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AQUIFER STORAGE AND RECOVERY STUDY FOR THE CITY OF ALAMOGORDO, NEW MEXICO

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ABSTRACT

An aquifer storage and recovery (ASR) feasibility study was prepared for the City of Alamogordo that included an estimation of excess spring flows that would be available for injection into the La Luz Well Field, and later recovered by pumping for municipal use. Water quality issues were evaluated to ensure that the source water (springs) would not be detrimental to the receiving water (groundwater). The maximum well injection rate and a plan for utilizing gravity flow instead of pumping for injection was designed. A 30-day pilot ASR well injection program was implemented. Approximately 21 million gallons of treated surface water was injected into the aquifer using the rehabilitated Well No. 6.

A three-layer, three-dimensional groundwater flow model was developed to simulate a long-term ASR program. The feasibility of an ASR program was evaluated, including operation and maintenance costs. Regulatory compliance issues were also discussed.

The results indicated that excess spring flows can be economically injected into the aquifer and recovered. The local water table around the La Luz Well Field would increase by as much as 40 feet or more after 10 years of ASR. Water can be successfully "banked" in the aquifer for future recovery, with more than 85% predicted recovery efficiency. The

quality of the recovered groundwater was also improved. Excess spring water can be injected and recovered for approximately $33.00 per acre-foot.

Introduction

Many water suppliers in the United States are using Aquifer Storage and Recovery (ASR) technology to improve water supply availability, quality, and conservation. A full-scale ASR program has not been implemented in New Mexico, and this study is one of the first of its kind in the state of New Mexico. The City of Alamogordo utilizes surface water for more than 80% of its supply. During the winter months, additional spring flows are available, but not needed to meet demands. ASR is a feasible technology to augment summer demand supplies.

The City of Alamogordo has a unique geographic setting for ASR where good-quality surface water, discharged along the Sacramento Mountain front, is available for storage in a transmissive aquifer located at the base of the mountains and near an existing well field.

Purpose

The purpose of the study was the following:

- quantify excess spring flows that would be available for an ASR program
- evaluate the chemical compatibility of the source and receiving waters
- characterize the aquifer parameters for ASR suitability
- determine the feasibility of a full-scale ASR program for Alamogordo
- determine the costs associated with the ASR program
- evaluate the results of a pilot-scale injection program
- develop a groundwater flow model to simulate long-term ASR

Source of Water Supply

The City of Alamogordo obtains its water supply from spring flows within the Sacramento Mountains, groundwater and Bonito Lake. The main spring collection systems are located in La Luz and Fresnal canyons to the north, and Alamo Canyon on the south (Figure 1). Surface water constitutes approximately 80 percent of the total current supply, and the quality of water from the springs is superior to the groundwater. The City of Alamogordo has a declared water right of 9,754.45 acre-feet per year (AFY) from surface water diversions in the La Luz/Fresnal canyons. Approximately 76 percent of the right is utilized for demand, and the remaining 24 percent (2,326.41 AFY) may be available for ASR. Bonito Lake supplies approximately 1,449.02 AFY when the pipeline to Alamogordo is operational.

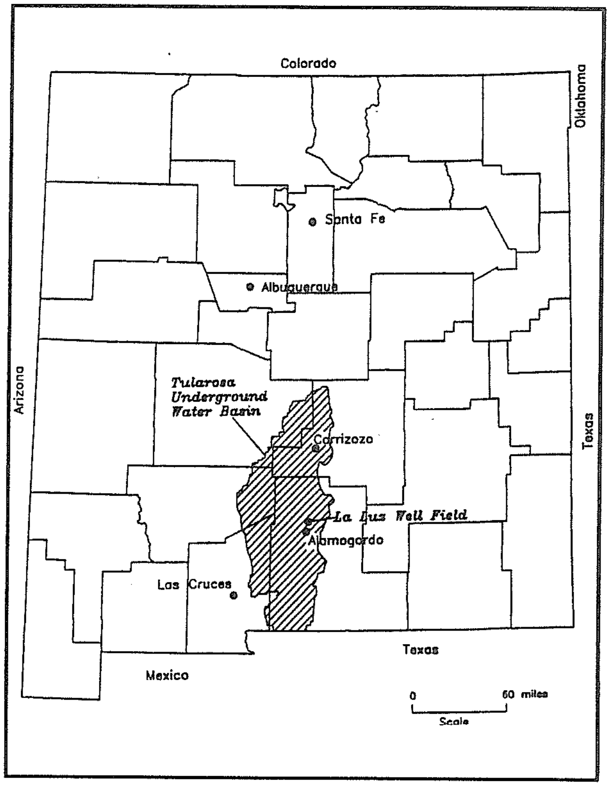

Figure 1. Regional map showing location of Tularosa Underground Water Basin and La Luz Well Field near Alamogordo, New Mexico.

The City supplements its surface-water supply with groundwater from the La Luz Well Field during the high-demand summer months when spring flows are at a minimum. The La Luz Well Field consists of six operational wells, with capacities ranging from 320 to 1,400 gallons per minute (gpm). The groundwater is pumped from the basin-fill aquifer of the Tularosa Basin, which is a hydrogeologically closed basin. Recharge to the basin is from mountain-front runoff and discharge is to evaporation in the basin center (in and near White Sands National Monument). Most of the groundwater is of poor quality, and has to be pumped from approximately 400 feet below ground surface. The City of Alamogordo has a water right of 4,572.88 AFY for the La Luz Well Field.

Alamogordo's Water Supply System

The springs in La Luz/Fresnal canyons are diverted to the La Luz Water Treatment Plant (WTP) on the north end of Alamogordo. From the La Luz WTP, water is gravity-fed to Green Reservoir, a five-million gallon above-ground storage tank. The La Luz Well Field is located near Green Reservoir, and groundwater is pumped into the reservoir before distribution. From Green Reservoir the water is gravity-fed to Alamogordo's distribution system.

There are six operating wells in the La Luz Well Field; nos. 2, 3, 4, 5, 6 (replacement) and 7. Well completions in relation to the geology are depicted on the cross-section provided as Figure 2.

According to well maintenance data, all the wells have problems with encrustation of mineral precipitants and corrosion from iron-reducing bacteria. Biofouling from iron-reducing bacteria will be a maintenance problem whether ASR is used or not, and a rigorous maintenance program is recommended to maintain the well field.

Many of the wells are over 30 years old and will need to be replaced to maintain the desired production from the well field. It is possible that the older wells, once replaced, could then be dedicated as recharge wells, or the replacement wells could be designed as hybrid wells to operate as both recharge and recovery (pumping) wells.

Availability of Excess Spring Flows

The excess spring flows occur during the low water demand months of October through March. Because the City water demands are low during these months, some spring flow is not needed to meet demands and is not now diverted or stored. These flows are therefore termed "excess," and are the primary source of water available for recharge.

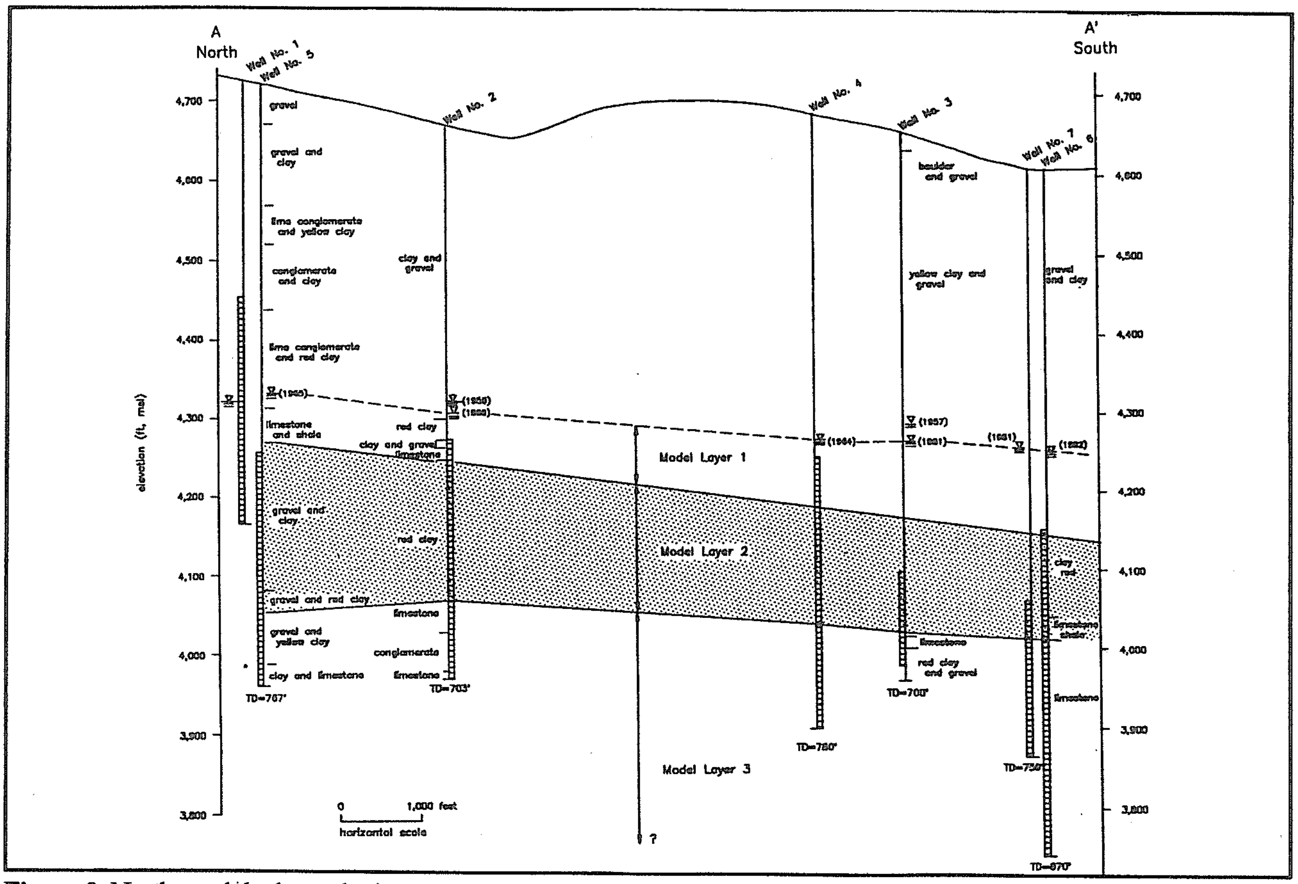

Figure 2. North-south hydrogeologic cross-section (A-A'), La Luz Well Field, Alamogordo, New Mexico.

The monthly spring flows vary, and are generally greater in the fall to spring months. In wet years, rainfall and snowmelt can be a substantial contributor to the amount of stream flow in the canyons. From April to September, when demand is greatest, all spring flows are diverted to meet demand; therefore, excess spring flows for ASR are only available in the low-demand winter months.

The minimum historical excess spring flows were determined from current diversion records and the maximum theoretical excess spring flows were based on Alamogordo's diversion right of 11.14 MGD. For the ten-year period of 1995 to 2005, both minimum and maximum excess spring flows were estimated, along with the potential to "bank" water that is stored but not needed. Table 1 summarizes the potential excess spring flows for ASR.

ASR Water Chemical Compatibility

The chemical compatibility of the recharge water with the groundwater determines the success of continued operation without damaging the aquifer or well materials by precipitation of salts and metal oxides, and corrosion. Changes in groundwater chemistry from mixing of recharge water and natural groundwater can create problems with degradation of groundwater quality, well plugging, aquifer damage, and corrosion of well casing (Pyne 1994). The general inorganic water chemistry was evaluated to determine the potential for compatibility between the proposed recharge water and groundwater beneath the La Luz Well Field.

Temperature of the spring waters, during February 1996, ranged from 43 to 48 degrees Fahrenheit, with a slightly alkaline pH ranging from 7.2 to 8.2. Temperature of the water discharged from the La Luz WTP varies with the seasonal changes in the ambient air temperature. The average TDS of all the spring water sampled is 1,076 mg/l.

The groundwater has a higher TDS (up to 2,500 mg/l) and hardness concentration than the surface water, but both are primarily calcium-magnesium-sulfate-bicarbonate type waters. Clay mineral stability and subsequent plugging of aquifer pore space is

Table 1. City of Alamogordo ASR Study: potential excess spring flows for ASR

scenario	total spring production, MGY	total demand, MGY	total excess spring flow, MGY	total well field production, MGY	potential water banked, MGY
minimum spring flow availability for 1995	2,634.0	2,420.4	368.18	154.58	213.60
minimum spring flow availability for 2000	2,634.0	3,216.0	110.20	692.20	0
minimum spring flow availability for 2005	2,634.0	3,450.12	56.37	872.39	0
maximum spring flow availability for 1995	4,244.0	2,420.4	1,849.8	26.0	1,823.8
maximum spring flow availability for 2000	4,244.0	3,216.0	1,317.2	289.0	1,028.2
maximum spring flow availability for 2005	4,244.0	3,450.0	1,182.3	388.1	794.2

MGY = million gallons per year

not a problem due to the similarities in water chemistry. Chemical equilibrium models (PHREEQE and PCWATEQ) were developed to evaluate the potential for water chemistry compatibility. It was concluded that the only chemical compatibility issue deals with precipitation of minerals in the well screen. This can be handled with the current well maintenance program. Utilization of water from the water treatment plant for recharge would improve the quality of the groundwater within the aquifer.

Hydrogeologic Setting

Water-supply wells in the La Luz Well Field are completed in the Cenozoic-age sediments of the Tularosa Basin, adjacent to the Sacramento Mountain Escarpment near La Luz, New Mexico. The Tularosa Basin is a physiographically closed basin bounded by the Sacramento Mountains to the east, the San Andres Mountains to the west, and bedrock highs to the north and south. A north-south hydrogeologic cross-section through the La Luz Well Field was developed from drillers' logs, and geophysical data provided by Orr and Myers (1986) (Figure 2). The basin fill in the vicinity of the well field is primarily composed of stratified gravel, sand, silt, and clay typical of coalescing alluvial fan and lacustrine (lake) deposits. Pray (1961) has noted landslide deposits along the mountain front that primarily consist of boulders. The drillers' logs from wells No. 6 and No. 7, drilled along the mountain front, have noted limestone boulders and high yield sediments at depths of 750 to 850 ft.

One of the most prominent stratigraphic features in the well-field area is a zone of red clay containing stringers of sand and gravel. Some domestic wells produce water from the sand and gravel in the red clay, but generally produce less than 10 gallons per minute. The coarser material above and below the red clay yields substantially more water. The best yield in the La Luz Well Field is from the coarser material below the red clay zone, such as that tapped by wells No. 6 and No. 7, but water quality is poor.

Orr and Myers (1986) have estimated the basin fill approximately 2 miles west of the La Luz Well Field to be approximately 3,000 feet, and thinning westward to a bedrock high near the basin center (Figure 3). In addition to the thinning of the fill to the west, the fill material becomes more fine-grained away from the mountain front.

It appears that much of the natural recharge occurs along the mountain front, either from upwelling along faults, such as the Sacramento Escarpment, through fractures in the limestone bedrock, or from stream flows discharging from mountain watersheds

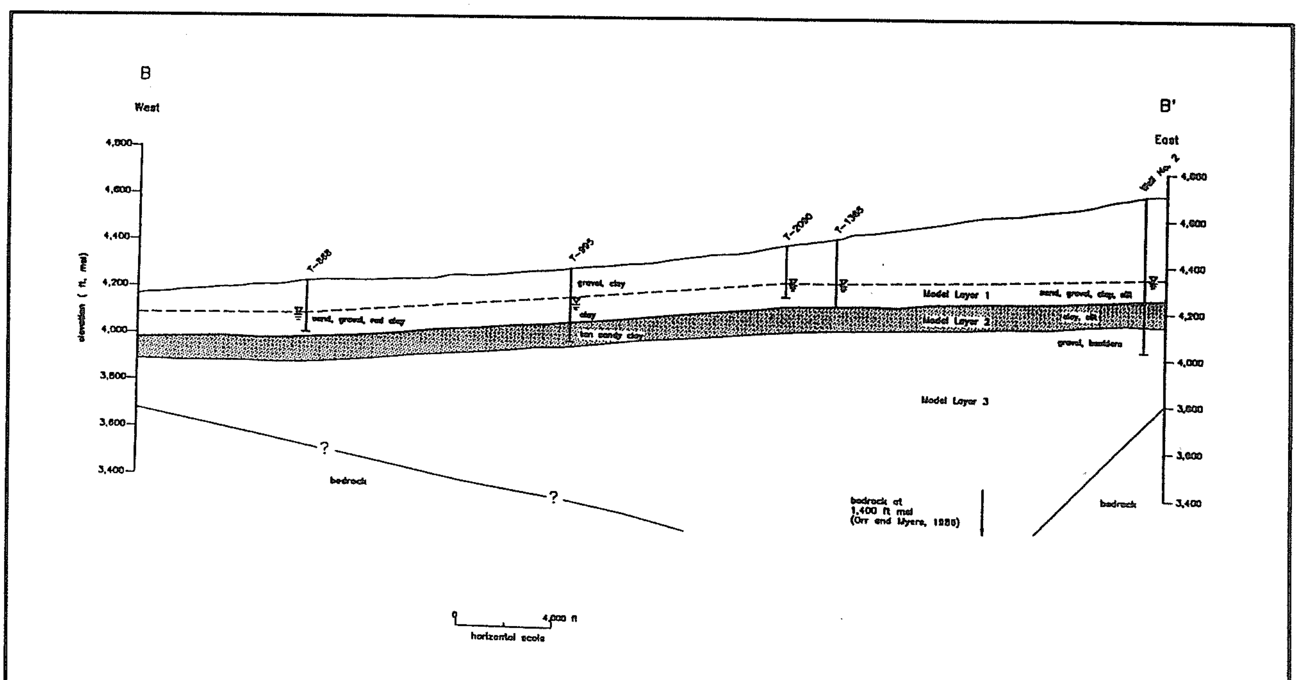

Figure 3. East-west hydrogeologic cross-section (B-B'), La Luz Well Field, Alamogordo, New Mexico.

to the fill material. Most of the recharge to the basin fill aquifer is discharged west of the mountain front, but east of the bedrock high, near the basin center. The discharge is evident where the water table approaches the land surface and forms the saline springs that surface near the bedrock outcrops 10 miles west of the La Luz Well Field.

Development of a Groundwater Flow Model

A multi-layer groundwater flow model of the La Luz Well Field area was developed for this study. The model has a smaller grid spacing around the La Luz Well Field for better resolution, and three layers to represent the hydrogeologic setting. The model is based on the MODFLOW code developed by the U.S. Geological Survey (McDonald and Harbaugh 1983). The model was calibrated using data for the years 1910 to 1995.

The model was prepared for

- estimating optimum injection rates for gravity recharge from the La Luz WTP to the well(s)
- estimating the aerial extent to which artificial recharge would replace storage to the depleted portion of the aquifer
- estimating effects or controls on saline encroachment from the western portion of the aquifer
- simulating the pilot project management of the ASR project and the La Luz Well Field, after calibration to pilot project results

The model was constructed to represent the three hydrogeologic layers described in the hydrogeologic setting, which were treated in the model as follows:

Layer 1 is an unconfined aquifer consisting of the first 100 ft of sediment below the water table, primarily sand, silt, and gravel. Hydraulic conductivity ranges from 4 to 10 ft/day.

Layer 2 is a semi-confined aquifer, representative of the red clay zone. The thickness was assumed to be constant at 100 ft, and the hydraulic conductivity was also estimated to be constant across the model area at 1.0 ft per day (transmissivity is 100 ft^2/day).

Layer 3 is a leaky confined aquifer. The thickness of layer 3 varies from east to west to represent the geometry of the aquifer. The hydraulic conductivity decreases to the west. In the La Luz Well Field, the hydraulic conductivity is 10 ft/day, similar to that determined from Replacement Well No. 6 pumping tests. The well is completed in layer 3. The storage coefficient for layer 3 is equivalent to a specific storage of 10^{-6} times the nominal thickness of the layer, a commonly accepted value estimated by Lohman (1972).

The groundwater flow model was set up to simulate one, five and ten years of operating aquifer storage and recovery, for the minimum and maximum excess spring flow conditions. The ASR operating plan assumes artificial recharge for 6 months during the winter months and recovery by pumping for 6 months during the spring and summer months. The wells determined to be most suitable for recharge by gravity are wells No. 3, No. 6 and No. 7.

Discharge from the La Luz Well Field during recovery included all of the existing pumping wells, with pumping rates based on projected demand from the well field. Other appropriators were included through the entire model simulation.

Well Injection Rates

The basic premise of ASR is to recharge the aquifer by injecting water into the aquifer via recharge wells. For this study it was assumed that the existing La Luz Well Field would be used for both recharge (injection) and recovery. Groundwater recharge through wells can be accomplished using pressurized (pumped) systems or by gravity flow, if available. For the La Luz wells, gravity flow from the La Luz WTP (via Green Reservoir) is preferred to minimize the costs associated with the ASR program. Using the overflow elevation of Green Reservoir to "drive" the injection wells, gravity flow can be accomplished for wells No. 3, No. 6 and No. 7. Wells 2, 4 and 5 would have to be recharged by pumping, therefore were not used for injection in this study.

To determine the maximum potential recharge to the local aquifer by utilizing the existing well field facility, the injection rates for each well were needed. A series of curves were developed which are based on residual pressure needed at the well-head and corresponding flow rates for each well. It was assumed that the existing piping would be utilized to "back-flow" water to the wells, with some minor modifications. An eductor (drop-pipe) was designed to ensure a positive injection head at the well, and minimize air-entrainment during injection.

Pilot ASR Program

A pilot ASR program was developed to obtain information that would be used in verifying assumptions made in the groundwater flow model. Additionally, the hydraulics of the well injection assembly (eductor) could be verified. The pilot program consisted of injecting treated surface water from the La Luz WTP (via gravity from Green Reservoir) into the abandoned Well No. 6 for 26 days, at an average rate of 580 gallons per minute (gpm). A total of 21,528,570 gallons was injected during the pilot program. Water level data (both at the injection well and observation wells) were recorded.

A series of step and constant-rate pumping tests were performed both pre- and post-injection to determine well efficiency and well screen and aquifer plugging potential. Water samples also were obtained for pre- and post-injection conditions to evaluate mixing and quality changes in the recovered water. After injection, a 55-foot rise in the water level was observed at the injection well, and a 28-foot rise at the observation well (Replacement Well No. 6) approximately 50 feet from the injection well. The quality of the recovered water was that of the injected water, so it was apparent that a high degree of mixing did not occur. Throughout the post-injection pumping test the recovery head remained stable at approximately 20 feet above static. There was no apparent loss of well screen efficiency.

Aquifer Storage Recovery Conceptual Plan

The maximum benefit of an ASR program for Alamogordo would be to inject treated excess spring flows into the La Luz Well Field during the winter months of October through March, and recover by pumping the wells during the higher demand months of April through September. Water stored but not needed for pumping is termed "banked" in the aquifer. All water used for injection would be first treated at the La Luz WTP, and contain a slight chlorine residual concentration. Gravity flow would be utilized from Green Reservoir to the injection wells (No. 3, No. 6 and No. 7) so that energy costs associated with pumping (for injection) would not be incurred.

Simulations were performed using the groundwater flow model for one, five, and ten-year injection/recovery cycles, assuming both the minimum and maximum excess spring flows. Rates for injection were assumed based on existing well-pumping rates and flows needed for continuous injection over the 6-month cycle. Results of the ASR simulations are discussed below.

ASR Plan Model Results

The first year of ASR operation (after the recovery cycle) with the "minimum excess spring flow" scenario results in a net increase in the groundwater table of about 2 feet around wells No. 3, No. 6, and No. 7 (Figure 4). The first year of ASR operation (after the recovery cycle) with the "maximum excess spring flow" scenario results in a net increase in the groundwater table of about 20 feet around wells No. 3, No. 6, and No. 7 (Figure 5). It is important to note that this increase in the water table is due to the "banking" effect of storing more water than is consumed by pumping. Additionally, as demand on the well field increases (with increased population), the opportunity for "banking" water decreases.

Assuming ASR is not used, and after 10 years of normal well-field pumping, the model predicted a net drawdown in the water table around wells No. 6 and No. 7 of more than 50 feet (Figure 6). After 10 years of ASR (after the recovery cycle) with the "minimum excess spring flow scenario," the model predicted a net drawdown in the water table around wells No. 3, No. 6 and No. 7 of about 40 feet (Figure 7). This drawdown occurs because the demand from the La Luz Well Field exceeds the availability of spring flows for recharge. However, the drawdown is less than what it would be without any ASR water, as discussed earlier. After 10 years of ASR (after the recovery cycle) with the "maximum excess spring flow scenario," the model predicted a net increase in the water table around wells No. 3, No. 6 and No. 7 of almost 30 feet (Figure 8).

Model-predicted changes in groundwater head were substantial for the "maximum excess spring flow" scenario. This is a result of the recharge being substantially greater than the required demands on the La Luz Well Field. After 10 years of maximum ASR the groundwater mound has spread, but maintains similar shape and height.

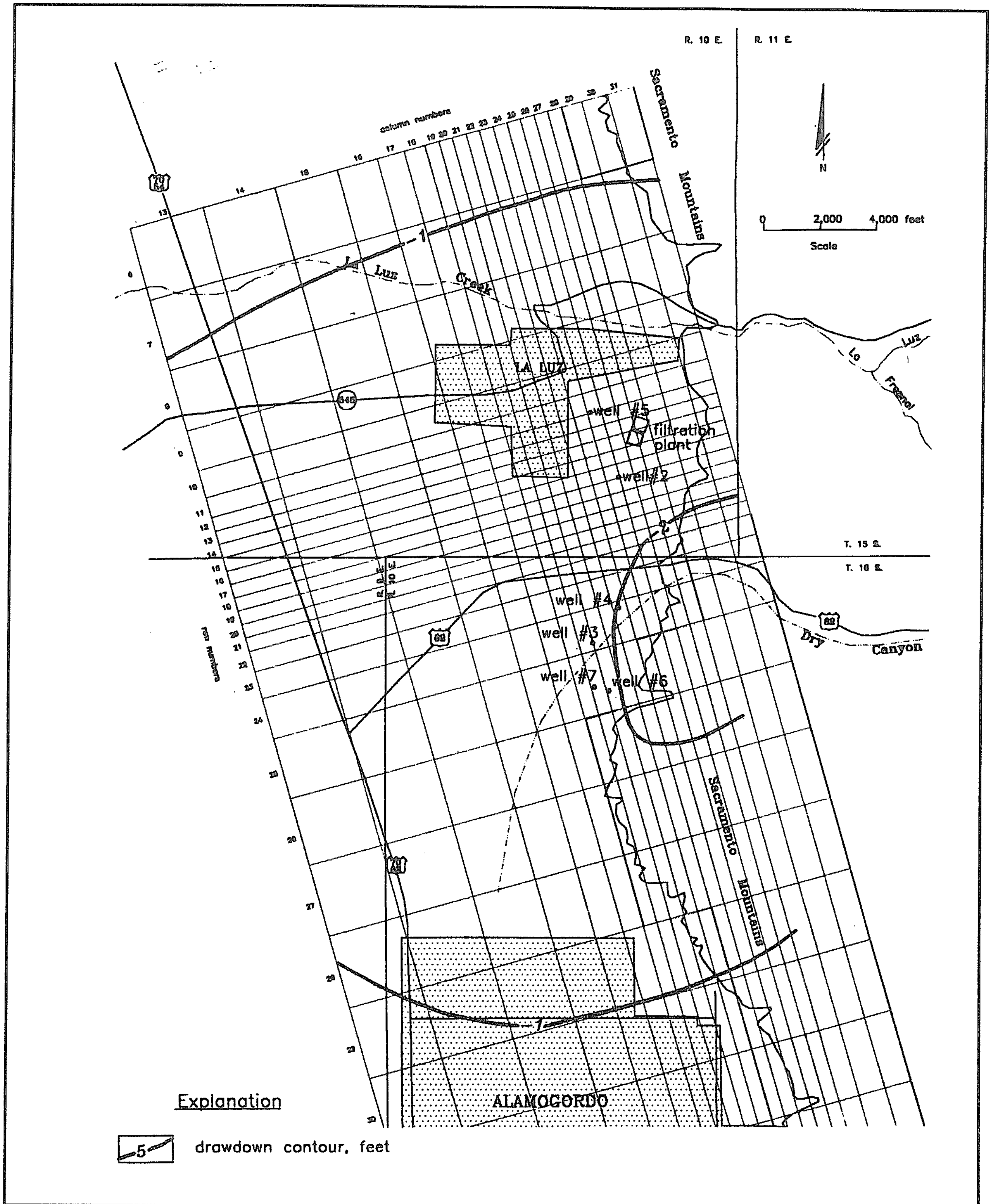

Figure 4. Map showing model-predicted change in groundwater head in Layer 3 at the end of the first recovery period considering 1 year of operating ASR "minimum excess spring flow" scenario, La Luz Well Field, Alamogordo, New Mexico. A negative value indicates groundwater mounding and a positive number indicates drawdown.

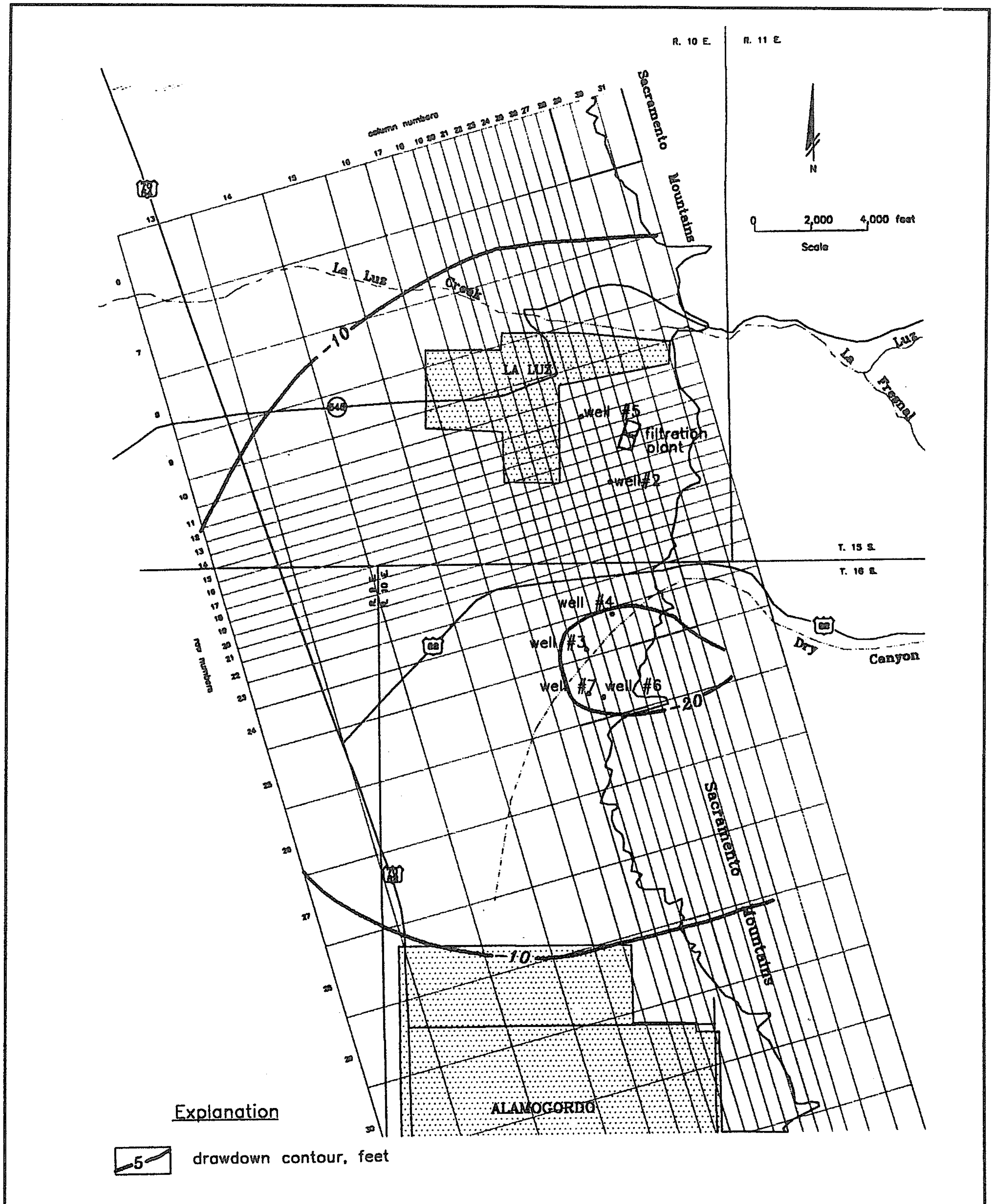

Figure 5. Map showing model-predicted change in groundwater head in Layer 3 at the end of the first recovery period considering 1 year of operating ASR "maximum excess spring flow" scenario, La Luz Well Field, Alamogordo, New Mexico. A negative value indicates groundwater mounding and a positive number indicates drawdown.

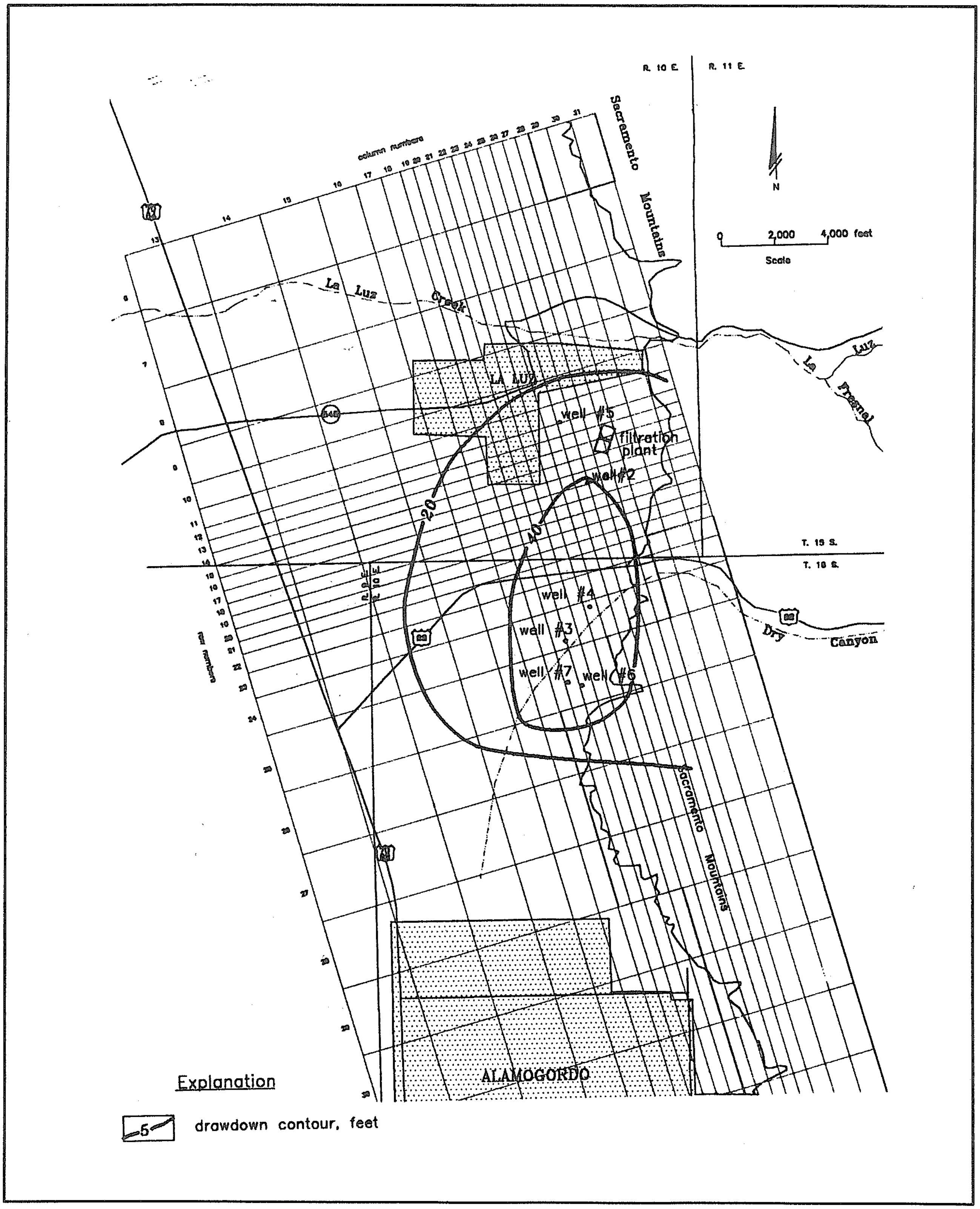

Figure 6. Map showing model predicted change in groundwater head in Layer 3 at the end of the 10th recovery period considering 10 years of operating no ASR excess spring flow scenario, La Luz Well Field, Alamogordo, New Mexico. A negative value indicates groundwater mounding and a positive number indicates drawdown.

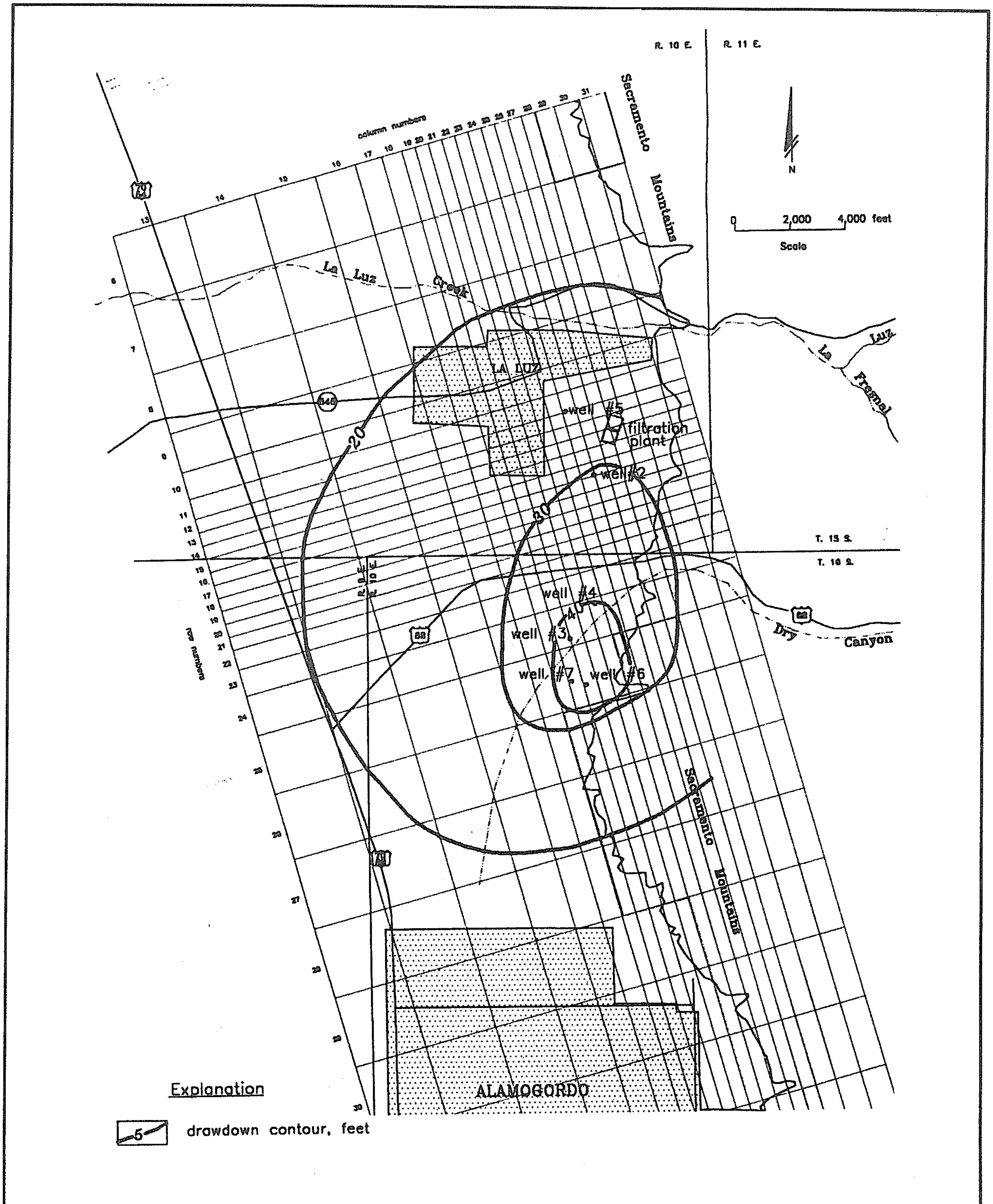

Figure 7. Map showing model-predicted change in groundwater head in Layer 3 at the end of the 10th recovery period considering 10 years of operating ASR "minimum excess spring flow" scenario, La Luz Well Field, Alamogordo, New Mexico. A negative value indicates groundwater mounding and a positive number indicates drawdown.

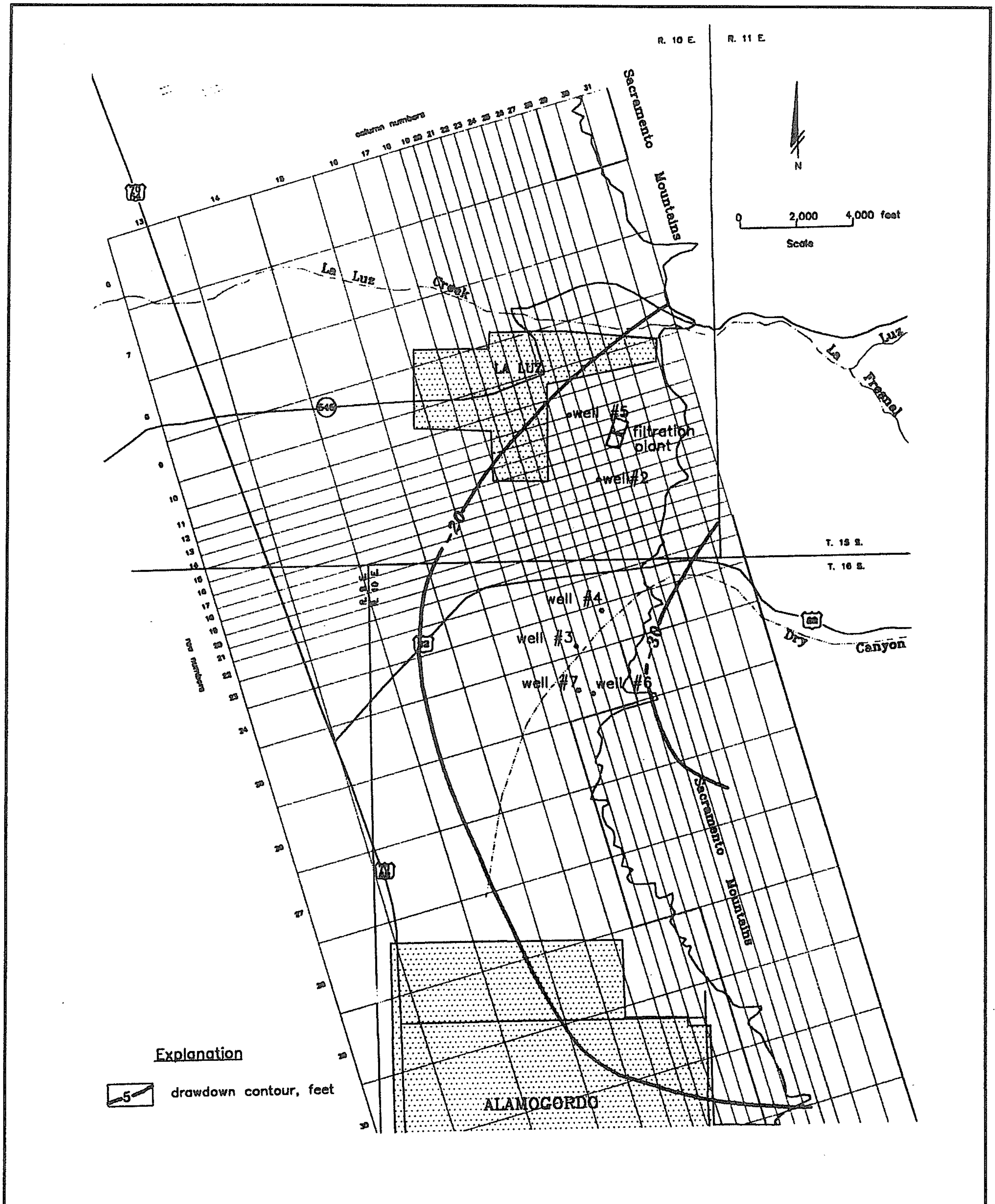

Figure 8. Map showing model-predicted change in groundwater head in Layer 3 at the end of the 10th recovery period considering 10 years of operating ASR "maximum excess spring flow" scenario, La Luz Well Field, Alamogordo, New Mexico. A negative value indicates groundwater mounding and a positive number indicates drawdown.

A summary of model results is shown below in Table 2, indicating the change in water levels after the 6-month recharge cycle, but prior to the recovery (pumping) cycle.

Recovery Efficiency

The amount of water recovered from storage was estimated from the volumetric budget output generated by the model. In general, the injected water displaces the groundwater around the well, and is retrieved by pumping. The change in head predicted by the model is a pressure response, and does not indicate the size of the mound of water stored in the aquifer. Water stored in the aquifer that is not recovered is potentially lost to aquifer storage and other appropriators. This depends on the properties of the aquifer material and the rate at which the water stored in the aquifer moves away from the well.

It is anticipated some of the stored water will be lost to other groundwater appropriators, and be unrecoverable from the aquifer. For the "minimum excess spring flow" scenario, the loss of recharge water will be minimal, because most of the injected water is recovered during the following pumping period. Greater losses of stored water are expected for the "maximum excess spring flow" scenario, but still may be a very small percentage due to the relatively short travel distance and the distances from the injection wells to the nearest other groundwater users. An overall efficiency of more than 85% recovery is expected.

ASR Costs

Costs associated with the ASR plan are minimal. A capital outlay of about $150,000 is needed to establish the program to inject into wells No. 3, No. 6 and No. 7. By utilizing gravity flow for injection, there will be no significant power costs (assuming the pumping costs associated with the recovery cycle would have been incurred even without ASR). A savings in power costs would be realized due to the reduction in pumping head during recovery pumping. Operation and maintenance costs would be low, making the overall cost of recovered ASR water about $0.10 per 1,000 gallons, or about $33 per acre-foot.

Table 2. ASR Model Results Summary

injection well	elapsed time (years)	injection rate (gpm)	change in model cell head (ft)	rise in well WL from SWL (ft)	depth to water in well (ft)
Minimum Excess Spring Flow Scenario					
No. 3	0.5	252	23.2	58	333
No. 6	0.5	784	70.6	125	241
No. 7	0.5	364	63.4	161	242
No. 3	5.5	111	10.5	26	365
No. 6	5.5	345	25.4	35	331
No. 7	5.5	160	40.7	116	287
No. 3	9.5	46	2.8	7	384
No. 6	9.5	143	10.9	6	360
No. 7	9.5	66	30.2	94	309
Maximum Excess Spring Flow Scenario					
No. 3	0.5	500	147.4	369	22
No. 6	0.5	1,440	193.6	371	-5
No. 7	0.5	675	153.0	340	63
No. 3	5.5	500	137.5	344	47
No. 6	5.5	1,440	185.2	355	11
No. 7	5.5	675	147.0	328	75
No. 3	9.5	500	133.1	333	58
No. 6	9.5	1,440	180.8	346	20
No. 7	9.5	675	143.2	320	83
SWL Well 3 is 391. SWL Well 6 is 366 SWL Well 7 is 403					

Conclusions

As a result of this study and the pilot program, the following conclusions regarding an ASR plan for the City of Alamogordo are reached:

- Aquifer Storage Recovery is feasible for Alamogordo
- a significant amount of water can be "banked," primarily during the earlier years when demand is lowest
- the ASR program can be established for low capital cost
- the operating and maintenance costs associated with ASR are low
- approximately 85% or more of the injected water can be recovered
- water quality of the recovered water is improved over the quality of the groundwater
- the success of an ASR program at the La Luz Well Field will depend on the availability of excess spring flows or the spring flows made available, and the ability to initiate the program within the next year or two
- the quality of groundwater in the deeper portion of the aquifer (layer 3) should increase in quality, in the well field itself
- layer 3 is the best zone for recharge because it is a confined aquifer with high transmissivity and it is less likely to experience plugging effects from precipitation of permanent hardness
- recharge at the proposed rates will reduce the water-level impacts from the past 40 years of pumping
- the rise in water levels due to ASR will reduce the amount of total pumping head and the cost of pumping
- approximately all recharge is recoverable and very little would be lost to other appropriators and to the aquifer as nonretrievable
- the water injected into the aquifer will displace natural groundwater and mound around the well; this displacement will cause a significant rise in the groundwater head
- as observed in the pilot study, the quality of the injected water will be preserved until removed by pumping
- the mound of injected water will spread radially away from the well at a rate of 0.20 to 0.50 ft/day, although this will depend on the hydraulic gradient and ratio of water injected to water pumped per ASR cycle

Regulatory Issues

The U.S. Environmental Protection Agency has issued several rules that apply to operation of an ASR facility. The Surface Water Treatment Rule became effective during June 1993, and pertains to the reduction of organic and solid content of recharge waters. This basically is a requirement for filtration and disinfection of surface water, which the City of Alamogordo is doing at the La Luz Water Treatment Plant.

In the state of New Mexico, there are three basic water-rights questions in connection with the contemplated ASR project. These are:

- whether storage in the aquifer is a use permitted under the existing right to divert surface water and spring water
- whether recovery of the stored water is permitted under the existing rights to produce groundwater from the wells
- how the ASR water might be protected from appropriation by others

Discharges to an aquifer in New Mexico are regulated by the issuance of discharge permits by the Ground Water Protection Bureau of the New Mexico Environment Department. The discharge plans must show that the water is in compliance with the New Mexico Water Quality Control Commission drinking water standards. This is for protection of existing groundwater quality, and the discharger is exempt if the discharge is determined to be nondegradational to the groundwater.

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