the narrows (Figure B). Table 4-4 summarizes the effect of the lining scenarios on drain return flows. From the figures and the table the following conclusions are drawn concerning the system as a whole:

- It will take about 10 years for the system to reach a new equilibrium after the lining of canals.
- If all canals are lined...
    - Drain flows system wide are reduced from 152 cfs to 78 cfs, indicating that canal leakage accounts for approximately half of drains flows.
    - Water savings as measured by Rio Grande flow at the Narrows will amount to about 32,000 acre-ft per year (≈ 45 cfs).
    - The Selden, Picacho, Leasburg, and Mesilla drains of the Las Cruces area will dry up. All other drains in the system will experience flow reductions of at least 37%.

- Under surface water Alternative 2...
    - Drain flows system wide are reduced by 35%.
    - Water savings as measured by Rio Grande flow at the Narrows will amount to about 18,000 acre-ft per year (≈ 25 cfs).
    - The Selden, Picacho, and Leasburg drains will dry up. On the east side of the river, south of the Picacho flume, drain flow depletions are less as one travels south. On the west side of the river drain flow depletions are predominant along the length of the valley.

4.7 Irrigation Efficiency Analysis

The scope of work calls for an estimate, if possible, of the minimum amount of irrigation required to keep salts mobile in the system. Unfortunately, this estimate cannot be performed with the current model because...

- It is discretized in neither time nor space to handle such a problem,
- It does not represent site specific variables that affect irrigation application rates, such as crop type (which affects water demand and salinity tolerance), wind speed, sunshine hours, temperature and humidity,
- It does not have mass transport capabilities,
- It is a saturated media flow model that is not capable of simulating flow in the unsaturated zone, and
- It doesn't specifically handle supplemental irrigation pumping, which plays a factor in the degradation of groundwater quality.

While an estimate of the minimum amount of water required to keep salts mobile in the system is not provided in this report, an analysis of the effects of changing irrigation efficiency is presented. The analysis illustrates how the hydrologic regime is affected when the amount of surface water applied to the fields is altered.

Irrigation efficiency is the ratio of the water consumed by a crop in proportion to the water applied to it. An irrigation efficiency of 100% implies that crops consume all applied water, that no water infiltrates past the root zone, that no water is wasted, and that a minimum amount is used.

While in theory an irrigation efficiency of 100% is ideal, in practice it is not possible. When infiltration past the root zone is zero, dissolved solids in the applied water become concentrated in the soil profile. After a few years of farming in this manner, the land will no longer support agriculture. To restore such land to arable quality, water must be flushed through the soil profile to remove the concentrated salts. As long as farming continues in the Mesilla Valley, salts will necessarily be flushed from the soil profile and into the shallow groundwater system with excess irrigation water.

The minimum required amount of water is to keep the salts mobile in the system will, in theory, be anything less than 100% efficiency. This is based on the assumption that even the most minuscule amount of water will completely flush the soil profile of salts. In reality, a more substantial amount of water is required to cleanse saline soil. Woodrow Gary, a farmer who sits on the EBID board of directors, estimates that, "as a rule of thumb," 3 feet of water applied to Mesilla Valley land provides crops with the necessary water, but up to 2 more feet must be applied to flush salts from the soil (1994). This corresponds to an irrigation efficiency of 60%.

As discussed in Chapter 3, irrigation efficiency is directly related the quality of excess irrigation water. An increase in irrigation efficiency corresponds to a decrease in excess irrigation water quality. For the purpose of this analysis, modeled irrigation efficiency is calculated as the net agricultural loss divided by the irrigation recharge rate. Irrigation efficiency in the held constant scenario is about 73.5%. Note that calculation of irrigation efficiency in this manner *does not* include water applied to the land from supplemental pumping. The true irrigation efficiency in these scenarios is lower than the presented values. Despite this shortcoming in the method of calculation, these simulations will illustrate how increasing or decreasing the efficiency will affect the hydrologic regime.

To evaluate the effects of irrigation efficiency on the hydrologic regime, six simulations with different irrigation efficiencies were conducted.[18] The efficiencies were altered by adjusting irrigation recharge in the recharge package, and farm deliveries in the streamflow routing package. Diversions at the Leasburg and Mesilla dams were not altered. These runs differ only in irrigation application rates, and surface system depletions for farm delivery. The presented results are not meant to determine which efficiency is best to farm at, but rather to illustrate the general effects of changing irrigation efficiency in the Mesilla Valley. Mass balance summaries for the irrigation efficiency simulations are provided in Appendix (Tables D-8 to D-13).

Figure 4-21 illustrates the effects of irrigation efficiency on system wide drain flows, Rio Grand flow at the Narrows, and system storage. The green line with square symbols in these figures is the Held Constant simulation (irrigation efficiency of 73.5%). These figures illustrate that:

- Decreasing irrigation efficiency increases drain flows and replenishes storage at the cost of reduced water supply.
- Increasing irrigation efficiency has the opposite effect; it increases water supply at the cost of lower drain flows and reduced storage.

Analysis of the mass balance results show that:

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[18] The held constant scenario represented current conditions with an efficiency of 73.5%. The remaining five simulations had irrigation efficiencies of of 100%, 90%, 80%, 60%, and 50%.

- When efficiency is *increased*, recharge is reduced, thereby lowering groundwater levels to a new equilibrium and causing a reduction in evapotranspiration and drain seepage. Storage loss is significant as the system adjusts to the new decreased recharge rate, but eventually approaches a depletion rate very close to current conditions. The opposite is true when the efficiency is *reduced.*
- Once the system equilibrates to *any* new increase in recharge rates, 78% of the increased recharge is discharged to the surface water system, 20% is consumed by evapotranspiration, and about 2% replenishes storage reserves. The percentages are the same when recharge is decreased, except that discharges to the surface water system are reduced, evapotranspiration rates drop, and storage reserves are depleted.
- Almost all simulated flow changes at the Narrows due to the manipulation of irrigation efficiency are attributable to changes in evapotranspiration.
- As less water is applied the land to increase irrigation efficiency and save water, less water is being flushed through the system. This implies that one or both of two processes is occurring: salts are being left behind in the groundwater system, and/or drain return flows have elevated TDS concentrations.

4.8 Sensitivity Analysis

A sensitivity analysis was performed to assess model sensitivity to selected input parameters. The analysis consists of 84 separate simulations altering evapotranspiration parameters, transmissivity, vertical conductance, specific yield, Rio Grande bed conductance, canal bed conductance, and drain bed conductance. For each parameter alteration two simulations were run: the Held Constant Valley Wide simulation and the Increased Valley Wide simulation. This was done to assess model sensitivity under different states of stress.

Model sensitivity to the adjusted parameters is assessed through differences between altered and undisturbed simulation results. Storage change, Rio Grande flow at the Narrows, drain flows and transmission losses from canals and the Rio Grande are the indicators used to evaluate model sensitivity. These are the same indicators used to asses the affects of pumping and canal lining.

Storage difference between the sensitivity runs and the standard runs are presented as the average flow difference (in cfs) into storage between the two runs over the 40 year simulation. Positive flow changes indicate an increase in storage, and negative changes indicate depleted storage. Differences in river flow, transmission losses and drain flows are presented as the percentage change from the standard simulation

Alterations to the parameters of interest represent a system wide bias in the estimated parameter. They imply that assumptions or information (or lack thereof) used to estimate the parameter of interest are incorrect or inaccurate, resulting in assigned parameter values that are too low or too high *throughout* the model.

Sensitivity analysis of parameters involving hydraulic conductivity (i.e. transmissivity, layer 1 conductivity, vertical conductance, and bed conductances) consist of six simulations where the parameter of interest is multiplied by 10.0, 5.0, 2.0, 0.5, 0.2 and 0.1. This range of multipliers was selected for two reasons: (1) errors of an order of magnitude are not uncommon when estimating hydraulic conductivity, and (2) it shows the sensitivity of the model to both small and large estimation errors.

Surface flows changes less than ±10% are considered insignificant. The accuracy of most natural stream discharge measurements is rarely better than ±10%, and usually worse. As such, model derived changes in flow that are less than ±10% would not be measurable in the field, and are thus insignificant from a practical standpoint. Similarly, changes in storage that are less than 1 cfs will be considered insignificant. Based on the specific yield of 0.2 used in the model, a 1 cfs change in flow to or from storage translates to a uniform 1.3 foot change in the water table elevation throughout the Mesilla Valley after 40 years. Such a change in water table elevation over 40 years is not considered significant.

Table 4-5 outlines model sensitivity to conductivities, storage parameters, and evapotranspiration parameters. Table 4-6 outlines the results of simulations altering bed conductance sensitivities. Each tested parameter is discussed below.

Transmissivity

Two sets of simulations were run to assess model sensitivity to transmissivity and layer 1 conductivity: one set altering *all* assigned transmissivities and horizontal conductivities in the model, and another altering only layer 1 conductivities.

As horizontal conductivities are increased, the system is able to convey more water from the canals and farmlands to the drains; and able to do so with a smaller gradient. This leads to increased drain flows and a lowering of the water table (i.e. storage depletion). Increasing hydraulic conductivities also leads to greater underflow at Selden Canyon and El Paso Narrows. A tenfold increase in transmissivity leads to increased underflow increases into and out of the system by the same factor.

Reducing transmissivities affects the *held constant* and *increased* simulations differently. Decreasing transmissivities in the *held constant* simulation leads to a slight increase in storage, while in the *increased* simulation it leads to a decrease in storage.

When horizontal conductivities are reduced, larger gradients are required to convey water from leaking canals and farmland to drains. This requires increased water levels and a subsequent increase in storage. Reducing transmissivity also results in deeper and less expansive cones of depression from pumping. Thus, in regions of pumping, significant storage losses are recorded, while at further distances from the wells, water levels will be unaffected or will actually rise. As transmissivities are reduced, the higher pumping rates of the *increased* simulation lead to drastic drawdown in the Las Cruces, Canutillo and Santa Teresa regions while allowing water levels to rise slightly in other sections of the Mesilla Valley. The net result is a reduction in Rio Grande losses and an increase in drain flows, which reduce storage reserves further.

The following general conclusions are drawn concerning model sensitivity to transmissivity:

- Water supply is relatively insensitive to changes in transmissivity.
- Transmission losses are significantly affected by changes in transmissivity. Losses increase with increasing transmissivity, and decrease with decreasing transmissivities.
- Drain flows are significantly affected by changes in transmissivity. Increasing transmissivity increases drain flows.
- Transmission losses and drain flows in the *increased* and *held constant* simulations are affected by the same magnitude.
- Storage change is more sensitive to transmissivity than any other parameter evaluated in this sensitivity analysis. Increasing transmissivity results in reduced storage. Decreasing transmissivity leads to slightly increased storage in the *held constant* simulation, and decreased storage in the *increased* simulation.
- With respect to storage change in the *increased* simulation, transmissivity decreases in the deeper aquifer have a greater effect than do conductivity reductions in the shallow aquifer.

- With respect to water supply, transmission losses and drain flows, the hydraulic conductivity of layer 1 has a greater effect on the system than do transmissivities in the deeper aquifer.

Table 4-5: Model Sensitivity to Conductivities, Specific Yield and Evapotranspiration Parameters

	Difference in ...for the *Held Constant Simulation*				**Difference in ...for the** *Increased Valley Wide Simulation*			
	Storage (Δ cfs)	**Water Supply (% Δ)**	**Trans. Losses (% Δ)**	**Drain Flows (% Δ)**	**Storage (Δ cfs)**	**Water Supply (% Δ)**	**Trans. Losses (% Δ)**	**Drain Flows (% Δ)**
All Transmissivities and Layer 1 Conductivity								
Multiply by 10.0	-13.32	2.2	20.1	39.6	-8.88	-0.2	22.9	54.6
Multiply by 5.0	-10.43	1.6	14.0	27.8	-6.46	-0.2	16.6	39.1
Multiply by 2.0	-4.09	0.8	6.3	12.7	-1.92	-0.3	7.4	16.7
Multiply by 0.5	2.23	-0.5	-7.0	-12.9	-0.91	0.9	-7.4	-14.4
Multiply by 0.2	2.50	-0.6	-15.9	-27.6	-4.43	3.5	-17.0	-27.2
Multiply by 0.1	1.49	-0.5	-21.1	-35.4	-9.37	6.0	-23.3	-32.7
Layer 1 Conductivity								
Multiply by 10.0	-14.76	2.2	16.3	33.5	-6.02	-1.5	20.5	43.7
Multiply by 5.0	-8.37	1.2	13.1	25.1	-1.78	-1.6	15.6	31.0
Multiply by 2.0	-2.84	0.4	6.5	11.6	0.14	-0.9	7.3	14.0
Multiply by 0.5	1.64	-0.3	-7.2	-12.3	-0.78	1.0	-7.4	-13.9
Multiply by 0.2	3.05	-0.3	-16.3	-27.2	-1.46	2.5	-16.4	-29.8
Multiply by 0.1	3.49	-0.3	-21.6	-35.6	-1.84	3.4	-21.5	-38.6
Vertical Conductance								
Multiply by 10.0	0.46	0.1	3.0	4.9	***	***	***	***
Multiply by 5.0	0.45	0.0	1.8	3.1	2.95	-1.5	3.5	2.5
Multiply by 2.0	0.30	0.0	0.7	1.1	1.64	-0.8	1.5	0.4
Multiply by 0.5	-0.74	0.0	-0.5	-0.7	-2.60	1.1	-1.3	1.1
Multiply by 0.2	-3.30	0.2	-1.1	-1.2	-8.53	3.2	-3.2	4.6
Multiply by 0.1	-6.41	0.4	-1.4	-1.1	-15.63	5.4	-5.2	8.5
Specific Yield								
Increase by 0.1	-0.41	0.1	-0.1	0.2	-3.23	1.2	-1.0	2.2
Decrease by 0.1	1.00	-0.2	0.2	-0.3	5.12	-1.7	1.3	-3.3
Evapotranspiration								
Decrease Max Rate 0.25 ft/yr	0.32	2.1	-2.5	3.2	0.29	2.0	-1.9	3.3
Increase Max Rate 0.25 ft/yr	-0.32	-2.0	2.3	-3.0	-0.27	-1.9	1.8	-3.1
Increase Ext. Depth 3 ft.	-1.07	-4.7	4.4	-8.9	-0.93	-4.9	3.8	-10.2
Decrease Ext. Depth 3 ft.	1.13	6.1	-6.1	10.8	0.94	5.8	-4.7	11.4

*** Simulation did not converge

Vertical Conductance

Modflow uses vertical conductance to represent confining layers and system anisotropy. When vertical conductance is increased, leakage from surface water sources increases slightly, allowing wells to capture more water per unit area. This results in a slight contraction of the pumping depression cones, and increased storage.

When vertical conductances are reduced, the shallow groundwater system becomes more disconnected from the lower aquifer, where most municipal and industrial pumping occurs. The result is a decrease in net leakage from the surface water system. Since less water per unit area is able to flow from the shallow system to the deep system, the cones of depression from pumping expand to capture more water. The net result is a decrease in storage.

Simulation results illustrate a greater sensitivity to changes in vertical conductance under the *increased* simulation than under the *held constant* simulation. They also indicate greater sensitivity when conductances are decreased as opposed to increased. Except for storage change, the model is relatively insensitive to changes in the vertical conductances.

Specific Yield

Two runs were conducted to evaluate the effects of specific yield on simulation results: one run increasing the specific yield from 0.2 to 0.3, and another reducing it from 0.2 to 0.1. Increases in specific yield are equivalent to increases in system porosity. When the porosity is higher, more water is produced from the same decline in water table elevation. The result is increased storage loss when specific yield is increased, and less storage loss when it is decreased. It should be remembered, though, that available storage changes with changing specific yield. Even though storage loss increases or decreases, water table elevations are not significantly affected. This is illustrated by the insensitivity of head dependent drain flows and transmission losses to changes in specific yield.

In general, changes in specific yield have little effect on the surface water flow system, and only a minor effect on storage.

Evapotranspiration

To evaluate the effects of assigned evapotranspiration parameters on simulated flow, the maximum evapotranspiration rate and the extinction depth were altered. Two pairs of runs were conducted:

- One set increasing and decreasing the maximum evapotranspiration rate by 0.25 feet per year (the rate used in the predictive simulations was 1.76 feet per year), and
- One set increasing and decreasing the assigned extinction depth by 3 feet (the depth used in the predictive simulations was 12 feet).

The effects of increasing the extinction depth are similar to that of increasing the maximum evapotranspiration rate — more water is drawn from the groundwater system by plant transpiration, leading to lower groundwater levels, higher transmission losses and reduced drain flows. The opposite is true when the maximum evapotranspiration rate is reduced or the extinction depth decreased.

Simulation results indicate a higher sensitivity to altering the extinction depth by 3 feet than to changing the maximum evapotranspiration rate by 0.25 feet per year. They also show that the *held constant* and *increased* simulations are affected by about the same magnitude. Drain flows are affected the most, transmission losses and water supply to a lesser extent, and storage is affected only minimally.

Table 4-6: Model Sensitivity to Bed Conductances

	Difference in ...for the *Held Constant Simulation*				**Difference in ...for the** *Increased Valley Wide Simulation*			
	Storage (acre-ft)	**Water Supply (% Δ)**	**Trans. Losses (% Δ)**	**Drain Flows (% Δ)**	**Storage (acre-ft)**	**Water Supply (% Δ)**	**Trans. Losses (% Δ)**	**Drain Flows (% Δ)**
Rio Grande Conductance								
Multiply by 10.0	0.89	-1.6	10.9	12.1	1.36	-2.2	12.2	20.7
Multiply by 5.0	0.76	-1.3	9.2	10.2	1.16	-1.9	10.4	17.5
Multiply by 2.0	0.42	-0.7	5.1	5.6	0.65	-1.1	5.7	9.6
Multiply by 0.5	-0.58	1.0	-6.7	-7.3	-1.06	1.6	-7.9	-12.5
Multiply by 0.2	-1.55	2.5	-15.8	-17.0	-3.21	4.1	-20.7	-34.0
Multiply by 0.1	-2.30	3.5	-21.7	-22.9	-4.68	5.9	-28.4	-45.5
Drain Conductance								
Multiply by 10.0	-3.49	5.3	33.7	72.0	-2.99	4.4	25.6	78.7
Multiply by 5.0	-2.91	4.5	25.9	56.7	-2.47	3.6	19.5	60.9
Multiply by 2.0	-1.53	2.4	12.3	27.7	-1.30	1.9	9.1	29.1
Multiply by 0.5	1.69	-2.7	-12.7	-29.5	1.47	-2.1	-9.1	-29.9
Multiply by 0.2	3.64	-5.8	-26.7	-62.2	3.21	-4.4	-18.7	-62.4
Multiply by 0.1	4.63	-7.3	-33.6	-78.6	4.13	-5.7	-23.4	-78.6
Canal Conductance								
Multiply by 10.0	4.02†	10.5†	51.2†	57.6†	4.69†	13.1†	44.3†	74.2†
Multiply by 5.0	3.87†	6.2†	45.9†	49.9†	4.72†	8.9†	39.5†	65.9†
Multiply by 2.0	2.99†	-2.1†	27.5†	28.0†	3.99†	-1.2†	24.2†	39.2†
Multiply by 0.5	-2.98	3.7	-22.3	-23.0	-3.55	3.8	-18.9	-30.5
Multiply by 0.2	-5.43	6.3	-37.5	-38.6	-6.45	6.4	-31.5	-51.0
Multiply by 0.1	-6.39	7.2	-42.6	-43.7	-7.54	7.3	-35.8	-57.8

†Results are erroneous due to drying up of canals — for details, see section on **Canal Bed Conductance**.

Rio Grande Bed Conductance

The effect of Rio Grande bed conductance is found to affect transmission losses and drain flows significantly, but to have little affect on aquifer storage and water supply at the Narrows. Increasing the bed conductance allows more water to leak into the groundwater system, providing pumping wells with additional water for capture, raising water levels, and increasing drain flows. The opposite is true when the bed conductance is reduced.

The effects of changing river bed conductance has an amplified affect on the *increased* simulation. The system is more sensitive to *decreases* in bed conductance than it is to *increases* in conductance. Drain flows and transmission losses are significantly affected, while water supply and storage depletion are influenced to a much lesser extent.

Drain Bed Conductance

Increasing the bed conductance of drains enhances the flushing of water through the shallow system. Since drain flows represent discharge from the groundwater system, increasing drain bed conductance removes more water from the flow system, leading to decreased water levels and increased transmission losses. Since the increase in drain flows is greater than the increase in transmission losses, there is a net increase in simulated river flow at the Narrows. The equal and opposite is true when drain bed conductances are decreased.

Altering drain bed conductances has the greatest affect on drain flows, but also has a substantial affect on transmission losses. Water supply is relatively insensitive to changes in drain bed conductance, and storage change is only moderately affected. The sensitivity to changes in drain bed conductance are about equal and opposite when they are increased and decreased, and there is no noticeable difference between the *held constant* and *increased* simulations.

Canal Bed Conductance

The effect of lining all canals in the system has already been illustrated in Section 4.6. If conductances are increased by a factor of 2, the Three Saints Eats canal looses all its water to the groundwater system before returning to the Rio Grande. Increasing the conductances by a factor of 5 or 10 results in zero canal return flows for the entire system. The model is not able to adequately handle the drying up of canals in the respect that the recharge package and the streamflow routing package are independent of each other. Simulated irrigation recharge continues while in actuality canal water is lost to the groundwater system through leakage, leaving none available to farmers. The result is a large quantity of water being recharged to the groundwater system twice: first when it leaks through the canal beds, and again when it is falsely applied to farmlands. This results in an increased water supply at the Narrows. Therefore, all results from increasing canal conductance values in Table 4-6 are erroneous.

When bed conductances are decreased, recharge to the groundwater system is reduced, leading to lower water table elevations, reduced drainflows, reduced transmission losses, and increased water supply at the Narrows.

Drainflows and transmission losses are substantially sensitive to canal bed conductance while storage is only moderately sensitive, and river flow at the Narrows relatively insensitive. Transmission losses are less affected less in the *increased* scenario than in the *held constant* scenario, while drain flows are affected more.

Summary

The sensitivity analysis presented in this section illustrates the following:

- Water supply, as measured in the Rio Grande at the Narrows, is insensitive to all the parameters tested in this analysis.
- Flow out of storage is most sensitive to layer 1 horizontal conductivity and deep aquifer transmissivities. Storage is moderately sensitive to vertical conductance, river bed conductance, drain bed conductance, and canal bed

conductance. It is relatively insensitive to specific yield and the evapotranspiration parameters evaluated.

- Transmission losses from canals and the Rio Grande are sensitive to all the parameters evaluated except vertical conductance, specific yield and evapotranspiration.
- Drain flows are very sensitive to all the parameters evaluated except vertical conductance and specific yield. They are moderately sensitive to the evapotranspiration extinction depth.

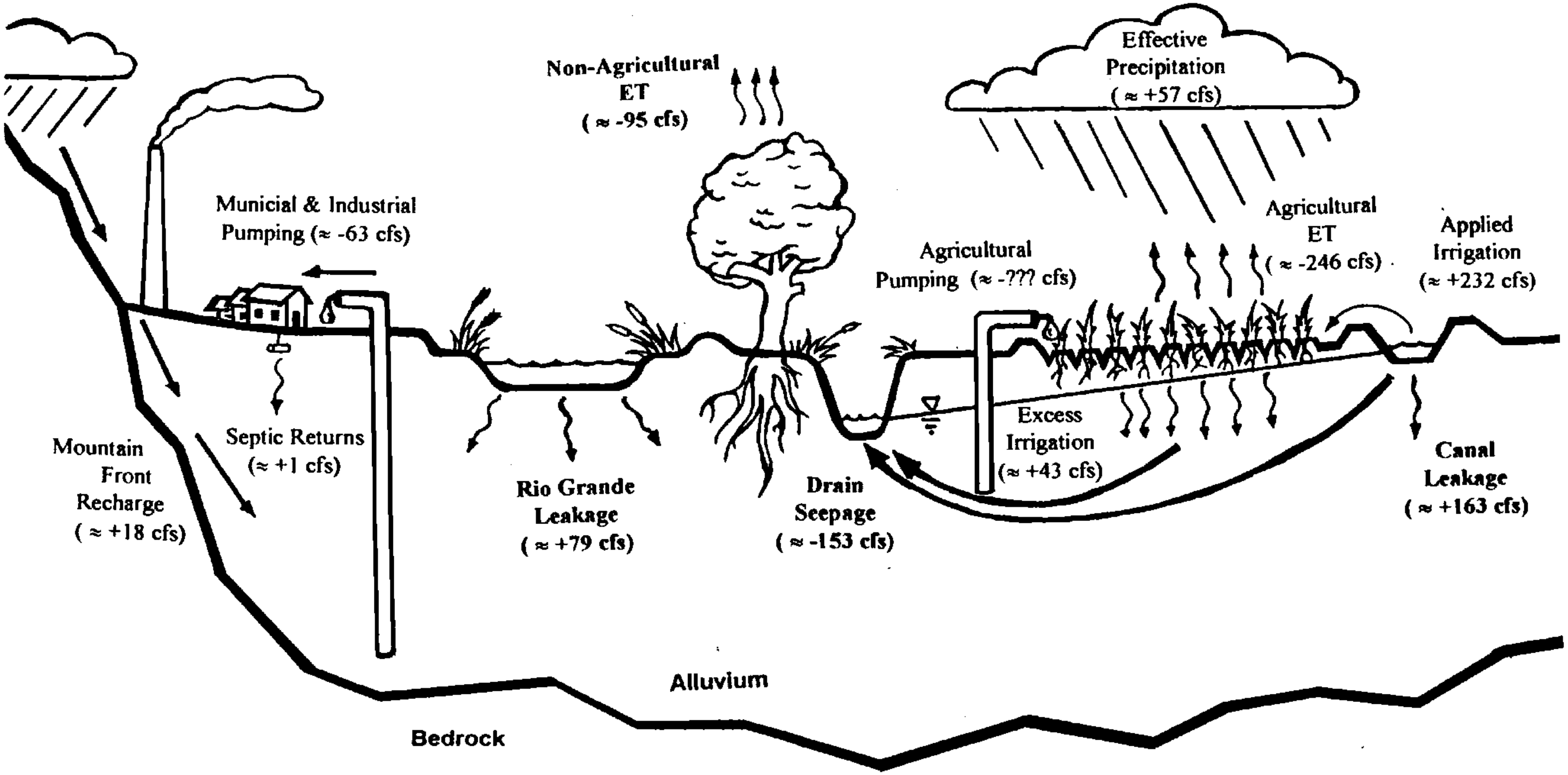


Figure 4-1: Schematic of simulated flows into and ont of the gronndwater flow system. River and canal leakage, drain seepage, and non-agricnlture evapotranspiration are model derived. All other flows are specified directly.

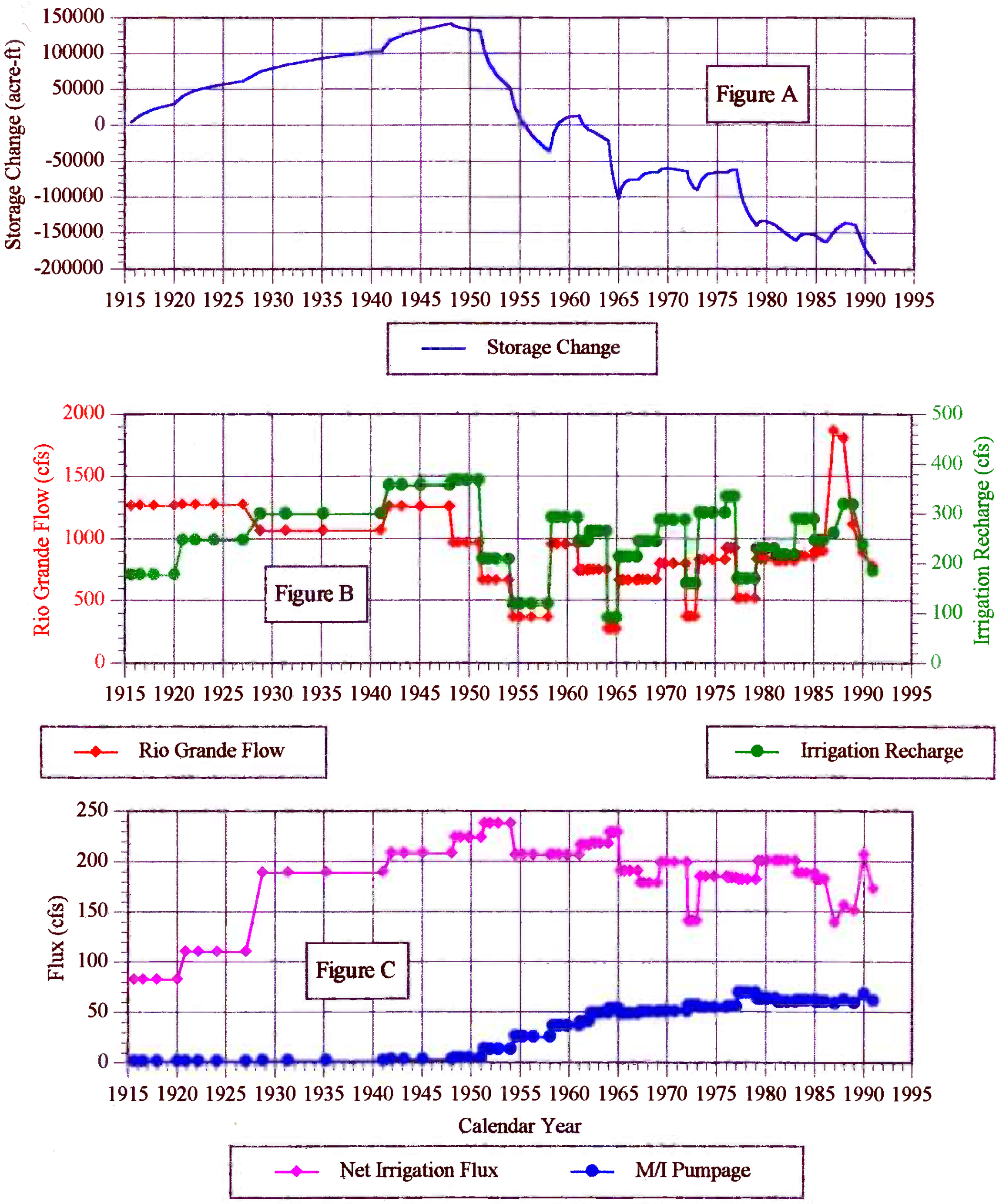


Figure 4-2: Historical Simulation

Simulated storage change and specified boundary fluxes.

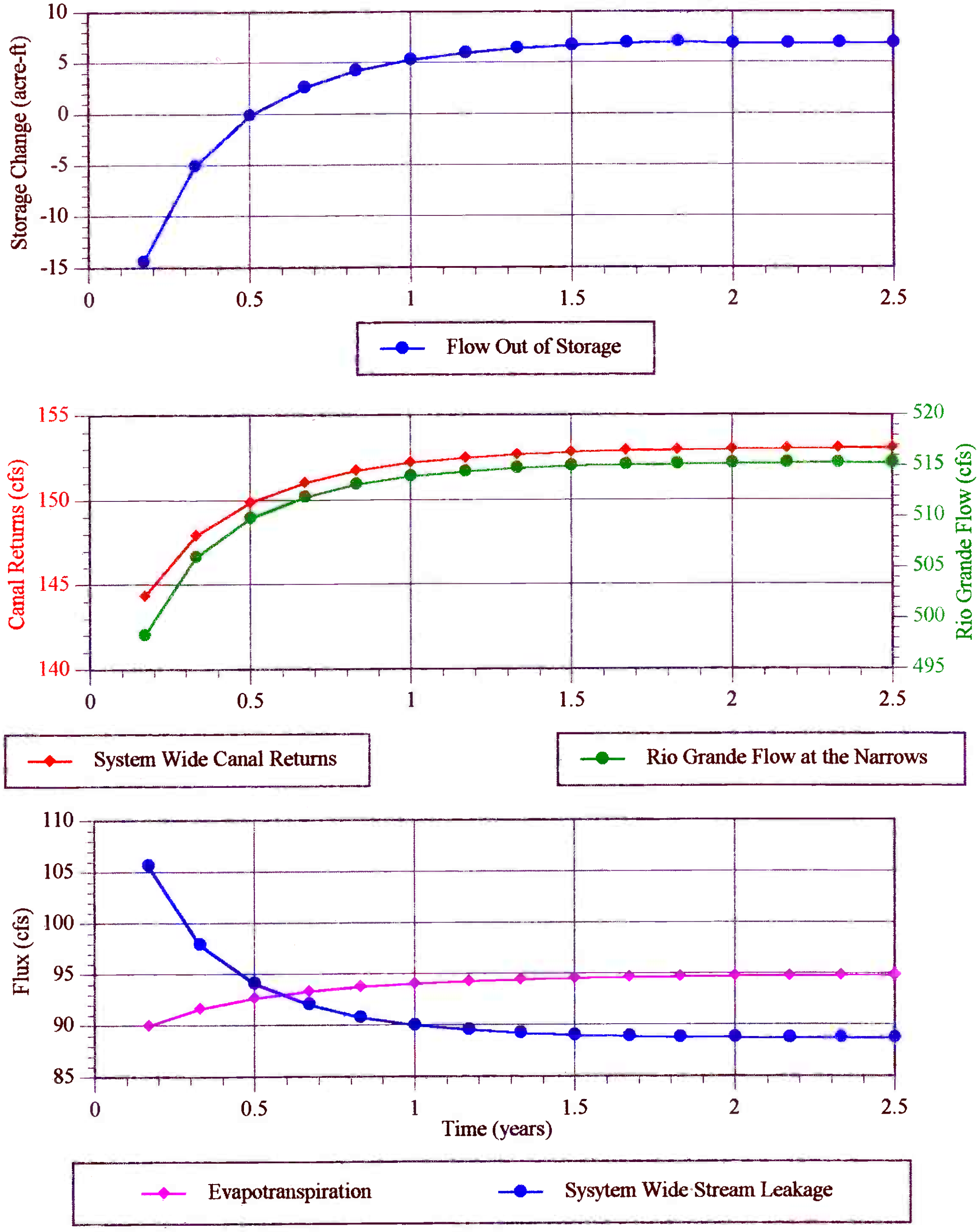


Figure 4-3: Model Adjustment to New Boundary Conditions

Simulated change in system flows to new average annual boundary conditions.

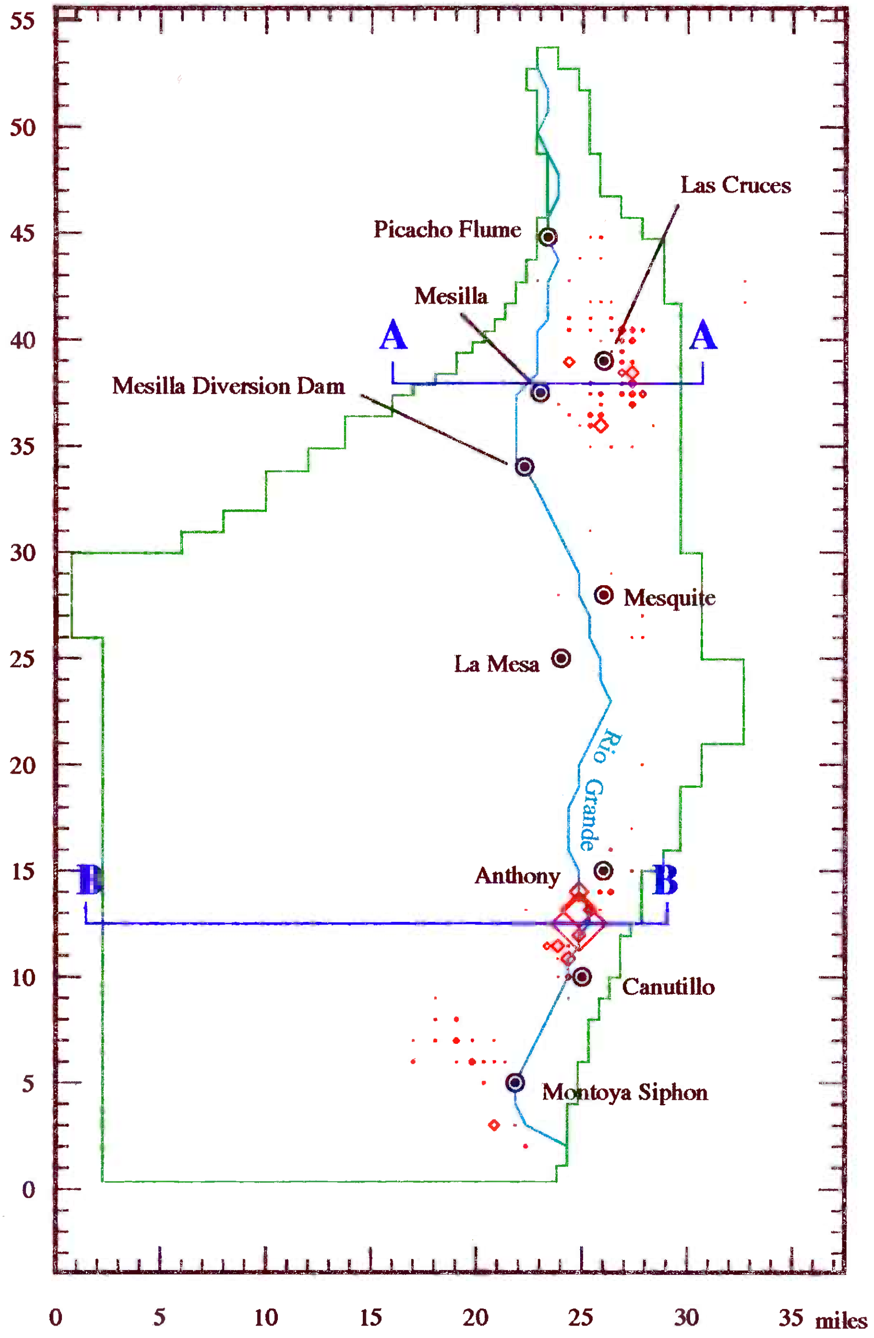


Figure 4-4

Plan map showing the location and relative magnitude of modeled municipal and industrial pumping, and the location of Cross Sections A-A and B-B.

Figure A: Simulated Water Table Drawdown (ft) After 40 Years of Increased Pumping

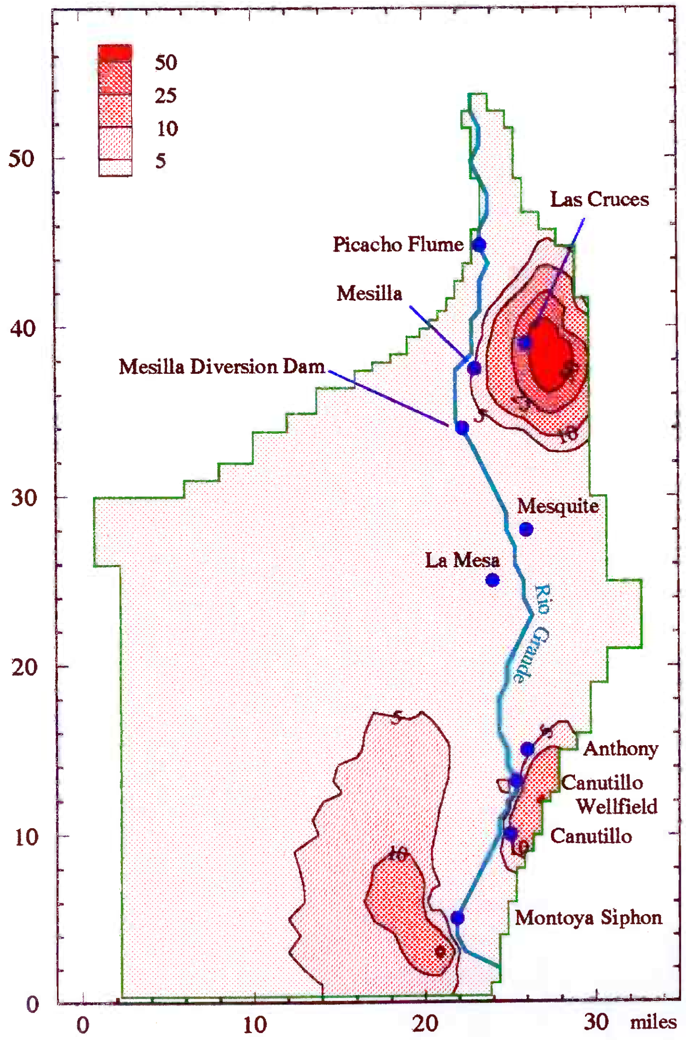


Figure B: Simulated Change in Storage

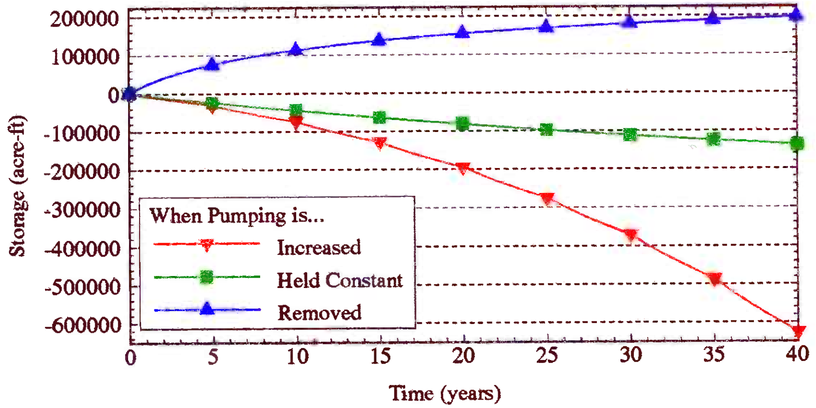


Figure C: Simulated River Discharge at The Narrows

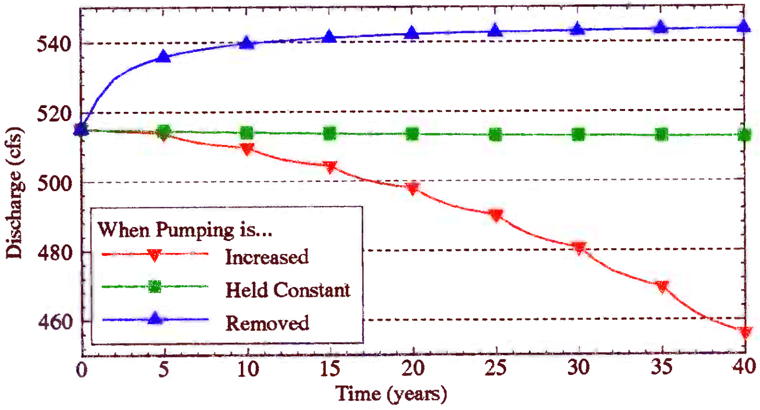
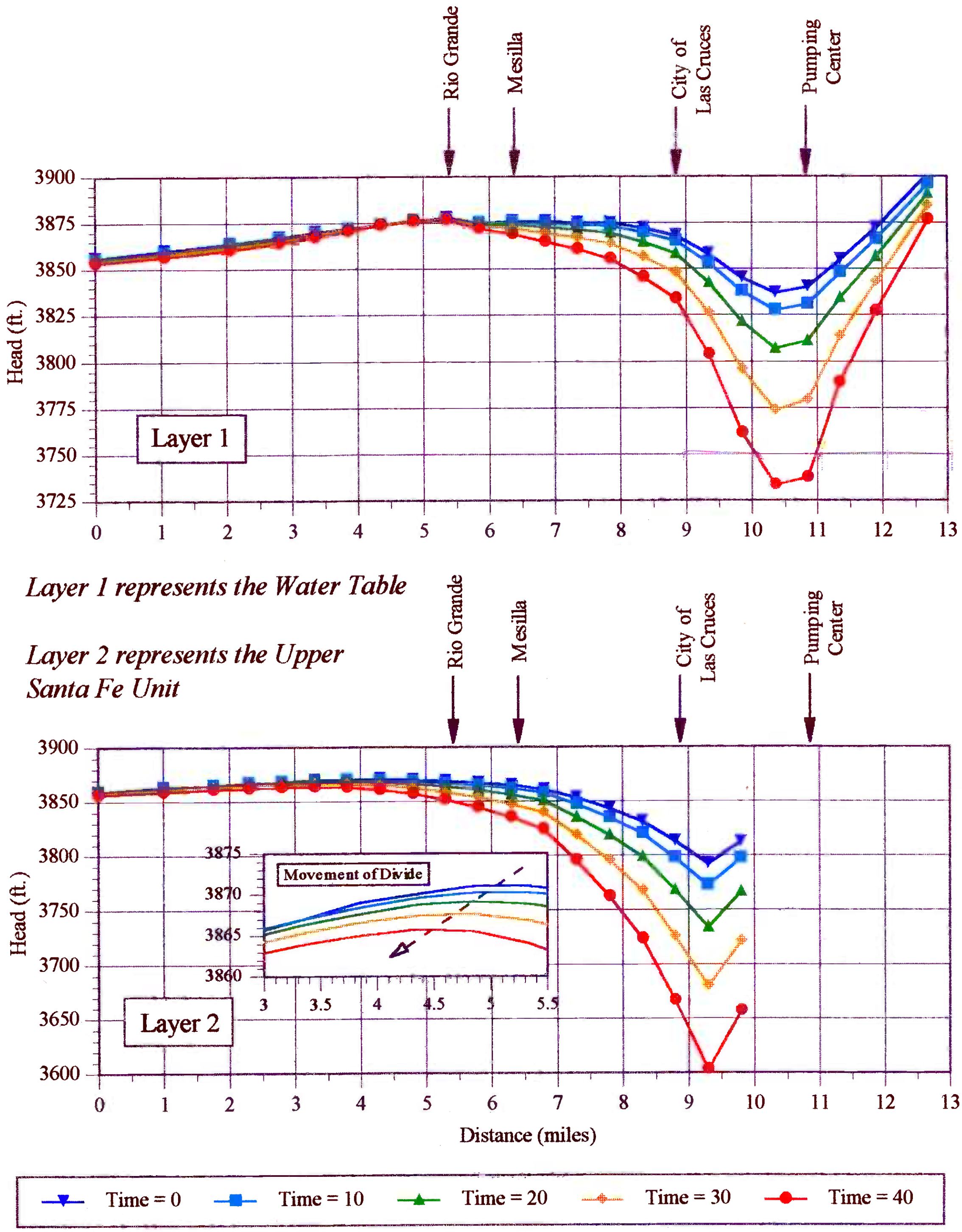


Figure 4-5: Basin Wide Pumping

Simulated effects of pumping on water table drawdown, aquifer storage, and Rio Grande discharge.

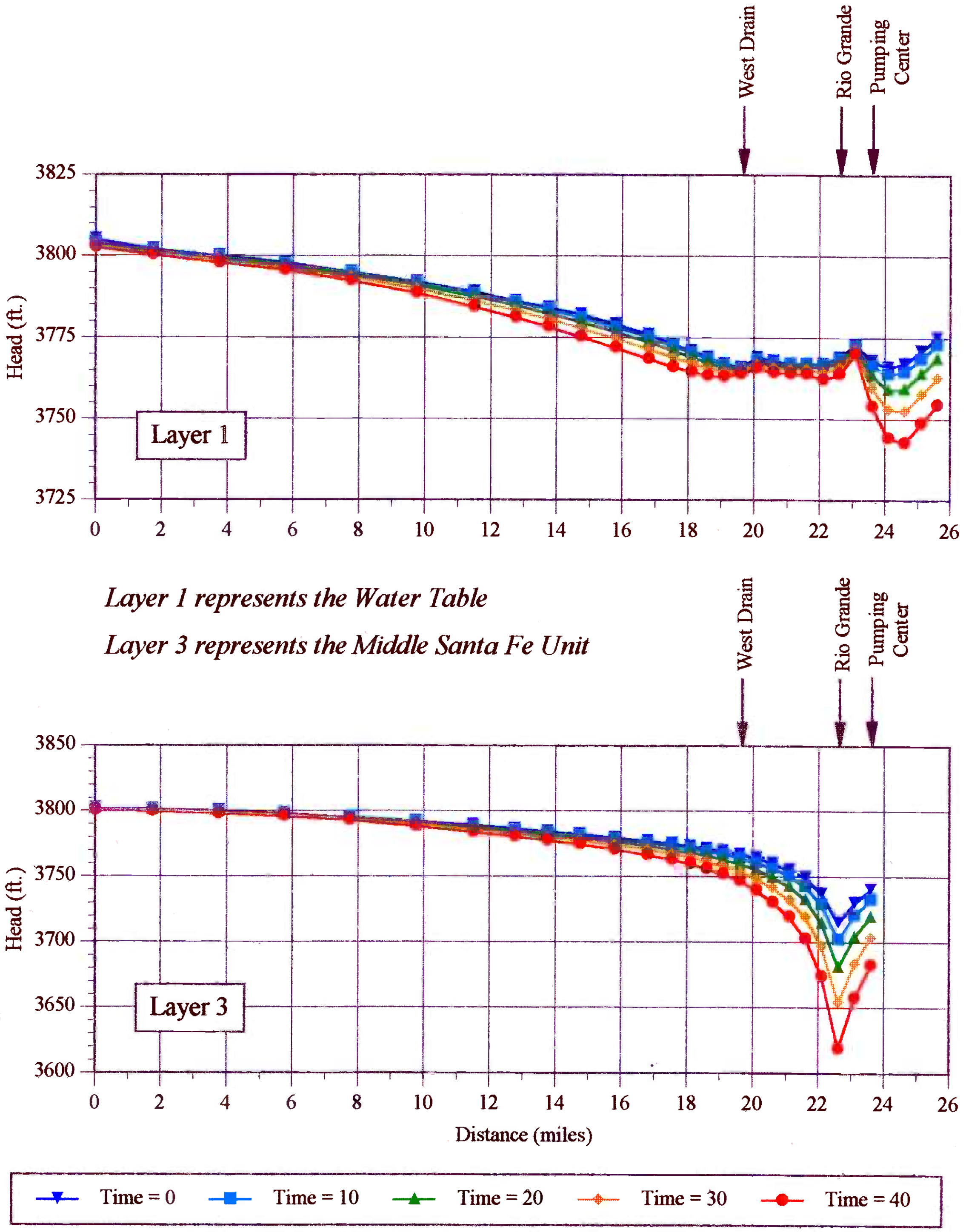


Layer 1 represents the Water Table

Layer 2 represents the Upper Santa Fe Unit

Figure 4-6: Basin Wide Pumping

Simulated heads along Cross Section A-A (west to east through Las Cruces) when all municipal and industrial pumping is increased 2.5% annually .



Layer 1 represents the Water Table

Layer 3 represents the Middle Santa Fe Unit

Figure 4-7: Basin Wide Pumping

Simulated heads along Cross Section B-B (west to east through the Canutillo Wellfield) when all municipal and industrial pumping is increased.

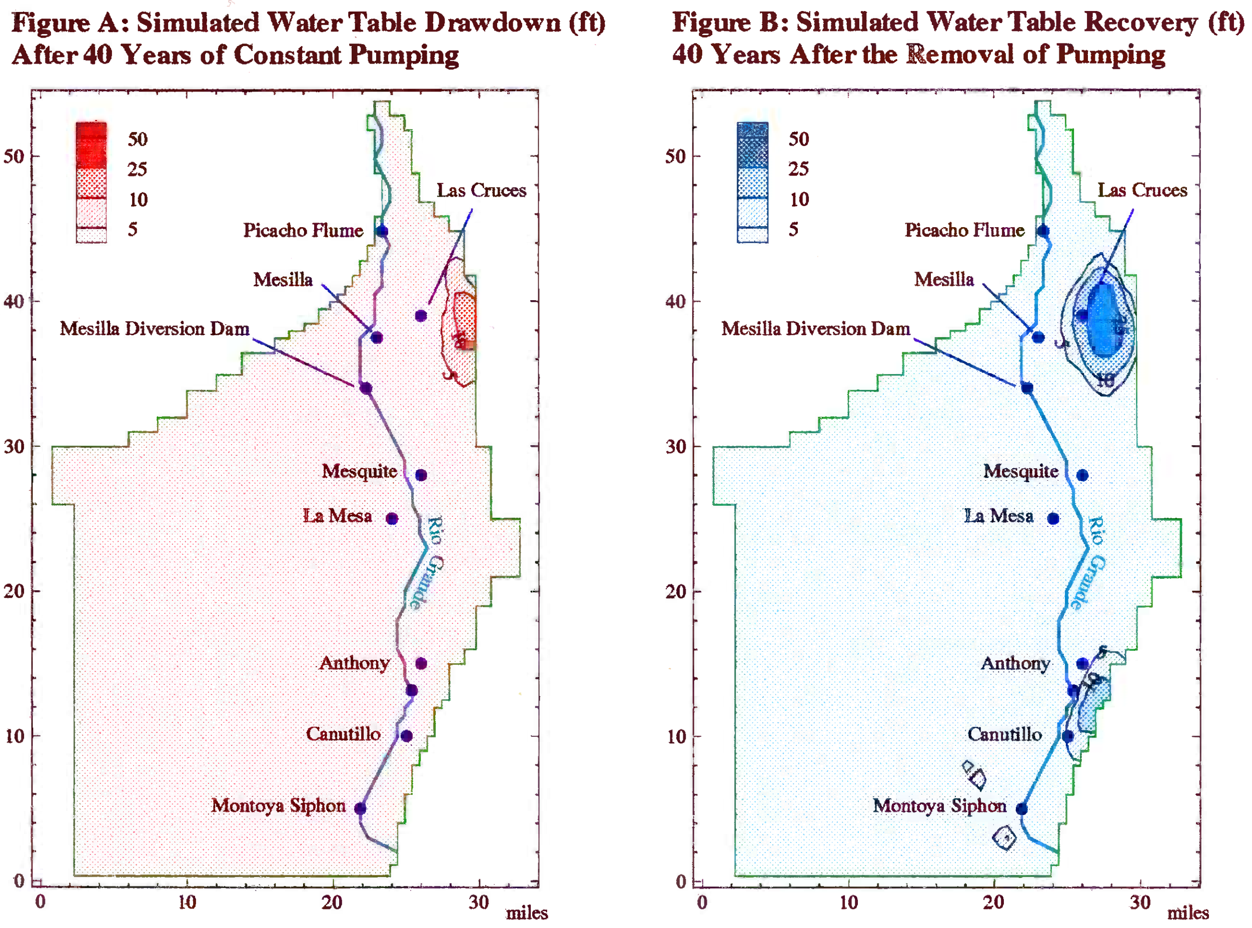


Figure A: Simulated Water Table Drawdown (ft) After 40 Years of Constant Pumping

Figure B: Simulated Water Table Recovery (ft) 40 Years After the Removal of Pumping

Figure 4-8: Basin Wide Pumping

Simulated Water Table...

A) Drawdown After 40 Years of Constant Pumping at Current Rates, and

B) Recovery 40 Years After the Removal of All Pumping.

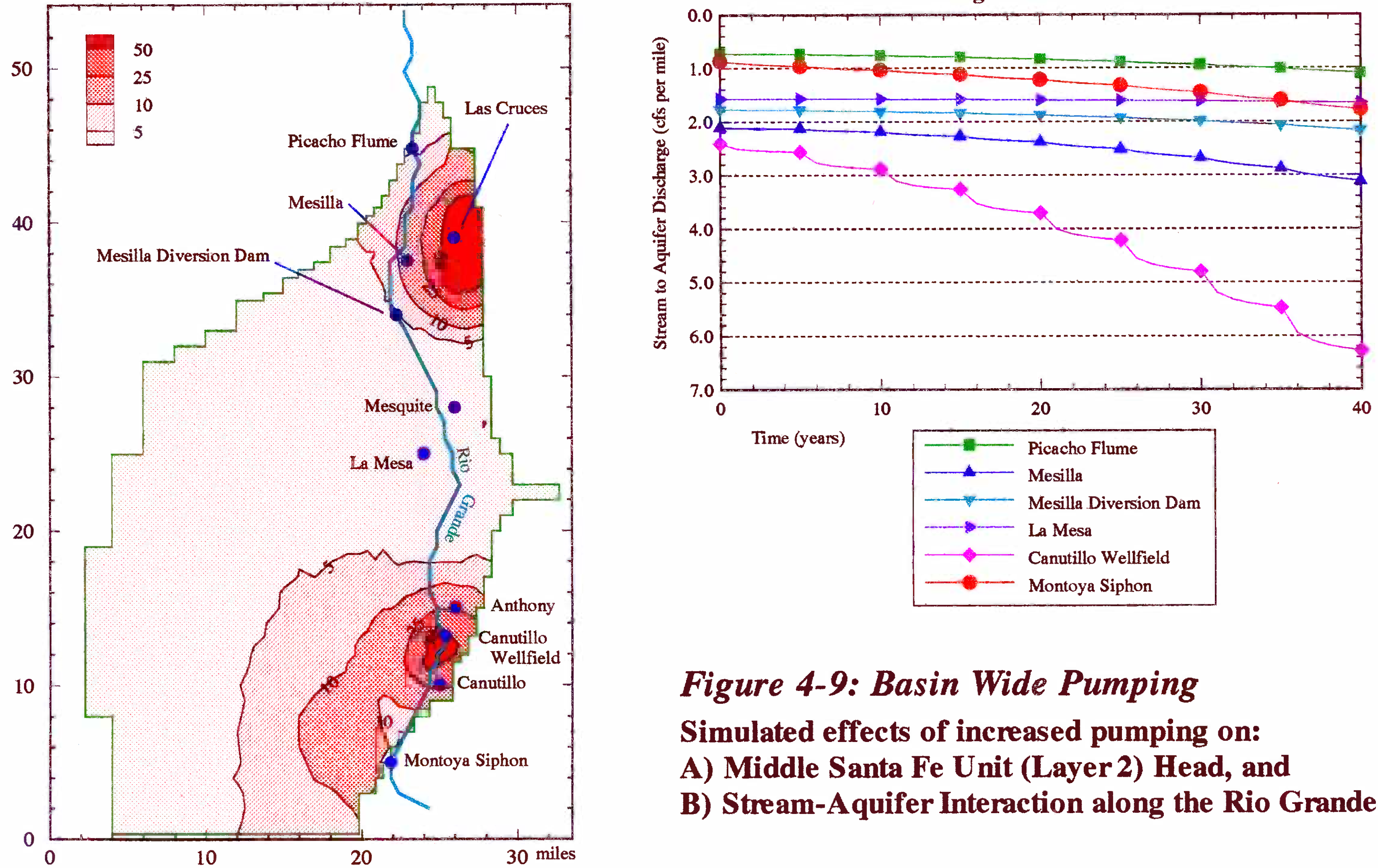


Figure A: Simulated Layer 2 Drawdown (ft) After 40 Years of Increased Pumping

Figure B: Stream to Aquifer Discharge (in cfs per river mile) At Selected Points Along the Rio Grande

Figure 4-9: Basin Wide Pumping

Simulated effects of increased pumping on:
A) Middle Santa Fe Unit (Layer 2) Head, and
B) Stream-Aquifer Interaction along the Rio Grande.

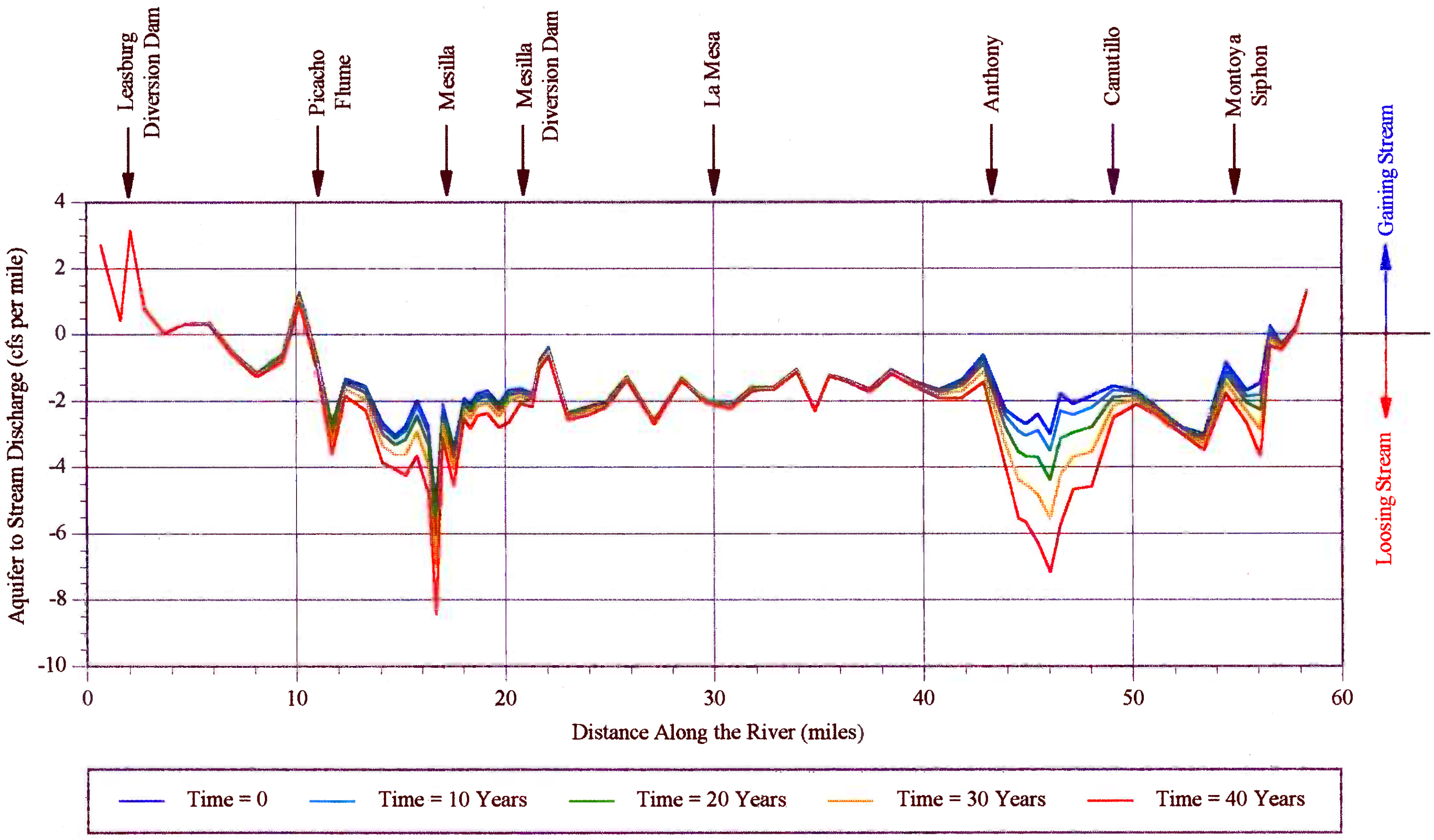


Figure 4-10: Basin Wide Pumping

Simulated aquifer to stream discharge along the Rio Grande when all municipal and industrial pumping is increased.

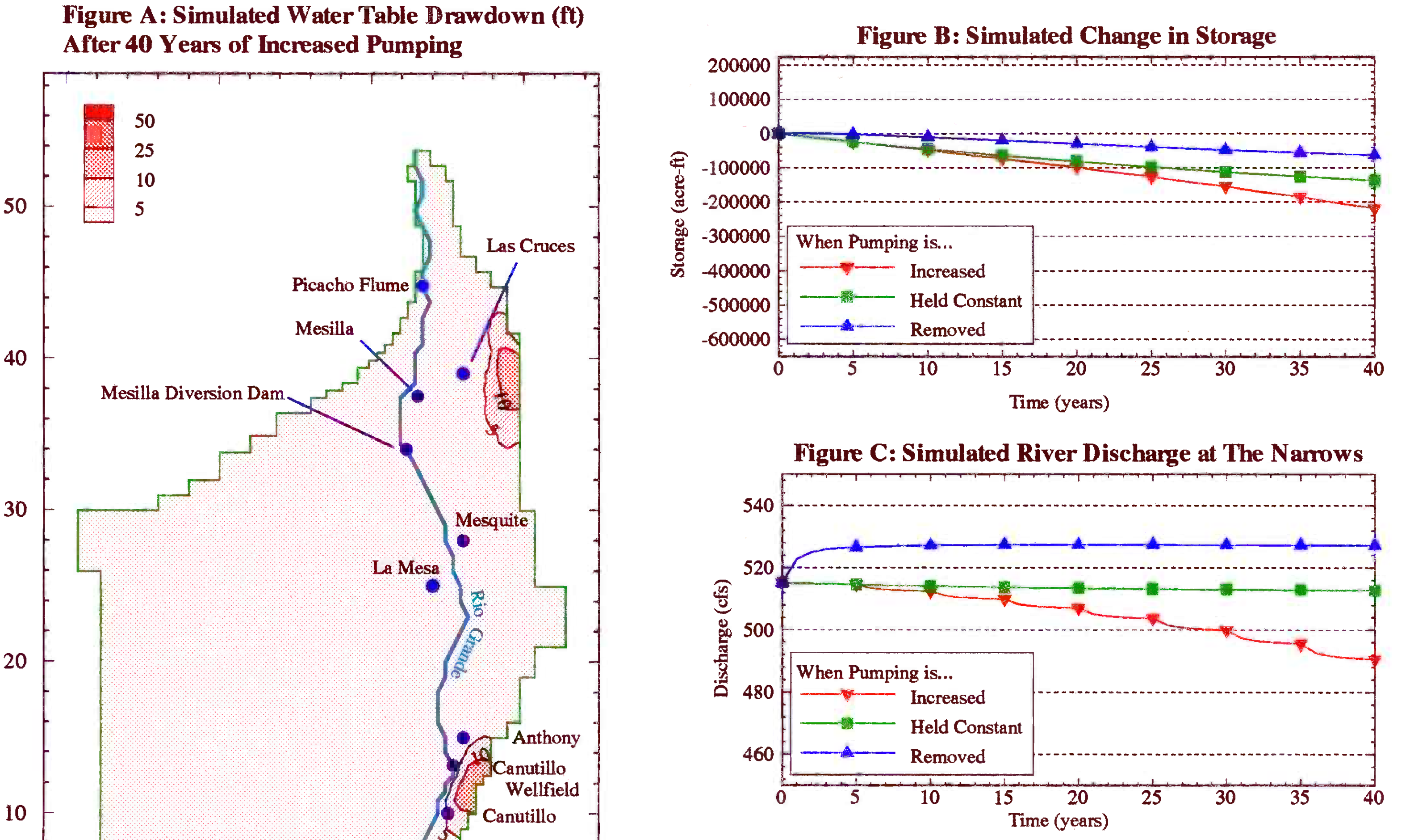


Figure A: Simulated Water Table Drawdown (ft) After 40 Years of Increased Pumping

Figure B: Simulated Change in Storage

Figure C: Simulated River Discharge at The Narrows

Figure 4-11: Canutillo Pumping

Simulated effects of pumping on water table drawdown, aquifer storage, and Rio Grande discharge.

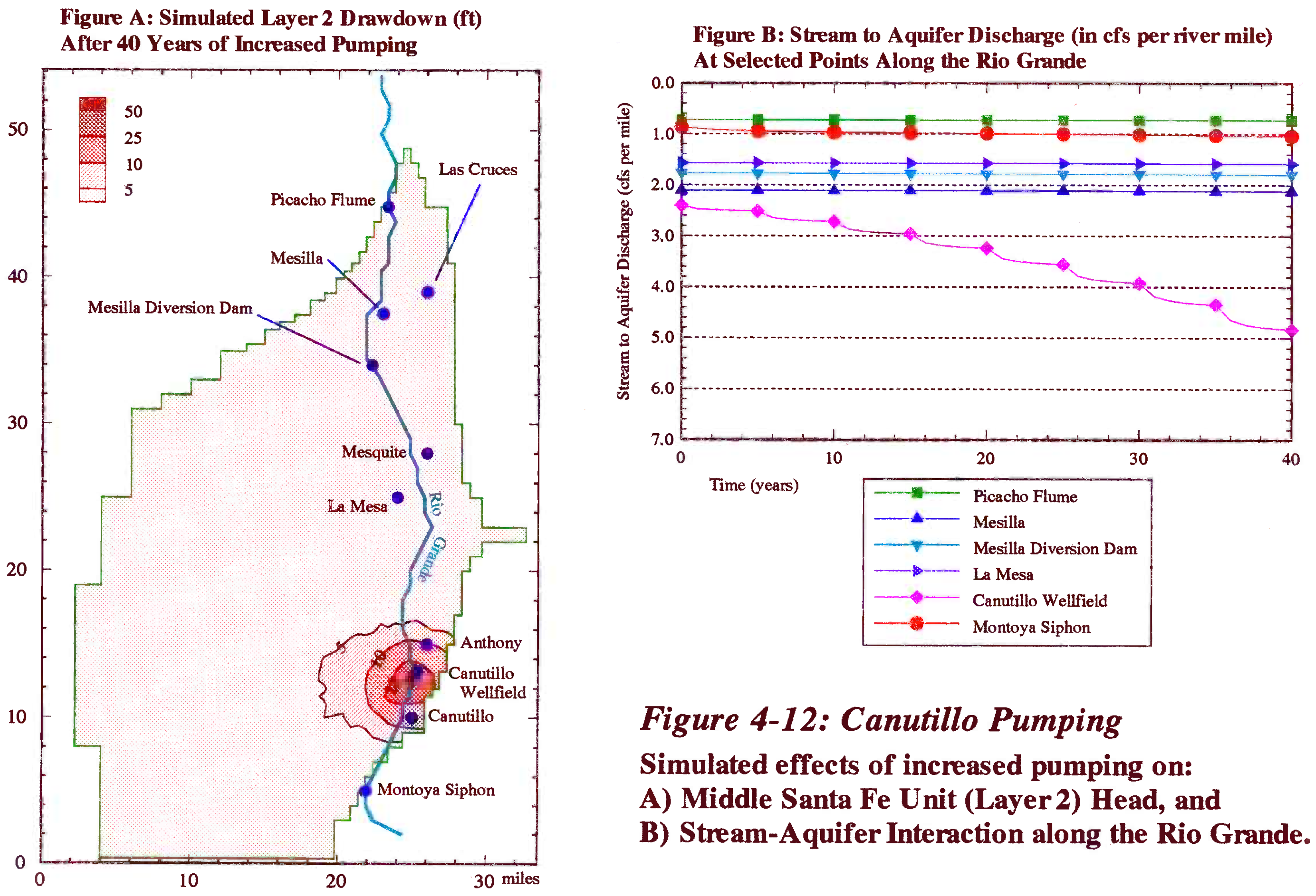


Figure 4-12: Canutillo Pumping

Simulated effects of increased pumping on:
A) Middle Santa Fe Unit (Layer 2) Head, and
B) Stream-Aquifer Interaction along the Rio Grande.

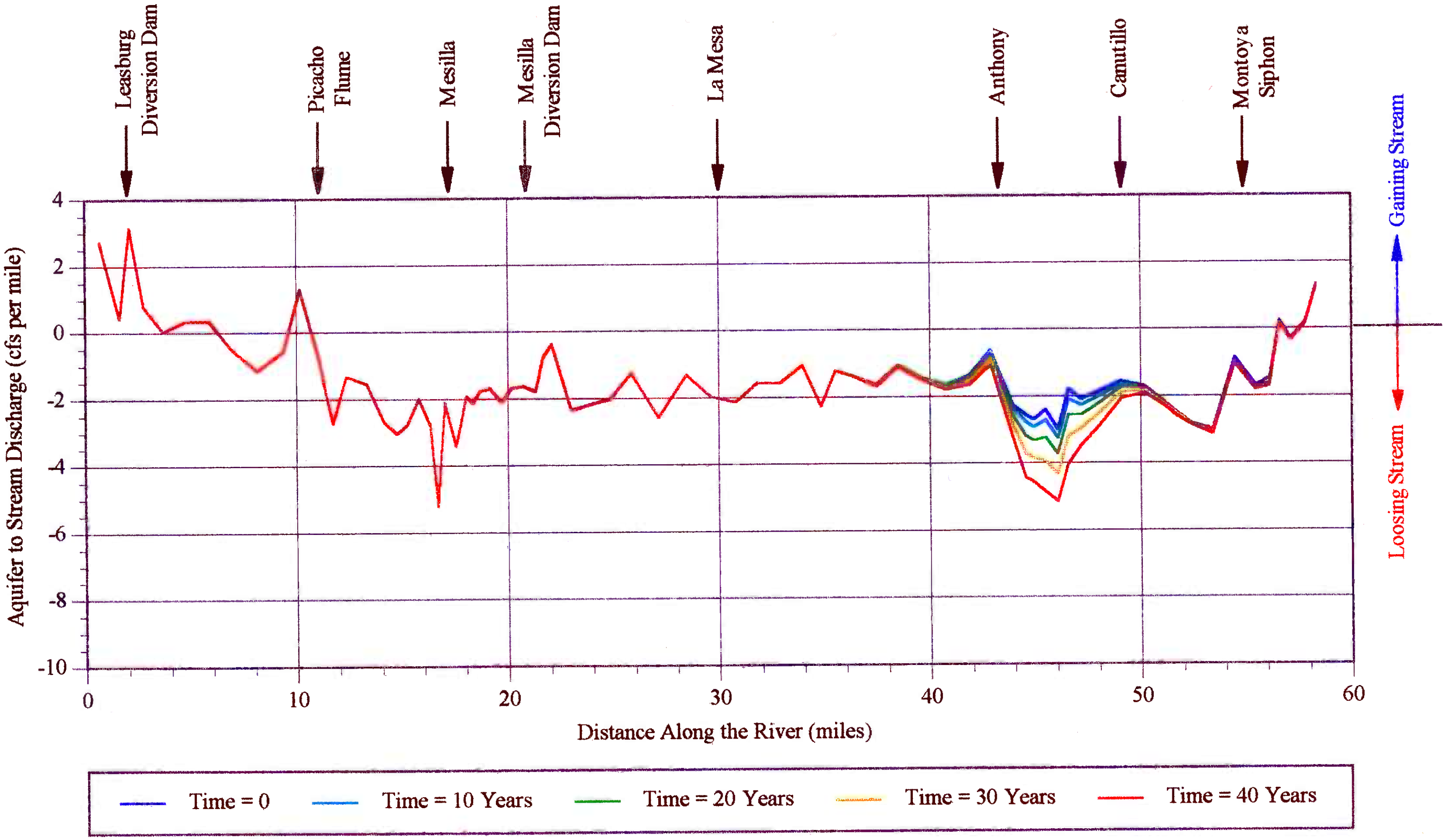


Figure 4-13: Canutillo Pumping
Simulated aquifer to stream discharge along the Rio Grande when Canutillo Wellfield pumping is increased 2.81% annually.

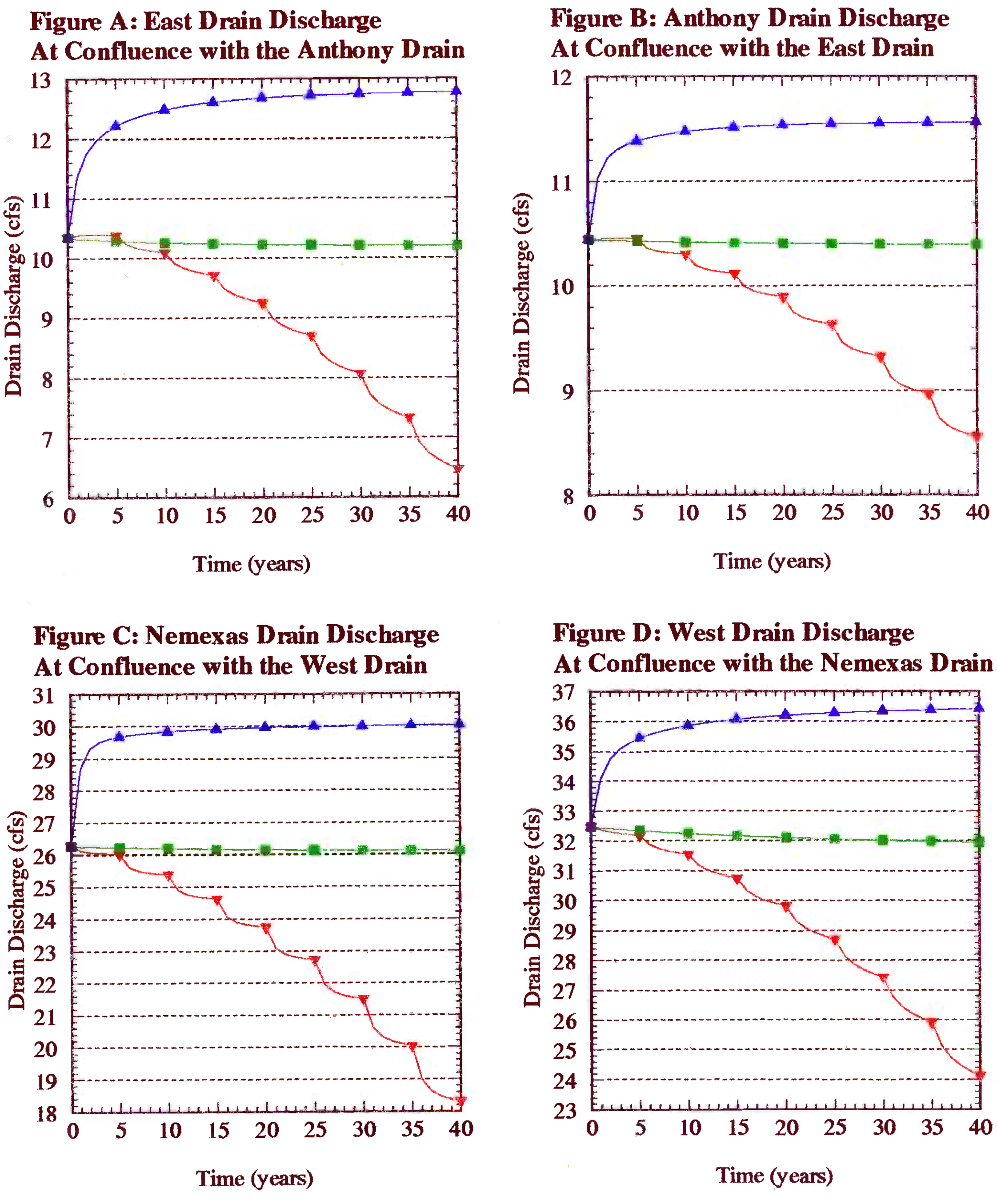


Figure 4-14: Valley Wide Pumping

Drains affected by pumping in the Canutillo/Anthony area.

Simulated Drain Discharge
When Pumping is ...

- ▼ Increased
- ■ Held Constant
- ▲ Removed

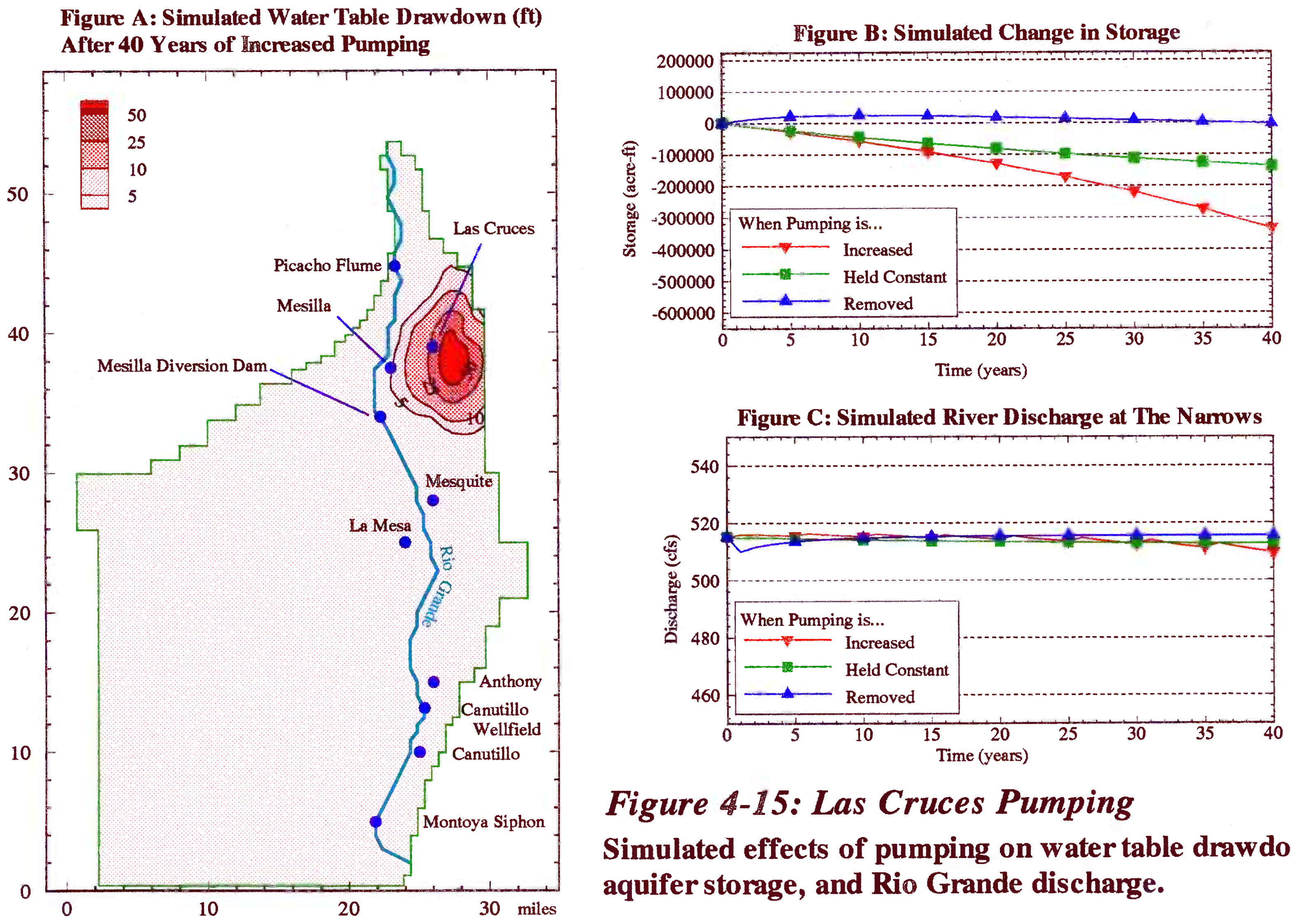


Figure A: Simulated Water Table Drawdown (ft) After 40 Years of Increased Pumping

Figure B: Simulated Change in Storage

Figure C: Simulated River Discharge at The Narrows

Figure 4-15: Las Cruces Pumping

Simulated effects of pumping on water table drawdown, aquifer storage, and Rio Grande discharge.

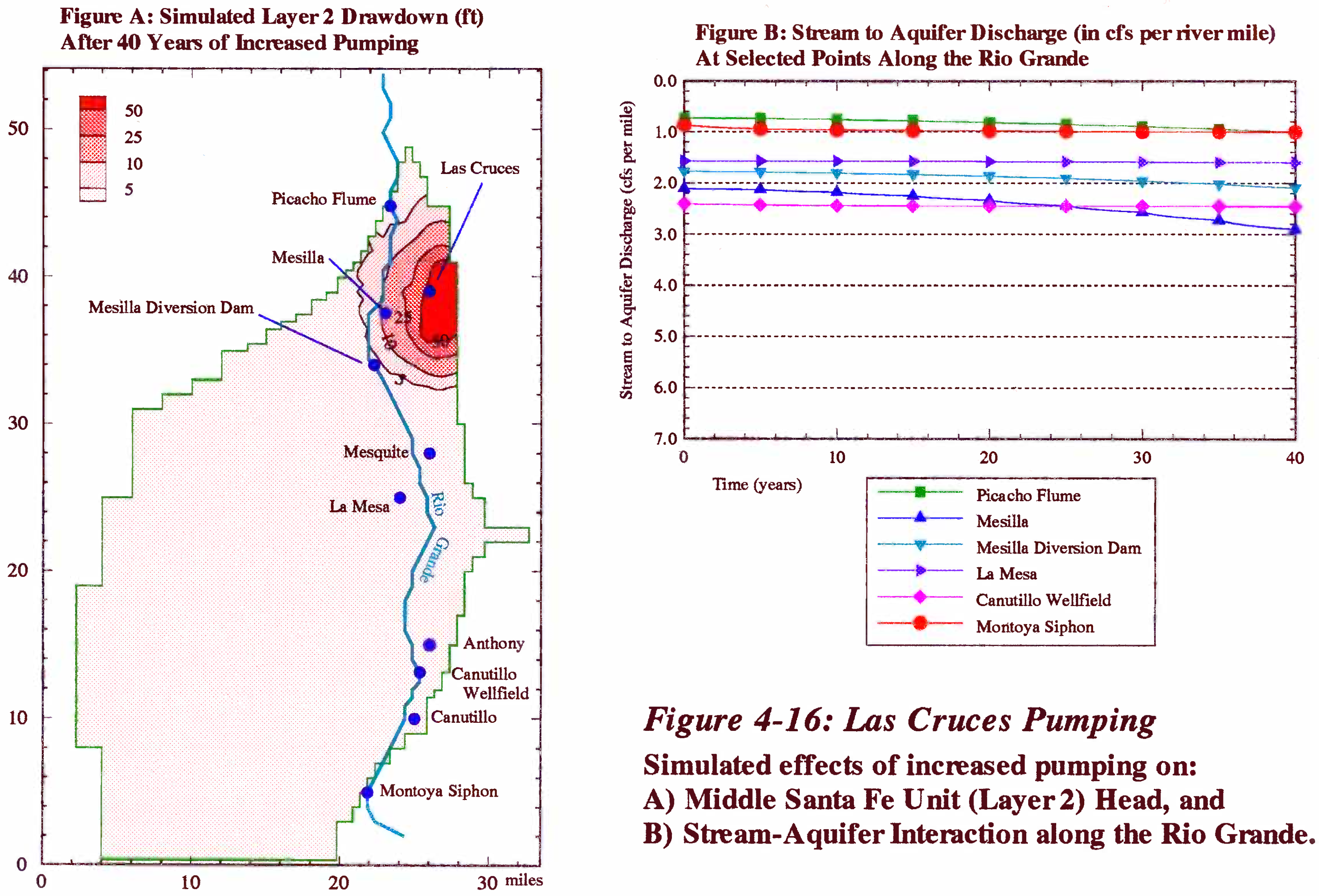


Figure A: Simulated Layer 2 Drawdown (ft)
After 40 Years of Increased Pumping

Figure B: Stream to Aquifer Discharge (in cfs per river mile)
At Selected Points Along the Rio Grande

Figure 4-16: Las Cruces Pumping

Simulated effects of increased pumping on:
A) Middle Santa Fe Unit (Layer 2) Head, and
B) Stream-Aquifer Interaction along the Rio Grande.

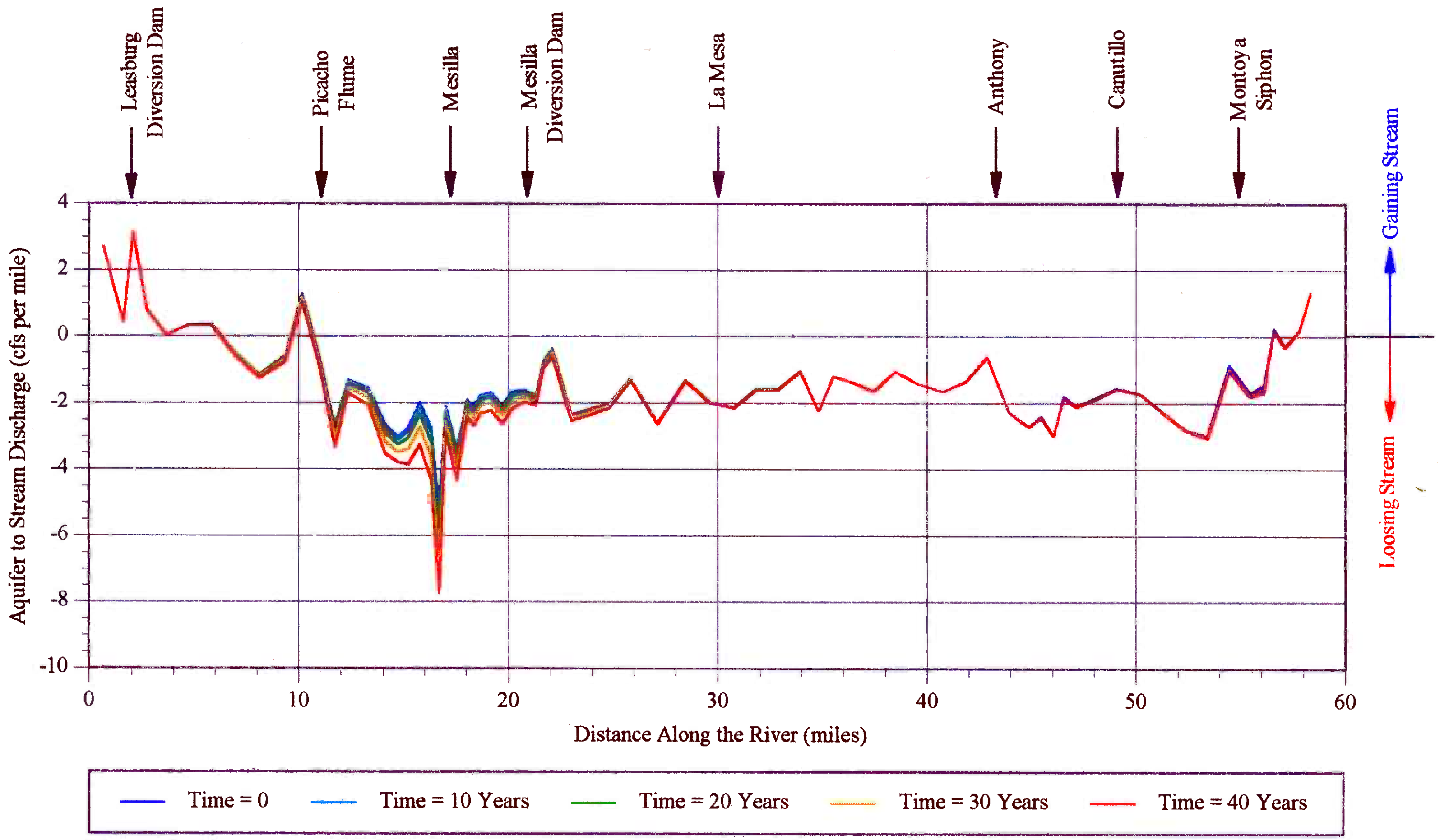


Figure 4-17: Las Cruces Pumping

Simulated aquifer to stream discharge along the Rio Grande when Las Cruces pumping is increased 2.81% annually .

Figure A: Leasburg Drain Discharge At Confluence with the Del Rio Drain

Figure B: Del Rio Drain Discharge At Confluence with the Mesilla Drain

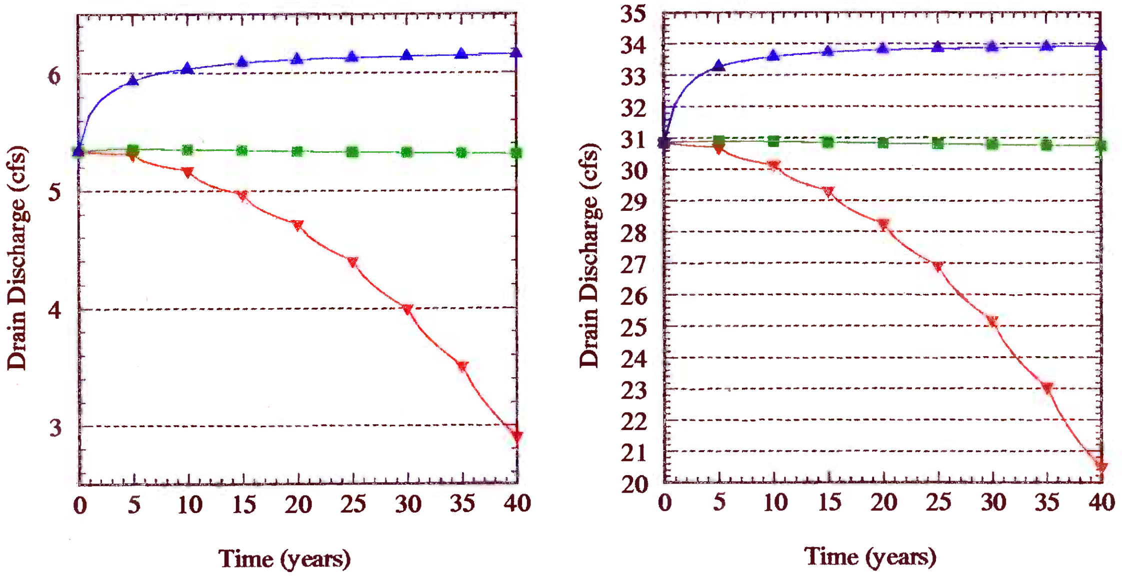


Figure C: Mesilla Drain Discharge At Confluence with the Del Rio Drain

Figure D: Picacho Drain Discharge At Confluence with the Rio Grande

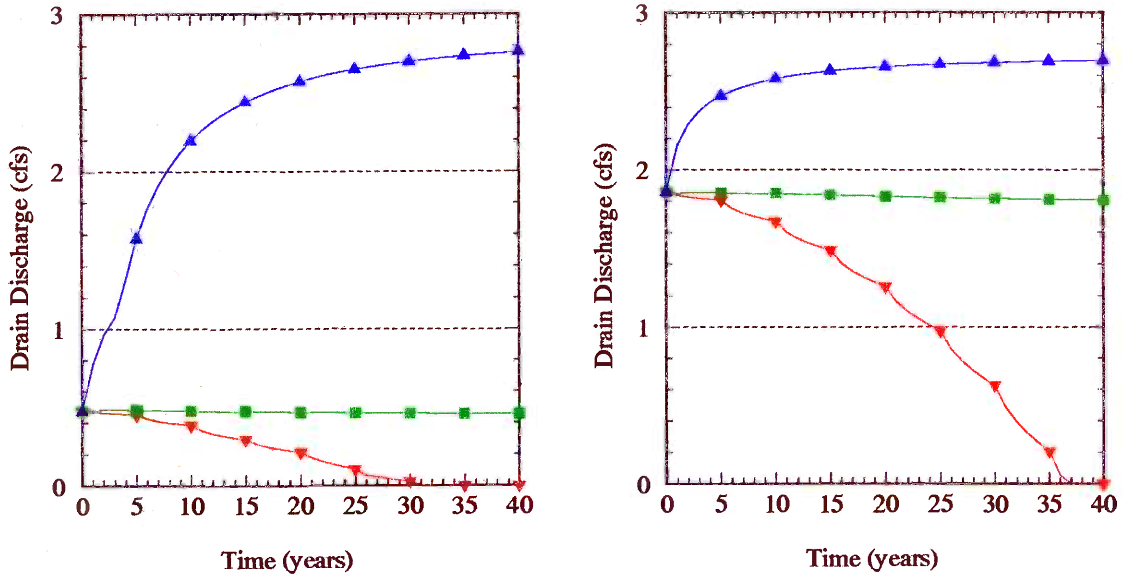
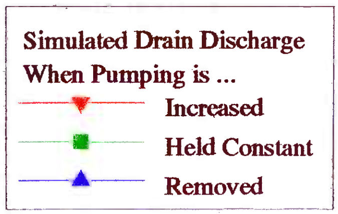


Figure 4-18: Valley Wide Pumping

Drains affected by Las Cruces area pumping.



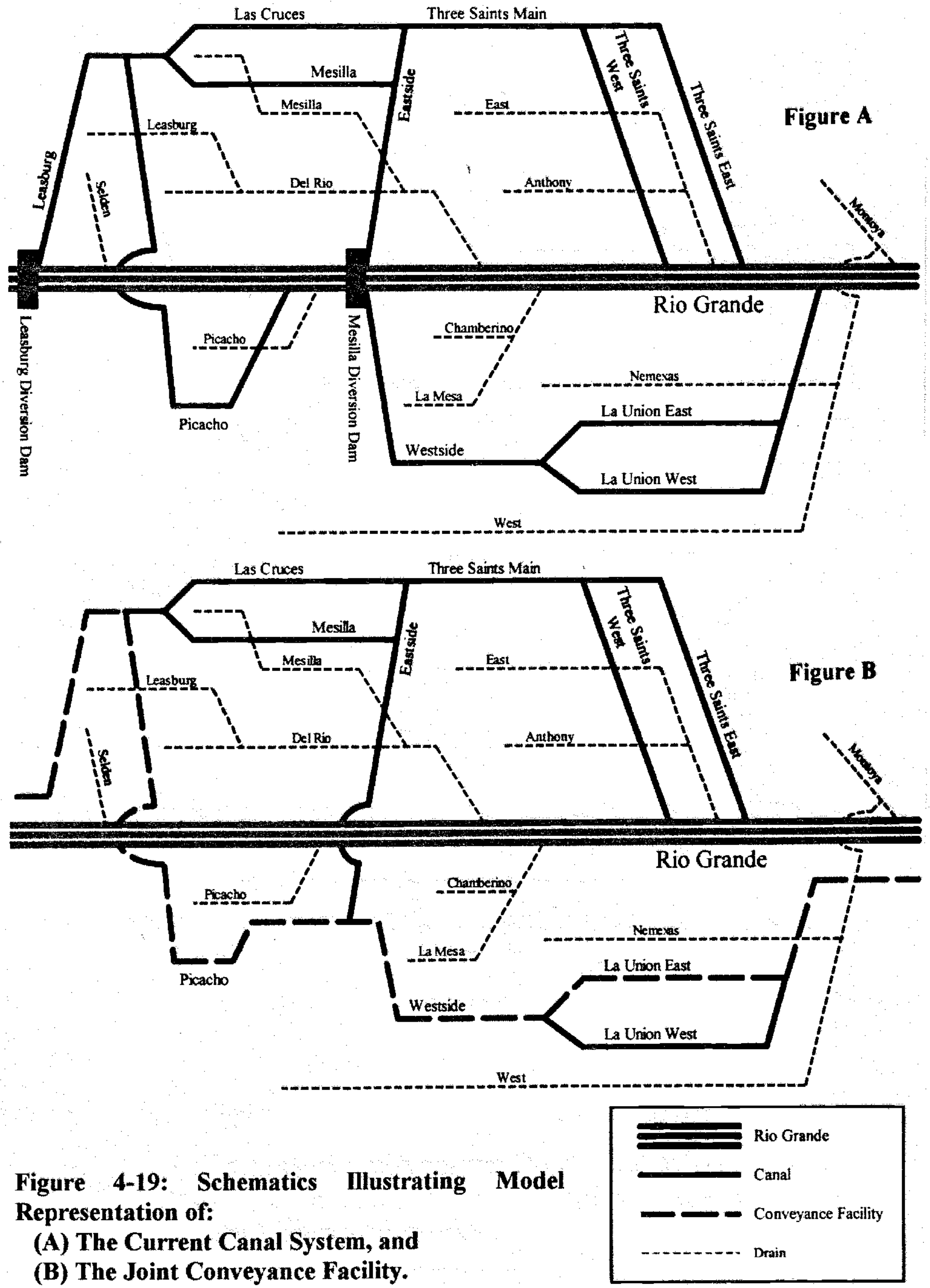


Figure 4-19: Schematics Illustrating Model Representation of:
(A) The Current Canal System, and
(B) The Joint Conveyance Facility.

Figure A: Simulated Drain Return Flows

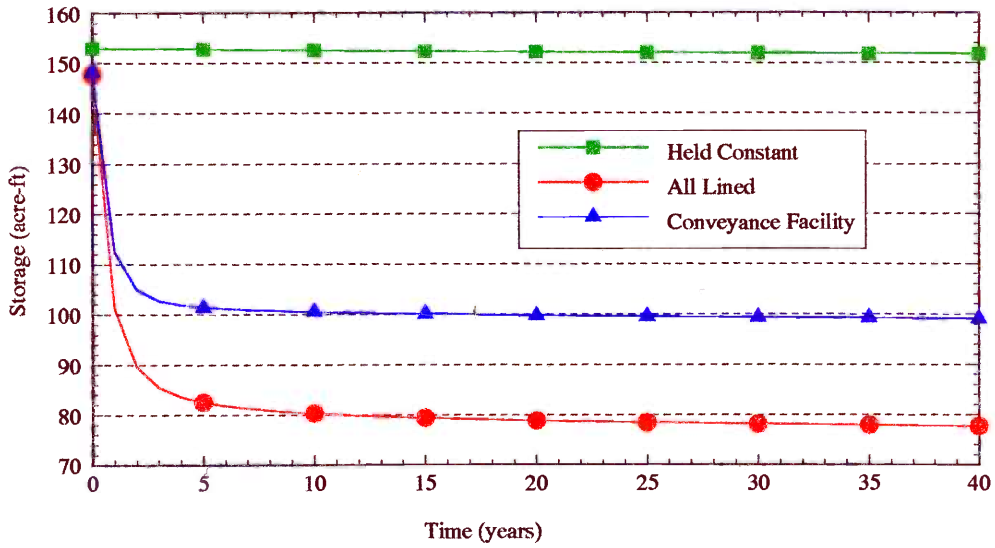


Figure B: Simulated River Discharge at The Narrows

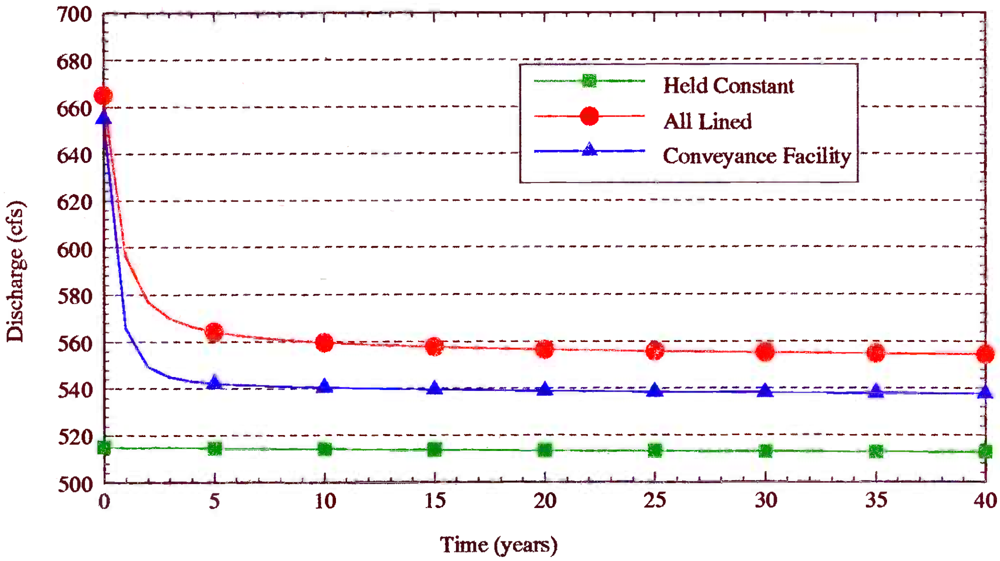


Figure 4-20: Canal Lining Scenarios

Simulated drain return flows and Rio Grande discharge at the Narrows under different canal lining scenarios.

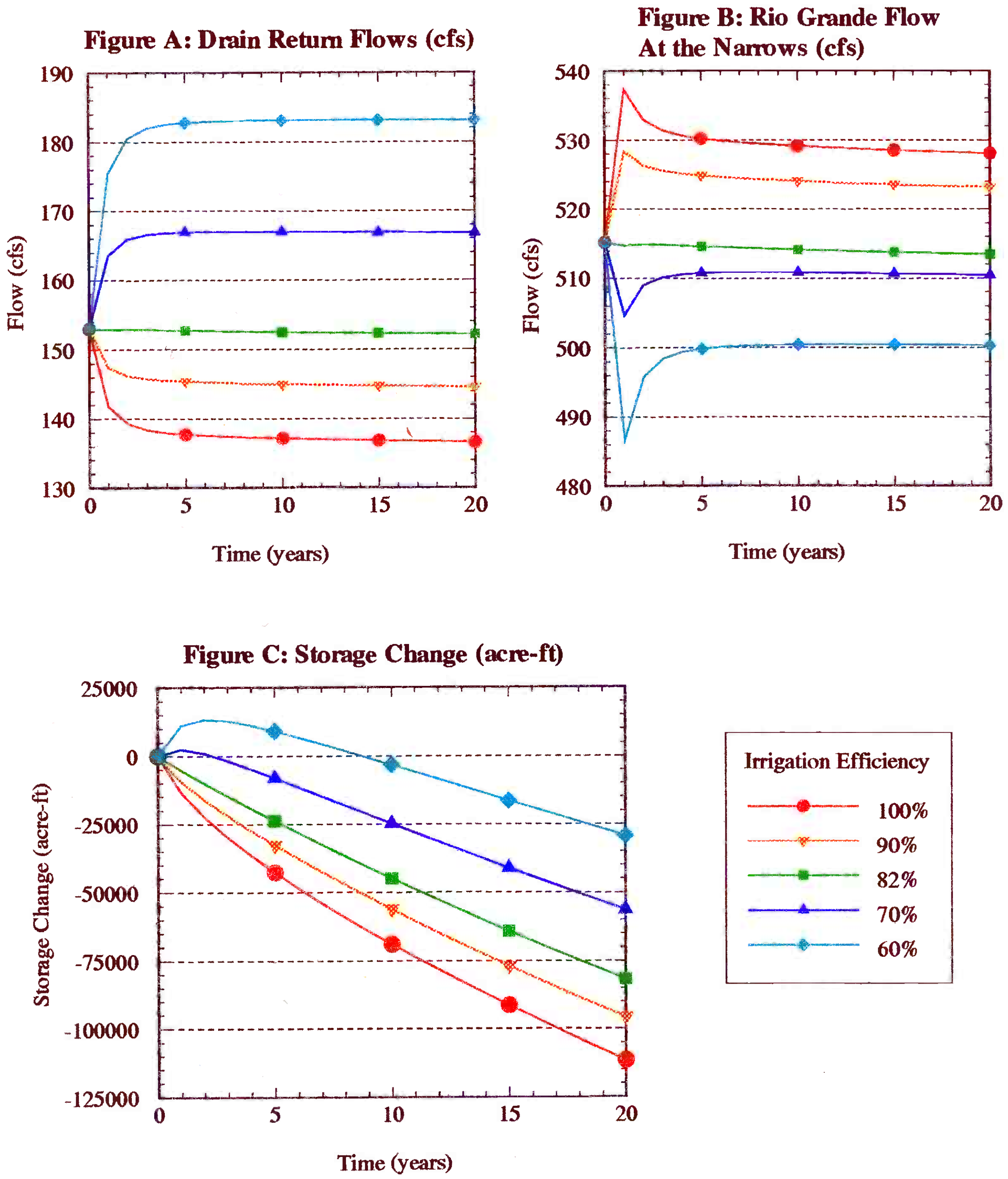


Figure A: Drain Return Flows (cfs)

Figure B: Rio Grande Flow At the Narrows (cfs)

Figure C: Storage Change (acre-ft)

Figure 4-21: Irrigation Efficiency

**Its Effect on Drain Flows,
Water Supply, and Aquifer Storage**

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Appendix A

Historical Simulation Mass Balance Summary

Table A-1
Historical Transient Simulation
Mass Balance Summary (All Flows in cfs)
Page 1 of 2

Simulation Time	Year	Storage	Constant Head	Net Pumpage	Non Ag. ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss	Farm Deliveries
0.00	1915.00									
0.62	0.62	-11.33	0.08	-0.54	-175.35	158.26	17.92	93.54	-82.52	158.86
1.54	1.54	-14.17	0.08	-0.54	-183.86	158.26	17.92	104.89	-82.52	158.86
2.92	2.92	-8.12	0.07	-0.54	-188.61	158.26	17.92	103.70	-82.52	158.86
5.00	5.00	-4.65	0.05	-0.54	-190.81	158.26	17.92	102.46	-82.52	158.86
5.86	5.86	-17.77	-0.07	-0.76	-196.54	228.65	17.92	79.37	-110.33	229.02
7.15	7.15	-7.97	-0.10	-0.76	-200.38	228.65	17.92	73.12	-110.33	229.02
9.09	9.09	-4.75	-0.12	-0.76	-201.71	228.65	17.92	71.24	-110.33	229.02
12.00	12.00	-3.31	-0.14	-0.76	-202.33	228.65	17.92	70.42	-110.33	229.02
13.72	13.72	-10.64	-0.11	-1.14	-117.64	280.85	18.28	20.08	-189.15	280.99
16.31	16.31	-4.97	-0.14	-1.14	-119.28	280.85	18.28	15.71	-189.15	280.99
20.18	20.18	-3.28	-0.17	-1.14	-119.77	280.85	18.28	14.54	-189.15	280.99
26.00	26.00	-2.40	-0.21	-1.14	-120.02	280.85	18.28	13.91	-189.15	280.99
26.86	26.86	-21.84	-0.36	-2.40	-101.65	337.23	19.00	-21.46	-208.01	345.05
28.15	28.15	-8.69	-0.41	-2.40	-103.83	337.23	19.00	-32.74	-208.01	345.05
30.09	30.09	-5.17	-0.44	-2.40	-104.51	337.23	19.00	-35.56	-208.01	345.05
33.00	33.00	-3.86	-0.46	-2.40	-104.76	337.23	19.00	-36.61	-208.01	345.05
33.37	33.37	11.39	-0.37	-4.23	-97.01	350.83	13.98	-50.83	-223.42	359.21
33.92	33.92	5.19	-0.32	-4.23	-96.61	350.83	13.98	-45.44	-223.42	359.21
34.75	34.75	3.65	-0.29	-4.23	-96.45	350.83	13.98	-44.09	-223.42	359.21
36.00	36.00	3.00	-0.26	-4.23	-96.33	350.83	13.98	-43.59	-223.42	359.21
36.37	36.37	96.73	0.08	-12.76	-79.98	194.85	12.55	25.79	-237.29	199.71
36.92	36.92	49.01	0.21	-12.76	-72.37	194.85	12.55	65.62	-237.29	199.71
37.75	37.75	28.18	0.27	-12.76	-68.22	194.85	12.55	82.17	-237.29	199.71
39.00	39.00	18.66	0.32	-12.76	-65.83	194.85	12.55	89.30	-237.29	199.71
39.49	39.49	71.58	0.55	-25.36	-72.51	100.10	15.95	116.15	-206.47	96.00
40.23	40.23	39.41	0.62	-25.36	-64.98	100.10	15.95	140.70	-206.47	95.97
41.34	41.34	25.36	0.65	-25.36	-61.04	100.10	15.95	150.55	-206.47	95.74
43.00	43.00	18.18	0.68	-25.36	-58.86	100.10	15.95	155.52	-206.47	95.56
43.37	43.37	-96.51	0.23	-35.63	-79.39	272.60	19.18	126.05	-206.47	278.85
43.92	43.92	-37.26	0.08	-35.63	-91.23	272.60	19.18	78.86	-206.47	278.85
44.75	44.75	-12.47	0.01	-35.63	-97.23	272.60	19.18	60.19	-206.47	278.85
46.00	46.00	-2.63	-0.02	-35.63	-99.94	272.60	19.18	53.08	-206.47	278.85
46.12	46.12	55.45	0.07	-39.87	-96.43	225.47	17.20	53.84	-215.72	230.81
46.31	46.31	35.59	0.13	-39.87	-93.54	225.47	17.20	70.63	-215.72	230.81
46.58	46.58	23.67	0.16	-39.87	-91.34	225.47	17.20	80.30	-215.72	230.81
47.00	47.00	16.66	0.18	-39.87	-89.78	225.47	17.20	85.77	-215.72	230.81
47.25	47.25	7.54	0.16	-47.82	-86.12	249.76	13.98	79.81	-217.26	255.78
47.62	47.62	10.30	0.17	-47.82	-86.78	249.76	13.98	77.65	-217.26	255.78
48.17	48.17	11.44	0.18	-47.82	-87.11	249.76	13.98	76.83	-217.26	255.78
49.00	49.00	11.53	0.20	-47.82	-87.23	249.76	13.98	76.80	-217.26	255.78
49.12	49.12	205.41	0.49	-52.32	-77.97	77.75	10.39	64.05	-228.04	67.14
49.31	49.31	144.65	0.67	-52.32	-66.62	77.75	10.39	113.22	-228.04	66.73
49.58	49.58	104.26	0.79	-52.32	-57.45	77.75	10.39	144.59	-228.04	66.70
50.00	50.00	77.31	0.88	-52.32	-51.12	77.75	10.39	165.10	-228.04	66.69
50.25	50.25	-79.75	0.56	-47.63	-68.83	193.40	17.92	174.86	-190.41	198.20
50.62	50.62	-32.93	0.42	-47.63	-77.04	193.40	17.92	136.50	-190.41	198.20
51.17	51.17	-10.34	0.37	-47.63	-82.23	193.40	17.92	119.12	-190.41	198.20
52.00	52.00	0.07	0.34	-47.63	-85.28	193.40	17.92	111.71	-190.41	198.20
52.25	52.25	-23.86	0.28	-48.99	-92.50	224.01	19.36	99.91	-178.23	229.21
52.62	52.62	-12.74	0.24	-48.99	-95.67	224.01	19.36	92.16	-178.23	229.21

Table A-1
Historical Transient Simulation
Mass Balance Summary (All Flows in cfs)
Page 2 of 2

Simulation Time	Year	Storage	Constant Head	Net Pumpage	Non Ag. ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss	Farm Deliveries
53.17	53.17	-5.58	0.22	-48.99	-97.89	224.01	19.36	87.24	-178.23	229.21
54.00	54.00	-1.45	0.20	-48.99	-99.29	224.01	19.36	84.48	-178.23	229.21
54.37	54.37	-15.59	0.14	-49.74	-96.34	270.66	14.87	74.79	-198.77	276.94
54.92	54.92	-3.27	0.12	-49.74	-98.83	270.66	14.87	65.09	-198.77	276.94
55.75	55.75	1.89	0.13	-49.74	-100.15	270.66	14.87	61.18	-198.77	276.94
57.00	57.00	4.08	0.14	-49.74	-100.79	270.66	14.87	59.64	-198.77	276.94
57.12	57.12	91.04	0.29	-55.99	-103.20	130.23	27.96	49.91	-140.22	131.81
57.31	57.31	53.43	0.36	-55.99	-96.73	130.23	27.96	80.78	-140.22	131.17
57.58	57.58	30.64	0.39	-55.99	-91.65	130.23	27.96	98.48	-140.22	130.76
58.00	58.00	16.82	0.38	-55.99	-87.98	130.23	27.96	108.65	-140.22	130.76
58.37	58.37	-56.15	0.09	-53.47	-94.10	280.86	19.53	88.20	-184.90	287.38
58.92	58.92	-18.41	0.00	-53.47	-100.85	280.86	19.53	57.43	-184.90	287.38
59.75	59.75	-4.58	-0.03	-53.47	-103.91	280.86	19.53	46.63	-184.90	287.38
61.00	61.00	0.38	-0.05	-53.47	-105.19	280.86	19.53	42.93	-184.90	287.38
61.12	61.12	-24.69	-0.10	-54.59	-106.85	314.39	18.64	36.56	-183.36	322.07
61.31	61.31	-11.74	-0.13	-54.59	-108.91	314.39	18.64	25.73	-183.36	322.07
61.58	61.58	-3.35	-0.15	-54.59	-110.48	314.39	18.64	19.08	-183.36	322.07
62.00	62.00	1.67	-0.16	-54.59	-111.58	314.39	18.64	15.13	-183.36	322.07
62.25	62.25	130.38	0.15	-68.52	-99.94	145.78	20.61	53.31	-181.82	132.20
62.62	62.62	73.43	0.27	-68.52	-87.60	145.78	20.61	97.67	-181.82	129.57
63.17	63.17	44.44	0.31	-68.52	-79.71	145.78	20.61	118.66	-181.82	128.62
64.00	64.00	29.09	0.33	-68.52	-75.00	145.78	20.61	129.31	-181.82	127.92
64.25	64.25	-31.01	0.20	-62.57	-80.18	210.40	18.28	145.11	-200.31	215.44
64.62	64.62	-6.14	0.15	-62.57	-84.50	210.40	18.28	125.07	-200.31	215.44
65.17	65.17	4.71	0.13	-62.57	-86.93	210.40	18.28	116.35	-200.31	215.44
66.00	66.00	9.10	0.13	-62.57	-88.05	210.40	18.28	113.06	-200.31	215.44
66.25	66.25	16.84	0.16	-59.58	-89.41	199.23	16.84	116.14	-200.31	203.95
66.62	66.62	14.70	0.17	-59.58	-88.92	199.23	16.84	117.79	-200.31	203.95
67.17	67.17	13.49	0.18	-59.58	-88.55	199.23	16.84	118.62	-200.31	203.95
68.00	68.00	12.60	0.19	-59.58	-88.25	199.23	16.84	119.20	-200.31	203.95
68.25	68.25	-28.55	0.08	-60.69	-104.80	268.23	19.32	94.37	-187.98	274.44
68.62	68.62	-11.27	0.04	-60.69	-108.88	268.23	19.32	81.36	-187.98	274.44
69.17	69.17	-1.99	0.02	-60.69	-111.42	268.23	19.32	74.61	-187.98	274.44
70.00	70.00	2.72	0.01	-60.69	-112.84	268.23	19.32	71.29	-187.98	274.44
70.12	70.12	21.17	0.03	-59.87	-110.58	225.47	19.69	85.94	-181.82	230.63
70.31	70.31	16.24	0.04	-59.87	-109.37	225.47	19.69	89.61	-181.82	230.63
70.58	70.58	12.59	0.04	-59.87	-108.41	225.47	19.69	92.22	-181.82	230.63
71.00	71.00	10.33	0.04	-59.87	-107.72	225.47	19.69	93.79	-181.82	230.63
72.00	72.00	-24.51	-0.34	-57.64	-124.85	240.53	19.69	85.09	-138.68	246.34
73.00	73.00	-12.65	-0.46	-60.78	-133.97	298.35	19.69	45.10	-155.63	305.36
74.00	74.00	3.78	-0.32	-58.32	-130.97	297.87	19.69	18.85	-151.00	304.82
75.00	75.00	46.44	0.02	-66.83	-107.09	215.26	19.69	98.52	-206.47	220.42
76.00	76.00	26.63	0.13	-59.80	-97.50	162.30	19.69	120.85	-172.58	165.97

Appendix B

Summary of Predictive Simulation Boundary Conditions

Table B-1
Historical Transient Simulation Data Used to Determine Average Annual *River and Canal Flows*

Segment 1 ==> Rio Grande above Leasburg Dam
Segment 3 ==> Leasburg Canal at Leasburg Dam
Segment 14 ==> Eastside Canal at Mesilla Diversion Dam
Segment 15 ==> Westside Canal at Mesilla Diversion Dam

Stress Period Length (Years)	**Year Beginning**	**Assigned Flow (cfs)**			
		Seg 1	**Seg 3**	**Seg 14**	**Seg 15**
3	1958	950.52	221.37	93.34	239.19
1	1961	739.84	172.33	85.66	222.89
2	1962	743.10	194.64	90.45	229.64
1	1964	264.01	49.12	31.27	111.77
2	1965	659.04	139.18	67.05	173.12
2	1967	662.94	187.14	83.64	206.74
3	1969	793.21	214.02	91.02	252.18
1	1972	364.13	119.55	40.90	135.74
3	1973	826.18	177.86	99.14	245.62
1	1976	918.38	200.50	115.72	280.20
2	1977	509.99	93.63	43.28	127.63
2	1979	826.54	167.28	84.20	221.41
2	1981	812.18	162.10	90.34	233.57
2	1983	851.40	169.68	90.99	246.98
1	1985	893.75	176.65	96.34	239.56
1	1986	1861.03	228.17	124.78	278.68
1	1987	1801.13	250.25	127.07	301.30
1	1988	1110.72	219.67	106.94	271.08
1	1989	881.04	205.55	106.93	267.58
1	1990	773.76	172.31	87.88	242.69
Average ==>		**831.75**	**177.61**	**87.09**	**225.47**
Standard Deviation ==>		**384.65**	**47.77**	**25.68**	**52.03**
STD/AVG ==>		**0.46**	**0.27**	**0.29**	**0.23**

Table B-2
Historical Transient Simulation Data Used to Determine Average Annual *Farm Deliveries*

Segment 3 ==> Leasburg Canal
Segment 4 ==> Picacho Canal
Segment 5 ==> Leasburg Canal
Segment 6 ==> Las Cruces Canal
Segment 7 ==> Mesilla Canal
Segment 8 ==> Mesilla Canal
Segment 14 ==> Eastside Canal
Segment 15 ==> Westside Canal

Segment 17 ==> La Union West Canal
Segment 18 ==> La Union East Canal
Segment 19 ==> Combined La Union Canal
Segment 20 ==> Eastside Canal
Segment 21 ==> Three Saints Main Canal
Segment 22 ==> Three Saints West Canal
Segment 23 ==> Three Saints East Canal

Stress Period	**Year**	**Assigned Delivery Rate (cfs)**															
Length (Years)	**Beginning**	**Seg 3**	**Seg 4**	**Seg 5**	**Seg 6**	**Seg 7**	**Seg 8**	**Seg 14**	**Seg 15**	**Seg 17**	**Seg 18**	**Seg 19**	**Seg 20**	**Seg 21**	**Seg 22**	**Seg 23**	**Total**
3	1958	18.71	18.98	10.70	20.44	0.93	41.67	8.88	59.53	30.07	26.66	4.23	4.44	17.76	3.91	11.94	**278.85**
1	1961	13.89	14.09	7.94	15.17	0.69	30.93	7.78	52.86	26.70	23.67	3.76	3.89	15.56	3.42	10.46	**230.81**
2	1962	16.23	16.47	9.29	17.73	0.81	36.15	8.53	56.33	28.45	25.23	4.01	4.27	17.06	3.75	11.47	**255.78**
1	1964	3.46	3.51	1.98	3.78	0.17	7.71	2.49	23.19	11.71	10.39	1.65	1.24	4.97	1.09	3.34	**80.68**
2	1965	12.19	12.37	6.97	13.32	0.61	27.15	6.63	44.74	22.60	20.04	3.18	3.31	13.26	2.92	8.91	**198.20**
2	1967	15.08	15.30	8.63	16.48	0.75	33.59	7.60	49.03	24.76	21.96	3.49	3.80	15.19	3.34	10.21	**229.21**
3	1969	17.86	18.13	10.22	19.52	0.89	39.79	8.56	61.92	31.27	27.73	4.40	4.28	17.11	3.76	11.50	**276.94**
1	1972	9.03	9.16	5.17	9.87	0.45	20.12	3.48	30.18	15.24	13.51	2.15	1.74	6.97	1.53	4.68	**133.28**
3	1973	16.42	16.66	9.39	17.94	0.82	36.57	10.32	66.73	33.70	29.88	4.75	5.16	20.63	4.54	13.87	**287.38**
1	1976	18.18	18.44	10.40	19.86	0.91	40.48	11.83	74.76	37.76	33.48	5.32	5.91	23.65	5.20	15.89	**322.07**
2	1977	8.86	8.99	5.07	9.68	0.44	19.74	4.62	35.57	17.96	15.93	2.53	2.31	9.24	2.03	6.21	**149.18**
2	1979	12.80	12.99	7.32	13.99	0.64	28.51	7.26	49.83	25.17	22.31	3.54	3.63	14.51	3.19	9.75	**215.44**
2	1981	11.42	11.59	6.53	12.48	0.57	25.44	7.18	48.42	24.45	21.68	3.44	3.59	14.35	3.16	9.65	**203.95**
2	1983	15.40	15.63	8.81	16.83	0.77	34.30	9.29	66.02	33.35	29.56	4.70	4.64	18.57	4.09	12.48	**274.44**
1	1985	13.34	13.54	7.63	14.58	0.67	29.72	8.20	53.26	26.90	23.85	3.79	4.10	16.41	3.61	11.03	**230.63**
1	1986	14.94	15.16	8.55	16.32	0.75	33.27	9.21	53.70	27.12	24.05	3.82	4.60	18.42	4.05	12.38	**246.34**
1	1987	18.90	19.18	10.82	20.66	0.94	42.11	10.82	66.99	33.83	30.00	4.76	5.41	21.64	4.76	14.54	**305.36**
1	1988	18.81	19.08	10.76	20.55	0.94	41.89	10.32	68.31	34.50	30.59	4.86	5.16	20.64	4.54	13.87	**304.82**
1	1989	13.11	13.31	7.50	14.33	0.65	29.21	7.69	50.24	25.37	22.50	3.57	3.84	15.38	3.38	10.34	**220.42**
1	1990	9.55	9.69	5.46	10.43	0.48	21.26	5.49	39.57	19.99	17.72	2.81	2.74	10.98	2.42	7.38	**165.97**
Average ==>		**14.43**	**14.64**	**8.25**	**15.77**	**0.72**	**32.14**	**7.96**	**53.86**	**27.20**	**24.12**	**3.83**	**3.98**	**15.92**	**3.50**	**10.70**	**237.04**
Standard Deviation ==>		**4.05**	**4.10**	**2.31**	**4.42**	**0.20**	**9.01**	**2.40**	**13.39**	**6.76**	**6.00**	**0.95**	**1.20**	**4.79**	**1.05**	**3.22**	**62.75**
STD/AVG ==>		**0.28**	**0.28**	**0.28**	**0.28**	**0.28**	**0.28**	**0.30**	**0.25**	**0.25**	**0.25**	**0.25**	**0.30**	**0.30**	**0.30**	**0.30**	**0.26**

Table B-3
Historical Transient Simulation Data Used to Determine Average Annual *Irrigation Recharge* Rate

Recharge Rate (ft/sec)	**Stress Period Number**	**Period Length (Years)**	**Year Beginning**	**(Period Length) X (Max Rate)**
5.61E-08	8	3	1958	1.68E-07
4.64E-08	9	1	1961	4.64E-08
5.14E-08	10	2	1962	1.03E-07
1.60E-08	11	1	1964	1.60E-08
3.98E-08	12	2	1965	7.96E-08
4.61E-08	13	2	1967	9.22E-08
5.57E-08	14	3	1969	1.67E-07
2.68E-08	15	1	1972	2.68E-08
5.78E-08	16	3	1973	1.73E-07
6.47E-08	17	1	1976	6.47E-08
3.00E-08	18	2	1977	6.00E-08
4.33E-08	19	2	1979	8.66E-08
4.10E-08	20	2	1981	8.20E-08
5.52E-08	21	2	1983	1.10E-07
4.64E-08	22	1	1985	4.64E-08
4.95E-08	23	1	1986	4.95E-08
6.14E-08	24	1	1987	6.14E-08
6.13E-08	25	1	1988	6.13E-08
4.43E-08	26	1	1989	4.43E-08
3.34E-08	27	1	1990	3.34E-08

Average Recharge Rate from
1958 - 1990 (SP 8 - 27) ==> 4.765E-08

Table B-4
Historical Transient Simulation Data Used to Determine Average Annual *Maximum Evapotranspiration* Rate

Maximum ET Rate (ft/sec)	**Stress Period Number**	**Period Length (Years)**	**Year Beginning**	**(Period Length) X (Max Rate)**
5.09E-08	8	3	1958	1.53E-07
5.10E-08	9	1	1961	5.10E-08
4.83E-08	10	2	1962	9.66E-08
5.03E-08	11	1	1964	5.03E-08
5.53E-08	12	2	1965	1.11E-07
5.75E-08	13	2	1967	1.15E-07
5.31E-08	14	3	1969	1.59E-07
5.85E-08	15	1	1972	5.85E-08
5.34E-08	16	3	1973	1.60E-07
5.30E-08	17	1	1976	5.30E-08
5.63E-08	18	2	1977	1.13E-07
5.49E-08	19	2	1979	1.10E-07
5.62E-08	20	2	1981	1.12E-07
6.30E-08	21	2	1983	1.26E-07
6.25E-08	22	1	1985	6.25E-08
6.25E-08	23	1	1986	6.25E-08
6.25E-08	24	1	1987	6.25E-08
6.25E-08	25	1	1988	6.25E-08
6.25E-08	26	1	1989	6.25E-08
6.25E-08	27	1	1990	6.25E-08

Average Maximum ET Rate from
1958 - 1990 (SP 8 - 27) ==> 5.585E-08

Table B-5

Summary of Discharges (cfs) Assigned in the Well File

Page 1 of 4

Description of Pumping Zones

Zone 1 ==> Las Cruces
Zone 2 ==> Canutillo
Zone 3 ==> Anthony
Zone 4 ==> La Mesa and La Union
Zone 5 ==> Texas

Held Constant Basin Wide (PS2)

Stress Period	Pumping	MF Recharge	Net Irrig. Loss	Septic Returns
1 to 8	-63.3	18.4	-189.6	1.4

Municipal/Industrial Pumping Broken Down By Zone (PS1)

SP	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
1 to 8	-25.0	-17.6	-2.0	-6.8	-11.9

Increased Basin Wide (PS2)

Stress Period	Pumping	MF Recharge	Net Irrig. Loss	
1	-66.4	18.4	-189.6	1.4
2	-76.8	18.4	-189.6	1.6
3	-88.9	18.4	-189.6	1.9
4	-103.0	18.4	-189.6	2.2
5	-119.3	18.4	-189.6	2.5
6	-138.4	18.4	-189.6	3.0
7	-160.7	18.4	-189.6	3.4
8	-186.7	18.4	-189.6	4.0

Municipal/Industrial Pumping Broken Down By Zone (PS2)

SP	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
1	-26.9	-18.9	-0.6	-7.3	-12.7
2	-31.2	-21.7	-0.8	-8.6	-14.6
3	-36.3	-24.9	-1.0	-10.0	-16.8
4	-42.2	-28.6	-1.2	-11.7	-19.2
5	-49.2	-32.8	-1.6	-13.6	-22.1
6	-57.4	-37.7	-2.1	-15.9	-25.4
7	-67.0	-43.3	-2.6	-18.5	-29.2
8	-78.4	-49.8	-3.4	-21.6	-33.5

Table B-5

Summary of Discharges (cfs) Assigned in the Well File

Page 2 of 4

Removed Basin Wide (PS3)

Stress Period	Pumping	MF Recharge	Net Irrig. Loss	Septic Returns
1 to 8	0.0	18.4	-189.6	0.0

Municipal/Industrial Pumping Broken Down By Zone (PS3)

SP	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
1 to 8	0.0	0.0	0.0	0.0	0.0

Increased Canutillo (PS4)

Stress Period	Pumping	MF Recharge	Net Irrig. Loss	
1	-63.0	18.4	-189.6	1.3
2	-65.8	18.4	-189.6	1.3
3	-69.1	18.4	-189.6	1.3
4	-72.8	18.4	-189.6	1.3
5	-77.0	18.4	-189.6	1.3
6	-81.9	18.4	-189.6	1.3
7	-87.5	18.4	-189.6	1.3
8	-93.9	18.4	-189.6	1.3

Municipal/Industrial Pumping Broken Down By Zone (PS4)

SP	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
1	-25.0	-18.9	-0.5	-6.8	-11.9
2	-25.0	-21.7	-0.5	-6.8	-11.9
3	-25.0	-24.9	-0.5	-6.8	-11.9
4	-25.0	-28.6	-0.5	-6.8	-11.9
5	-25.0	-32.8	-0.5	-6.8	-11.9
6	-25.0	-37.7	-0.5	-6.8	-11.9
7	-25.0	-43.3	-0.5	-6.8	-11.9
8	-25.0	-49.8	-0.5	-6.8	-11.9

Table B-5

Summary of Discharges (cfs) Assigned in the Well File

Page 3 of 4

Removed Canutillo (PS5)

Stress Period	Pumping	MF Recharge	Net Irrig. Loss	Septic Returns
1 to 8	-44.2	18.4	-189.6	1.3

Municipal/Industrial Pumping Broken Down By Zone (PS5)

SP	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
1 to 8	-25.0	0.0	-0.5	-6.8	-11.9

Increased Las Cruces (PS6)

Stress Period	Pumping	MF Recharge	Net Irrig. Loss	
1	-63.4	18.4	-189.6	1.3
2	-67.0	18.4	-189.6	1.4
3	-71.2	18.4	-189.6	1.5
4	-76.0	18.4	-189.6	1.6
5	-81.5	18.4	-189.6	1.7
6	-87.8	18.4	-189.6	1.8
7	-95.1	18.4	-189.6	1.9
8	-103.5	18.4	-189.6	2.1

Municipal/Industrial Pumping Broken Down By Zone (PS6)

SP	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
1	-26.6	-17.6	-0.5	-6.8	-11.9
2	-30.3	-17.6	-0.5	-6.8	-11.9
3	-34.4	-17.6	-0.5	-6.8	-11.9
4	-39.2	-17.6	-0.5	-6.8	-11.9
5	-44.7	-17.6	-0.5	-6.8	-11.9
6	-51.1	-17.6	-0.5	-6.8	-11.9
7	-58.3	-17.6	-0.5	-6.8	-11.9
8	-66.7	-17.6	-0.5	-6.8	-11.9

Table B-5

Summary of Discharges (cfs) Assigned in the Well File

Page 4 of 4

Removed Canutillo (PS7)

Stress Period	Pumping	MF Recharge	Net Irrig. Loss	Septic Returns
All	-38.3	18.4	-189.6	0.9

Municipal/Industrial Pumping Broken Down By Zone

SP	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
All	0.0	-17.6	-0.5	-6.8	-11.9

Appendix C

Description Of Model Runs

Pumping Scenarios

PS0 Starts with final heads from the original transient run, and runs for 5 years using the files listed below. The primary purpose of this run is, after allowing the system to equilibrate to the new average boundary conditions, to obtain the starting heads for the predictive simulations.

PS0_BAS.DAT	Identical to the basic input file of the historical transient simulation except that it starts with the heads at the termination of the historical transient simulation, and it consists of only one stress period of 5 years divided into 2 month time steps.
PS0_RCH.DAT	Averages maximum ET rates from the historical transient simulation from 1958 to 1990 (SP8 to SP27, see Table B-3).
PS0_OUT.DAT	Outputs Layer 1, 2, and 3 heads for the first 15 time steps, and all layers for the rest of the simulation.
PS0_EVT.DAT	Averages maximum ET rates from 1958 to 1990 (SP8 to SP27, see Table B-4).
PS0_STR.DAT	Averages all assigned flows and irrigation diversions from 1958 to 1990 (SP8 to SP27, see Tables B-1 and B-2). Sewage return flows for Las Cruces and Anthony are held constant.
PS0_WEL.DAT	Averages mountain front recharge (MFR) and net irrigation loss (NIL) rates from the original transient run from 1958 to 1990 (SP8 to SP27), and municipal and industrial (M/I) pumpage from 1977 to 1991 (SP18 to SP27) in the original transient simulation.

PS0 *(continued)*

PS0_BCF.DAT	Identical to the block centered flow package input file of the historical transient simulation, except for cell (30,48) in the Las Cruces area. The elevation of the bottom of Layer 1 for this cell was dropped from 3800 feet to 3790 feet to prevent drying up of the cell in the Increased Valley Wide simulation.
PS0_SIP.DAT	Exactly the same as the strongly implicit procedure package input file used in the historical transient file.

PS1 The *Held Constant* scenario. It is identical to PS0 except for the files listed below.

PS1_BAS.DAT	Identical to PS0_BAS.DAT except for the starting heads, which are obtained at simulation time 2.5 years in the PS0 simulation. The simulation consists of 8 stress periods, each 5 years in length and divided into 1 year time steps.
PS1_OUT.DAT	Outputs Layers 1, 2, and 3 heads for the entire simulation.

PS2 The *Increased Valley Wide* scenario. It is identical to PS1 except for the files listed below.

PS2_WEL.DAT	Increases all pumping in the model. Pumping in Zones 1, 2, and 5 is increased 2.81% annually, Zone 3 is increased 5.09% annually, and Zone 4 is increased 3.13% annually.
PS2_STR.DAT	Identical to PS0_STR.DAT except that sewage return flows for Las Cruces and Anthony are increased 2.81% and 5.09% annually, respectively.

PS3 The *Removed Valley Wide* scenario. It is identical to PS1 except for the files listed below.

PS3_WEL.DAT	Sets all pumping in the model to zero.
PS2_STR.DAT	Identical to PS0_STR.DAT except that sewage return flows for Las Cruces and Anthony are set to zero.

PS4 The *Increased Canutillo* scenario. It is identical to PS1 except for the file listed below.

PS4_WEL.DAT	Pumping in Zone 2 is increased 2.81% annually; all other pumping in the model is held constant.

PS5 The *Removed Canutillo* scenario. It is identical to PS1 except for the file listed below.

PS5_WEL.DAT	Sets all pumping in Zone 2 to zero; holds all other pumping in the model constant.

PS6 The *Increased Las Cruces* scenario. It is identical to PS1 except for the files listed below.

PS6_WEL.DAT	Pumping in Zone 1 is increased 2.81% annually; all other pumping in the model is held constant.
PS6_STR.DAT	Identical to PS0_STR.DAT except that sewage return flows for Las Cruces are increased 2.81% annually; Anthony sewage return flows are held constant.

PS7 The *Removed Las Cruces* scenario. It is identical to PS1 except for the files listed below.

PS7_WEL.DAT	Sets all pumping in Zone 1 to zero; holds all other pumping in the model constant.
PS7_STR.DAT	Identical to PS0_STR.DAT except that sewage return flows for Las Cruces are set to zero; sewage return flows for Anthony are held constant.

Surface Water Alternative Scenarios

SW1 Sets stream conductance for all canals in the model to zero. It is identical to PS1 except for the files listed below.

SW1_STR.DAT	Identical to PS0_STR.DAT except that the conductance of segments 3 - 8, 14, 15, 17 - 19, and 20 - 23 are set to zero.
SW1_OUT.DAT	Outputs Layer 1 heads only.

SW2 This run simulates the surface water conveyance facility.

SW2_STR.DAT	50 cfs is left in the river and 780 cfs is conveyed through the Leasburg/Picacho/Westside Canal system. The main conveyance canal is lined (i.e. conductance is set to zero), and all other canals in the system are left in their current state. Canals left unchanged convey essentially the same volume of water as they do in all the other scenarios. Connectivity is changed in three places: (1) The Leasburg canal is no longer a diversion from the Leasburg Diversion Dam, but independent of the Rio Grande, (2) The Picacho/Westside/Eastside canals form a junction, bypassing the use of Mesilla diversion dam, and (3) the combined La Union canal does not return to the river (see Figure 4-19).

Irrigation Efficiency Runs

IE00 Identical to PS1 except for the files listed below. This run is used to evaluate the system under an irrigation efficiency of 100%.

IE_BAS.DAT	Identical to PS1_BAS.DAT except that the simulation only runs for 20 years.
IE00_RCH.DAT	Adjusts recharge to equal Net Irrigation Loss (NIL), achieving an irrigation efficiency of 100%.
IE00_STR.DAT	Adjusts diversions for farm deliveries to equal the applied irrigation recharge in IE00_RCH.DAT.

IE90 Identical to IE00 except for the files listed below. This run is used to evaluate the system under an irrigation efficiency of 90%.

IE90_RCH.DAT	Adjusts recharge to achieve an irrigation efficiency of 90% (1.111 × NIL).
IE90_STR.DAT	Adjusts diversions for farm deliveries to equal the applied irrigation recharge in IE90_RCH.DAT.

IE80 Identical to IE00 except for the files listed below. This run is used to evaluate the system under an irrigation efficiency of 80%.

IE80_RCH.DAT	Adjusts recharge to achieve an irrigation efficiency of 80% (1.250 × NIL).
IE80_STR.DAT	Adjusts diversions for farm deliveries to equal the applied irrigation recharge in IE80_RCH.DAT.

IE60 Identical to IE00 except for the files listed below. This run is used to evaluate the system under an irrigation efficiency of 60%.

IE60_RCH.DAT	Adjusts recharge to achieve an irrigation efficiency of 60% (1.667 × NIL).
IE60_STR.DAT	Adjusts diversions for farm deliveries so to equal the applied irrigation recharge in IE60_RCH.DAT.

IE50 Identical to IE00 except for the files listed below. This run is used to evaluate the system when irrigation efficiency is 50%.

IE50_RCH.DAT	Adjusts recharge so that to achieve an irrigation efficiency of 50% (2.000 × NIL).
IE50_STR.DAT	Adjusts diversions for farm deliveries to equal the applied irrigation recharge in IE50_RCH.DAT.

Sensitivity Runs

All sensitivity simulations consist of two runs: the "A" run, which is identical to PS1 (Held Constant Valley Wide), and the "B" run, which is identical to PS2 (Increased Valley Wide), except for the described alterations. For each of the described runs S_OUT.DAT was used for output control. This file simply suppresses all head printout except for the final time step.

S1 *ET* sensitivity run.

S1_EVT.DAT	Decreases the maximum ET rate 0.25 ft/year to 1.511 ft/year

S2 *ET* sensitivity run.

S2_EVT.DAT	Increases the maximum ET rate 0.25 ft/year to 2.011 ft/year

S3	*ET* sensitivity run.	
	S3_EVT.DAT	Increases the ET extinction depth 3 ft to a depth of 15 ft.
S4	*ET* sensitivity run.	
	S4_EVT.DAT	Decreases the ET extinction depth 3 ft to a depth of 9 ft.
S5	*Model wide conductivity and transmissivity* sensitivity run.	
	S5_BCF.DAT	Multiplies all transmissivities in the model by 10.0.
S6	*Model wide conductivity and transmissivity* sensitivity run.	
	S6_BCF.DAT	Multiplies all transmissivities in the model by 5.0.
S7	*Model wide conductivity and transmissivity* sensitivity run.	
	S7_BCF.DAT	Multiplies all transmissivities in the model by 2.0.
S8	*Model wide conductivity and transmissivity* sensitivity run.	
	S8_BCF.DAT	Multiplies all transmissivities in the model by 0.5.
S9	*Model wide conductivity and transmissivity* sensitivity run.	
	S9_BCF.DAT	Multiplies all transmissivities in the model by 0.2.
S10	*Model wide conductivity and transmissivity* sensitivity run.	
	S10_BCF.DAT	Multiplies all transmissivities in the model by 0.1.
S11	*Vertical conductance* sensitivity run.	
	S11_BCF.DAT	Multiplies all vertical conductivities in the model by 10.0.
S12	*Vertical conductance* sensitivity run.	
	S12_BCF.DAT	Multiplies all vertical conductivities in the model by 5.0.

S13 *Vertical conductance* sensitivity run.

S13_BCF.DAT Multiplies all vertical conductivities in the model by 2.0.

S14 *Vertical conductance* sensitivity run.

S14_BCF.DAT Multiplies all vertical conductivities in the model by 0.5.

S15 *Vertical conductance* sensitivity run.

S15_BCF.DAT Multiplies all vertical conductivities in the model by 0.2.

S16 *Vertical conductance* sensitivity run.

S16_BCF.DAT Multiplies all vertical conductivities in the model by 0.1.

S17 *Rio Grande bed conductance* sensitivity run.

S17_BCF.DAT Multiplies all Rio Grande bed conductances in the model by 10.0.

S18 *Rio Grande bed conductance* sensitivity run.

S18_BCF.DAT Multiplies all Rio Grande bed conductances in the model by 5.0.

S19 *Rio Grande bed conductance* sensitivity run.

S19_BCF.DAT Multiplies all Rio Grande bed conductances in the model by 2.0.

S20 *Rio Grande bed conductance* sensitivity run.

S20_BCF.DAT Multiplies all Rio Grande bed conductances in the model by 0.5.

S21 *Rio Grande bed conductance* sensitivity run.

S21_BCF.DAT Multiplies all Rio Grande bed conductances in the model by 0.2.

S22 *Rio Grande bed conductance* sensitivity run.

S22_BCF.DAT Multiplies all Rio Grande bed conductances in the model by 0.1.

S23 *Drain bed conductance* sensitivity run.

S23_BCF.DAT Multiplies all Drain bed conductances in the model by 10.0.

S24 *Drain bed conductance* sensitivity run.

S24_BCF.DAT Multiplies all Drain bed conductances in the model by 5.0.

S25 *Drain bed conductance* sensitivity run.

S25_BCF.DAT Multiplies all Drain bed conductances in the model by 2.0.

S26 *Drain bed conductance* sensitivity run.

S26_BCF.DAT Multiplies all Drain bed conductances in the model by 0.5.

S27 *Drain bed conductance* sensitivity run.

S27_BCF.DAT Multiplies all Drain bed conductances in the model by 0.2.

S28 *Drain bed conductance* sensitivity run.

S28_BCF.DAT Multiplies all Drain bed conductances in the model by 0.1.

S29 *Canal bed conductance* sensitivity run.

S29_BCF.DAT Multiplies all Canal bed conductances in the model by 10.0.

S30 *Canal bed conductance* sensitivity run.

S30_BCF.DAT Multiplies all Canal bed conductances in the model by 5.0.

S31 *Canal bed conductance* sensitivity run.

S31_BCF.DAT Multiplies all Canal bed conductances in the model by 2.0.

S32 *Canal bed conductance* sensitivity run.

S32_BCF.DAT Multiplies all Canal bed conductances in the model by 0.5.

S33 *Canal bed conductance* sensitivity run.

S33_BCF.DAT Multiplies all Canal bed conductances in the model by 0.2.

S34 *Canal bed conductance* sensitivity run.

S34_BCF.DAT Multiplies all Canal bed conductances in the model by 0.1.

S35 *Specific yield* sensitivity run.

S35_BCF.DAT Increases the specific yield of Layer 1 0.1 to 0.3.

S36 *Specific yield* sensitivity run.

S36_BCF.DAT Decreases the specific yield of Layer 1 0.1 to 0.1.

S37 *Layer 1 conductivity* sensitivity run.

S37_BCF.DAT Multiplies the conductivity of Layer 1 by 10

S38 *Layer 1 conductivity* sensitivity run.

S38_BCF.DAT Multiplies the conductivity of Layer 1 by 5

S39 *Layer 1 conductivity* sensitivity run.

S39_BCF.DAT Multiplies the conductivity of Layer 1 by 2

S40 *Layer 1 conductivity* sensitivity run.

S40_BCF.DAT Multiplies the conductivity of Layer 1 by 0.5

S41 *Layer 1 conductivity* sensitivity run.

S41_BCF.DAT Multiplies the conductivity of Layer 1 by 0.2

S42 *Layer 1 conductivity* sensitivity run.

S42_BCF.DAT Multiplies the conductivity of Layer 1 by 0.1

Appendix D

Predictive Simulation Mass Balance Summaries

Table D-1
Held Constant Basin Wide Simulation (PS1)
Mass Balance Summary (All Flows in cfs)

Year	Storage	Constant Head	Net Pumpage	Non Ag. ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss
1.00	7.25	0.04	-61.85	-94.79	231.78	18.35	89.17	-189.59
2.00	6.67	0.05	-61.85	-94.83	231.78	18.35	88.98	-189.59
3.00	6.50	0.05	-61.85	-94.83	231.78	18.35	89.06	-189.59
4.00	6.34	0.05	-61.85	-94.81	231.78	18.35	89.18	-189.59
5.00	6.19	0.06	-61.85	-94.79	231.78	18.35	89.30	-189.59
6.00	6.06	0.06	-61.85	-94.76	231.78	18.35	89.40	-189.59
7.00	5.93	0.06	-61.85	-94.74	231.78	18.35	89.50	-189.59
8.00	5.81	0.07	-61.85	-94.71	231.78	18.35	89.60	-189.59
9.00	5.69	0.07	-61.85	-94.69	231.78	18.35	89.70	-189.59
10.00	5.59	0.07	-61.85	-94.66	231.78	18.35	89.78	-189.59
11.00	5.48	0.07	-61.85	-94.63	231.78	18.35	89.87	-189.59
12.00	5.38	0.07	-61.85	-94.61	231.78	18.35	89.95	-189.59
13.00	5.29	0.07	-61.85	-94.58	231.78	18.35	90.03	-189.59
14.00	5.20	0.08	-61.85	-94.56	231.78	18.35	90.09	-189.59
15.00	5.11	0.08	-61.85	-94.54	231.78	18.35	90.16	-189.59
16.00	5.03	0.08	-61.85	-94.51	231.78	18.35	90.22	-189.59
17.00	4.95	0.08	-61.85	-94.49	231.78	18.35	90.28	-189.59
18.00	4.87	0.08	-61.85	-94.47	231.78	18.35	90.35	-189.59
19.00	4.79	0.08	-61.85	-94.45	231.78	18.35	90.41	-189.59
20.00	4.72	0.08	-61.85	-94.43	231.78	18.35	90.47	-189.59
21.00	4.65	0.08	-61.85	-94.40	231.78	18.35	90.52	-189.59
22.00	4.58	0.09	-61.85	-94.39	231.78	18.35	90.57	-189.59
23.00	4.52	0.09	-61.85	-94.37	231.78	18.35	90.62	-189.59
24.00	4.45	0.09	-61.85	-94.35	231.78	18.35	90.67	-189.59
25.00	4.39	0.09	-61.85	-94.33	231.78	18.35	90.71	-189.59
26.00	4.33	0.09	-61.85	-94.31	231.78	18.35	90.77	-189.59
27.00	4.27	0.09	-61.85	-94.29	231.78	18.35	90.81	-189.59
28.00	3.83	0.09	-61.85	-94.28	231.78	18.35	90.84	-189.59
29.00	4.13	0.09	-61.85	-94.26	231.78	18.35	90.88	-189.59
30.00	3.72	0.09	-61.85	-94.25	231.78	18.35	90.92	-189.59
31.00	3.61	0.09	-61.85	-94.24	231.78	18.35	90.94	-189.59
32.00	3.54	0.09	-61.85	-94.23	231.78	18.35	90.97	-189.59
33.00	3.48	0.09	-61.85	-94.22	231.78	18.35	90.99	-189.59
34.00	3.43	0.09	-61.85	-94.21	231.78	18.35	91.03	-189.59
35.00	3.38	0.09	-61.85	-94.19	231.78	18.35	91.05	-189.59
36.00	3.34	0.09	-61.85	-94.18	231.78	18.35	91.09	-189.59
37.00	3.30	0.09	-61.85	-94.17	231.78	18.35	91.11	-189.59
38.00	3.26	0.09	-61.85	-94.16	231.78	18.35	91.14	-189.59
39.00	3.22	0.10	-61.85	-94.15	231.78	18.35	91.16	-189.59
40.00	3.19	0.10	-61.85	-94.14	231.78	18.35	91.18	-189.59

Table D-2
Increased Basin Wide Simulation (PS2)
Mass Balance Summary (All Flows in cfs)

Year	Storage	Constant Head	Net Pumpage	Non Ag. ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss
1.00	9.21	0.04	-65.01	-94.59	231.78	18.35	89.58	-189.59
2.00	8.73	0.05	-65.01	-94.47	231.78	18.35	89.95	-189.59
3.00	8.36	0.05	-65.01	-94.38	231.78	18.35	90.23	-189.59
4.00	8.05	0.06	-65.01	-94.30	231.78	18.35	90.47	-189.59
5.00	7.77	0.06	-65.01	-94.22	231.78	18.35	90.67	-189.59
6.00	14.17	0.06	-75.20	-93.40	231.78	18.35	93.67	-189.59
7.00	12.53	0.07	-75.20	-93.00	231.78	18.35	94.77	-189.59
8.00	11.64	0.07	-75.20	-92.74	231.78	18.35	95.44	-189.59
9.00	10.99	0.07	-75.20	-92.56	231.78	18.35	95.91	-189.59
10.00	10.46	0.07	-75.20	-92.40	231.78	18.35	96.28	-189.59
11.00	17.81	0.08	-87.03	-91.46	231.78	18.35	99.87	-189.59
12.00	15.79	0.08	-87.03	-90.98	231.78	18.35	101.27	-189.59
13.00	14.64	0.09	-87.03	-90.67	231.78	18.35	102.13	-189.59
14.00	13.78	0.09	-87.03	-90.44	231.78	18.35	102.76	-189.59
15.00	13.08	0.09	-87.03	-90.25	231.78	18.35	103.27	-189.59
16.00	21.69	0.10	-100.78	-89.21	231.78	18.35	107.46	-189.59
17.00	19.30	0.10	-100.78	-88.69	231.78	18.35	109.15	-189.59
18.00	17.91	0.10	-100.78	-88.34	231.78	18.35	110.21	-189.59
19.00	16.86	0.11	-100.78	-88.07	231.78	18.35	111.01	-189.59
20.00	15.99	0.11	-100.78	-87.85	231.78	18.35	111.66	-189.59
21.00	26.11	0.11	-116.79	-86.74	231.78	18.35	116.53	-189.59
22.00	23.30	0.12	-116.79	-86.17	231.78	18.35	118.55	-189.59
23.00	21.64	0.12	-116.79	-85.79	231.78	18.35	119.86	-189.59
24.00	20.37	0.13	-116.79	-85.50	231.78	18.35	120.86	-189.59
25.00	19.32	0.13	-116.79	-85.26	231.78	18.35	121.68	-189.59
26.00	31.18	0.14	-135.46	-84.13	231.78	18.35	127.42	-189.59
27.00	27.93	0.14	-135.46	-83.53	231.78	18.35	129.85	-189.59
28.00	25.99	0.15	-135.46	-83.15	231.78	18.35	131.44	-189.59
29.00	24.48	0.15	-135.46	-82.86	231.78	18.35	132.67	-189.59
30.00	23.22	0.16	-135.46	-82.61	231.78	18.35	133.70	-189.59
31.00	37.24	0.16	-157.24	-81.43	231.78	18.35	140.37	-189.59
32.00	33.51	0.17	-157.24	-80.82	231.78	18.35	143.26	-189.59
33.00	31.20	0.18	-157.24	-80.40	231.78	18.35	145.14	-189.59
34.00	29.41	0.18	-157.24	-80.06	231.78	18.35	146.60	-189.59
35.00	27.92	0.19	-157.24	-79.78	231.78	18.35	147.84	-189.59
36.00	44.61	0.20	-182.69	-78.58	231.78	18.35	155.54	-189.59
37.00	40.25	0.20	-182.69	-77.94	231.78	18.35	158.96	-189.59
38.00	37.56	0.21	-182.69	-77.50	231.78	18.35	161.25	-189.59
39.00	35.44	0.22	-182.69	-77.16	231.78	18.35	163.01	-189.59
40.00	33.68	0.22	-182.69	-76.87	231.78	18.35	164.49	-189.59

Table D-3
Removed Basin Wide Simulation (PS3)
Mass Balance Summary (All Flows in cfs)

Year	Storage	Constant Head	Net Pumpage	Non Ag. ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss
1.00	-31.61	0.04	0.00	-99.84	231.78	18.35	70.91	-189.59
2.00	-23.17	0.04	0.00	-102.25	231.78	18.35	65.10	-189.59
3.00	-19.01	0.04	0.00	-103.65	231.78	18.35	62.27	-189.59
4.00	-16.21	0.04	0.00	-104.61	231.78	18.35	60.38	-189.59
5.00	-14.09	0.04	0.00	-105.35	231.78	18.35	58.96	-189.59
6.00	-12.47	0.04	0.00	-105.92	231.78	18.35	57.89	-189.59
7.00	-11.16	0.03	0.00	-106.39	231.78	18.35	57.03	-189.59
8.00	-10.08	0.03	0.00	-106.77	231.78	18.35	56.34	-189.59
9.00	-9.18	0.03	0.00	-107.10	231.78	18.35	55.76	-189.59
10.00	-8.41	0.03	0.00	-107.37	231.78	18.35	55.24	-189.59
11.00	-7.74	0.03	0.00	-107.60	231.78	18.35	54.82	-189.59
12.00	-7.16	0.03	0.00	-107.80	231.78	18.35	54.44	-189.59
13.00	-6.66	0.03	0.00	-107.98	231.78	18.35	54.10	-189.59
14.00	-6.21	0.02	0.00	-108.13	231.78	18.35	53.82	-189.59
15.00	-5.82	0.02	0.00	-108.26	231.78	18.35	53.57	-189.59
16.00	-5.47	0.02	0.00	-108.38	231.78	18.35	53.33	-189.59
17.00	-5.16	0.02	0.00	-108.49	231.78	18.35	53.13	-189.59
18.00	-4.88	0.02	0.00	-108.58	231.78	18.35	52.94	-189.59
19.00	-4.63	0.02	0.00	-108.67	231.78	18.35	52.77	-189.59
20.00	-4.40	0.01	0.00	-108.75	231.78	18.35	52.62	-189.59
21.00	-4.18	0.01	0.00	-108.82	231.78	18.35	52.48	-189.59
22.00	-3.99	0.01	0.00	-108.88	231.78	18.35	52.35	-189.59
23.00	-3.82	0.01	0.00	-108.94	231.78	18.35	52.23	-189.59
24.00	-3.65	0.01	0.00	-108.99	231.78	18.35	52.13	-189.59
25.00	-3.38	0.01	0.00	-109.04	231.78	18.35	52.04	-189.59
26.00	-3.23	0.01	0.00	-109.08	231.78	18.35	51.96	-189.59
27.00	-3.11	0.01	0.00	-109.13	231.78	18.35	51.88	-189.59
28.00	-3.00	0.00	0.00	-109.16	231.78	18.35	51.81	-189.59
29.00	-2.89	0.00	0.00	-109.20	231.78	18.35	51.74	-189.59
30.00	-2.79	0.00	0.00	-109.23	231.78	18.35	51.67	-189.59
31.00	-2.70	0.00	0.00	-109.27	231.78	18.35	51.60	-189.59
32.00	-2.62	0.00	0.00	-109.30	231.78	18.35	51.54	-189.59
33.00	-2.54	0.00	0.00	-109.32	231.78	18.35	51.49	-189.59
34.00	-2.46	0.00	0.00	-109.35	231.78	18.35	51.43	-189.59
35.00	-2.39	0.00	0.00	-109.38	231.78	18.35	51.38	-189.59
36.00	-2.32	0.00	0.00	-109.40	231.78	18.35	51.33	-189.59
37.00	-2.26	0.00	0.00	-109.42	231.78	18.35	51.29	-189.59
38.00	-2.20	0.00	0.00	-109.44	231.78	18.35	51.25	-189.59
39.00	-2.14	-0.01	0.00	-109.46	231.78	18.35	51.20	-189.59
40.00	-2.09	-0.01	0.00	-109.48	231.78	18.35	51.16	-189.59

Table D-4

Increased Canutillo Simulation (PS4)

Mass Balance Summary (All Flows in cfs)

Year	Storage	Constant Head	Net Pumpage	Non Ag. ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss
1.00	7.01	0.04	-61.73	-94.82	231.78	18.35	88.87	-189.59
2.00	6.58	0.05	-61.73	-94.84	231.78	18.35	88.94	-189.59
3.00	6.41	0.05	-61.73	-94.83	231.78	18.35	89.04	-189.59
4.00	6.25	0.05	-61.73	-94.82	231.78	18.35	89.15	-189.59
5.00	6.12	0.06	-61.73	-94.80	231.78	18.35	89.26	-189.59
6.00	7.83	0.06	-64.53	-94.53	231.78	18.35	90.53	-189.59
7.00	6.87	0.06	-64.53	-94.44	231.78	18.35	90.94	-189.59
8.00	6.55	0.07	-64.53	-94.38	231.78	18.35	91.18	-189.59
9.00	6.33	0.07	-64.53	-94.35	231.78	18.35	91.34	-189.59
10.00	6.16	0.07	-64.53	-94.31	231.78	18.35	91.48	-189.59
11.00	8.09	0.07	-67.75	-94.00	231.78	18.35	92.95	-189.59
12.00	7.02	0.07	-67.75	-93.89	231.78	18.35	93.42	-189.59
13.00	6.66	0.07	-67.75	-93.83	231.78	18.35	93.68	-189.59
14.00	6.42	0.08	-67.75	-93.78	231.78	18.35	93.87	-189.59
15.00	6.24	0.08	-67.75	-93.74	231.78	18.35	94.03	-189.59
16.00	8.43	0.08	-71.45	-93.39	231.78	18.35	95.70	-189.59
17.00	7.24	0.08	-71.45	-93.27	231.78	18.35	96.23	-189.59
18.00	6.84	0.08	-71.45	-93.20	231.78	18.35	96.52	-189.59
19.00	6.59	0.08	-71.45	-93.15	231.78	18.35	96.74	-189.59
20.00	6.39	0.09	-71.45	-93.11	231.78	18.35	96.91	-189.59
21.00	8.88	0.09	-75.70	-92.71	231.78	18.35	98.81	-189.59
22.00	7.93	0.09	-75.70	-92.56	231.78	18.35	99.49	-189.59
23.00	7.17	0.09	-75.70	-92.49	231.78	18.35	99.82	-189.59
24.00	6.85	0.09	-75.70	-92.45	231.78	18.35	100.04	-189.59
25.00	6.62	0.09	-75.70	-92.41	231.78	18.35	100.23	-189.59
26.00	9.44	0.09	-80.58	-91.98	231.78	18.35	102.41	-189.59
27.00	8.38	0.10	-80.58	-91.82	231.78	18.35	103.18	-189.59
28.00	7.55	0.10	-80.58	-91.75	231.78	18.35	103.54	-189.59
29.00	7.19	0.10	-80.58	-91.70	231.78	18.35	103.79	-189.59
30.00	6.93	0.10	-80.58	-91.66	231.78	18.35	103.99	-189.59
31.00	10.17	0.10	-86.18	-91.20	231.78	18.35	106.51	-189.59
32.00	8.96	0.10	-86.18	-91.02	231.78	18.35	107.40	-189.59
33.00	8.03	0.10	-86.18	-90.95	231.78	18.35	107.82	-189.59
34.00	7.63	0.11	-86.18	-90.89	231.78	18.35	108.09	-189.59
35.00	7.35	0.11	-86.18	-90.85	231.78	18.35	108.32	-189.59
36.00	11.06	0.11	-92.62	-90.34	231.78	18.35	111.21	-189.59
37.00	9.68	0.11	-92.62	-90.15	231.78	18.35	112.23	-189.59
38.00	9.06	0.11	-92.62	-90.06	231.78	18.35	112.77	-189.59
39.00	8.26	0.11	-92.62	-90.00	231.78	18.35	113.08	-189.59
40.00	7.90	0.11	-92.62	-89.96	231.78	18.35	113.32	-189.59

Table D-5
Removed Canutillo Simulation (PS5)
Mass Balance Summary (All Flows in cfs)

Year	Storage	Constant Head	Net Pumpage	Non Ag. ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss
1.00	-2.64	0.04	-42.86	-96.43	231.78	18.35	81.12	-189.59
2.00	0.23	0.04	-42.86	-96.93	231.78	18.35	78.88	-189.59
3.00	1.25	0.05	-42.86	-97.11	231.78	18.35	78.00	-189.59
4.00	1.76	0.05	-42.86	-97.19	231.78	18.35	77.56	-189.59
5.00	2.03	0.05	-42.86	-97.23	231.78	18.35	77.32	-189.59
6.00	2.21	0.05	-42.86	-97.25	231.78	18.35	77.14	-189.59
7.00	2.34	0.05	-42.86	-97.27	231.78	18.35	77.00	-189.59
8.00	2.44	0.06	-42.86	-97.27	231.78	18.35	76.89	-189.59
9.00	2.52	0.06	-42.86	-97.28	231.78	18.35	76.80	-189.59
10.00	2.57	0.06	-42.86	-97.28	231.78	18.35	76.73	-189.59
11.00	2.62	0.06	-42.86	-97.28	231.78	18.35	76.67	-189.59
12.00	2.65	0.06	-42.86	-97.28	231.78	18.35	76.63	-189.59
13.00	2.68	0.06	-42.86	-97.27	231.78	18.35	76.58	-189.59
14.00	2.69	0.06	-42.86	-97.26	231.78	18.35	76.55	-189.59
15.00	2.70	0.06	-42.86	-97.26	231.78	18.35	76.54	-189.59
16.00	2.71	0.06	-42.86	-97.25	231.78	18.35	76.52	-189.59
17.00	2.70	0.06	-42.86	-97.24	231.78	18.35	76.51	-189.59
18.00	2.70	0.06	-42.86	-97.23	231.78	18.35	76.50	-189.59
19.00	2.69	0.06	-42.86	-97.22	231.78	18.35	76.50	-189.59
20.00	2.68	0.06	-42.86	-97.21	231.78	18.35	76.50	-189.59
21.00	2.66	0.06	-42.86	-97.20	231.78	18.35	76.49	-189.59
22.00	2.65	0.06	-42.86	-97.19	231.78	18.35	76.50	-189.59
23.00	2.63	0.06	-42.86	-97.18	231.78	18.35	76.51	-189.59
24.00	2.61	0.06	-42.86	-97.17	231.78	18.35	76.52	-189.59
25.00	2.59	0.07	-42.86	-97.15	231.78	18.35	76.53	-189.59
26.00	2.57	0.07	-42.86	-97.14	231.78	18.35	76.53	-189.59
27.00	2.54	0.07	-42.86	-97.13	231.78	18.35	76.55	-189.59
28.00	2.31	0.07	-42.86	-97.12	231.78	18.35	76.56	-189.59
29.00	2.48	0.07	-42.86	-97.11	231.78	18.35	76.57	-189.59
30.00	2.26	0.07	-42.86	-97.11	231.78	18.35	76.58	-189.59
31.00	2.21	0.07	-42.86	-97.10	231.78	18.35	76.59	-189.59
32.00	2.18	0.07	-42.86	-97.09	231.78	18.35	76.60	-189.59
33.00	2.15	0.07	-42.86	-97.08	231.78	18.35	76.61	-189.59
34.00	2.12	0.07	-42.86	-97.07	231.78	18.35	76.61	-189.59
35.00	2.10	0.07	-42.86	-97.07	231.78	18.35	76.63	-189.59
36.00	2.07	0.07	-42.86	-97.06	231.78	18.35	76.65	-189.59
37.00	2.05	0.07	-42.86	-97.05	231.78	18.35	76.65	-189.59
38.00	2.03	0.07	-42.86	-97.04	231.78	18.35	76.67	-189.59
39.00	2.01	0.07	-42.86	-97.03	231.78	18.35	76.68	-189.59
40.00	1.99	0.07	-42.86	-97.02	231.78	18.35	76.70	-189.59

Table D-6
Increased Las Cruces Simulation (PS6)
Mass Balance Summary (All Flows in cfs)

Year	Storage	Constant Head	Net Pumpage	Non Ag. ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss
1.00	7.55	0.04	-62.07	-94.79	231.78	18.35	88.60	-189.59
2.00	7.40	0.05	-62.07	-94.75	231.78	18.35	88.63	-189.59
3.00	7.19	0.05	-62.07	-94.70	231.78	18.35	88.76	-189.59
4.00	7.00	0.05	-62.07	-94.64	231.78	18.35	88.89	-189.59
5.00	6.82	0.06	-62.07	-94.59	231.78	18.35	89.02	-189.59
6.00	9.26	0.06	-65.64	-94.23	231.78	18.35	89.70	-189.59
7.00	8.72	0.06	-65.64	-94.00	231.78	18.35	90.04	-189.59
8.00	8.24	0.06	-65.64	-93.84	231.78	18.35	90.30	-189.59
9.00	7.90	0.07	-65.64	-93.71	231.78	18.35	90.53	-189.59
10.00	7.61	0.07	-65.64	-93.60	231.78	18.35	90.71	-189.59
11.00	10.52	0.07	-69.73	-93.19	231.78	18.35	91.54	-189.59
12.00	9.76	0.07	-69.73	-92.93	231.78	18.35	91.98	-189.59
13.00	9.24	0.07	-69.73	-92.74	231.78	18.35	92.32	-189.59
14.00	8.81	0.07	-69.73	-92.59	231.78	18.35	92.61	-189.59
15.00	8.45	0.08	-69.73	-92.46	231.78	18.35	92.85	-189.59
16.00	11.74	0.08	-74.43	-92.02	231.78	18.35	93.80	-189.59
17.00	10.89	0.08	-74.43	-91.73	231.78	18.35	94.32	-189.59
18.00	10.28	0.08	-74.43	-91.52	231.78	18.35	94.73	-189.59
19.00	9.77	0.08	-74.43	-91.34	231.78	18.35	95.06	-189.59
20.00	9.34	0.08	-74.43	-91.19	231.78	18.35	95.35	-189.59
21.00	13.19	0.08	-79.84	-90.77	231.78	18.35	96.46	-189.59
22.00	12.22	0.08	-79.84	-90.48	231.78	18.35	97.08	-189.59
23.00	11.51	0.08	-79.84	-90.25	231.78	18.35	97.58	-189.59
24.00	10.92	0.08	-79.84	-90.06	231.78	18.35	97.99	-189.59
25.00	10.41	0.08	-79.84	-89.90	231.78	18.35	98.35	-189.59
26.00	14.89	0.09	-86.04	-89.48	231.78	18.35	99.62	-189.59
27.00	13.79	0.09	-86.04	-89.19	231.78	18.35	100.35	-189.59
28.00	12.98	0.09	-86.04	-88.96	231.78	18.35	100.96	-189.59
29.00	12.31	0.09	-86.04	-88.77	231.78	18.35	101.45	-189.59
30.00	11.72	0.09	-86.04	-88.61	231.78	18.35	101.88	-189.59
31.00	16.94	0.09	-93.17	-88.23	231.78	18.35	103.38	-189.59
32.00	15.68	0.09	-93.17	-87.95	231.78	18.35	104.27	-189.59
33.00	14.76	0.09	-93.17	-87.73	231.78	18.35	104.99	-189.59
34.00	13.99	0.09	-93.17	-87.54	231.78	18.35	105.61	-189.59
35.00	13.31	0.09	-93.17	-87.39	231.78	18.35	106.13	-189.59
36.00	19.42	0.09	-101.36	-87.01	231.78	18.35	107.80	-189.59
37.00	18.01	0.09	-101.36	-86.71	231.78	18.35	108.81	-189.59
38.00	16.94	0.09	-101.36	-86.47	231.78	18.35	109.67	-189.59
39.00	16.02	0.09	-101.36	-86.27	231.78	18.35	110.40	-189.59
40.00	15.22	0.09	-101.36	-86.09	231.78	18.35	111.04	-189.59

Table D-7
Removed Las Cruces Simulation (PS7)
Mass Balance Summary (All Flows in cfs)

Year	Storage	Constant Head	Net Pumpage	Non Ag. ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss
1.00	-10.06	0.04	-38.08	-97.14	231.78	18.35	84.76	-189.59
2.00	-6.94	0.05	-38.08	-98.62	231.78	18.35	83.23	-189.59
3.00	-5.13	0.05	-38.08	-99.59	231.78	18.35	82.35	-189.59
4.00	-3.87	0.05	-38.08	-100.29	231.78	18.35	81.76	-189.59
5.00	-2.85	0.06	-38.08	-100.83	231.78	18.35	81.25	-189.59
6.00	-2.05	0.06	-38.08	-101.25	231.78	18.35	80.85	-189.59
7.00	-1.43	0.06	-38.08	-101.59	231.78	18.35	80.54	-189.59
8.00	-0.94	0.06	-38.08	-101.85	231.78	18.35	80.31	-189.59
9.00	-0.54	0.07	-38.08	-102.08	231.78	18.35	80.13	-189.59
10.00	-0.20	0.07	-38.08	-102.27	231.78	18.35	79.98	-189.59
11.00	0.08	0.07	-38.08	-102.43	231.78	18.35	79.84	-189.59
12.00	0.32	0.07	-38.08	-102.57	231.78	18.35	79.74	-189.59
13.00	0.54	0.07	-38.08	-102.69	231.78	18.35	79.66	-189.59
14.00	0.71	0.07	-38.08	-102.79	231.78	18.35	79.59	-189.59
15.00	0.85	0.07	-38.08	-102.88	231.78	18.35	79.52	-189.59
16.00	0.97	0.07	-38.08	-102.96	231.78	18.35	79.47	-189.59
17.00	1.08	0.08	-38.08	-103.03	231.78	18.35	79.43	-189.59
18.00	1.17	0.08	-38.08	-103.09	231.78	18.35	79.39	-189.59
19.00	1.25	0.08	-38.08	-103.14	231.78	18.35	79.36	-189.59
20.00	1.33	0.08	-38.08	-103.19	231.78	18.35	79.34	-189.59
21.00	1.39	0.08	-38.08	-103.24	231.78	18.35	79.31	-189.59
22.00	1.44	0.08	-38.08	-103.28	231.78	18.35	79.29	-189.59
23.00	1.49	0.08	-38.08	-103.31	231.78	18.35	79.27	-189.59
24.00	1.43	0.08	-38.08	-103.34	231.78	18.35	79.26	-189.59
25.00	1.44	0.08	-38.08	-103.37	231.78	18.35	79.25	-189.59
26.00	1.46	0.08	-38.08	-103.40	231.78	18.35	79.25	-189.59
27.00	1.49	0.08	-38.08	-103.42	231.78	18.35	79.23	-189.59
28.00	1.51	0.08	-38.08	-103.44	231.78	18.35	79.23	-189.59
29.00	1.54	0.08	-38.08	-103.46	231.78	18.35	79.22	-189.59
30.00	1.56	0.08	-38.08	-103.48	231.78	18.35	79.22	-189.59
31.00	1.58	0.08	-38.08	-103.50	231.78	18.35	79.22	-189.59
32.00	1.60	0.08	-38.08	-103.51	231.78	18.35	79.22	-189.59
33.00	1.61	0.08	-38.08	-103.53	231.78	18.35	79.22	-189.59
34.00	1.62	0.08	-38.08	-103.54	231.78	18.35	79.22	-189.59
35.00	1.64	0.08	-38.08	-103.56	231.78	18.35	79.22	-189.59
36.00	1.65	0.08	-38.08	-103.57	231.78	18.35	79.22	-189.59
37.00	1.66	0.08	-38.08	-103.58	231.78	18.35	79.23	-189.59
38.00	1.66	0.08	-38.08	-103.59	231.78	18.35	79.22	-189.59
39.00	1.48	0.09	-38.08	-103.60	231.78	18.35	79.22	-189.59
40.00	1.44	0.09	-38.08	-103.61	231.78	18.35	79.22	-189.59

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Table D-8
100% Irrigation Efficiency (IE00)

Year	Storage	Constant Head	Pumpage	ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss	Farm Deliveries
1.00	18.66	0.11	-61.85	-89.45	189.85	18.35	114.01	-189.59	189.62
2.00	12.36	0.13	-61.85	-87.91	189.85	18.35	118.38	-189.59	189.62
3.00	10.25	0.14	-61.85	-87.30	189.85	18.35	119.92	-189.59	189.62
4.00	9.21	0.14	-61.85	-86.99	189.85	18.35	120.67	-189.59	189.62
5.00	8.53	0.15	-61.85	-86.81	189.85	18.35	121.12	-189.59	189.62
6.00	8.09	0.15	-61.85	-86.68	189.85	18.35	121.44	-189.59	189.62
7.00	7.44	0.16	-61.85	-86.60	189.85	18.35	121.67	-189.59	189.62
8.00	7.12	0.16	-61.85	-86.52	189.85	18.35	121.86	-189.59	189.62
9.00	6.88	0.16	-61.85	-86.46	189.85	18.35	122.04	-189.59	189.62
10.00	6.67	0.17	-61.85	-86.40	189.85	18.35	122.18	-189.59	189.62
11.00	6.49	0.17	-61.85	-86.36	189.85	18.35	122.32	-189.59	189.62
12.00	6.33	0.17	-61.85	-86.31	189.85	18.35	122.45	-189.59	189.62
13.00	6.18	0.18	-61.85	-86.27	189.85	18.35	122.57	-189.59	189.62
14.00	6.04	0.18	-61.85	-86.23	189.85	18.35	122.68	-189.59	189.62
15.00	5.91	0.18	-61.85	-86.20	189.85	18.35	122.78	-189.59	189.62
16.00	5.79	0.18	-61.85	-86.16	189.85	18.35	122.88	-189.59	189.62
17.00	5.68	0.19	-61.85	-86.13	189.85	18.35	122.97	-189.59	189.62
18.00	5.57	0.19	-61.85	-86.10	189.85	18.35	123.05	-189.59	189.62
19.00	5.46	0.19	-61.85	-86.07	189.85	18.35	123.13	-189.59	189.62
20.00	5.37	0.19	-61.85	-86.05	189.85	18.35	123.21	-189.59	189.62

Table D-9
90% Irrigation Efficiency (IE90)

Year	Storage	Constant Head	Pumpage	ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss	Farm Deliveries
1.00	12.85	0.08	-61.85	-92.15	210.94	18.35	101.62	-189.59	210.95
2.00	9.58	0.09	-61.85	-91.40	210.94	18.35	103.67	-189.59	210.95
3.00	8.11	0.09	-61.85	-91.11	210.94	18.35	104.40	-189.59	210.95
4.00	7.52	0.10	-61.85	-90.96	210.94	18.35	104.82	-189.59	210.95
5.00	7.14	0.10	-61.85	-90.85	210.94	18.35	105.10	-189.59	210.95
6.00	6.86	0.11	-61.85	-90.77	210.94	18.35	105.31	-189.59	210.95
7.00	6.64	0.11	-61.85	-90.71	210.94	18.35	105.49	-189.59	210.95
8.00	6.44	0.11	-61.85	-90.66	210.94	18.35	105.64	-189.59	210.95
9.00	6.27	0.11	-61.85	-90.61	210.94	18.35	105.78	-189.59	210.95
10.00	6.12	0.12	-61.85	-90.57	210.94	18.35	105.90	-189.59	210.95
11.00	5.98	0.12	-61.85	-90.53	210.94	18.35	106.02	-189.59	210.95
12.00	5.85	0.12	-61.85	-90.49	210.94	18.35	106.11	-189.59	210.95
13.00	5.73	0.12	-61.85	-90.46	210.94	18.35	106.22	-189.59	210.95
14.00	5.61	0.13	-61.85	-90.43	210.94	18.35	106.31	-189.59	210.95
15.00	5.51	0.13	-61.85	-90.40	210.94	18.35	106.39	-189.59	210.95
16.00	5.40	0.13	-61.85	-90.37	210.94	18.35	106.48	-189.59	210.95
17.00	5.31	0.13	-61.85	-90.34	210.94	18.35	106.56	-189.59	210.95
18.00	5.21	0.13	-61.85	-90.32	210.94	18.35	106.62	-189.59	210.95
19.00	5.12	0.14	-61.85	-90.29	210.94	18.35	106.69	-189.59	210.95
20.00	5.04	0.14	-61.85	-90.27	210.94	18.35	106.76	-189.59	210.95

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Table D-10
82% Irrigation Efficiency (PS1)

Year	Storage	Constant Head	Pumpage	ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss	Farm Deliveries
1.00	7.25	0.04	-61.85	-94.79	231.78	18.35	89.17	-189.59	237.02
2.00	6.67	0.05	-61.85	-94.83	231.78	18.35	88.98	-189.59	237.02
3.00	6.50	0.05	-61.85	-94.83	231.78	18.35	89.06	-189.59	237.02
4.00	6.34	0.05	-61.85	-94.81	231.78	18.35	89.18	-189.59	237.02
5.00	6.19	0.06	-61.85	-94.79	231.78	18.35	89.30	-189.59	237.02
6.00	6.06	0.06	-61.85	-94.76	231.78	18.35	89.40	-189.59	237.02
7.00	5.93	0.06	-61.85	-94.74	231.78	18.35	89.50	-189.59	237.02
8.00	5.81	0.07	-61.85	-94.71	231.78	18.35	89.60	-189.59	237.02
9.00	5.69	0.07	-61.85	-94.69	231.78	18.35	89.70	-189.59	237.02
10.00	5.59	0.07	-61.85	-94.66	231.78	18.35	89.78	-189.59	237.02
11.00	5.48	0.07	-61.85	-94.63	231.78	18.35	89.87	-189.59	237.02
12.00	5.38	0.07	-61.85	-94.61	231.78	18.35	89.95	-189.59	237.02
13.00	5.29	0.07	-61.85	-94.58	231.78	18.35	90.03	-189.59	237.02
14.00	5.20	0.08	-61.85	-94.56	231.78	18.35	90.09	-189.59	237.02
15.00	5.11	0.08	-61.85	-94.54	231.78	18.35	90.16	-189.59	237.02
16.00	5.03	0.08	-61.85	-94.51	231.78	18.35	90.22	-189.59	237.02
17.00	4.95	0.08	-61.85	-94.49	231.78	18.35	90.28	-189.59	237.02
18.00	4.87	0.08	-61.85	-94.47	231.78	18.35	90.35	-189.59	237.02
19.00	4.79	0.08	-61.85	-94.45	231.78	18.35	90.41	-189.59	237.02
20.00	4.72	0.08	-61.85	-94.43	231.78	18.35	90.47	-189.59	237.02

Table D-11
70% Irrigation Efficiency (IE70)

Year	Storage	Constant Head	Pumpage	ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss	Farm Deliveries
1.00	-3.46	-0.03	-61.85	-99.94	271.19	18.35	65.57	-189.59	270.68
2.00	2.14	-0.03	-61.85	-101.48	271.19	18.35	61.23	-189.59	270.68
3.00	3.75	-0.03	-61.85	-102.01	271.19	18.35	60.11	-189.59	270.68
4.00	4.28	-0.03	-61.85	-102.26	271.19	18.35	59.68	-189.59	270.68
5.00	4.51	-0.03	-61.85	-102.39	271.19	18.35	59.51	-189.59	270.68
6.00	4.61	-0.03	-61.85	-102.46	271.19	18.35	59.42	-189.59	270.68
7.00	4.65	-0.03	-61.85	-102.50	271.19	18.35	59.39	-189.59	270.68
8.00	4.65	-0.03	-61.85	-102.53	271.19	18.35	59.40	-189.59	270.68
9.00	4.64	-0.03	-61.85	-102.54	271.19	18.35	59.41	-189.59	270.68
10.00	4.61	-0.02	-61.85	-102.54	271.19	18.35	59.43	-189.59	270.68
11.00	4.57	-0.02	-61.85	-102.54	271.19	18.35	59.47	-189.59	270.68
12.00	4.53	-0.02	-61.85	-102.53	271.19	18.35	59.49	-189.59	270.68
13.00	4.48	-0.02	-61.85	-102.52	271.19	18.35	59.53	-189.59	270.68
14.00	4.44	-0.02	-61.85	-102.51	271.19	18.35	59.57	-189.59	270.68
15.00	4.39	-0.02	-61.85	-102.50	271.19	18.35	59.61	-189.59	270.68
16.00	4.34	-0.02	-61.85	-102.49	271.19	18.35	59.65	-189.59	270.68
17.00	4.28	-0.02	-61.85	-102.47	271.19	18.35	59.68	-189.59	270.68
18.00	4.23	-0.02	-61.85	-102.46	271.19	18.35	59.72	-189.59	270.68
19.00	4.18	-0.02	-61.85	-102.44	271.19	18.35	59.76	-189.59	270.68
20.00	4.13	-0.02	-61.85	-102.43	271.19	18.35	59.80	-189.59	270.68

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Table D-12
60% Irrigation Efficiency (IE60)

Year	Storage	Constant Head	Pumpage	ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss	Farm Deliveries
1.00	-15.32	-0.10	-61.85	-105.79	316.43	18.35	38.05	-189.59	316.19
2.00	-3.07	-0.12	-61.85	-109.07	316.43	18.35	28.96	-189.59	316.20
3.00	0.71	-0.13	-61.85	-110.26	316.43	18.35	26.30	-189.59	316.20
4.00	2.23	-0.13	-61.85	-110.78	316.43	18.35	25.32	-189.59	316.20
5.00	2.83	-0.13	-61.85	-111.04	316.43	18.35	24.89	-189.59	316.20
6.00	3.15	-0.13	-61.85	-111.19	316.43	18.35	24.64	-189.59	316.20
7.00	3.34	-0.13	-61.85	-111.28	316.43	18.35	24.49	-189.59	316.20
8.00	3.47	-0.13	-61.85	-111.35	316.43	18.35	24.40	-189.59	316.20
9.00	3.55	-0.13	-61.85	-111.39	316.43	18.35	24.33	-189.59	316.20
10.00	3.60	-0.13	-61.85	-111.42	316.43	18.35	24.30	-189.59	316.20
11.00	3.62	-0.13	-61.85	-111.44	316.43	18.35	24.27	-189.59	316.20
12.00	3.64	-0.13	-61.85	-111.45	316.43	18.35	24.26	-189.59	316.20
13.00	3.64	-0.13	-61.85	-111.46	316.43	18.35	24.26	-189.59	316.20
14.00	3.64	-0.13	-61.85	-111.46	316.43	18.35	24.26	-189.59	316.20
15.00	3.63	-0.13	-61.85	-111.47	316.43	18.35	24.28	-189.59	316.20
16.00	3.61	-0.14	-61.85	-111.46	316.43	18.35	24.28	-189.59	316.20
17.00	3.59	-0.14	-61.85	-111.46	316.43	18.35	24.30	-189.59	316.20
18.00	3.57	-0.14	-61.85	-111.45	316.43	18.35	24.32	-189.59	316.20
19.00	3.55	-0.14	-61.85	-111.45	316.43	18.35	24.34	-189.59	316.20
20.00	3.52	-0.14	-61.85	-111.44	316.43	18.35	24.36	-189.59	316.20

Table D-13
50% Irrigation Efficiency (IE50)

Year	Storage	Constant Head	Pumpage	ET	Irrig. Recharge	MF Recharge	Stream Leakage	Net Irrig. Loss	Farm Deliveries
1.00	-30.66	-0.22	-61.85	-113.32	379.70	18.35	-2.51	-189.59	350.29
2.00	-9.61	-0.26	-61.85	-118.71	379.70	18.35	-17.99	-189.59	352.45
3.00	-3.14	-0.27	-61.85	-120.63	379.70	18.35	-22.58	-189.59	353.10
4.00	-0.61	-0.27	-61.85	-121.47	379.70	18.35	-24.31	-189.59	353.29
5.00	0.68	-0.27	-61.85	-121.89	379.70	18.35	-25.14	-189.59	353.39
6.00	1.34	-0.28	-61.85	-122.13	379.70	18.35	-25.58	-189.59	353.45
7.00	1.73	-0.28	-61.85	-122.28	379.70	18.35	-25.88	-189.59	353.49
8.00	2.00	-0.28	-61.85	-122.38	379.70	18.35	-26.09	-189.59	353.52
9.00	2.20	-0.28	-61.85	-122.46	379.70	18.35	-26.25	-189.59	353.54
10.00	2.34	-0.29	-61.85	-122.52	379.70	18.35	-26.36	-189.59	353.55
11.00	2.45	-0.29	-61.85	-122.56	379.70	18.35	-26.45	-189.59	353.57
12.00	2.54	-0.29	-61.85	-122.59	379.70	18.35	-26.51	-189.59	353.57
13.00	2.60	-0.30	-61.85	-122.62	379.70	18.35	-26.56	-189.59	353.58
14.00	2.65	-0.30	-61.85	-122.64	379.70	18.35	-26.60	-189.59	353.59
15.00	2.68	-0.30	-61.85	-122.65	379.70	18.35	-26.63	-189.59	353.59
16.00	2.71	-0.30	-61.85	-122.66	379.70	18.35	-26.65	-189.59	353.60
17.00	2.73	-0.31	-61.85	-122.67	379.70	18.35	-26.66	-189.59	353.60
18.00	2.51	-0.31	-61.85	-122.67	379.70	18.35	-26.67	-189.59	353.60
19.00	2.47	-0.31	-61.85	-122.68	379.70	18.35	-26.68	-189.59	353.60
20.00	2.45	-0.31	-61.85	-122.68	379.70	18.35	-26.69	-189.59	353.60