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Estancia Basin Dynamic Water Budget

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Estancia Basin Dynamic Water Budget

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Abstract

The Estancia Basin lies about 30 miles to the east of Albuquerque, NM. It is a closed basin in terms of surface water and is somewhat isolated in terms of groundwater. Historically, the primary natural outlet for both surface water and groundwater has been evaporation from the salt lakes in the southeastern portion of the basin. There are no significant watercourses that flow into this basin and groundwater recharge is minimal.

During the 20th Century, agriculture grew to become the major user of groundwater in the basin. Significant declines in groundwater levels have accompanied this agricultural use. Domestic and municipal use of the basin groundwater is increasing as Albuquerque population continues to spill eastward into the basin, but this use is projected to be less than 1% of agricultural use well into the 21st Century.

This Water Budget model keeps track of the water balance within the basin. The model considers the amount of water entering the basin and leaving the basin. Since there is no significant surface water component within this basin, the balance of water in the groundwater aquifer constitutes the primary component of this balance. Inflow is based on assumptions for recharge made by earlier researchers. Outflow from the basin is the summation of the depletion from all basin water uses. The model user can control future water use within the basin via slider bars that set values for population growth, water system per-capita use, agricultural acreage, and the types of agricultural diversion. The user can also adjust recharge and natural discharge within the limits of uncertainty for those parameters.

The model runs for 100 years beginning in 1940 and ending in 2040. During the first 55 years model results can be compared to historical data and estimates of groundwater use. The last 45 years are predictive. The model was calibrated to match to New Mexico Office of State Engineer (NMOSE) estimates of aquifer storage during the historical period by making adjustments to recharge and outflow that were within the parameters uncertainties.

Although results of this calibrated model imply that there may be more water remaining in the aquifer than the Estancia Water Plan estimates, this answer is only another possible result in a range of answers that are based on large parameter uncertainties.

Acknowledgements

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Acronyms and Abbreviations

AF	acre-feet
yr	year
gpcd	gallons per person per day
NMOSE	New Mexico Office of the State Engineer

1. Introduction

The Estancia Basin Dynamic Water Budget is a water balance simulation model for the Estancia Basin. It was built to provide an interactive tool for water planners to test policy options and water planning concepts for this basin. This model is based on the concept of system dynamics. Through the incorporation of the concept of constant change, system dynamics can provide a means of simulating the complex reality of the interactive natural and social systems that make up the world in which we live. These systems are seldom in equilibrium and are often in a state of continuous change. Dynamic simulation is a computational tool that allows us to understand and adapt to this dynamic world.

The Estancia Basin Dynamic Water Budget is a very simple application of system dynamics. It is a “what if” model that makes no attempt to physically model the movement of water through the aquifer. In this model, the aquifer is like a tub with and inlet and an outlet. This model keeps track of the water balance within the basin - the amount of water entering the basin and leaving the basin. Since there is no significant surface water component within this basin, the balance of water in the groundwater aquifer constitutes the primary component of this balance.

This model keeps track of the water balance, but cannot keep track of water levels across the basin. It considers inflow from mountain fronts and from other basins, but it does not keep track of the time it would take for water to move through these media.

This model was built primarily using data from reports by Shomaker [1997], Balleau [1998], and Corbin [1999]. No new data was developed as a result of this effort.

The model runs for 100 years beginning in 1940 and ending in 2040. The first 55 years are a historical calibration period in the sense that the model parameters are adjusted to make model match the estimate of groundwater decline as appraised by Shomaker [1997]. The last 45 years are predictive in the sense that a range of model outcomes can be computed within the framework of model uncertainty.

2. Background

The Estancia Basin (Figure 1) is a closed basin that lies about 30 miles to the east of Albuquerque, NM. This basin, which is about 2400 square miles in area, is closed in terms of surface water; there are no significant watercourses that flow into or out of this basin. And although there are connections to other groundwater basins, it is somewhat isolated in terms of groundwater with minimal recharge.

Some hydrologists [DeBrine, 1971], [Smith, 1957] have suggested that the basin was in balance before extensive pumping began. In this “balance” evaporation from the salt lakes in the southeastern portion of the basin was an outlet that was balanced by an equivalent inflow from mountain front recharge and from other basins. Shomaker [1997] used mountain front recharge rates that were developed by the USGS in 1995 to estimate recharge to the Rio Grande basin to make recharge estimates for the Estancia Basin. The USGS [Bartolino, 2002] has subsequently revised their estimation techniques, dramatically reducing estimates of mountain front recharge to the Rio Grande Basin.

During the 20th Century, agriculture grew to become the major user of groundwater in the basin. The population of Estancia Basin used to be primarily associated with farming and ranching, but as the basin has become a bedroom community for Albuquerque, the portion of the population whose livelihood is associated with the agricultural sector has become a minority. Basin population, which was estimated at 5,800 in 1960, had grown to approximately 23,000 people by 1999 and is projected to be around 70,000 by 2040. In addition to these water uses within the basin, some water is being exported from the basin to housing developments on the east side of the Sandia Mountains.

The significant declines in groundwater levels that have accompanied these increased uses are mostly associated with agricultural use. The net depletion of the primary basin aquifer is about 40,000 acre-feet per year [Corbin, 1999]. The aquifer volume was estimated to be approximately 8.1 million acre-feet in 1910 and 6.6 million acre-feet in 1995 [Shomaker, 1997].

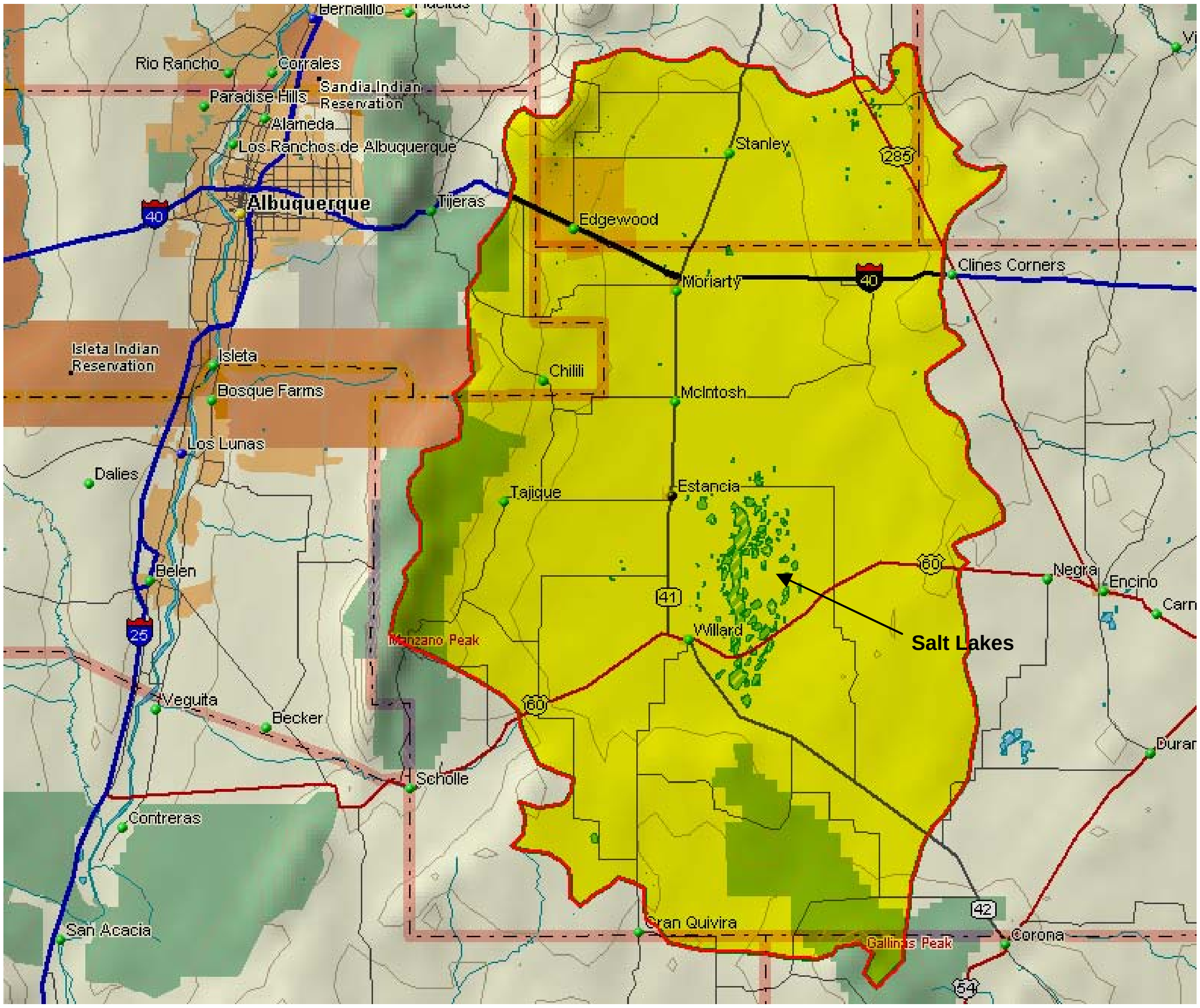

Figure 1 -- The Estancia basin lies to the east of Albuquerque and the Rio Grande Valley.

3. Model Description

The Estancia Basin Dynamic Water Budget model keeps track of the water balance within the basin. The model considers the amount of water entering the basin and the amount leaving the basin. Since there is no significant surface water component in this basin, the balance of water in the groundwater aquifer constitutes the primary component.

The model runs on annual time steps beginning in 1940 and ending in 2040.

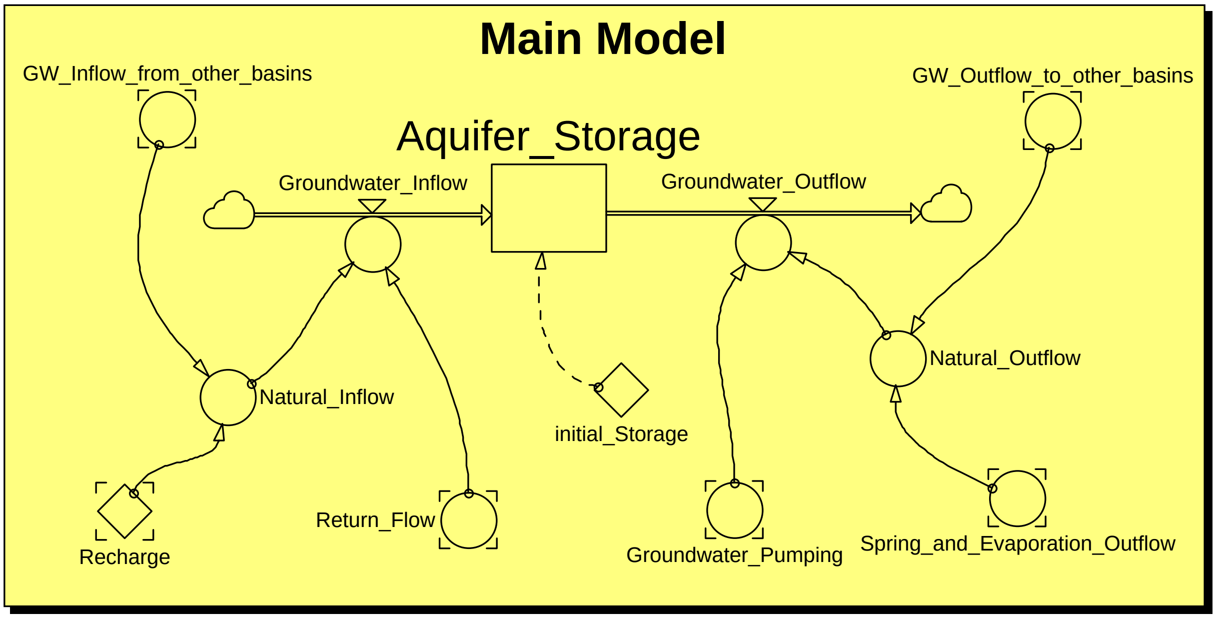

Figure 2 - The primary components of the Estancia Basin Model are "Aquifer_Storage", "Groundwater_Inflow" and "Groundwater_Outflow".

Figure 2 shows the primary components of the model. The primary components are the Aquifer_Storage and the inflow and outflow to that storage. Groundwater_Inflow is comprised of Recharge and Return_Flow. Groundwater_Outflow is comprised of Groundwater_Pumping and Natural_Outflow.

3.1. Aquifer Storage

The rectangle named “Aquifer_Storage” represents the amount of water in the valley fill aquifer; this value is recalculated at each model step. The “initial_storage_value” is the estimate of storage in 1940. The initial value of ~7.9 million acre-feet (AF) is based on storage estimates for 1910 and 1995, and on estimates of the amount of mined water from 1910 to 1956. Shomaker [1997] provided estimates for 1910 and 1995 of 8 million AF and 6.58 million AF, respectively. Shomaker [1997] also provided 160,000 AF as an estimate of the amount of water mined from the basin between 1910 and 1956. The Estancia Basin Recommended Regional Water Plan (Year 2000 to Year 2040) [Corbin, 1999] uses the Shomaker [1997] estimates for aquifer storage (8.1 AF in the early 1900’s and 6.6 million AF 1995).

It is important to note that the model currently considers only the storage of water within the valley fill aquifer. According to Shomaker [1997] 98% of the withdrawal in the Estancia basin is from the valley fill aquifer.

3.2. Groundwater Inflow

Inflow to the Estancia basin (valley fill aquifer) is from two major sources: recharge and return flow. Inflow from adjacent basins is included in recharge.

3.2.1. Recharge

Recharge is water that infiltrates into the valley fill aquifer from rainfall, rainfall runoff, or inflow from adjacent basins. Although the rate of recharge to the Estancia basin is not known, it has been estimated using two different methods. One method is to assume that prior to large scale pumping, the basin was in balance, and that inflow equaled outflow. Shomaker [1997] estimated the pre-pumping outflow (evaporation from the salt lakes) to be between 27,000 and 50,000 AF/yr. Shomaker [1997] also used the mountain front recharge method used by the USGS for the Albuquerque Basin to compute a recharge estimate of 37,744 AF/yr. The Estancia Basin Recommended Regional Water Plan (Year 2000 to Year 2040) [Corbin, 1999] uses 10,000 to 15,000 AF/yr as an estimate of recharge. The model uses 37,744 AF/yr as a default starting point.

> **Model Assumption**
>
> **Recharge**
>
> The model uses 37,744 AF/yr as the default value of total recharge.

It should be noted that the method used to estimate mountain front recharge for the USGS has now been superceded by newer methods that have lowered estimates of recharge by a factor of 6. The original estimates for mountain front recharge *on the west side* of the Sandia and Manzano Mountains was 72,000 AF/yr; the latest estimate is 12,000 AF/yr [Bartolino and Cole, 2002]. It should also be noted that the USGS method is specifically for the west side of the mountains, and may or may not be applicable to flow on the east side for the mountains. If this method were applicable to the east side, the estimate made by Shomaker [1997] could be reduced from 37,744 AF/yr to 6,290 AF/yr.

3.2.1.1. Inflow from Adjacent Basins

The Estancia basin is adjacent to several other underground water basins, including the Rio Grande and Sandia basins on the west and north, the Galisteo Basin to the north, and the Upper Pecos, Ft. Sumner, Roswell, and Tularosa basins on the east and south. Although it would be reasonable to assume that there is some movement of groundwater between these basins, the only estimates of inflow or outflow from the estancia basin were those that were made by Balleau [1998] as a part of groundwater model computations under steady-state conditions. Under these conditions, Balleau [1998] estimated inflow into the Madera limestone formation in the Estancia Basin to be 950 AF/yr.

> **Model Assumption**
>
> **Inflow from adjacent Basins**
>
> Inflow to the Madera Limestone is assumed to be 950 AF/yr (included in the recharge estimate).

3.2.2. Return flow

Return flow is the amount of withdrawn water that is returned to the aquifer. The largest portion of return flow is from the agricultural sector, but small amounts are returned from domestic septic tanks and municipal sewage systems. The amount of return flow is calculated on the basis of water withdrawn for each of these sectors.

> **Model Assumption**
>
> **Return flow**
>
> Return flow domestic use is based on the assumption that 55% of the water used is returned to the aquifer.
>
> Return flow for the agricultural sector is dependent on the method of irrigation used

Return flow is a parameter that cannot be directly measured and as such is uncertain. Return flow for both domestic use and for municipal systems is based on a fixed percentage, 55% [Shomaker, 1997]. Return flow for domestic septic tanks and for municipal and public water systems is also assumed to be 55% [Shomaker, 1997].

Return flow from the agricultural sector is based on estimated agricultural depletion for the year 1990. Agricultural diversion is the total amount of water applied to a crop; depletion is the amount used by the crop (including evapotranspiration), and return flow is the remainder, which is assumed to return to the groundwater.

Both agricultural diversion and return flow are dependent on irrigation type. Table 1 presents values for diversion, depletion, and return flow that are derived from 1990 diversion data for the Estancia basin [Shomaker, 1997]. This table shows that agricultural return flow ranges from 15% to 40% of the diversion.

Model Assumption

Agricultural Diversion

Agricultural diversion is based on the number of acres estimated to be under irrigation.

Historic estimates of agricultural acreage are based on values that have been reported to or estimated by the Office of the State Engineer.

Future estimates are based on estimates in the Estancia Basin Water Plan.

Table 1. Diversion, Depletion and Return flow as a function of Irrigation Type (based on diversion data for 1990 presented by Shomaker [1997]).

Irrigation Type	Diversion (AF/acre)	Depletion		Return Flow	
		%	AF/acre	%	AF/acre
flood	2.57	60%	1.54	40%	1.03
sprinkler	2.08	65%	1.35	35%	0.73
drip	1.26	85%	1.07	15%	0.19

3.3. Groundwater Outflow

Outflow from the Estancia basin aquifer occurs through two mechanisms: groundwater withdrawal (by pumping) and natural outflow.

3.3.1. Groundwater Withdrawal

Groundwater withdrawal is the water that is pumped (diverted) from the aquifer. Some of this water is returned to the aquifer. The difference between the amount diverted and the amount returned is the depletion to the aquifer. The five major uses for water in the Estancia basin are (in order of significance) 1) agriculture, 2) livestock watering, 3) commercial and industrial uses, 4) public water systems, and 5) domestic wells.

Agricultural Diversion: Water pumped for agricultural uses is the major diversion in this basin. Figure 3 shows 100 years of irrigated acreage. The period from 1940 to 1995 is based on historical data from the Office of the State Engineer [Shomaker, 1997], [Balleau, 1998]; the period from 1995 to 2040 shows a projected acreage for the year 2040 that ranges from 20,000 to 35,000 acres [Shomaker, 1997]. The value of the acreage for 2040 defaults in the model to the lower number, 20,000 acres, but this value can be adjusted by the user with a slider bar.

Irrigation falls in to three basic types: sprinkler irrigation, flood irrigation, and drip irrigation. Shomaker [1997] reported that in 1990 agricultural diversion was distributed 71% by sprinkler irrigation, 29% by flood irrigation, and less than 1% by drip irrigation. These values are used as the default values for all diversions for each year, but this distribution can be adjusted by the user to consider the option of using more or less efficient irrigation types. Table 1 shows the differences in diversion, groundwater depletion, and return flow for each of the irrigation types.

> **Model Assumption**
>
> **Irrigation Type**
>
> The default distribution of irrigation types is based on a 1990 estimate that showed 71% sprinkler irrigation, 29% flood irrigation, and less than 1% drip irrigation. The model user can adjust the distribution of irrigation types.

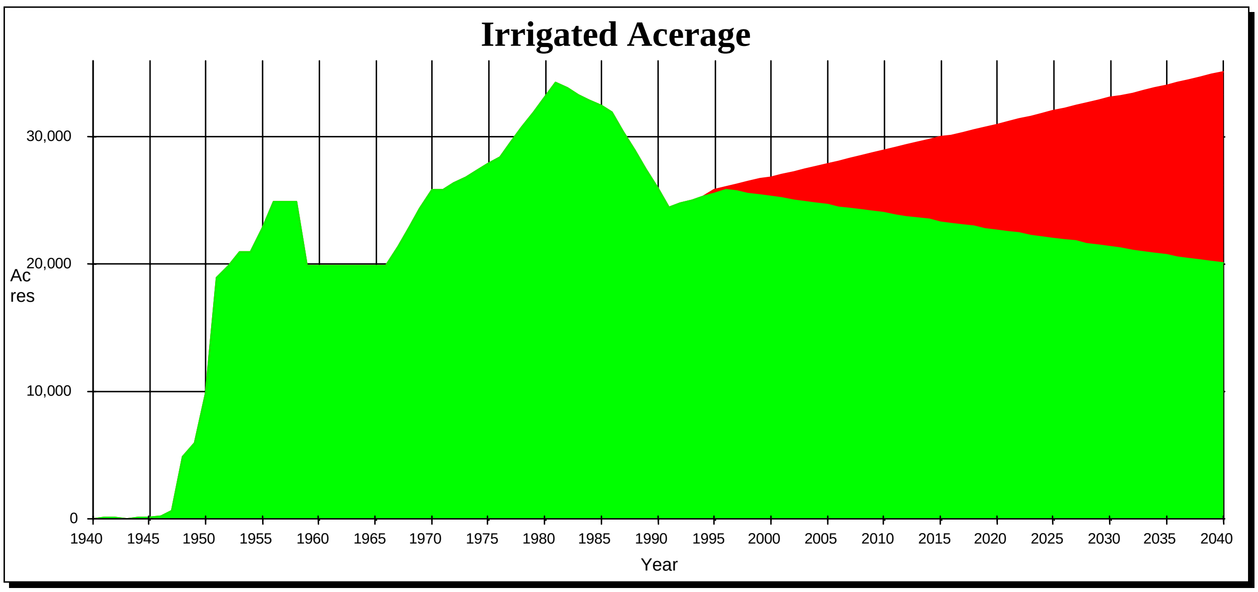

Figure 3 - Historical irrigated acreage in the Estancia basin from 1940 to 1995. Acreage from 1990 to 2040 is based a projected range for 2040 of 20,000 to 35,000 acres [Shomaker, 1997].

Livestock Watering: Shomaker [1997] estimated that livestock watering used 604 AF/yr with 440 AF/yr being from groundwater wells, and the remaining 164 AF/yr being from surface water sources.

Commercial and Industrial Use: Shomaker [1997] estimated industrial use from one user, Transwestern PL to be 16.57 AF/yr. Commercial uses include businesses, campgrounds, picnic areas, and

> **Model Assumption**
>
> **Livestock, Commercial, and Industrial Use**
>
> These uses are based on estimates made in 1997 and are used as constants throughout the model period.

visitor centers. Shomaker [1997] estimated use in 1990 to be a total of 46.83 AF/yr.

Public Water Systems: Public water system use is based on the per capita usage and population estimates for each major water supplier. Shomaker [1997] estimated the 1995 usage for these systems in gallons per person per day (gpcd) (Table 2). Annual population estimates used in the model are based on the populations these systems served from 1940 to1995 [Shomaker, 1997] and on the projected populations for the respective counties or areas that those systems are in. Table 2 shows the population that each of the water systems served in 1995 and the estimates for the water system populations in 2040.

Model Assumption

Public Systems water use

Public Water Systems use is based on the estimated population and the per capita use for each water system.

Table 2. Water usage and population estimates for Public Water Systems

Public Water System	Usage (gpcd)	Population in 1995	Population Estimate for 2040
Entranosa Water Co-op	91	4,400	13,728
Edgewood Water Co-op	79	4,500	14,040
Edgewood	76	1,200	3,744
Estancia Water System	285	792	1,919
Moriarity Water System	207	1,399	5,191
Tajique Water System	13.5	452	1,699
Echo Ridge Subdivision	106	225	846
Mountainair	173	926	1,616
Willard Water system	99	200	752

In addition to the population estimates for the year 2040 as shown in Table 2, the model has a "no-growth" population option for these systems. This option freezes the population at 2001 levels.

Domestic Wells: Domestic wells provide water for the population that is not served by public water systems. The per capita water use for rural users is estimated to be between 64 and 125.5 gallons per capita per day (gpcd) by Shomaker [1997]. The USGS estimated rural water use in New Mexico at 86 gpcd [Solley, 1998]. The number of rural users is estimated by subtracting the population served by the water systems from the total basin population for each year. The rural population is estimated to grow from 7,433 in 1995 to 27,262 in 2040.

Model Assumption

Domestic Well Use

Domestic use from private wells is estimated to be 86 gpcd. This is considerably below the full water right for domestic wells use of 3 AF/year.

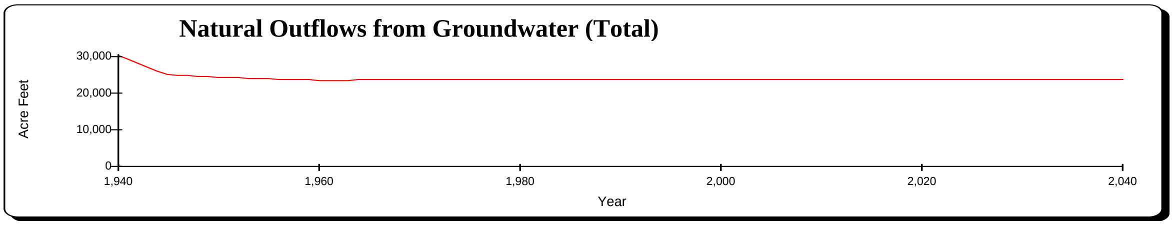

Figure 4 - Natural Outflows begin the modeling period in 1940 in balance with natural inflows, but then decreases as pumping increases.

3.3.2. Natural Outflow

Natural Outflow (Figure 4) consists of spring flow; river discharge; evaporation from lakes, ponds, and reservoirs, and the movement of groundwater to adjacent basins.

Spring Flow:

Balleau [1998] estimated spring flows from Estancia Spring and Antelope Spring for steady-state groundwater computations to be 50 AF/yr and 480 AF/yr respectively. Since neither of these springs is currently flowing, the model has assumed that flow in these springs declined from the Balleau estimate in 1940 to zero by 1990 (Figure 5).

> **Model Assumption**
>
> **Spring Flow**
>
> Spring flows decline from the Balleau estimates in 1940 to zero by 1990.

River Discharge:

Balleau [1998] estimated river discharge from the Estancia basin to be 1320 AF/yr for steady-state groundwater computations, but did not provide any specifics as to how this value was estimated and for what river(s) this value applies. The model assumes river discharge to be zero.

> **Model Assumptions**
>
> **River Discharge**
>
> River Discharge is set to a default of zero.

Evaporation:

Salt Lake Evaporation: The salt lakes in the central part of the basin (Figure 1.) are a natural discharge for the groundwater aquifer. Evaporation from these lakes has been estimated to be from 22,000 AF/yr to 81,000 AF/yr [Balleau, 1998]. The model uses a beginning value for Salt Lake Evaporation of 28,279 AF/yr; this value declines to 22,000 AF/yr by 1960.
Stock Pond Evaporation: Evaporation from stock ponds was estimated at 1780 AF/yr by Shomaker [1997] for the year 1980. Stock ponds are assumed to have increased during the modeling period and therefore, evaporation from stock ponds is modeled to increase from 400 AF/yr (arbitrary) in 1940 to the Shomaker estimate in 1980.

> **Model Assumption**
>
> **Evaporation**
>
> Evaporation from the Salt Lakes is estimated to decline from an initial value of 34,100 AF/yr to 22,000 AF/yr by 1960.
>
> Evaporation from stock ponds is modeled to increase from 400 AF/yr in 1940 to the Shomaker estimate (1780 AF/yr) in 1980.
>
> The model uses a constant value of 15 AF/yr for reservoir evaporation throughout the modeling period.

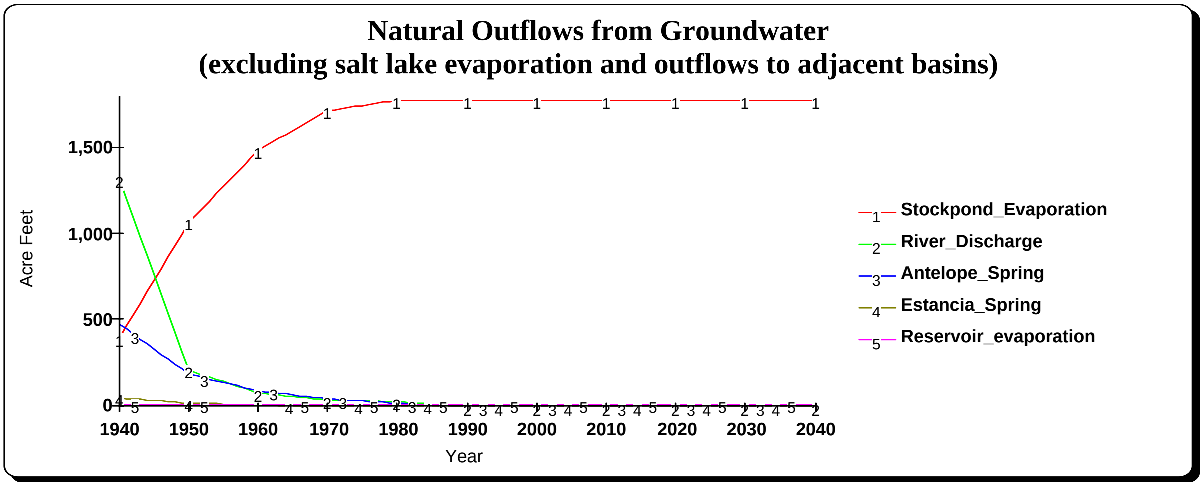

Figure 5 - Natural Outflows from the basin (excluding salt lake evaporation and outflow to adjacent basins) generally decrease over time with the exception of stock pond evaporation which increase as new stock ponds are built.

Reservoir Evaporation: The model uses a constant value of 15 AF/yr [Shomaker, 1997] for reservoir evaporation throughout the modeling period.

Outflow to Adjacent Basins

The Estancia basin is adjacent to several other underground water basins, including the Rio Grande and Sandia basins on the west and north, the Galisteo Basin to the north, and the Upper Pecos, Ft. Sumner, Roswell, and Tularosa basins on the east and south. Although it would be reasonable to assume that there is some movement of groundwater between these basins, the only estimates of inflow or outflow from the estancia basin were those that were made by Balleau [1998] as a part of groundwater model computations under steady-state conditions. Under these conditions, Balleau [1998] estimated outflow to the Galisteo Basin (to the north) and to the Tularosa Basin (to the south) to respectively be 6,800 AF/yr and 400 AF/yr.

Model Assumptions

Outflow to Adjacent Basins

Outflow is estimated at 6,800 AF/yr to the Galisteo Basin, and 400 AF/yr. to the Tularosa Basin.

4. Model Calibration

This model was calibrated to the estimates of change in aquifer storage reported by Shomaker [1997]. The first 55 years of the modeling period, 1940 to 1995, represent the historical period that the model was calibrated to. Estimates of groundwater storage for this period were made by the New Mexico Office of the State Engineer (NMOSE) [Shomaker, 1997] on the basis of records of water that was pumped, water-level declines, and an assumed specific yield for the valley fill aquifer of 0.125. The red dashed line in Figure 6 represents two estimates of aquifer storage; the first segment, from 1940 to 1995, is based on NMOSE estimates of alluvial aquifer storage [Shomaker, 1997]; the second segment, from 1995 to 2040, is based on Estancia Water

Plan estimates of groundwater use. The black line in Figure 6 represents a model run with all parameters set to the values used by the Estancia Basin Water Plan [Corbin, 1999].

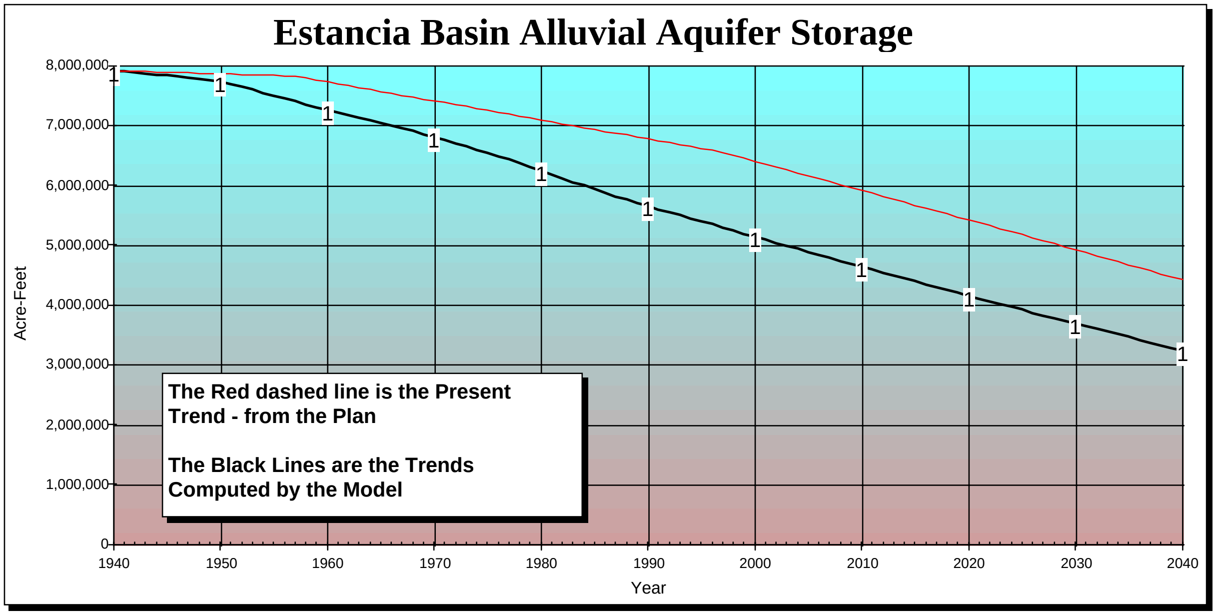

Figure 6 - Model Run before Calibration: The black line represents the model results when variables are set to the values used in the Basin Water Plan. The red dashed line represents the known historical trend (to 1997) and the predicted trend (after 1997).

When the model is run with all the variables set to the values used by the Basin Water Plan, the results (Figure 6) do not calibrate to the estimates historical changes in aquifer storage as estimated by the NMOSE. The model shows a much larger depletion to the aquifer over time, but the slope of the modeled curve is a pretty good match to the slope of the Basin Water Plan predictive curve (post 1997).

The model was calibrated by making assumptions about the natural inflows and outflows that would be consistent with estimates that were made by Shomaker and the NMOSE. Natural inflows may vary with climatic changes but are assumed to be constant for the period of time that is being modeled. Natural outflows would are assumed to be in balance with the inflows at the beginning of the modeling period, but would be assumed to decrease as pumping increases within the basin:

1. *Recharge:* The first step was to set total recharge (including inflow from adjacent basins) to 37,744 AF/yr, the value that Shomaker estimated (1997).
2. *Natural Outflow – Beginning values:* The second step was to set the total value of natural basin outflow for the beginning of the period to be the same as natural inflow. The major adjustments here were in Salt Lake evaporation (to a beginning value of 28,279 AF/yr), and in stock pond evaporation (to a beginning value of 400 AF/yr). Flows from springs were set to the values estimated by Balleau for steady state conditions.
3. *Natural Outflow – Change Curve:* The third step was to estimate a change curve for each of the output values from the beginning value to the estimates used in the Basin Water Plan. Figures 4 and 5 illustrate these changes.

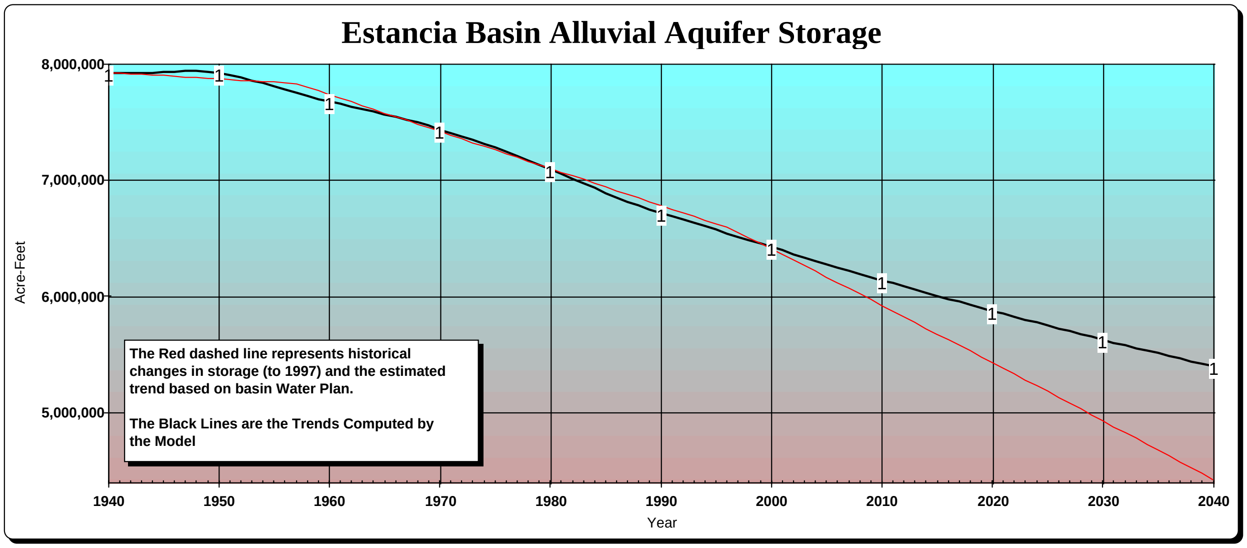

Figure 7 - Model Run after Calibration: The black line represents the model results when inflow and outflow variables are adjusted to be in balance at the beginning of the modeling period. The red dashed line represents the estimated historical trend (to 1995) and the predicted trend (after 1995).

The results of these changes are shown in Figure 7. This run of the model is now quite closely calibrated to the historical period estimates, but not the Basin Water Plan predictive estimates (post 1995). The slope of the predictive portion of the model results is now significantly different than the slope of the Basin Water Plan predictive curve.

Variables can be adjusted in other ways to bring the historical period into calibration; the model can be calibrated if we assume that the numbers of acres under irrigation during the historical period are less than 50% of what was reported, or through a combination of fewer acres under irrigation and adjustments to recharge and outflow.

5. Conclusions

Model results, as calibrated to the estimates of aquifer storage during the historical period, illustrate that there are large uncertainties in what we know about this basin and that the estimated predictions of aquifer storage are equally uncertain. These model results are dependent on the NMOSE estimates of aquifer storage, which are based on a specific yield estimate for the whole basin. Updated estimates of specific yield could dramatically change these estimates. The change in slope in the red dashed line in Figure 6 illustrates a difference in assumptions used to estimate the aquifer storage for historical period and for the predictive period. The fact that the estimates made using this model are different than those made using the Estancia Water Plan data do not imply that these model results are more accurate than the results based on the Water Plan. These results do imply is that there is no single answer to question of how much water currently remains in this basin or how much will remain in the basin in 2040.

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