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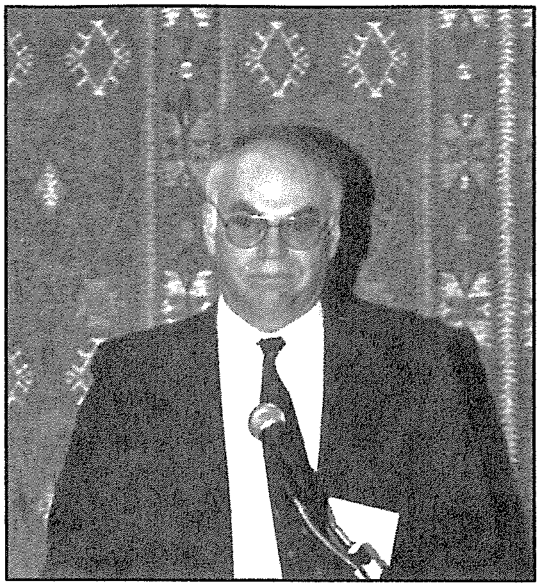

Groundwater Modeling in the Lower Rio Grande

The main water-management problem in the Lower Rio Grande (LRG) Basin involves operation of the stored resources, including groundwater. To find how to convert the problem to a solution, a quantitative tool in the form of a model is required to tell us how the system responds. The overall resource is accounted for in two components, stored groundwater and interrelated surface water that helps feed the aquifer when groundwater is developed. With those two components in mind, we can recognize the framework of the resource management issues; stored groundwater from wells is always available, interrelated surface water is the subject of competition among users during times of shortage.

In Figure 1, the topographic basin is the shaded area. The hydrologic units are defined by the U.S. Geological Survey (USGS) and the administrative basins are defined by the New Mexico Office of the State Engineer (OSE). The administrative and hydrologic basins generally are consistent, except for Nutt-Hockett.

The outline of the main groundwater modeling tool available in the LRG to date is shown on the grid. The model was developed by Frenzel and Kaehler (1990), revised in 1992 (Frenzel 1992), and repeatedly adapted since.

Geologic basins in the LRG (Figure 2) include Mesilla, Jornada and Palomas. Groundwater is stored in the basinfill. The indication from the Frenzel model is that 14 million acre-feet (maf) are stored in the top 100 feet of sedimentary material below the west mesa of Mesilla Basin. For context on the size of the stored resource, Elephant Butte and Caballo reservoirs hold approximately 2.2 maf, so seven times the stored surface-water amount is stored in the ground below the west mesa. It is estimated that there are 50 maf in groundwater storage in the top 100 feet of saturated basinfill in all three basins.

The hydrograph on Figure 3 shows monthly values of flow at the El Paso gage station since 1889. The hydrograph illustrates how the surface-water system has been developed. In the first 25 years to 1915, there was no Elephant Butte Dam on the stream. Without a reservoir, we see extreme fluctuation due to spring floods and dry summers. After the dam was built, flow was successfully controlled, but we see two dry periods when the stream was practically dry in El Paso during some months. By skimming the level of the flood peaks, the reservoir generally has sufficient water to support the low-flow periods. Summer - winter fluctuations are very regular, except when the storage capacity of the surface-water system is either exceeded in spill years or used up in drought years. Groundwater development in the 1950s affected streamflow to some degree. The 1980s have been wet again with repeated reservoir spills. A groundwater model can answer the question, how much of this variation in the hydrograph is accounted for by groundwater development?

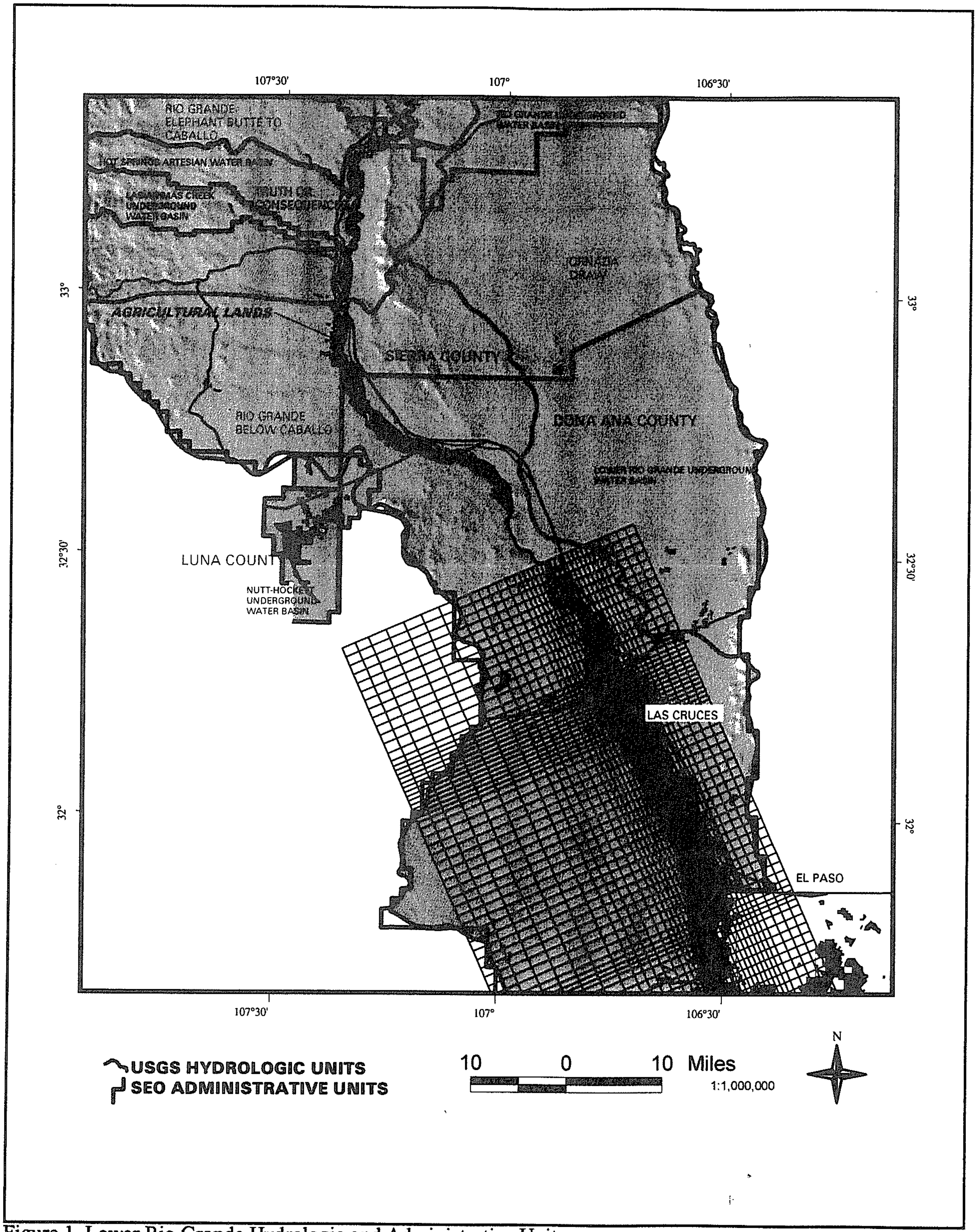

Figure 1. Lower Rio Grande Hydrologic and Administrative Units

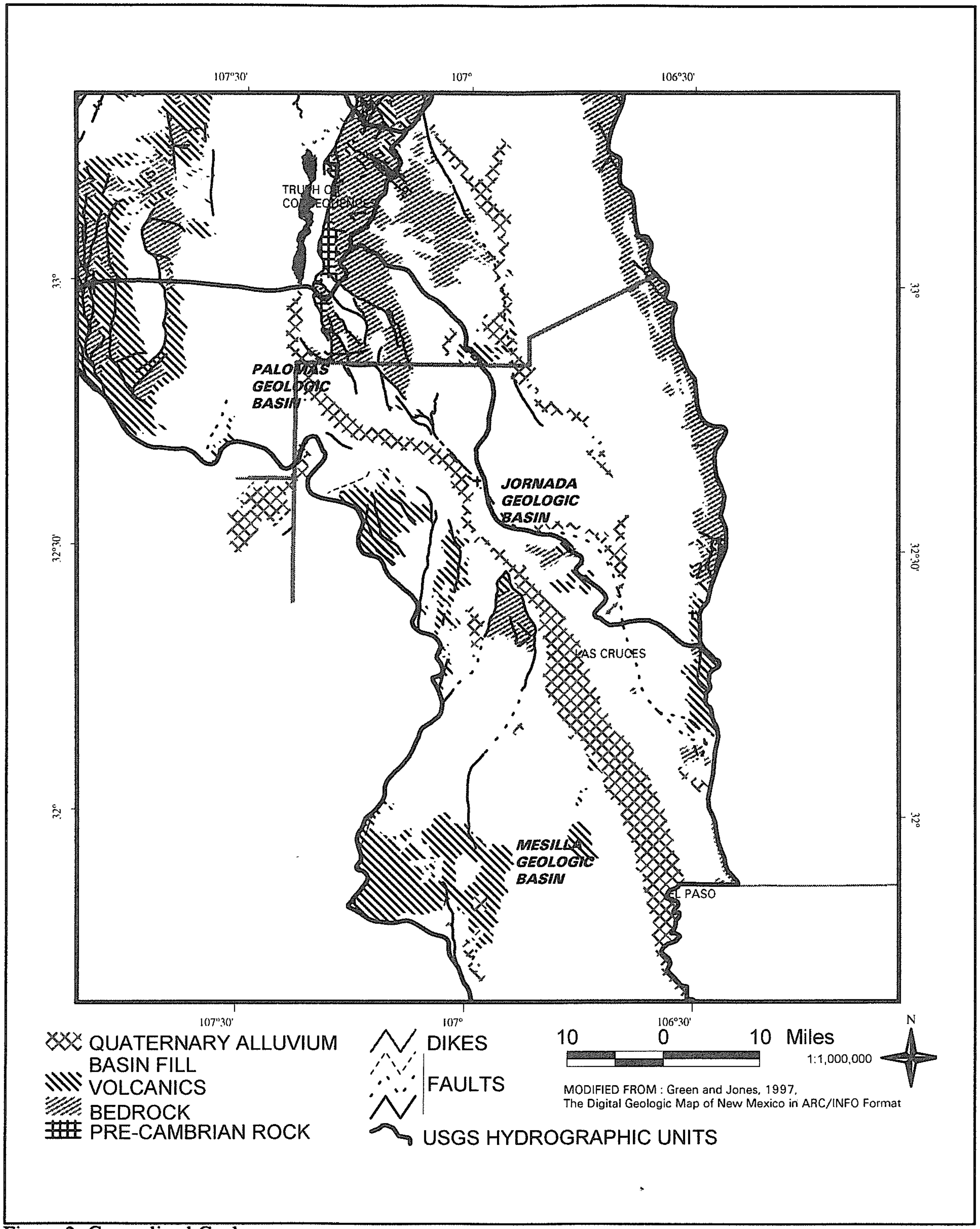

Figure 2. Generalized Geology

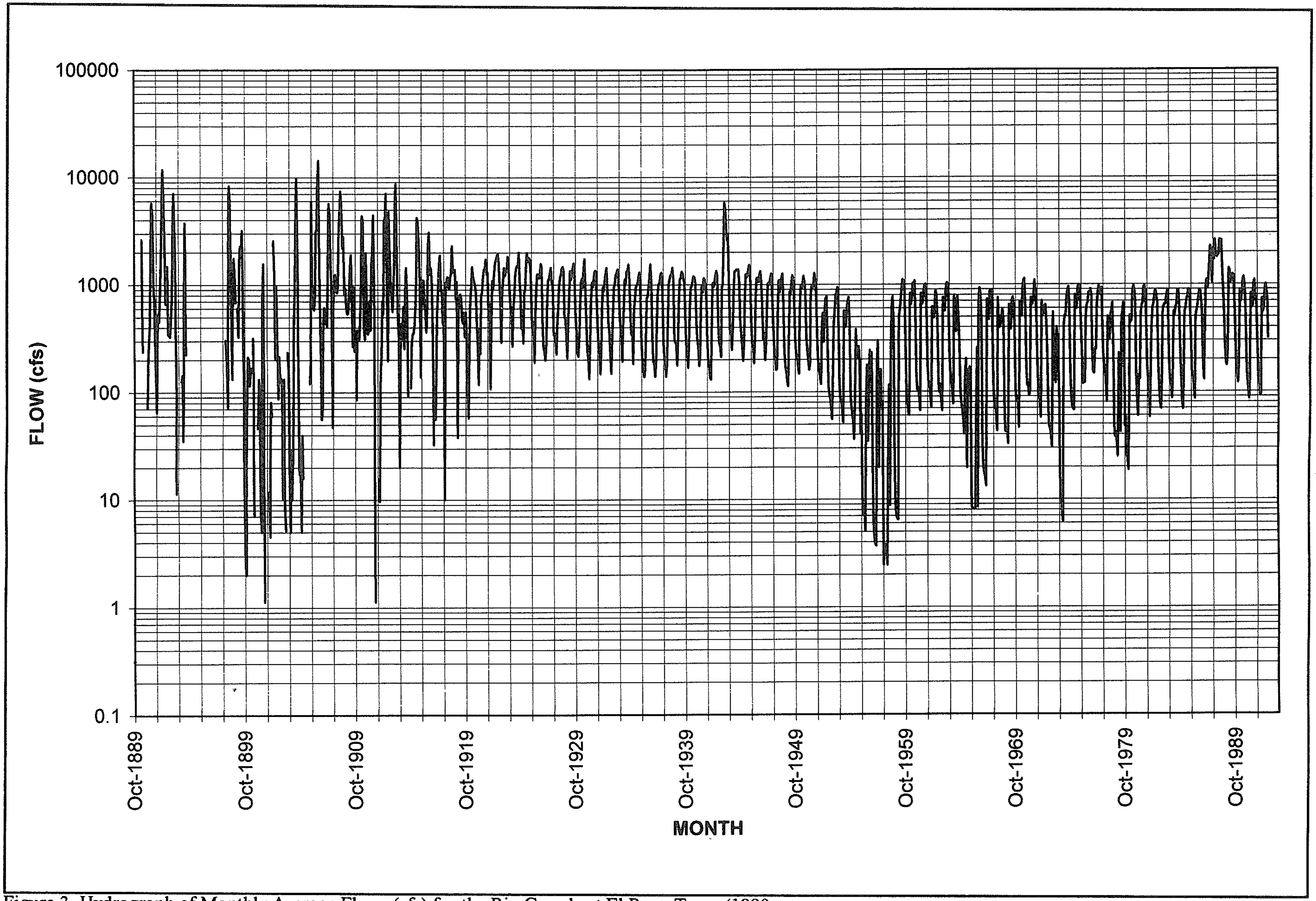

Figure 3. Hydrograph of Monthly Average Flows (cfs) for the Rio Grande at El Paso, Texas (1889-1992)

Models generally serve two purposes; explaining past observations and projecting future conditions. One cannot perfectly verify and validate future projections with any modeling tool, no matter how well it matches past history. The test of an acceptable model is one that is used by other specialists and accepted by the modeling community for studying, managing and operating a basin. A model that is widely used and accepted is the best measure of a successful model. In that sense, the USGS model (Frenzel and Kaehler 1990 and Frenzel 1992) has been very successful.

Models always are somewhat uncertain (Figure 4). One can observe the historical pattern of stress and response in a system, and recognize some error in both terms. There also is great uncertainty in the projected future stress. Commonly, modelers agree or stipulate what future scenario will be examined. The best history simulation and history match might result in the middle curve of projected response on Figure 4 with some acceptable degree of error. However excellent the historical match, the future response curve hinges on the conceptual model. If the conceptual model is changed, for example, by providing more source terms - river, drains, wetlands, evapotranspiration salvage, then the different concept of the system may cause a new response far outside the error expected from the old response. Alternatively, an opposite deviation can be caused by considering barrier boundaries. Every author has his own concepts of the system, therefore, models differ as the product of the author's understanding.

> "...it would appear that our goal in modeling a phenomenon should be to formulate as simple a model as possible that is still robust for the class of realizations to be analyzed by the model." (Wan 1990)

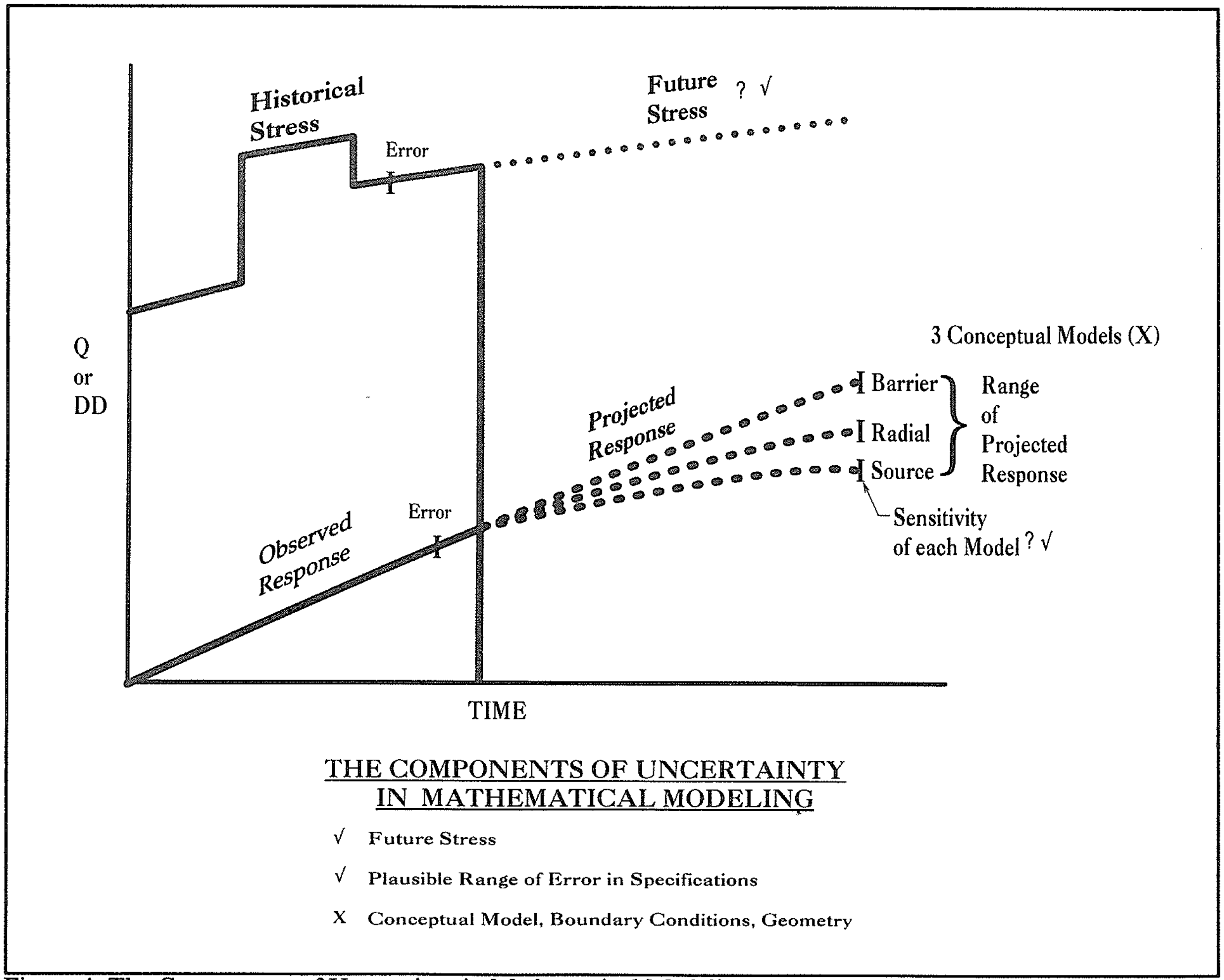

Figure 4. The Components of Uncertainty in Mathematical Modeling

There are some conventions in preparation of groundwater models. Various authorities suggest the process on Table 1. My experience indicates that following standard procedures does not ensure acceptance of the model. Generally, a model should be based on prior knowledge, which informs the conceptual understanding of the system. Model work begins by simulating an initial pattern of head and flow. When the initial pattern is simulated, the modeler moves on to simulate historical observed head and flow. With initial and historical conditions in the basin matched, the modeler can have some confidence in his model parameters (transmissivity, storage, vertical conductance). When history, time-variable flow, and head are matched with all parameters together, then one may proceed with a model to explain hydrologic history and future projections.

Table 1. Groundwater Modeling Process

1. Examine data and literature	
2. Formulate conceptual model of pattern of head, flow	
3. Simulate initial pattern of head and flow to verify compatible terms of Q and T	$Q = T\,\Delta h/\Delta l\,L$ or $Q = C\,\Delta h$; $C = TL/\Delta l$ L = Geometry known L = Geometry known Δl = Geometry known Δh = Observed data (known) T = Unknown Q = Literature (approximate)
4. Simulate history of head response to a known stress to verify compatible term T/S	$s/Q = k_1/T \log k_2\,T/S$ s Known, Q known, k constants Ratio T/S unknown T estimated previously, now calibrated S = calibrated
5. The model is a specified relationship of:	Geometry (3D) Flow rate T Storage properties Head Time
6. The governing relationships, with flow conditions and initial heads, constitute a model that is used to calculate the effects on initial head and flow throughout the model area caused by imposed changes in head and flow. The results may be used to explain history or to manage future effects.	

Modelers have been through this process 14 times since 1972 in the LRG basin, as seen in Table 2. Models were produced for the water hearings in the mid-1980s over El Paso's application. Frenzel (1990 and 1992) and Hamilton-and Maddock (1993) share the same basic model structure. The last three models on the list are Barroll (1998), Boyle (in preparation) and Maddock (in preparation). Barroll (1998) is a superposition adaptation of Hamilton and Maddock (1993). Boyle (in preparation) and Maddock (in preparation) both are preparing subsequent refined versions of Frenzel. Maddock is extending the old model grid from below Selden Canyon and bringing it up to Caballo Reservoir through Rincon Valley, as shown on Figure 5.

Table 2. Lower Rio Grande Groundwater Models

- **Richardson, G.L, Gebhard, T.G., Jr., and Brutsaert, W.F., 1972**. "Water Table Investigation in the Mesilla Valley," New Mexico State University, Technical Report 76.
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- **Maddock, III, T. and Wright Water Engineers, Inc., 1987**. "An Investigation of the Effects of Proposed Pumping in the Lower Rio Grande Declared Basin"
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- **Hamilton, S.L, and Maddock, III, T., 1993**. "Application of a Groundwater Flow Model to the Mesilla Basin, New Mexico and Texas," Department of Hydrology and Water Resources, University of Arizona, HWR No. 93-020.
- **Lang, P.T., and Maddock, III, T., 1995.** "Simulation of Ground-Water Flow to Assess the Effects of Pumping and Canal Lining on the Hydrology Regime of the Mesilla Basin, Doña Ana County, New Mexico and El Paso County, Texas," Department of Hydrology and Water Resources, University of Arizona.
- **Barroll, P., 1998**. "Maddock and Papadopulos Models of the Lower Rio Grande," State Engineer Office memorandum and electronic files (August 26, 1998)
- **Boyle Engineering Corporation (in preparation)**
- **Maddock, III, T. (in preparation)**

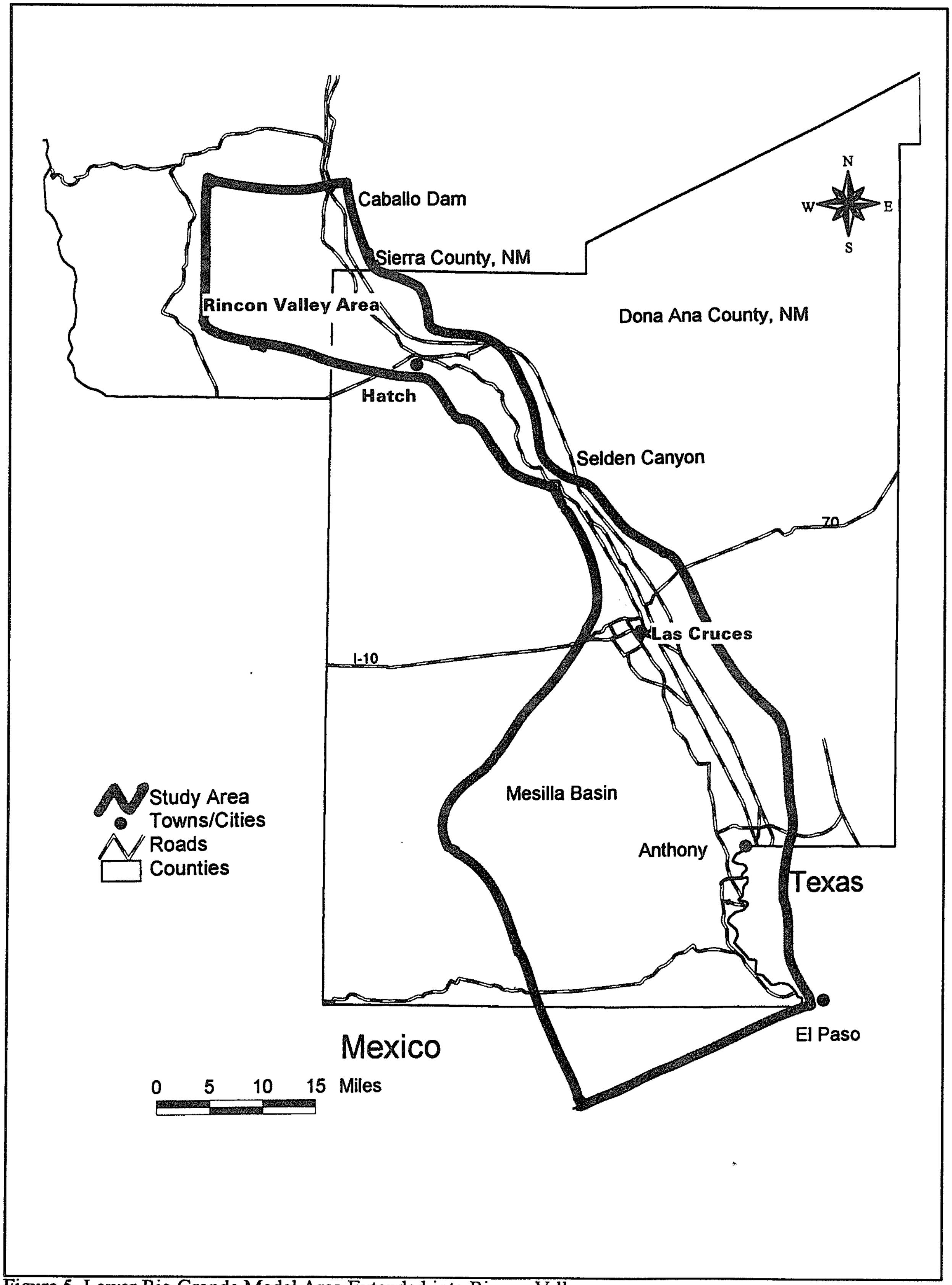

Figure 5. Lower Rio Grande Model Area Extended into Rincon Valley

The three models currently in preparation are compared on Table 3. The OSE model is being used for administration of water rights. The Maddock version is in preparation to extend the area and bring the history match up to 1995. The Boyle model will link a detailed surface-water model to an existing groundwater-flow model. All three models use the same program - MODFLOW (McDonald and Harbaugh 1988). In Boyle's model, a streamflow allocation model, is set up to interact with MODFLOW. The antecedent model versions all rely on Maddock and Hamilton (1993). The areas of the models are somewhat different.

The OSE superposition model is not an elevation referenced model and does not simulate evapotranspiration. The lack of evapotranspiration in an administrative model is a concern to some users. Maddock has added the very important aspect of seasonality, so wellfields can be simulated in the irrigation season and left off in winter. The Boyle work includes surface-water interaction on a daily basis, including a water-priority package and a water-quality package, and will have irrigation wells added. All modeling work in the past 26 years has excluded explicit treatment of irrigation well location and pumping rates. The models used net surface-water depletion and assumed that wells fill in the gap to meet diversion demand on farms. There is no specific irrigation well simulation in the LRG to date.

TABLE 3. Current Models

Author	Barroll (1998)	Maddock (in prep.)	Boyle (in prep.)
Purpose	OSE administration	Extend to Rincon & year 95	Link to MODFLOW
Program	MODFLOW	MODFLOW	BESTSM & MODFLOW
Antecedent	Frenzel (1992) & Hamilton & Maddock (1993)	Frenzel (1992) & Hamilton & Maddock (1993)	BESTSM & Hamilton & Maddock
Area	Mesilla Valley	Lower Rio Grande	Lower Rio Grande
Scenarios	OSE permits	GW/SW operations history to 1995, future well effects	Project delivery alternatives, involving acreage, diversion methods, canal lining
Approach	Superposition No ET	Elevation based, detailed surface water features, seasonality added	No historical baseline, SW interaction detailed, daily data, priority, water quality, irrigation wells
Result	Drawdown & stream depletion	Drawdown, stream depletion by feature & ET salvage	Detailed streamflow effects, drawdown & water quality

The nature of the output available from the models is illustrated on figures 6 through 8. Figure 6 shows drawdown contours for an arbitrary 10,000 acre-feet per year wellfield pumping for 40 years near the location of downtown Las Cruces. Such a wellfield would cause a cone of depression to develop at 40 years with a ten-foot drawdown line around the downtown area. Water levels would drop 80 feet locally and the cone of depression would extend to a four-mile radius, elongated by response to the river boundary.

Another category of information from the models is the effect on surface-water bodies (Figure 7). The model charts the pumping rate through time and illustrates the sources of water to a wellfield six miles from the river. The simulation is for 200 years. In the early decades, almost all water is produced from aquifer storage depletion. As time goes on, the Rio Grande and drain-depletion effects begin to supply more water due to pumping from a wellfield on the west mesa. After 200 years, approximately two-thirds of withdrawals come from the river. It would take millennia to approach 100 percent. Evapotranspiration salvage is a piece of the water balance that should be kept in the administrative assessment to avoid overstating the impact on the river.

All MODFLOW model versions can be post-processed to show particle tracking. Figure 8 shows the aquifer space where water has been displaced to move into a wellfield. This hypothetical wellfield in the LRG shows the 10-year, 40- and 100-year displacement zone. Water is actually arriving at the wellfield from a river source between 40 to 100 years.

For the moment, the great weakness in quantifying relationships in the basin is that modelers do not have a history of well pumping. Wells are the critical stress to simulate in any of these models. Nevertheless, the tools are becoming available in several forms to assist management, operation and administration of the groundwater/surface-water interaction in the LRG.

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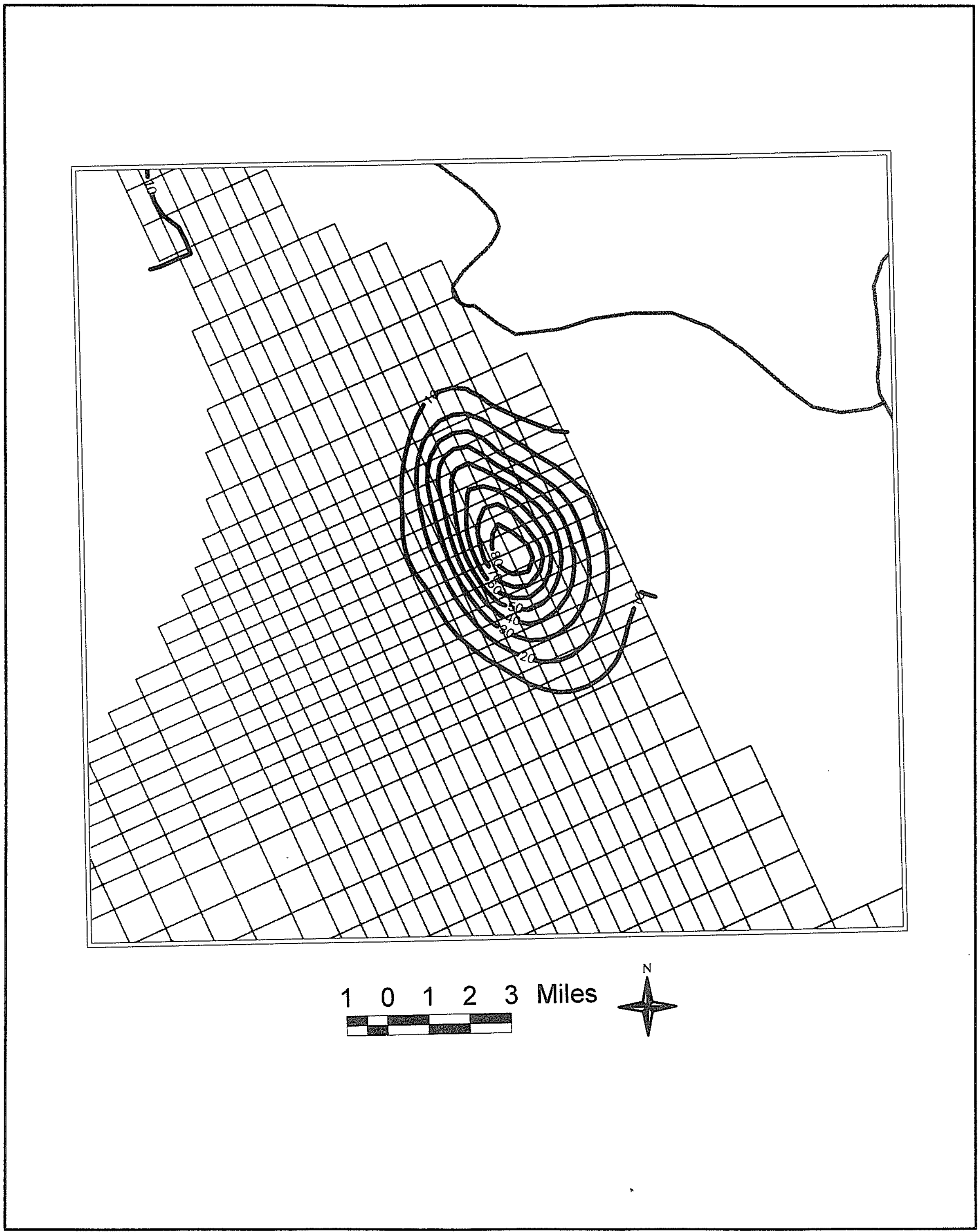

Figure 6. Simulated Drawdown Contours from Pumping 10,000 AFY for Forty Years

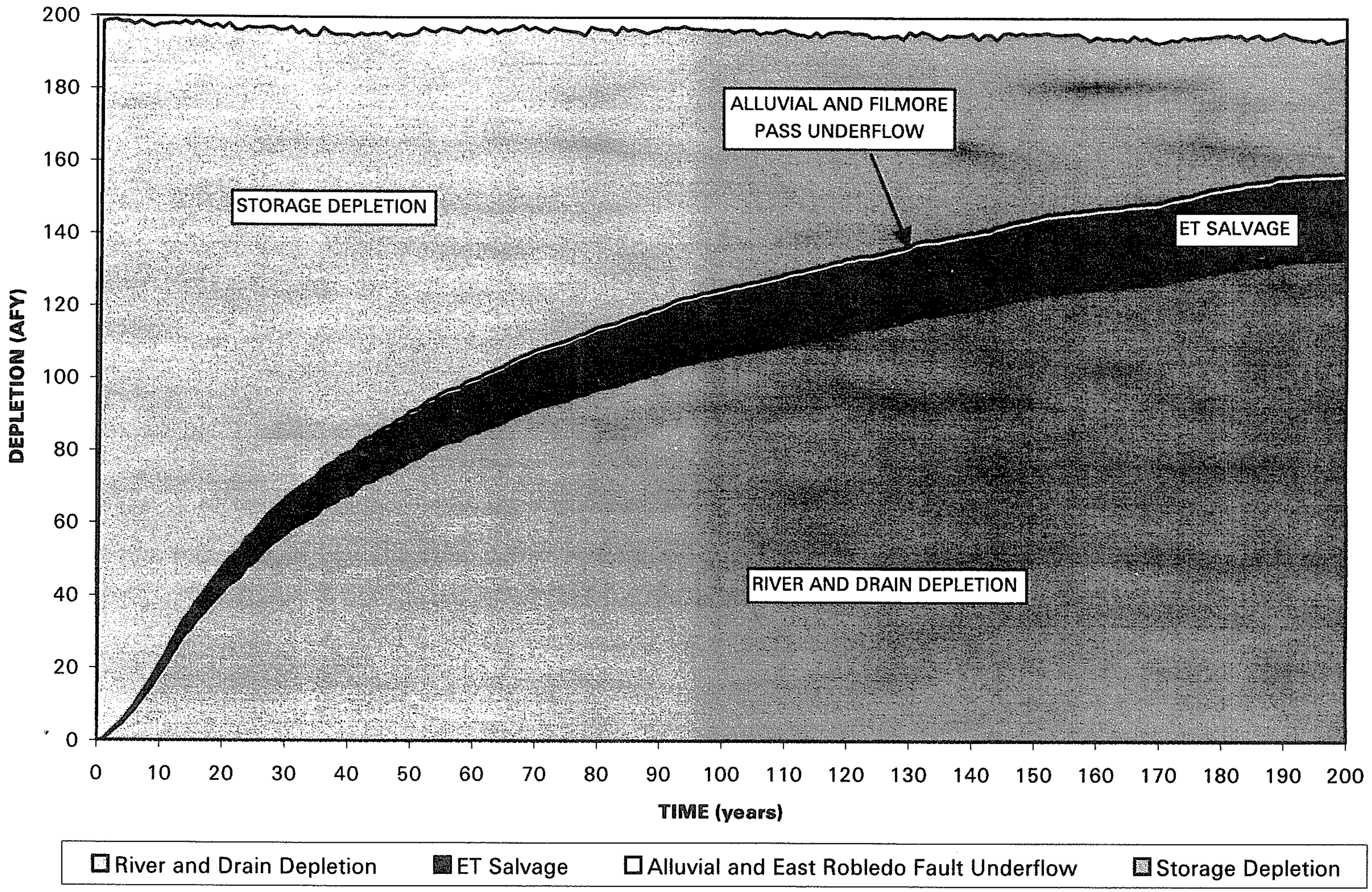

Figure 7. Sources of Flow to Well from Pumping 200 AFY on West Mesa (USGS Frenzel Model, 1992)

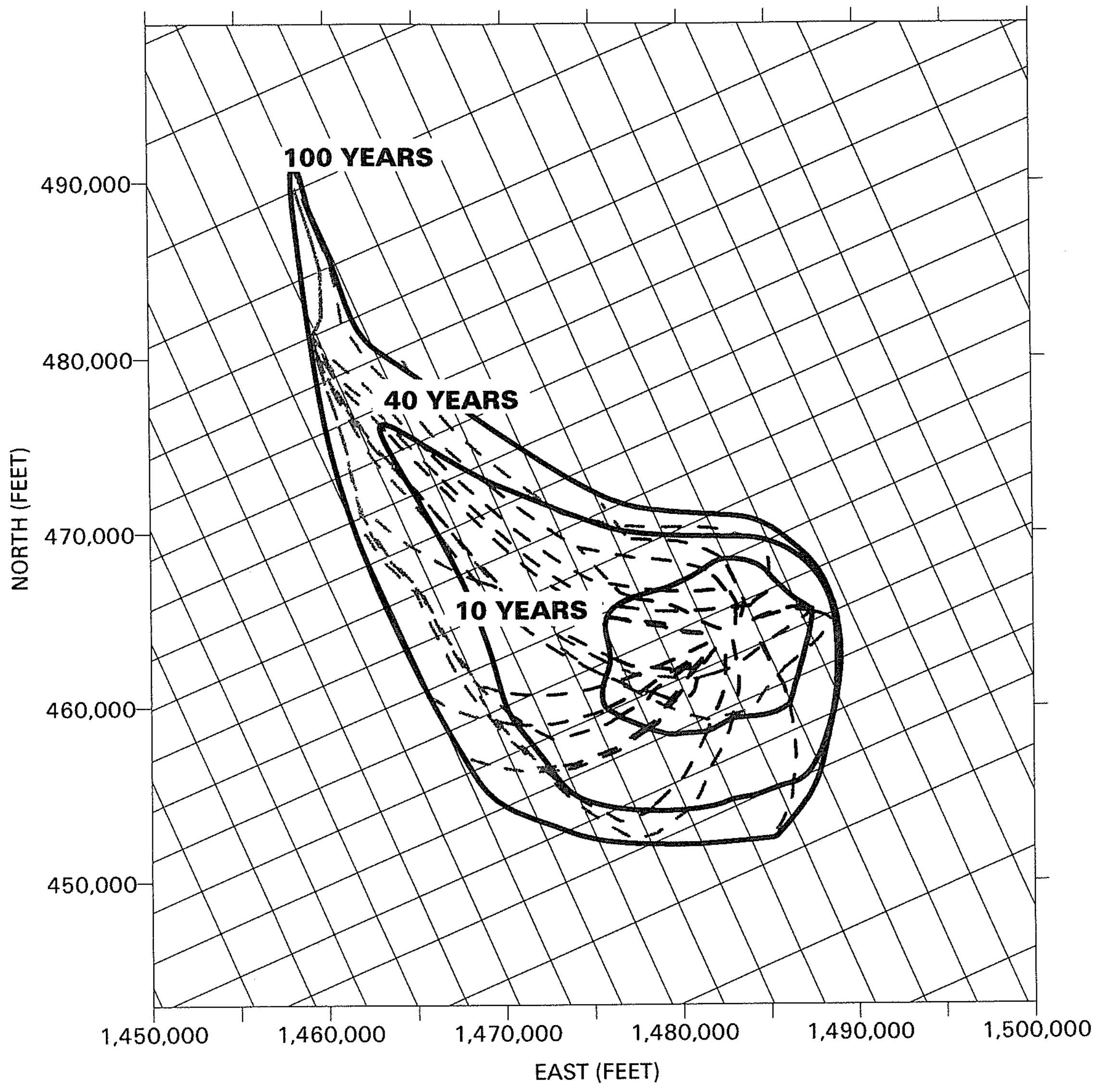

Figure 8. 10-, 40- and 100-Year Displacement of Groundwater