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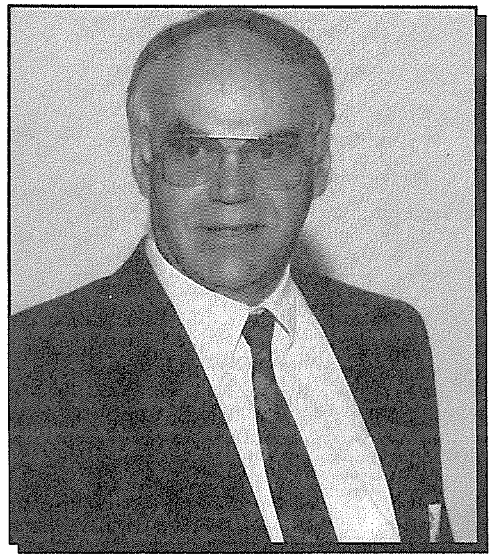

SURFACE WATER AND GROUNDWATER FOR GROWTH IN THE ALBUQUERQUE BASIN

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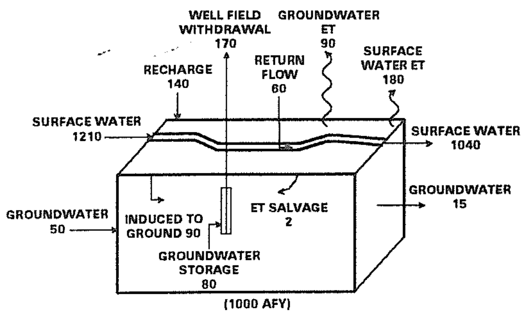
EXISTING CONDITION

In examining the sources of water to accommodate growth of demand in the Albuquerque Basin, we should review the present status of water supplies and uses. Figure 1 illustrates the balance of inflow and outflow to the Middle Rio Grande. Values are compiled from Thorn et al. (1993), and recent agency information (public meetings, October 16, 1994 and September 16, 1994). The system yield is about 1,500,000 acre-feet per year (a-f/y). Surface water brings in about 1,300,000 a-f/y, of which 180,000 a-f/y is returned to the atmosphere. Wellfields withdraw 170,000 a-f/y, accounted for by 90,000 a-f/y of induced river recharge, 80,000 a-f/y of aquifer storage depletion, and 2,000 a-f/y of salvaged evapotranspiration. There is no physical shortage of surface water.

The water-rights picture is summarized on Table 1. Albuquerque produces about 124,000 a-f/y from wells under a State Engineer Office (SEO) permit to withdraw 132,000 a-f/y. Using that 132,000 a-f/y permit, the City has the right to consume about 70,500 a-f/y from vested, purchased and contracted consumptive-use rights. The San Juan-Chama (SJ-C) Project contract for 48,200 a-f/y is the largest component of the City's consumptive-use right.

The SEO calculates the net surface-water depletion from City withdrawals after accounting for the amount of the withdrawal that is taken from groundwater storage depletion and the amount returned to the Rio Grande from the wastewater treatment plant return flow. Return flow serves to offset some part of the water induced to the ground from the river. According to the SEO calculations,



SYSTEM BALANCE (AFY)

	IN	OUT
RIVER	1,210,000	1,040,000
RECHARGE	140,000	-
EVAPOTRANSPIRATION	-	270,000
WELLFIELD	-	170,000
RETURN FLOW	60,000	-
GROUNDWATER	50,000	15,000
GROUNDWATER STORAGE	80,000	-
	1,540,000	1,495,000

WELLFIELD BALANCE (AFY)

	IN	OUT
WELLFIELD	-	170,000
INDUCED SURFACE WATER	90,000	-
SALVAGED ET	2,000	-
AQUIFER STORAGE	80,000	-
	172,000	170,000

Figure 1. Middle Rio Grande Basin water balance (a-f/y).

126,000 a-f/y of City withdrawals is supplied by 47,000 a-f/y from aquifer storage, 60,000 a-f/y of wastewater treatment plant return flow and about 19,000 a-f/y of net Rio Grande streamflow depletion. Thus, the SEO currently requires about 20,000 a-f/y of the City's consumptive-use right to be exercised (Table 1). About 50,000 a-f/y of consumptive-use rights is held in reserve unexercised for the future.

Table 1 also illustrates the magnitude of other water rights in and downstream of the Middle Rio Grande Basin. The major holder in the mid-basin other than municipal rights is the Middle Rio Grande Conservancy District (MRGCD) with nearly 150,000 a-f/y of exercised and contracted rights (MRGCD 1993), an amount exceeding, but comparable to, the City's current withdrawals. Lower in the Rio Grande valley, Elephant Butte and Caballo Reservoir evaporation consumes 165,000 a-f/y (Wilson 1992); also exceeding the City's current withdrawals. Below those reservoirs, Doña Ana County irrigation consumes 220,000 a-f/y supported from the reservoirs and wellfields.

TABLE 1. WATER RIGHTS (UNADJUDICATED) BELOW MIDDLE RIO GRANDE BASIN

	Consumptive Use (a-f/y)
Albuquerque (vested, purchased) and 48,200 a-f/y San Juan-Chama Project	70,500
Albuquerque exercise of surface water rights (per SEO)	~20,000+
Albuquerque surface water rights available for growth	~50,000
MRGCD irrigation in four counties	128,000
MRGCD SJ-C Project	20,900
Other municipalities, Bernalillo to Socorro	26,000
Elephant Butte/Caballo Reservoir evaporation loss	165,000
Doña Ana County irrigation	220,000
Available for transfer:	
½ of irrigation?	174,000?
reservoir loss?	165,000?

+ SEO calculation of surface water depletion
= groundwater withdrawal - groundwater storage sources - city return flow
= 126,000 - 47,000 - 60,000
= 19,000 a-f/y

With 50,000 a-f/y in reserve, there is no current shortage of surface-water rights for the City's consumptive use. If the 50,000 a-f/y were to become fully exercised to support future growth, the potential to acquire other rights would involve transferring rights from the existing rights now used for irrigation. Several hundreds of thousands a-f/y appear to be in exercise for irrigation, with a potential for transfer to municipal or industrial purposes.

I calculate the volume of stored groundwater to a depth of 600 feet below the water table in 2,100 square miles of the middle basin, using an assumed specific yield of 10 percent, to be 80 million a-f (Table 2). That is equivalent to a 600-year supply at current pumping rates. Hawley and Haase (1992) identified the most productive part of the aquifer as the Upper Santa Fe unit of the Santa Fe Group. They mapped a 4 mile x 10 mile area near the City having a saturated thickness of 600 feet as the most productive aquifer zone. At an assumed 20 percent specific yield, the water volume in this most productive part of the aquifer is 3 million a-f. The City has produced an equivalent volume from the aquifer; 2.7 million a-f 1960-1992 (Thorn et al. 1993), or 3.14 million a-f since 1933 (City of Albuquerque, written communication, June 6, 1994). By contouring the cone of depression created by withdrawing 2.7 million a-f in 32 years, Thorn and others (1993) estimated that 0.99 million a-f (37 percent of withdrawals) to 0.50 million a-f (18 percent of withdrawals) had been derived from aquifer storage. Thus, most of the City's historic production (82 to 63 percent) has been derived from the surface-water sources.

ISSUES

The current situation is one of increasing water demand for municipal, industrial, recreational and environmental maintenance. Municipal use is increasing at about 25,000 a-f/y per decade. Each new purpose of use is bidding to obtain water used by existing purposes. Agricultural water is susceptible to transfer. The theme of this conference, "The Water Future of Albuquerque and Middle Rio Grande Basin," arises from concern about the aquifer's capacity and longevity, the limitations on Rio Grande impacts, and access to water rights for future consumption. My perspective on managing these three components of the situation is presented below, while acknowledging other important issues about water quality, environmental goals, land subsidence, Bosque preservation and economic burdens and benefits.

TABLE 2. MIDDLE RIO GRANDE AQUIFER STORAGE VOLUMES

Total basin	2,100 sq. mi. x 600' x 0.10 =	80 million a-f
USF at Albuquerque		
	40 sq. mi. x 600' x 0.20 =	3 million a-f
Albuquerque Vicinity Usage 32 Years to 1992		
Groundwater withdrawal (1960-1992) =		2.7 million a-f
Amount from aquifer storage		
	(if Sy = 0.2)	0.99 million a-f
	(if Sy = 0.1)	0.50 million a-f
	(if Sy = 0.05)	0.25 million a-f
Estimate of <u>Appropriable</u> Storage		
SEO 1983 letter to Water Law Committee		2.7 million a-f
	low T estimate	6.4 million a-f
	high T estimate	1.7 million a-f

Stream Depletion Concepts

Figure 2 illustrates the Glover (1974) curve relied on to date for SEO administration of stream depletion effects. The model is two-dimensional in that the well and river are considered linked by a uniform transmissivity (T). The magnitude of the depletion effect increases with time of pumping and decreases with distance from the pumping center. Since 1987, three-dimensional numerical models have been applied for scientific study, but not for administrative purposes, to the question of stream/aquifer interrelationships in the Albuquerque Basin. Table 3 summarizes the history of stream depletion ratios (induced stream source per unit of well withdrawal) projected since 1953. In the 1992 and 1994 modeling by the U.S. Geological Survey (USGS), the percentage of City pumping calculated to be derived from the Rio Grande has decreased, and the percentage considered to be derived from aquifer storage has increased from the earlier work. I note, however, that a different (smaller) effective specific yield in the three-dimensional models would result in depletion ratios comparable to those derived earlier by the two-dimensional models.

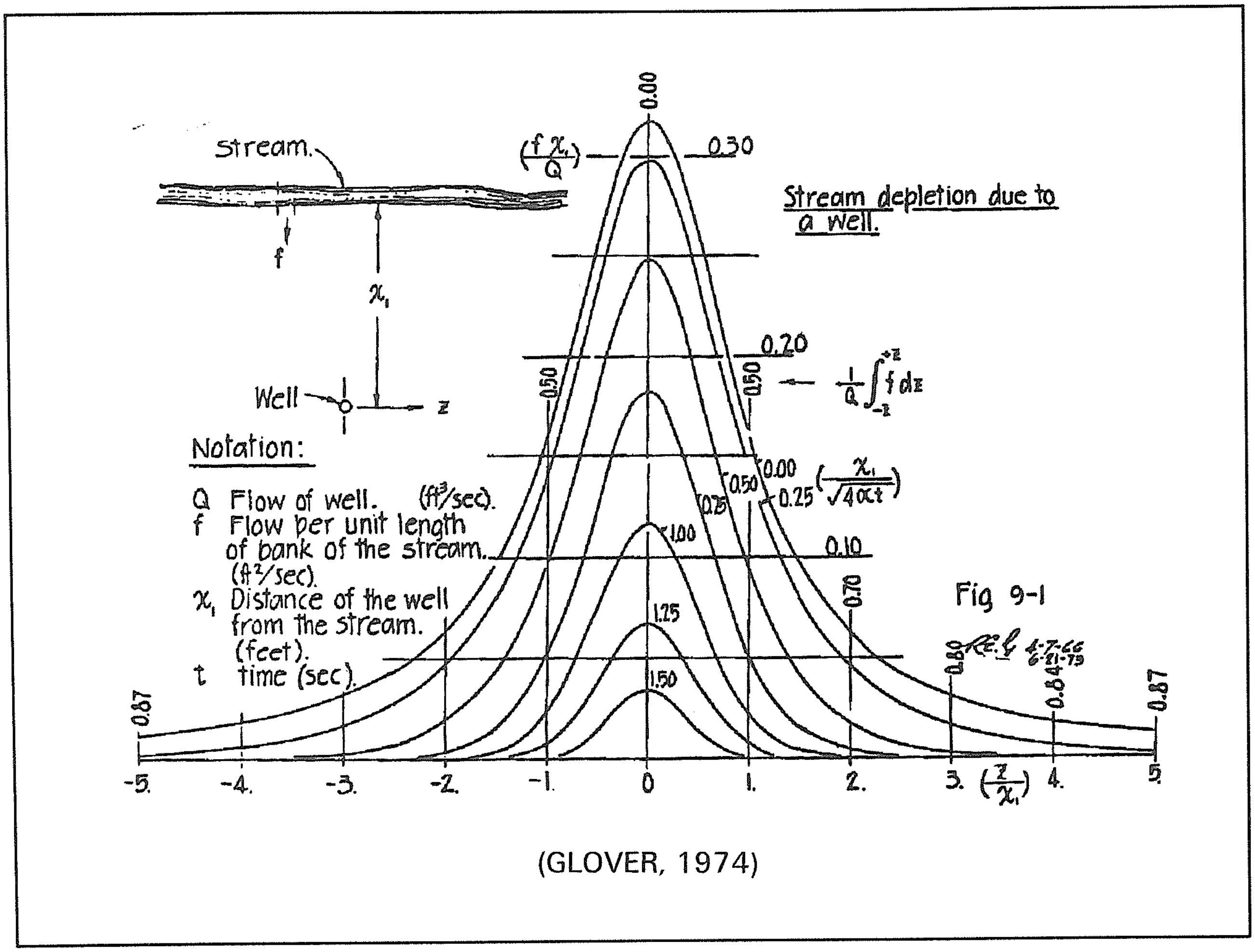


Figure 2. Glover stream depletion curve.

TABLE 3. HISTORY OF STREAM DEPLETION PROJECTIONS

Projected Year	2D 1953 C.V. Theis[1]	2D 1967 Reeder et al.[2]	2D 1979 Kelly[3]	3D 1987 Kernodle[4]	3D 1993 Thorn et al.[5] S=0.2	3D 1993 Thorn et al.[5] S=0.1	2D 1993 SEO[6]	3D 1994 USGS[7]
1980	75%	72%	71%	74%	25%	63%		
1990		73%					68%	43%
2020								49%
2030				87%				

[1] Theis 1953
[2] Reeder et al. 1967
[3] Kelly 1979
[4] Kernodle et al. 1987
[5] Thorn et al. 1993
[6] New Mexico State Engineer Office. 1993. Verbal communication.
[7] U.S. Geological Survey. 1994. Verbal communication.

Aquifer Yield Concepts

The aquifer structure is of concern due to consequences on its capacity and longevity. The hydrogeologic understanding has been refined progressively, not radically. A 1970s and 1990s cross section near Gibson Street are compared on Figure 3. The recent river alluvium, the axial gravels and the deeper Santa Fe Group geometry are remarkably consistent in both presentations. The Rio Grande axial gravels that constitute the best aquifer material were described by Spiegel in 1961 much as they were by Hawley and Haase in 1992 (Figure 4). The current estimates of parameter specifications for the various geologic units in Table 4 are substantially similar to those noted in earlier decades. For example, the alluvium was characterized by Theis (National Resources Committee 1938) with the same properties (50,000 gallons per day/foot) as were adopted in the 1994 SEO hearing on Intel's application for appropriating groundwater.

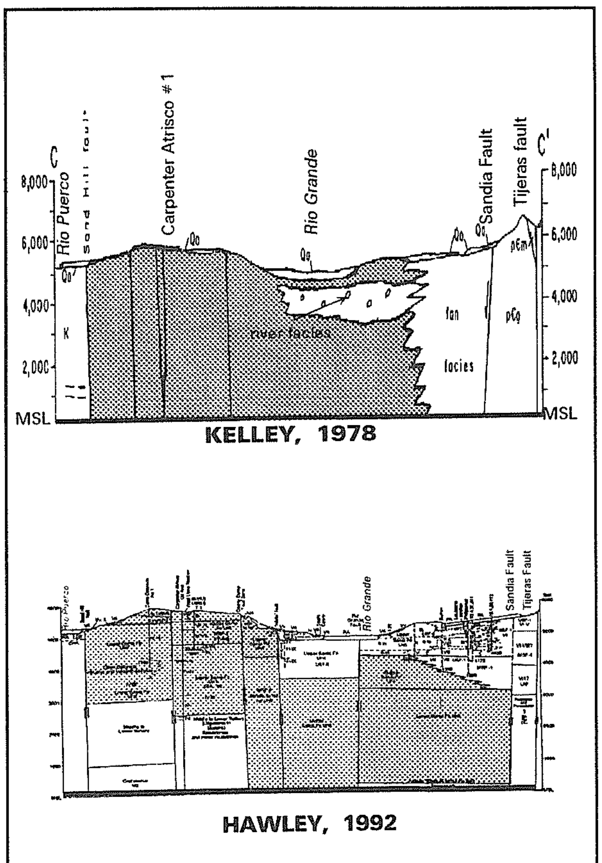


Figure 3. Development of geology concept.

"The principal thalweg of the ancient river probably trended southwest from Otowi to near Cochiti, and trended southward from a point about 6 miles west of Cochiti to Algodones, thence just east of the present inner valley of the Rio Grande to San Acacia, and through Socorro valley just west of the present river." (Spiegel 1961)

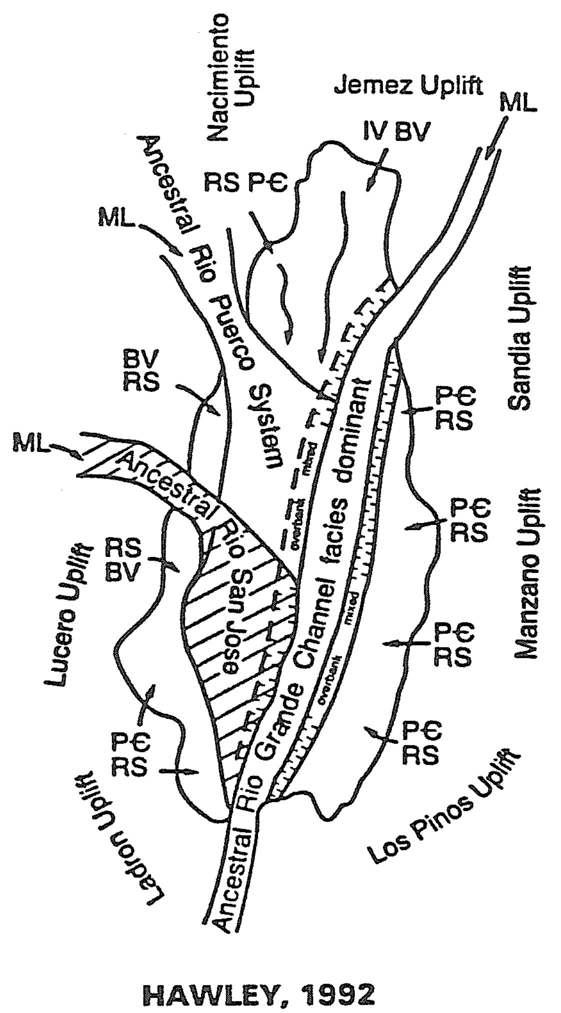


Figure 4. Concepts of axial gravels.

TABLE 4. DEVELOPMENT OF PARAMETER ESTIMATES

	Characteristic Hydraulic Conductivity (ft/day)
National Resources Comm. 1938 (p. 282)	70
Bjorklund and Maxwell 1961 (p. 2)	2-112
McAda and Kernodle (written comm.)	2-70

One aspect that has caused confusion is the three-dimensional pattern of multiple water tables and heads that vary with depth in the system. Figure 5 illustrates the situation. Multiple and inverted water tables have been observed. A continuum of up to 12 different water levels has been observed at various depths in piezometers at a nested site in the south valley. Identifying and determining the volume of the dewatered water table is difficult. Where that volume is overstated, then is multiplied by a specific yield of 20 percent, an excessive value for the amount of water taken from aquifer storage can result.

The cone of depression reported for 1992 (Thorn et al. 1993, Figure 32) is compared on figures 6 and 7 to predictions made in 1967 (Reeder et al. 1967) and in 1978 (Kelly 1979, in AGUA). The 60-foot and 100-foot contours have been highlighted so that the differences in area and magnitude of drawdown can be compared. Considering the data problems discussed above, I do not consider the differences of 0 to 40 feet to indicate any significant problem in the forecasts that would have misled water planners about the reliability of the aquifer resource.

The nature of the geologic materials, their general distribution and hydrologic character has been appreciated and used by water planners for decades. In the 1990s, the hydrogeologic information has been refined in detail and interpretation has progressed as an advance in, not as a radical departure from, the earlier understanding.

SYSTEM YIELD

Appropriable Groundwater

The 80 million a-f accessible from 600 feet of saturated valley fill in the middle valley is not available for development because 600 feet of uniform drawdown would cause the Rio Grande to dry up. The SEO places an administrative limit on groundwater appropriation set at that volume of groundwater production which results in an induced river recharge rate (capture) that can be offset by retiring rights from the river. Figure 8 illustrates the administrative principle and shows that the appropriable volume depends on the hydraulic connection between the aquifer and the surface-water body. A poorer connection (lower hydraulic diffusivity) means more aquifer volume can be dewatered before the water-rights limitation on the stream is met.

There is no immediate hydrologic or economic barrier to doubling or tripling the dewatered volume of the aquifer. Extending the time of pumping from 60 to 100 years at a constant rate would cause about 15 percent additional drawdown. Doubling the pumping rate would, of course, double the drawdown. A few 100 feet of additional pumping lift would be a tolerable part of the cost of operating the City water system. Rapid growth in the withdrawal rate has caused the decline in aquifer water levels.

The SEO estimated in 1983 the volume of stored groundwater subject to appropriation from the Middle Rio Grande valley to be 2.7 million a-f. As described above, 0.5 to 1.0 million a-f may have been produced from aquifer storage to date. The SEO assumed a T of 100,000 gallons per day/foot (gpd/ft) in this calculation. Assuming 130,000 a-f/y of offset rights in the basin, Figure 9 illustrates the sensitivity of the appropriable volume to the characteristic T. Up to 6.4 million a-f could be taken from storage if T is as low as 50,000 gpd/ft, or as little as 1.7 million a-f if T is as high as 200,000 gpd/ft. After the limit is reached on that appropriable volume, the aquifer would be held at a new steady-state water level with the surface-water right being exercised through the wells. The advantage of using appropriable groundwater storage in the basin is a substantial, but a transitory, one.

Growth Scenarios

Figures 10A-10E illustrate five example management approaches to providing City water from surface-water and groundwater sources. Each curve displays history to 1990, when withdrawals were about 125,000 a-f/y, followed by four different ways of using groundwater for growth to 300,000 a-f/y in year 2100.

Scenario	Approach
A	Groundwater only to year 2100 for a total supply of 300,000 a-f/y.
B	Groundwater steady at 125,000 a-f/y after 1990 to year 2100. Surface-water

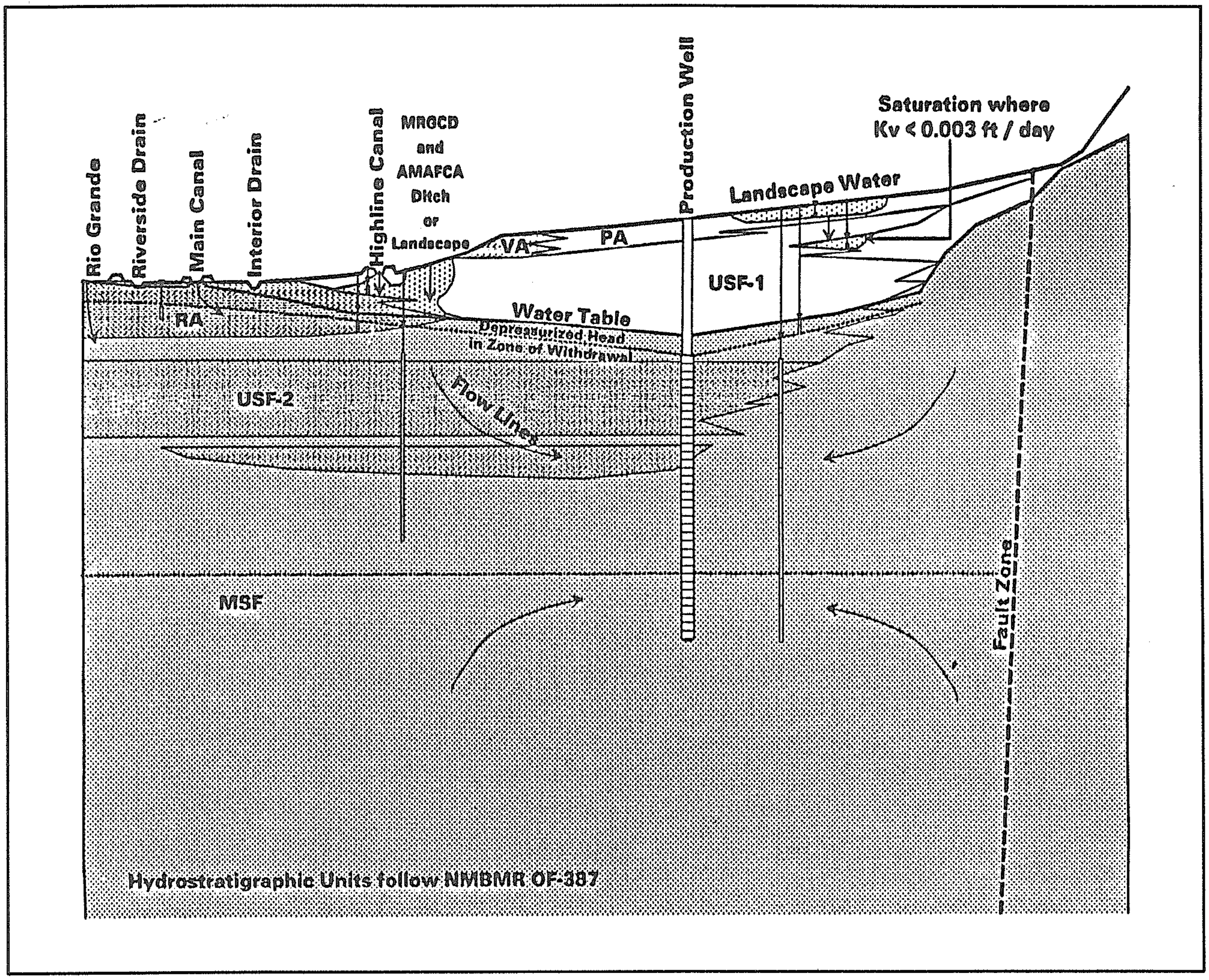


Figure 5. Saturated zone and variable head with depth.

direct diversion grows to 175,000 a-f/y in year 2100 for a total supply of 300,000 a-f/y.

C Groundwater declines from year 1990 to 0 withdrawal by year 2040. Surface water grows to provide the total supply of 300,000 a-f/y by year 2100.

D Groundwater source as "A," but injection of surface water to the limit of exercise of 70,500 a-f/y of City water rights.

E Groundwater source as "A," but after 1990 all wastewater treatment plant return flow is recharged to the aquifer.

Each example is calculated using the Glover-Balmer two-dimensional model. The examples are set to indicate 60,000 a-f/y of river depletion in 1990, a value near that in the 1994 USGS three-dimensional modeling work. The four examples indicate the operation of the components subject to management and the trends of the system. These examples are not intended to be forecasts for other than the purpose of illustrative examples for understanding and discussion at this conference.

The calculations imply that:

a) Under Scenario A, City rights in SJ-C Project water can carry the wellfields to year 2050, at which time other mid-basin rights would need to be acquired. Mid-basin rights are not exhausted even by year 2100 if the City continues to rely on wells. Groundwater storage remains a significant source for growth, but the volume depleted is untenable in that it exceeds the appropriable volume.

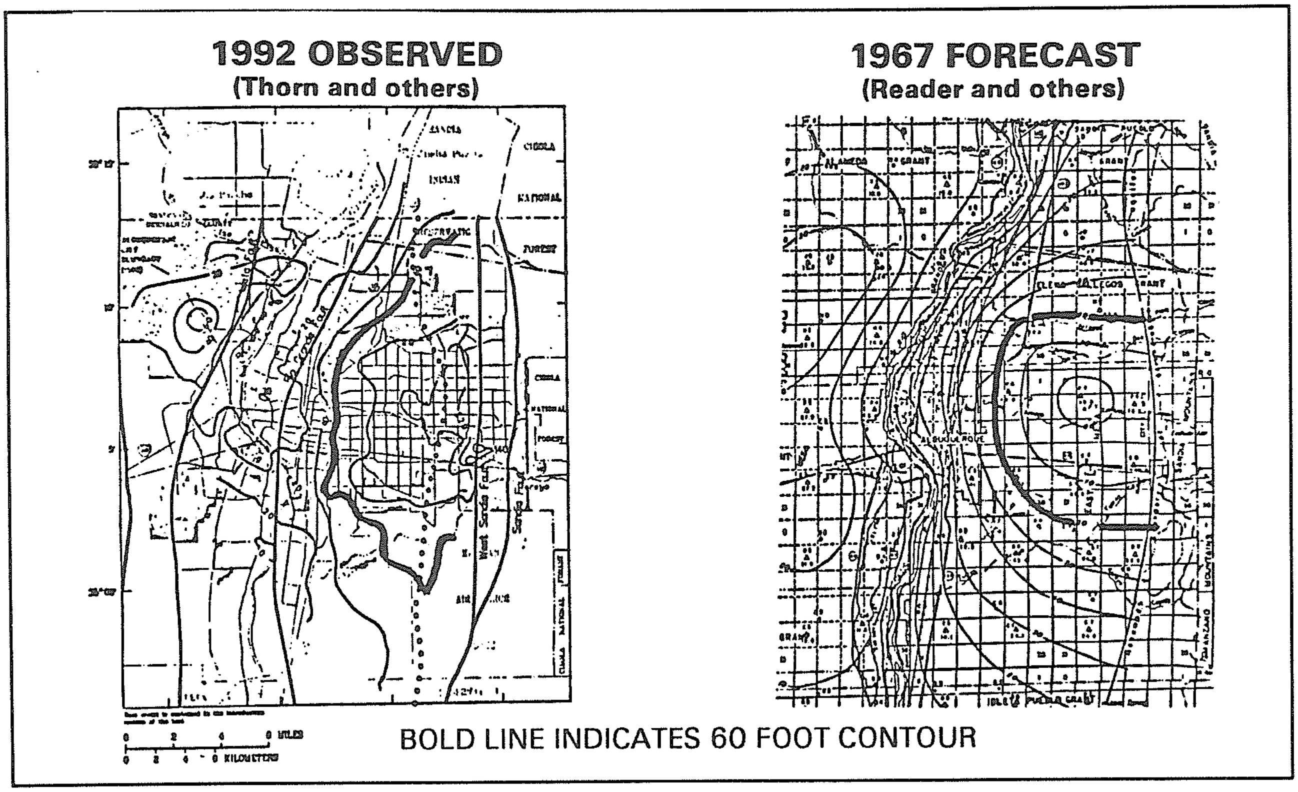


Figure 6. Observed and predicted drawdown.

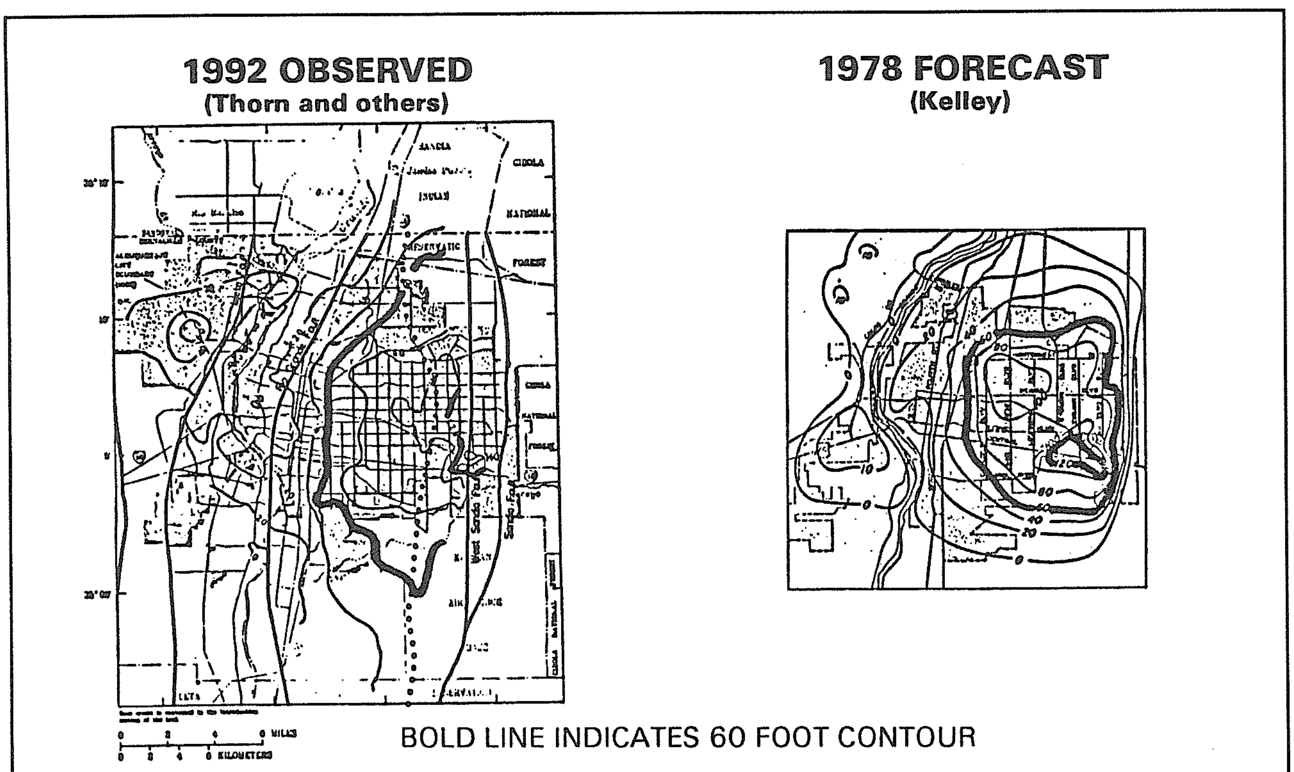


Figure 7. Observed and predicted drawdown.

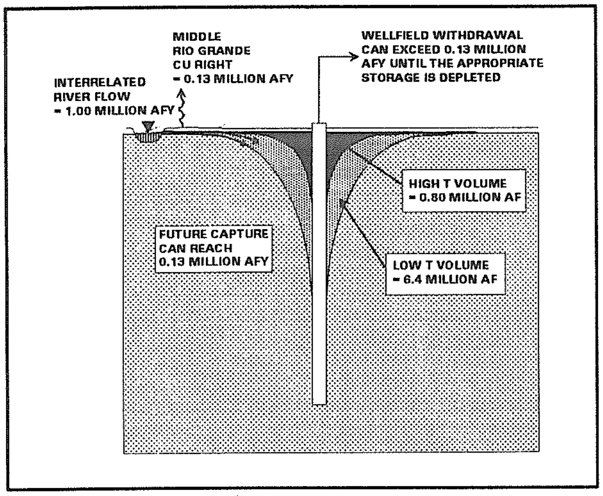


Figure 8. Groundwater appropriation is limited by the amount of interrelated surface water rights.

b) Converting to direct surface water diversions and holding groundwater steady at 125,000 a-f/y (Scenario B) would shorten the time at which new rights are needed to about year 2020. The beneficial source from groundwater storage would become a minor part of the City supply, but would use the appropriable volume.

c) Reducing the rate of groundwater withdrawal and substituting surface water (Scenario C) causes a substantial water-rights penalty. The time at which new rights are needed is shortened to year 2010. *More* rights are needed than are in exercise because the river is depleted beyond the consumptive-use rate while additional water fills aquifer storage. The rights penalty could be as much as 1.5 million a-f from 1990 to year 2100. Reducing pumping is an undesirable alternative.

d) Scenario D indicates that the water rights deadline can be extended about 10 years to year 2060 by using or injecting the idle rights, up to 70,500 a-f/y, during the next five decades. Storage depletion becomes untenable, however, after about year 2060.

e) Injecting all of the wellfield return flow extends the lifetime of the appropriable volume of groundwater, but requires water rights acquisition by year 2010. Recharging the entire return flow means that Rio Grande water rights are exceeded sooner than by discharging return flow to the stream.

f) As much of the City's excess SJ-C Project contract water as is not in use or is not effectively stored should be artificially recharged to the depleted aquifer storage, instead of being delivered downstream.

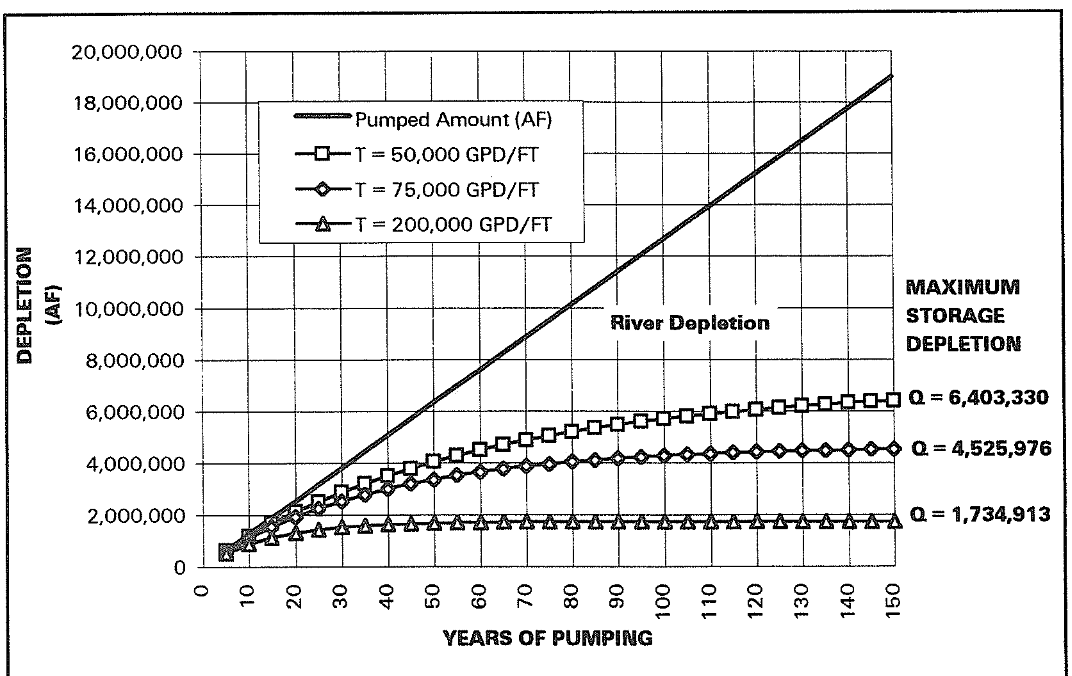


Figure 9. Groundwater and river depletion varied by transmissivity for steady wellfield production of 126,630 a-f/y.

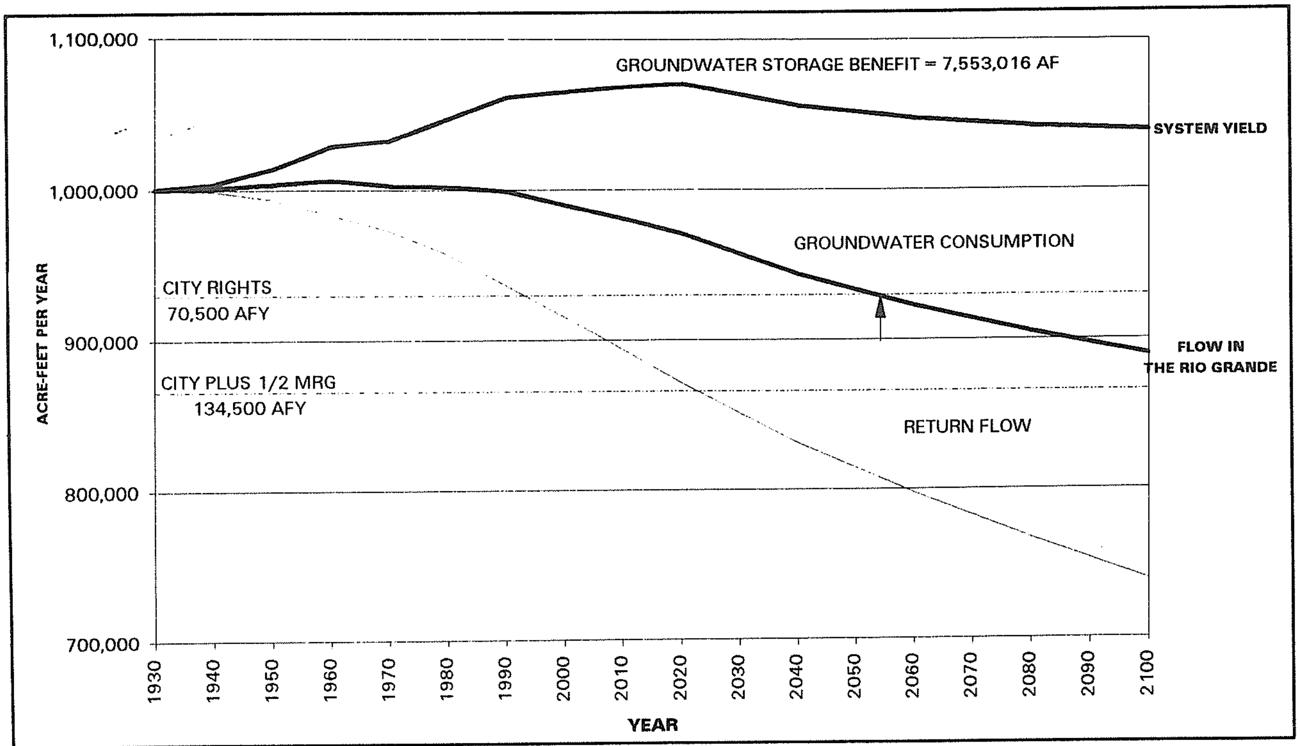


Figure 10A. Scenario A - Rio Grande flow and water availability based on pumping growing from 125,000 a-f/y to 300,000 a-f/y.

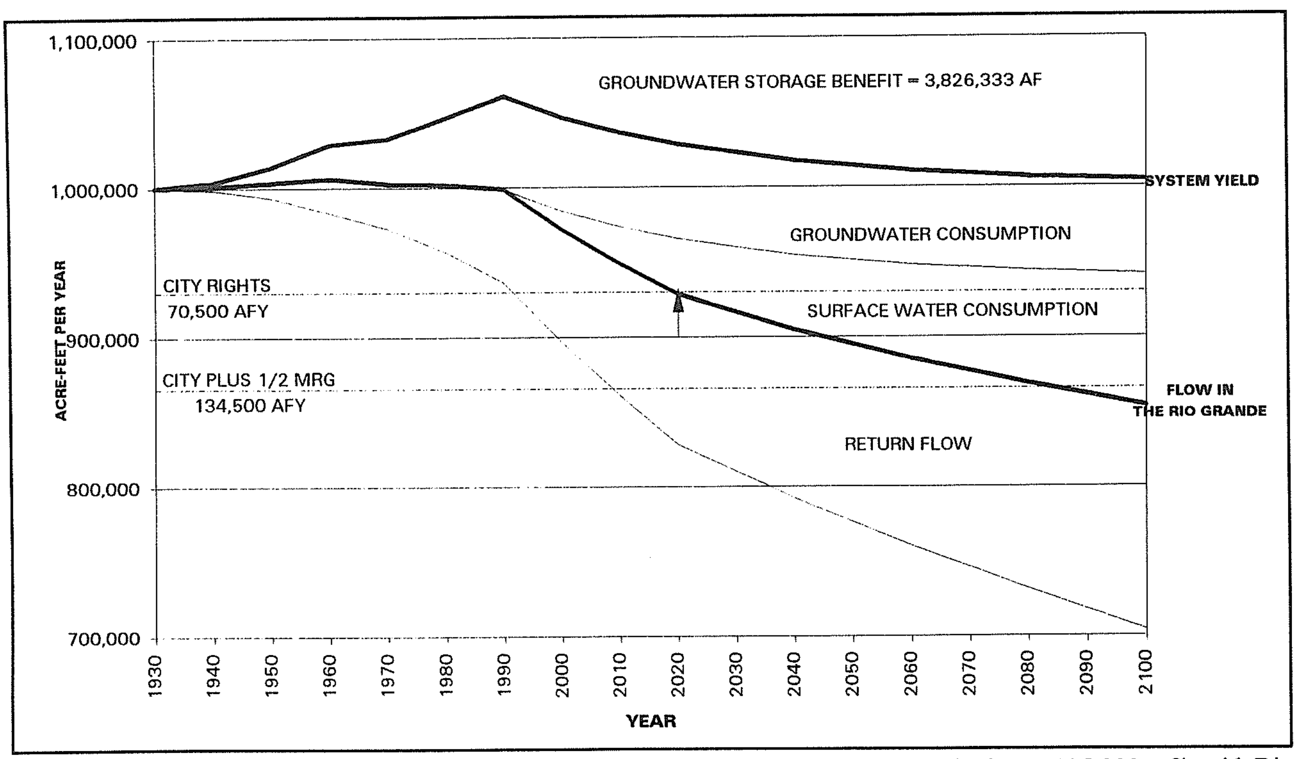


Figure 10B. Scenario B - Rio Grande flow and water availability based on pumping continuing at 125,000 a-f/y with Rio Grande surface water providing growth to 300,000 a-f/y.

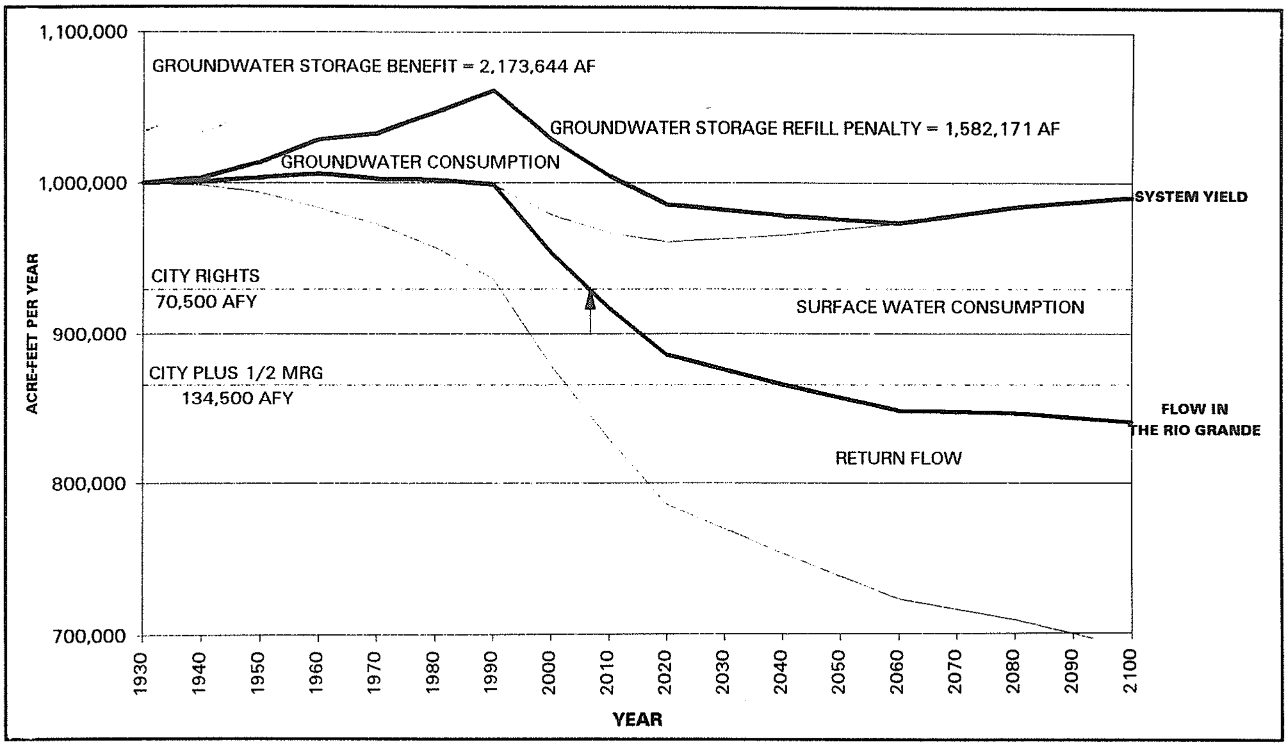


Figure 10C. Scenario C - Rio Grande flow and water availability based on pumping declining from 125,000 to 0 a-f/y with Rio Grande surface water providing growth to 300,000 a-f/y.

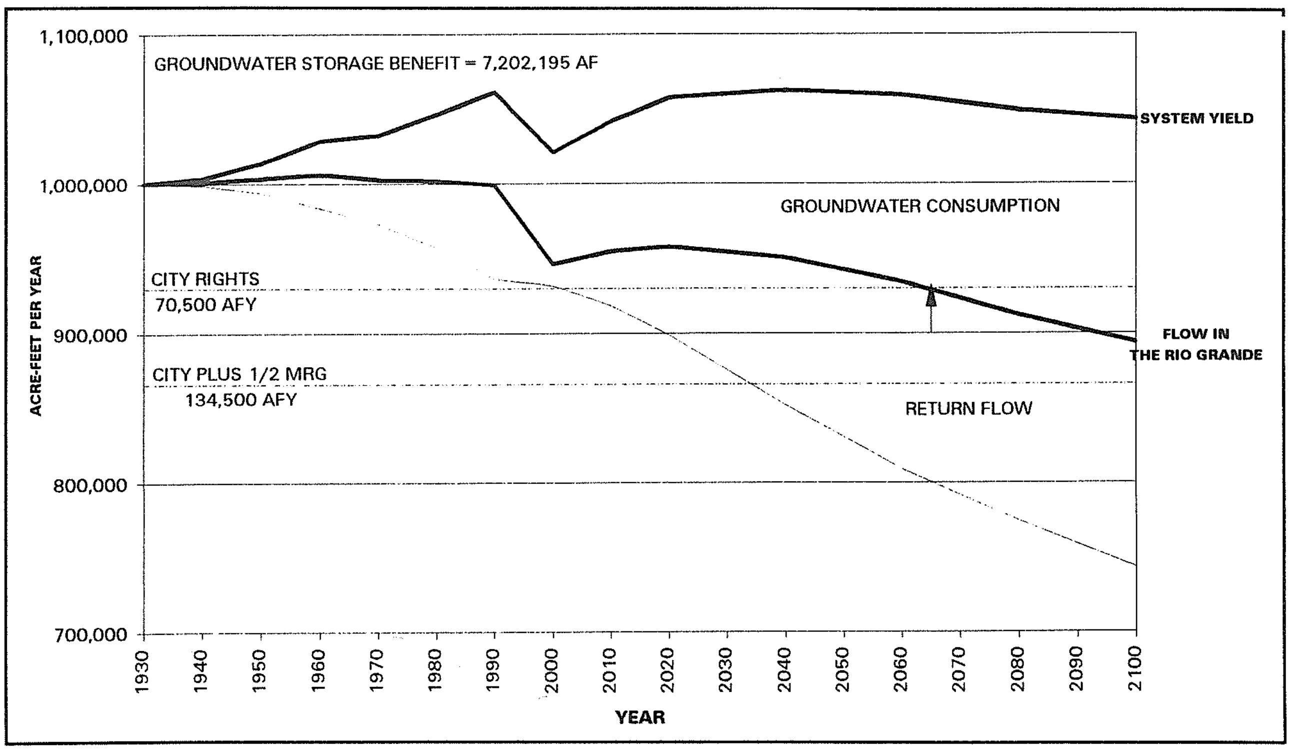


Figure 10D. Scenario D - Rio Grande flow and water availability based on pumping growing from 125,000 to 300,000 a-f/y with injection of return flow to limit of City water right.

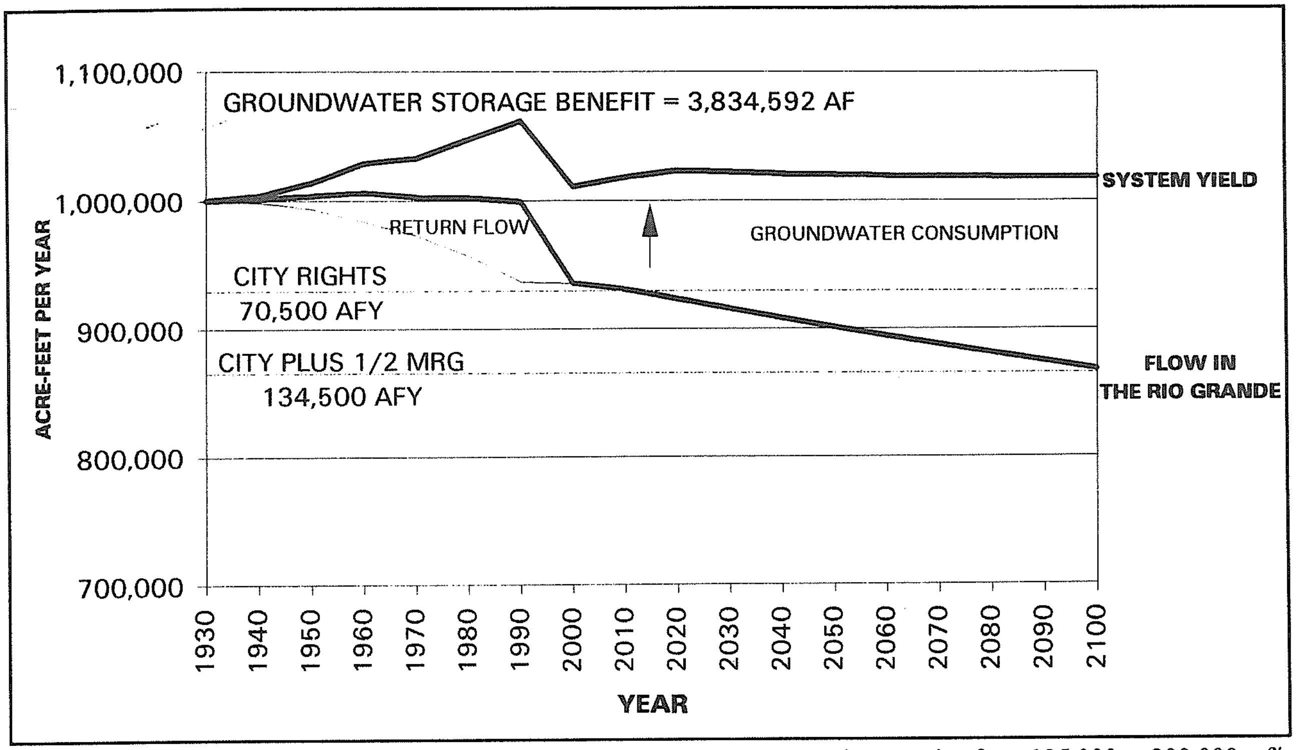


Figure 10E. Scenario E - Rio Grande flow and water availability based on pumping growing from 125,000 to 300,000 a-f/y with injection of all return flow.

g) The Albuquerque Basin has been donating excess water to Elephant Butte in excess of the administrative requirement to keep the river in balance at the cost of 147,000 a-f of the basin resources.

h) A danger is that using return flow derived from aquifer storage can result in untenable water rights effects if the pumping, and thus the return flow, is ever reduced after the appropriable volume of storage is exceeded.

Table 5 quantifies the difference in the City's water-rights future if the river and the aquifer are less well connected than presently administered. By using groundwater and taking advantage of the stored component of the aquifer resource, the water-rights reserve held by the City is 70,000 a-f/y with a 70-year lifetime. If surface water is directly diverted, equivalent surface-water rights are immediately required and the reserve would last less than 30 years.

TABLE 5. GROWTH SENSITIVITY TO RIVER CONNECTION

	Low Projection a-f/y	SEO Projection a-f/y
City right (vested, purchased, SJ-CP)	70,500	70,500
City withdrawal	126,000	126,000
aquifer storage depletion	69,000 (55%)	47,000 (37%)
Rio Grande depletion	57,000 (45%)	79,000 (63%)
City return flow	-60,000	-60,000
net Rio Grande depletion	~0	~20,000
City rights available for growth	~70,000	~50,000
Years at 25,000 a-f growth/decade	~28 yrs	20 yrs
Years at 10,000 a-f growth/decade	~70 yrs	50 yrs
Potential to acquire rights:		
½ of 128,000 a-f/y MRGCD	64,000	64,000
	+ 25 yrs	+25 yrs
½ of 395,000 a-f/y Lower Basin	190,000	190,000
	+75 yrs	+75 yrs

ADMINISTRATION OF GROUNDWATER AND SURFACE WATER

The two goals of promoting development and preserving prior rights are not incompatible. Adjudication of priority would help the transfer process. Good models are needed for administration of interrelated surface water and groundwater. The models are continuously being upgraded. Present decisions are made using available tools.

In the recent Intel hearing and decision, some indications were given of the direction of administrative practice. Table 6 summarizes some of these. Models are used for guidance, but monitoring can confirm the findings. Permit conditions can be modified as necessary under continuing jurisdiction of the administrative agency. Serviceable well life and water columns are among the parameters of impairment. The number of wells that would have to be deepened due to a new appropriation may become a welfare issue. A SEO Task Force is engaged in a second phase of collecting public input on the issues in Table 7. A policy on dedication/retirement and public notice has been published. Other policies are pending. Those policies should recognize the value of developing the stored groundwater resource, and the utility of the transfer process in capturing the value of the old purpose of use for the benefit of the existing owners.

TABLE 6. SELECTED STATE ENGINEER OFFICE FINDINGS IN INTEL APPLICATION

1. "... a groundwater model is at best an educated estimate."
2. Minimum serviceable water-column depth for Corrales area = 15 feet.
3. Useful life of a domestic well is 30 years.
4. Number of domestic wells in Corrales area which would have less than 15-foot water column due to Intel pumping 4,500 a-f/y was estimated as 9 by the state and 4 by the applicant.
5. Pumping less will reduce those effects.
6. All existing wells in Corrales vicinity can be deepened to recover the water column.
7. The zone of fresh groundwater exceeds 2,000 feet.
8. No impact on wetlands and bosque.

PROGRAM NEED

The City, other users in the middle valley and the administrative agencies need the following:

a) Observation well nests for monitoring water levels in three-dimensions throughout the area of influence of existing wellfields.
b) An inventory and publication of the surface and groundwater resource. Groundwater use should be inventoried in two categories: withdrawals of stored groundwater and induced withdrawal of surface water. A listing of vested rights, uses, locations, diversion and consumption.
c) Public access to the hydrologic models used in administration.
d) Adjudication of priority to allow senior rights to capture the value of their right when rights are moved to new community places and purposes of use.
e) A regional water plan on how much of the 126,000 a-f/y of riparian agricultural use the community wishes to convert to municipal and industrial purposes.

TABLE 7. SEO TASK FORCE II ISSUES

	Issue	Approach
1.	Aquifer mining	pending
2.	Return flow credits	pending
3.	Regional water planning	pending
4.	Shallow well construction	pending
5.	Metering of agriculture and other uses	pending
6.	Conservation	pending
7.	Supplemental irrigation wells	pending
8.	Dedication/retirement	published
9.	Public notice	published
10.	Public welfare	pending

CONCLUSIONS

- The Albuquerque City water demand should continue to be served from wells in preference to direct diversion of the river. Wells provide a large part of their supply from the aquifer's stored resource which augments the City's Rio Grande water rights.
- Limit the aquifer storage depletion to a volume that is associated with the accessible water rights. The limiting volume probably is about 4.5 million a-f. Induced recharge should not be allowed to grow to exceed the amount of river rights to the extent that the water rights account would be bankrupt.
- Any idle City rights should be put to use or recharged to the groundwater body, and stored there for future use.
- Within the foreseeable future, 20 to 50 years, the City will need to transfer supplemental rights to municipal use from other existing uses.

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