AQUIFER STORAGE RECOVERY FEASIBILITY INVESTIGATION

PHASE I--PRELIMINARY ASSESSMENT

PREPARED FOR

Upper Guadalupe River Authority
Kerrville, Texas

April 1988

CH2M HILL

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EXECUTIVE SUMMARY

INTRODUCTION

Aquifer storage recovery, or ASR, is a fairly new concept in which treated drinking water is stored underground in a suitable aquifer by recharge wells during "wet" months, and then recovered later in "dry" months to meet peak water demands which exceed the capacity of water treatment facilities. No further treatment of the recovered water is needed other than disinfection. The ASR concept allows a utility to use recharge-recovery wells to meet increasing peak demands in lieu of an immediate increase in water treatment plant expansion, and typically at less than half the cost.

Although ASR is new to Texas, there are five successfully operating systems in the U.S. and several abroad. Of the five U.S. facilities, three have been installed in Florida since 1983 following design by CH2M HILL. The additional two U.S. facilities are in Wildwood, New Jersey (since 1968) and Goleta, California (since 1978).

Water treatment facilities--such as upper Guadalupe River Authority's 5 million gallon per day (mgd) plant in Kerrville--are usually designed to meet the annual maximum day demand. In Kerrville, this maximum day demand is 2.2 times the average annual demand. Consequently there is a large investment in peaking capacity which is underutilized much of the year. With ASR wells, a utility can run the water treatment plant at near-capacity all year long, recharging the excess treated water during low demand periods. When treatment plant capacity is exceeded by peak season demands, the ASR wells can operate in the recovery mode to supply the needed extra water. Thus ASR can be used to maximize the use of a relatively high cost water treatment plant and provide a higher degree of reliability and safety with the addition of another supply source.

Three criteria found to govern ASR feasibility were found in this investigation to be met in Kerrville: 1) seasonal variation in water demands, 2) potential for ASR facilities of greater than 1 mgd, and 3) a suitable subsurface storage zone.

This Feasibility Investigation is Phase One of a potential three-phase study and development program. At UGRA's discretion, the two following phases may be undertaken based on this report: a 30-month testing program on a full scale prototype ASR well (Phase Two), and a twelve- to eighteen-month well field expansion program to install the recommended number of ASR production wells (Phase Three).

WATER SUPPLY AND DEMAND

Municipal water is supplied to Kerrville customers from two sources--well water and Guadalupe River water. Although treated river water from UGRA's plant supplies the bulk of water demands, ground water from City wells is used to meet peak demands, and accounts for about 5 to 25 percent of annual demand.

Water demands were estimated through the year 2030 based on projections by the Texas Water Development Board (TWDB) issued in November 1984. Values adopted in this study are the average of TWDB's "High Case" and "Low Case" demands. Demands and available supplies are summarized as follows:

Year	Projected Kerrville Population	Projected Demand, mgd			Supply, mgd	
		Average	Maximum Month	Maximum Day	Maximum Month	Maximum Day
1990	20,000	4.2	6.4	9.3	7.0	14.0
2000	25,000	5.4	8.3	12.0	7.0	14.0
2010	29,000	6.4	9.8	14.0	7.0	14.0
2020	32,000	7.0	10.7	15.3	7.0	14.0
2030	34,000	7.4	11.3	16.2	7.0	14.0

The "maximum month" total supply capacity of 7 mgd--5 mgd from UGRA and 2 mgd from wells--will be exceeded after about 1992. Therefore, if ground water drawdown is to be avoided, an increase in supply capacity is needed. The increase could come from a UGRA plant expansion or new ASR wells, or a combination of both.

ASR INVESTIGATION

This investigation of ASR feasibility for Kerrville addressed the following issues: hydrogeology, water quality suitability, phasing of future supply facilities, costs of facilities, and permitting.

Ground water in Kerr County comes from the Trinity Group aquifer, which is subdivided by geologists into several distinct layers. Although small yields for domestic and livestock purposes are obtained from 300 foot deep wells in the Glen Rose Limestone, high yields for municipal use can only be obtained from the deeper Hosston-Sligo formation.

The City of Kerrville has 13 wells in this formation, drilled to a depth of 600 to 700 feet. A search of State records revealed no private or other wells developed in this formation. City well yields range from 200 to 900 gallons per minute (gpm) and average 560 gpm. Present depth to water surface is about 200 to 400 feet. Recharge to the Hosston-Sligo formation occurs due to rainfall and overland flow of water to the exposed portion of this formation about 20 miles northeast in Gillespie County. Subterranean water flows slowly south and southeast through Kerrville.

The water-bearing formation chosen for ASR operations--the Hosston-Sligo--was found to be well suited to proposed ASR operations. It has adequate ability to accept and yield water to wells and has adequate storage volume. Recharge operations are projected to raise water levels in an ASR well by 40 to 60 feet and then return them to about the starting point at the end of a pumping season if all water stored is recovered. This compares to an available rise of 200 to 400 feet before water would spill to the river or out of the ground.

Quality of the native ground water and of the treated drinking water to be recharged appear acceptable and compatible for the intended use. Detailed testing of recharge water and recovered water are proposed for the Phase Two testing program to verify this assumption.

Analyses of various supply facilities options would be conducted during a Phase Two study. It is apparent at this time that an ASR program would fit well as one component in the City of Kerrville's water supply plan. A month-by-month calculation of supply versus demand indicates that 2 mgd of ASR recovery capacity could be added by around 1992 which would postpone required expansion of the water treatment plant by 10 years--from 1992 to 2002. The present worth in 1988 dollars of future expansions with and without ASR for the one alternative examined for each approach are as follows: $2.26 million with ASR, versus $2.98 million without ASR. This assumes 5% inflation and 8% financing costs. The present worth costs will vary somewhat based on the percentages assumed. In any case, the ASR option can save about 25% compared to treatment plant expansion costs, and possibly save millions of dollars if ASR storage can be used in lieu of, or to defer, construction of an off-channel reservoir.

No major permitting efforts are foreseen. An amended water right to divert more Guadalupe River water must be obtained soon whether or not ASR is pursued. The UGRA is currently pursuing this independent of the ASR study. The only specific permit required for ASR wells is a Class V injection permit from the Texas Water Commission which is expected to be a routine matter.

A separate legal issue is how to maintain the right to water once it is recharged. Although this issue will be studied in more detail during a Phase Two investigation, it appears that protection is achievable. Three techniques appear promising: (1) special legislation for UGRA to store and recover water from the ground; (2) City of Kerrville ordinance prohibiting drilling of wells into the recharge area; and (3) purchase of the rights to underground water from overlying landowners, or an easement from these owners to use the aquifer for storage.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this investigation, an aquifer storage recovery program appears feasible in Kerrville. Indicators are all positive in the areas of aquifer performance, cost, and institutional/legal concerns.

It is therefore recommended that a Phase Two Field Investigation be undertaken to confirm ASR feasibility in a prototype ASR well. A phased approach including detailed testing and analysis is recommended in order to provide a firm basis for efficient design and permitting of additional ASR facilities. A 12-inch diameter ASR well is proposed to be constructed on the UGRA plant site to a depth of about 600 feet. Two monitoring wells would also be installed a short distance away on the plant site.

After installation of wellhead facilities on the test wells, a series of five ASR test cycles would be run, lasting from 26 to 365 days. The full 30-month study would provide data to estimate long-term recharge and recovery flow rates, trends in water levels, changes in water quality with successive cycles, and other factors. A recharge rate of 300 gallons per minute (gpm) is assumed at this time, with a corresponding recovery rate of 500 gpm. Testing of recovered water prior to delivery to the existing City water supply system would be conducted in accordance with Texas Department of Health requirements.

If Phase Two begins in June 1988, completion of testing and issuance of a Phase Two report would occur in December 1990. It appears that adequate time would then remain to install the projected necessary ASR production wells by 1992 without having to draw on the ground water resource in excess of safe yield levels.

Chapter 1
INTRODUCTION

Aquifer Storage Recovery (ASR) is a relatively new water supply concept in the United States, in which treated drinking water is stored underground by recharge wells into a suitable aquifer during those months of the year when available capacity of water treatment facilities exceeds system demand. The stored water is later recovered from the same wells to meet peak summer months' or emergency demands exceeding treatment plant capacity, without the necessity for retreatment other than disinfection.

Many water utilities are faced with a steady increase in average demand and in maximum day demand, due to increased population growth or per capita consumption. Water supply and treatment facilities are usually designed to meet annual maximum day demand, which may typically exceed average demand by a factor ranging from 1.3 to 2.5. In Kerrville, this factor has averaged about 2.2 over the past 10 years. Furthermore, due to economies of scale, water facilities are typically designed to meet peak demands several years in the future. Consequently, there is usually a large investment in peak capacity which is rarely utilized. In Kerrville, this excess peak capacity in the existing Upper Guadalupe River Authority Water Treatment Plant will be fully utilized in just a few years (see Chapter 3).

The usual approach to this situation is to expand the water treatment plant in advance of the year when demand will exceed the present capacity. This then repeats the cycle of large front-end investment in peaking capacity, which is again underutilized until demand catches up with the increased supply capacity, assuming growth continues to occur.

The ASR concept allows a utility to use new recharge-recovery wells to meet increased peak demands in lieu of an immediate water treatment plant expansion. Since groundwater resources are limited, Kerrville is at the point of needing a river water supply capacity expansion as provided under contract with UGRA. Therefore an investigation of ASR feasibility is a timely undertaking for evaluating future water supply options for the City.

1.1 ASR BACKGROUND

Although the ASR concept is new in Texas, there are several successfully operating systems in the U.S. and abroad. Five ASR systems are known to be operational in the United States while testing is underway at several additional sites. The operational sites are in Florida (Manatee County, Peace

River and Cocoa); New Jersey (Wildwood); and California (Goleta). Testing is underway at six additional sites in Florida, South Carolina, Arizona, and Washington. Listed below is information on the five currently operational ASR facilities in the U.S. Overseas experience includes extensive ASR facilities in Israel that have been in operation since 1972 in sand and sandstone aquifers. A recent review of aquifer recharge literature suggest that ASR facilities may also be operational in the Netherlands and other countries.

OPERATIONAL ASR FACILITIES IN THE UNITED STATES

Location	Year Operation Began	Storage Zone	ASR Recovery Capacity (mgd)	Maximum Day Demand (mgd)
Wildwood, NJ	1968	Sand	3.5	12
Goleta, CA	1978	Silty, clayey sand	5	15
Manatee County, FL	1983	Limestone	1.5	40
Peace River, FL	1985	Limestone	4.9	10
Cocoa, FL	1987	Limestone	1.5	37

As shown in Figure 1, ASR may be used to store water during those months when supply capacity exceeds demand, and recover it to meet peak demands which exceed existing capacity. Seasonal ASR storage to meet diurnal demand variations may typically reach several hundred million gallons. This compares with the few million gallons conventionally located in distribution systems at elevated or ground storage tanks.

Although there are many similarities in concept, ASR may be distinguished from other aquifer recharge measures by the use of dual-purpose wells for both recharge and recovery. Single purpose injection wells have been used for aquifer recharge in several areas of the U.S., with untreated water from a variety of sources including wastewater treatment plant effluent. However, in most cases recovery occurs at distant wells after substantial movement and mixing with native groundwater. This is the approach currently being used in El Paso, where highly treated wastewater is being injected into the Hueco Bolson Aquifer and then recovered several miles away by other wells.

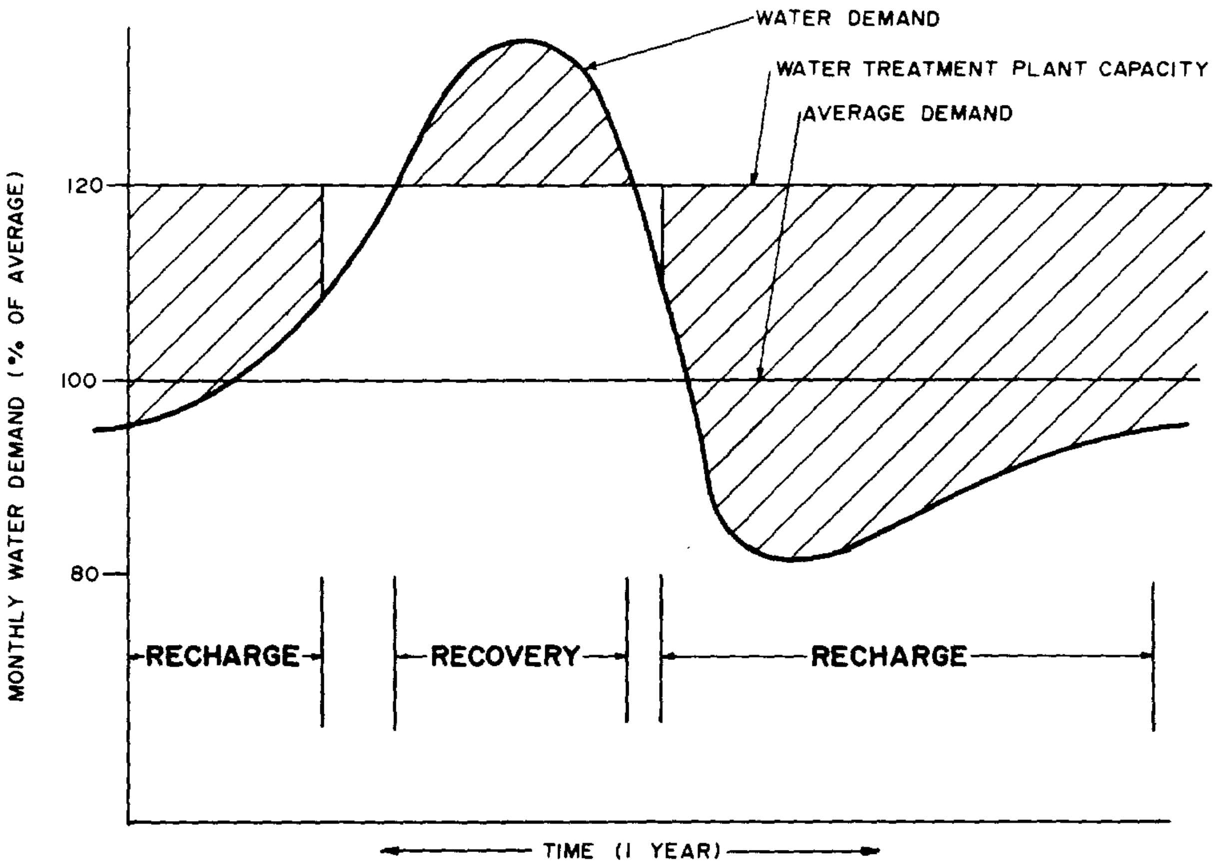

Figure 1
Typical ASR Operating Schedule

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Another common recharge practice is to pond stormwater in permeable spreading basins or dry river beds through which the water percolates to the aquifer. This is generally feasible where confining layers such as clay or shale are absent. A variation on this technique is to convey the ponded water to the aquifer via recharge wells. Both of these methods have been practiced on an experimental basis with rainfall/runoff in the playa lakes of West Texas.

Advantages of ASR compared to these two traditional methods are:

- Minimal environmental permitting requirements since there is negligible risk of pathogen presence which must be considered with untreated surface water or wastewater effluent used for recharge.

- No clogging of wells or surface spreading basins due to silt buildup, common with stormwater recharge systems.

1.2 ASR CRITERIA

Three principal criteria that govern the site-specific feasibility of ASR have been developed, based upon long-term, undocumented operation at two sites, shorter term satisfactory operation at three fully documented sites, and several test programs by the U.S. Geological Survey and others:

1. A seasonal variation in water supply, water demand, or both. Typically when the ratio of maximum to average day demand exceeds 1.3, this criterion is met.

2. A reasonable scale of water facilities capacity. Due to economies of scale and the initial cost of developing ASR wells, it may be an inappropriate technology below 1 mgd useful recovery capacity.

3. A suitable storage zone, considering geologic, hydrologic, quantity, quality, engineering, and several other factors.

These criteria appear to be met in Kerrville. The ratio of maximum to average day demand averages 2.2. An ASR system in Kerrville could easily exceed 1 mgd since current maximum day demand is in excess of 7 mgd. Finally, the Hosston and Sligo formations of the Lower Trinity Aquifer appear to be a good storage zone, based on a review of aquifer data.

1.3 ADVANTAGES OF ASR

Each ASR application to date appears to have a unique reason or combination of reasons that indicate the advantages of ASR. The principal potential advantages for the Kerrville area are as follows:

- Reduction of facilities expansion costs, typically from 25 to 50 percent or more, by seasonal storage of treated water.
- Improved utility system reliability in the event of droughts or emergency loss of river pumps, treatment plant or other key facilities.
- Restoration of declining groundwater levels.

The major benefit of ASR for most clients is that, by making more efficient use of existing raw water supply, ASR typically reduces capital costs of water supply expansions by up to 50 percent. In growing communities, ASR facilities can postpone or eliminate the need for a water treatment plant expansion. It can also often reduce the need for expensive ground level storage tanks or reservoirs.

1.4 CURRENT STUDY

CH2M HILL was authorized to proceed with the current investigation during November 1987. This is a Phase One Preliminary Feasibility Assessment. Based upon the results of this report, UGRA may elect to proceed with a Phase Two Field Investigation to confirm ASR feasibility in a prototype ASR well. Assuming ASR feasibility is confirmed, the well field could then be expanded as required to meet increasing water demands during Phase Three, Well Field Expansion.

Chapter 2
WATER SUPPLY AND DEMAND

2.1 WATER SUPPLY

Before 1981, the City of Kerrville's ("the City" hereafter) water needs were supplied from municipal wells, drawing water from the Hosston Sand and Sligo Limestone members of the lower Trinity aquifer. Wells are from 250 to 600 feet deep, with the water bearing deposits averaging 75 feet in thickness. The Hosston formation consists of conglomerate, sandstone, and shale, while the Sligo formation contains sandy dolomite and dolomitic limestone.

From the time of the first major well drilling in the 1940's to 1960, water table levels fell about 100 feet. As water demands continued to increase, water table levels continually declined, ranging from 120 to 190 feet drop in individual wells over a 20-year period from 1960 to 1980 (for City well numbers 4, 8, and 10 as representative examples). Beginning in February 1981, the City switched to surface water as its primary source, due to limited capacity of the groundwater resource in the Kerrville area and rapidly declining water levels in the wells.

Treated surface water from the Guadalupe River is supplied under contract with the Upper Guadalupe River Authority (UGRA). The UGRA operates a riverside filtration plant with a capacity of 5 million gallons per day (5 mgd). A practical maximum capacity for sustained seasonal operation is about 4.5 mgd. The 13 wells (and two not in use) comprising the original source are still used to supplement the surface water source such as during periods of peak demand. From 1982 to 1985, well water accounted for 5 to 25 percent of the total water supplied in a given year.

River water is diverted by UGRA under Texas Water Commission Permit No. P-3505. Maximum permitted diversion rate is 9.7 cubic feet per second (6.2 mgd) and annual authorized usage is 3,603 acre-feet (an annual average of 3.22 mgd). The raw water pumps at the river are rated at 11.6 mgd. A study is currently being conducted by UGRA to demonstrate that the diversion amount could be increased while still satisfying downstream prior water rights. The opportunity exists for operating the UGRA plant during off-peak months at rates higher than actual demand, and placing the surplus treated water in underground storage. Then in peak demand months, this temporarily stored water could be recovered and used to help meet the peaks without having any negative impact on the total amount of groundwater in storage.

The sustained "safe yield" of the Hosston-Sligo groundwater aquifer at Kerrville is estimated at 0.5 to 0.6 mgd. This annual average pumpage rate is the estimated amount that can be pumped year after year with no net change in the average groundwater level. It is based on an examination of historic annual pumpage rates and groundwater levels. From the 1940's through 1981, water levels continuously declined with annual pumpage rates at 3 mgd and less. After pumpage was decreased upon the addition of surface water supplies in 1981, water levels have generally risen when pumpage was less than 0.5 mgd, declined with pumpage at 0.8 mgd, and stayed relatively constant with pumpage at about 0.5 to 0.6 mgd. This is shown graphically in Figure 2.

It must be noted that this estimate of 0.5 to 0.6 mgd is only approximate, being based on just a few years of record. An additional several years of detailed data would be needed to refine the estimate. However, it is considered a realistic and conservative estimate based upon the available data at this time which exhibits a consistent trend.

The amount of groundwater available to Kerrville has likely declined over the past decades due to the increased use of groundwater by others in the area. Other municipal users in Kerr County have increased their usage by 1.7 mgd during the period 1966 to 1980--from 1.3 to 3.0 mgd. By comparison, Kerrville increased its water usage by 1.0 mgd in the same period. Although the other users draw from the overlying Glen Rose and Cow Creek formations, some of the water in these formations migrates down to the Hosston-Sligo formation. Increased pumping from these other formations thus reduces the inflow to, and available water in, the Hosston-Sligo formation which supplies City of Kerrville wells.

The aquifer and installed City wells are physically capable of delivering considerably more than this. To meet peak-day demands and emergencies, such as a water treatment plant shutdown, the wells are estimated to be able to deliver about 8 to 10 mgd. This is based on extrapolation of values presented in a 1973 report by William F. Guyton and Associates[1]. However, pumping at this rate on a sustained basis would quickly lower the groundwater table and eventually dry up the wells. Therefore, to maintain a "bank account" of water in the ground available for peaking and emergency use, groundwater usage should continue at the present average yearly rate of 0.5 to 0.6 mgd. Any reduction in current withdrawals or increase in recharge will cause water levels to rise.

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[1]William F. Guyton & Associates. Report on Groundwater Conditions in the Kerrville Area. December 1973.

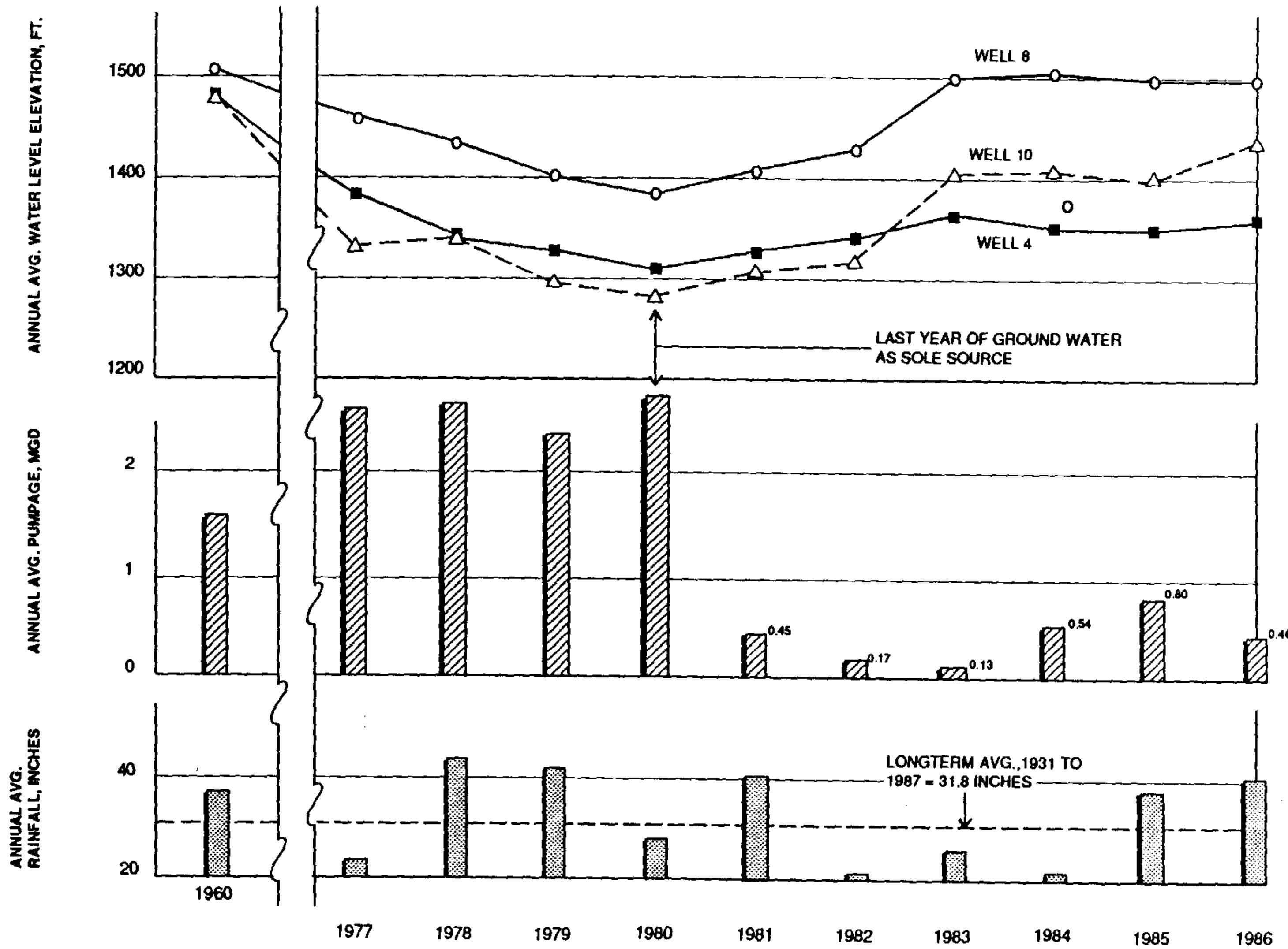

Figure 2
Kerrville Pumpage and Well Water Levels

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2.2 WATER QUALITY

River water quality is generally excellent. Physical and chemical quality of treated water sampled at the UGRA water treatment plant are listed in Table 1 for three samples taken between September 1985 and November 1986. Treated water, rather than raw river water, is of interest in this study since it would be the source for the proposed aquifer storage recovery project.

Well water from the Kerrville municipal wells is of good quality also. It has a fairly high total dissolved solids content of 500 to 700 mg/l, but the concentrations are under the limit of 1,000 mg/l set by the Texas Department of Health. Calcium carbonate hardness (as $CaCO_3$) values of 270 to 380 mg/l put the water in the "very hard" category, which is anything greater than 180 mg/l. There have been iron concentrations from specific wells exceeding the 0.3 mg/l limit, but the water from a combination of wells has been well below the limit in the few sample results that were reviewed. Analysis results of water quality taken from individual well tests dated 1966 to 1973 are shown in Table 2. More recent test results (1983 to 1987) of the combined water (wells and river water) indicate similar or better quality.

2.3 WATER DEMANDS

Over the past 10 years, demand has increased from a yearly average of 2.7 mgd in 1977 to 3.2 mgd in 1986. The maximum day demand has increased over the same period from 5.6 to 7.6 mgd. The historic demands in this period are shown in Figure 3 and listed below.

Year	Annual Average Day	Maximum Day	Maximum ÷ Average
1977	2.71	5.63	2.07
1978	2.72	5.69	2.09
1979	2.49	6.16	2.47
1980	2.85	6.56	2.30
1981	2.71	6.44	2.38
1982	2.82	5.69	2.02
1983	2.70	6.76	2.50
1984	3.39	5.86	1.73
1985	3.23	6.92	2.14
1986	3.25	7.61	2.34
Mean			2.20

Table 1
QUALITY OF UGRA TREATED GUADALUPE RIVER WATER

Constituent	Concentration Range, in mg/l	Texas Department of Health Limits
pH	7.8 to 8.3	>7.0[a]
Total dissolved solids	219 to 259	1,000
Total hardness as $CaCO_3$	194 to 237	None (water is very hard)
Bicarbonate	209 to 265	None
Calcium	46 to 66	None
Chloride	16 to 24	300[a]
Fluoride	0.5 to 1.3	1.6 for air temperature of 71° to 79°
Magnesium	15 to 19	None
Nitrate as N	0.4 to 1.2	10
Sodium	8 to 10	None
Sulfate	16 to 26	300[a]
Arsenic	<0.01	0.05
Barium	<0.5	1.0
Cadmium	<0.005	0.01
Chromium	<0.02	0.05
Copper	<0.02 to 0.03	1.0[a]
Iron	<0.02 to 0.04	0.3[a]
Lead	<0.02	0.05
Manganese	<0.02	0.05[a]
Mercury	<0.0002	0.002
Selenium	<0.002	0.01
Silver	<0.01	0.05
Zinc	<0.02 to 0.12	5.0[a]

[a]These are "secondary standards" related to aesthetics and taste, not to health risks.

Source of Data: Texas Department of Health samples taken at treatment plant on September 4, 1985; November 12, 1985; and November 18, 1986.

Table 2
QUALITY OF KERRVILLE WELL WATER

Constituent	Concentration Range, in mg/l	Texas Department of Health Limits
pH	7.3 to 8.0	>7.0[a]
Total dissolved solids	540 to 710	1,000
Total hardness as $CaCO_3$	312 to 445	None (water is very hard)
Bicarbonate	354 to 382	None
Calcium	60 to 97	None
Chloride	13 to 109	300[a]
Fluoride	0.9 to 1.5	1.6 for air temperature of 71° to 79°
Magnesium	37 to 56	None
Nitrate as NO_3	<0.4	45
Sodium	12 to 34	None
Sulfate	27 to 92	300[a]
Arsenic	<0.01	0.05
Barium	<0.5	1.0
Cadmium	<0.005	0.01
Chromium	<0.02	0.05
Copper	<0.02	1.0[a]
Iron	0.06 to 1.15	0.3[a]
Lead	<0.02	0.05
Manganese	<0.05	0.05[a]
Mercury	<0.0002	0.002
Selenium	<0.002	0.01
Silver	<0.01	0.05
Zinc	0.02	5.0[a]

[a]These are "secondary standards" related to aesthetics and taste, not to health risks.

Source of Data: 17 samples taken from 13 individual City of Kerrville wells by Texas Department of Health between 1963 and 1973. Quoted from Report on Ground-Water Conditions in the Kerrville Area, William F. Guyton & Associates, December 1973. Heavy metals concentrations are for a sample taken from the distribution system on November 12, 1985, by the Texas Department of Health. Well water constituted about 60% of the supply that day.

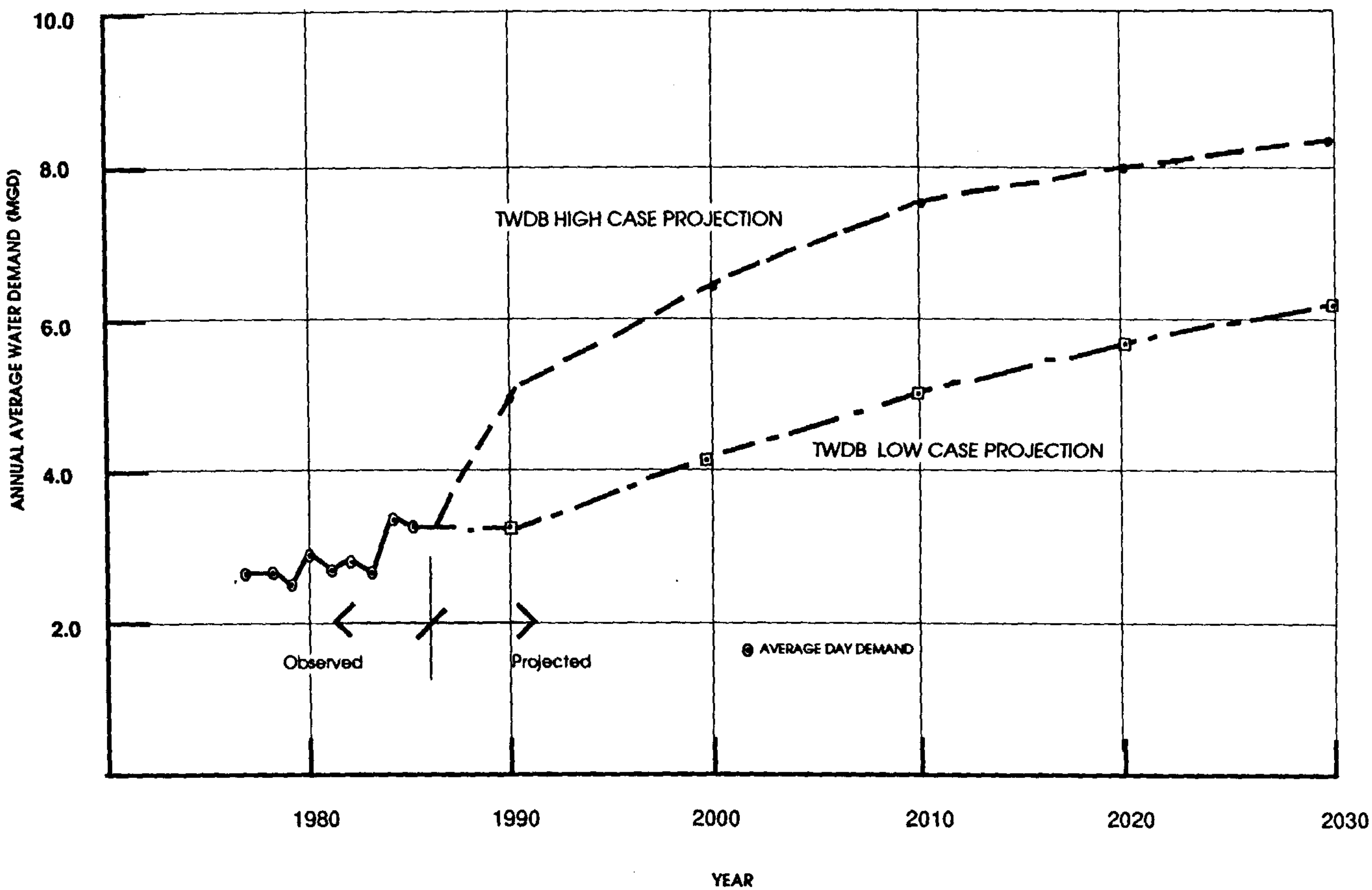

Figure 3
Annual Average Water Demand

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Projected water demands through the year 2030 are shown in Figure 4. The selected demand values are the average of Texas Water Development Board "High Case" and "Low Case" demands shown in Figure 3. These projections are from the November 1984 publication, Water for Texas. "High" is characterized by high migration to the State characteristic of the 1970's, and per capita water use at drought rates. "Low" is characterized by lower migration to the State typical of the 1940 to 1970 period, and average water use under normal weather conditions. A maximum day to average day peaking factor of 2.2 was used based on the historical data presented above.

Estimates from other sources were sought for comparison. The most recent study provided by the City of Kerrville, listing population projections from various sources is the Regional Wastewater Treatment Plan, prepared by Freese and Nichols Inc. in February 1985. Table 3 is a reproduction of a table presented in that report, showing six population projections by various consultants and the Texas Department of Water Resources (now the Texas Water Development Board). Note that the population projection prepared for year 2020 by three consultants ranges from the "High" of the TWDB to 15 percent higher than that value. Projections prepared prior to 1985 were made during a period of very high growth rates. In light of the 1986 downturn in oil prices and accompanying slowdown in economic growth of the State, these early projections may be overly optimistic at present. Therefore, a lower number (average of TWDB "High" and "Low") has been selected for the purposes of this study. Note that the variation between "High" and "Low" is only 6 percent for year 2020, so any projection in this general range is considered reasonable for study purposes.

The selected population and yearly average water demand are given below. The long-term average population growth rate for the period 1990 to 2030 is computed to be 1.4 percent per year. The averaged TWDB projections show a high initial annual growth rate of 2.3 percent for 1990 to 2000, slowing to 0.5 percent for the decade 2020 to 2030. These rates

	Projections		
		Water Demand (in mgd)	
Year	Population	Average	Maximum Day
1990	20,000	4.2	9.3
2000	25,000	5.4	12.0
2010	29,000	6.4	14.0
2020	32,000	7.0	15.3
2030	34,000	7.4	16.2

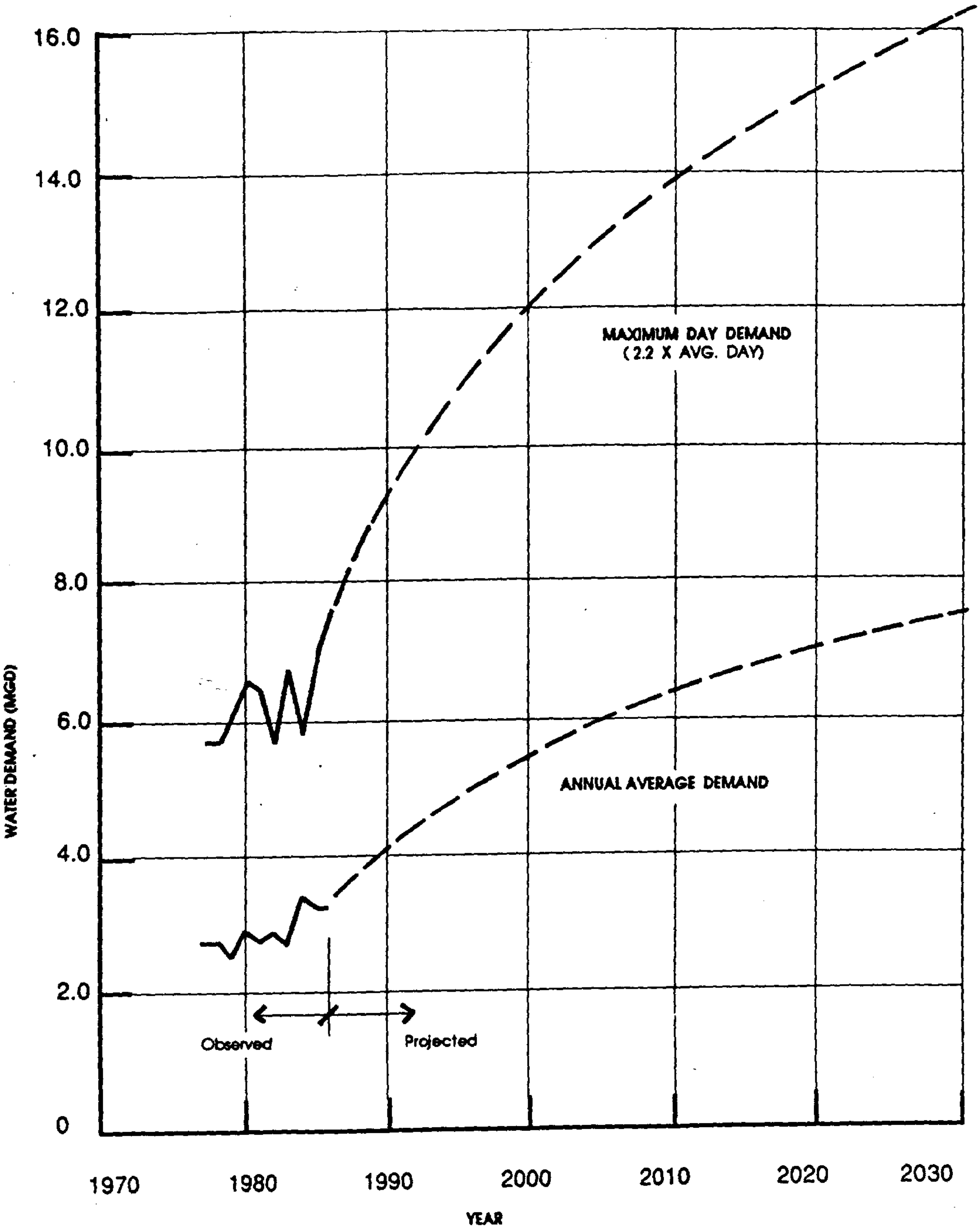

Figure 4
Average and Maximum Day Water Demand Projection

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Table 3
POPULATION PROJECTIONS
1980 - 2020

City of Kerrville	Freese and Nichols, Inc.	Espey, Huston And Associates, Inc.	Espey, Huston And Associates, Inc. (Adjusted)	Bovay	Texas Department of Water Resources High	Texas Department of Water Resources Low	U.S. Census
1980	15,276	17,355	15,276	17,500	15,276	15,276	15,276
1985	18,448	19,650	17,571	20,300			
1990	21,619	22,030	19,951	22,500	21,619	18,041	--
1995	24,293	24,520	22,441	24,300			
2000	26,966	27,090	25,011	26,200	26,966	22,859	--
2005	29,056	29,760	27,681	27,800			
2010	31,147	32,460	30,381	29,700	31,147	27,609	--
2015	32,126	35,290	33,211	31,600			
2020	33,104	38,200	36,121	33,500	33,104	31,297	--

Source: Freese and Nichols, Inc., Regional Wastewater Treatment Plan, City of Kerrville, Upper Guadalupe River Authority, and City of Ingram, February 1985.

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compare to the record 2.4 percent per year for all of Texas from 1970 to 1980, and 1.1 percent for the U.S. in the same period.[2]

Figure 5 shows the seasonal variation of water demands in Kerrville. Monthly demands as a percentage of annual demands range from a low of about 72 percent in December, January, and February to a high of 153 percent in August. This variation in demand provides the opportunity to store treated water during months when water treatment capacity exceeds demand. This water can then be recovered to meet emergency or dry season demands that exceed existing plant capacity.

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[2] U.S. Department of Commerce, Bureau of the Census, General Social and Economic Characteristics, Texas, Vol. I, 1983.

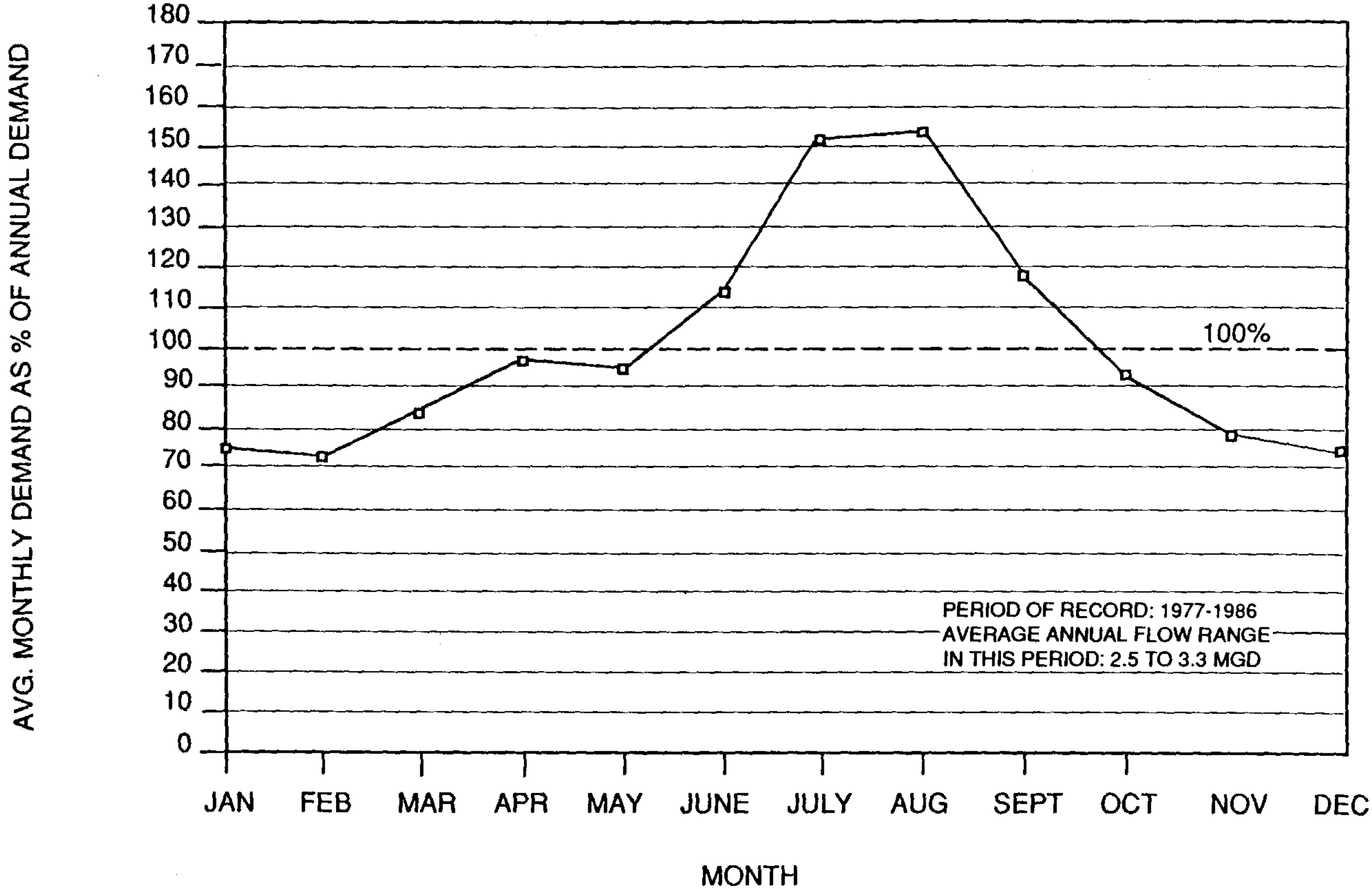

Figure 5
Typical Monthly Demand Variation

Chapter 3
AQUIFER STORAGE RECOVERY INVESTIGATION

3.1 SUPPLY VERSUS DEMAND

To prevent a recurrence of ground water overdraft that occurred up until 1981, it will be necessary to expand surface water supplies around 1992 based on demand projections presented herein. This assumes that wells are used primarily for peaking but also at a minimal rate (all wells) of about 0.1 to 0.5 mgd for all months but July and August. This has been the current pattern over the past 5 years in order to keep the pumps in good operating condition. In July and August, a maximum pumping rate of about 2.0 mgd could be maintained which would hold the yearly average total to the safe yield target of about 0.55 mgd. At a groundwater withdrawal rate of 2.0 mgd in August, typically the peak demand month in Kerrville, and with the surface water plant running at a maximum 5.0 mgd, the peak monthly supply capacity is 7 mgd if groundwater levels are to remain stable. This August demand rate will be reached by 1993 or 1994.

Peak monthly demand controls facilities design in Kerrville when conjunctive use of both ground and surface water is used. This contrasts with the typical maximum day demand criterion in sole-source systems. In a system with both wells and surface water, the wells can meet short-term peaking demands of a day or many days, and then have their output reduced during off-peak periods when the base-load water treatment plant can satisfy the demands. The 1973 Guyton report[1] concluded that City wells could meet June, July, and August sustained demands of from 2.3 to 4.0 mgd without experiencing excessive drawdowns of water below the pump settings. Therefore a lower rate of 2.0 mgd in August is considered a conservative assumption for future planning purposes.

The surface water supply capacity could be augmented with either a UGRA plant expansion, ASR wells, or a combination of both. If demand continues to increase as projected, the UGRA plant will eventually have to be expanded in any event. This is because as average day demands approach and exceed UGRA plant capacity, very little water would be available to store in ASR wells during the off-peak season.

Since ASR facilities are generally less than half the cost of equivalent capacity treatment plant additions and since a

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[1]William F. Guyton & Associates, "Report on Ground-Water in the Kerrville Area," December 1973.

plant expansion will be needed in any case, it is recommended that both ASR development and UGRA plant expansion be pursued to minimize future costs of treated water. The exact proportions of ASR and plant expansion increment selected will depend on several factors including the following:

- Ease of expansion of existing UGRA plant
- Physical limits on amount of underground storage volume available without major leakage or spillage
- Financing constraints
- Capacity limits on river diversion and offstream storage volume.

It is recommended that these issues be explored further during a subsequent ASR study phase.

Without ASR, a plant expansion would be required around 1992 as explained above. This is shown graphically in Figure 6.

One alternative expansion plan that would meet the projected demands without overdrafting the groundwater would be to add 2 mgd of ASR capacity around 1992. This would defer the need for a plant expansion until the year 2002 as shown in Figure 7.

Thus, use of ASR could postpone treatment plant expansion for about 10 years. Also, the plant expansion after ASR addition could be smaller--2.5 mgd required through the year 2030 with ASR, versus 5 mgd without. This is because ASR maximizes the efficiency of surface water treatment plants by using excess off-peak capacity that is normally idle in a conventional operation.

3.2 HYDROGEOLOGY

The Trinity Group aquifer is essentially the only ground water source in Kerr County.[2] Quality and well yields are variable depending on the specific geologic formation drawn from, and specific location of a given well. However, good yields and quality can be obtained to suit the purposes of specific users in the area, as described in succeeding paragraphs.

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[2] Texas Department of Water Resources, Report 273, "Ground-Water Availability of the Lower Cretaceous Formations in the Hill Country of South-Central Texas," January 1983.

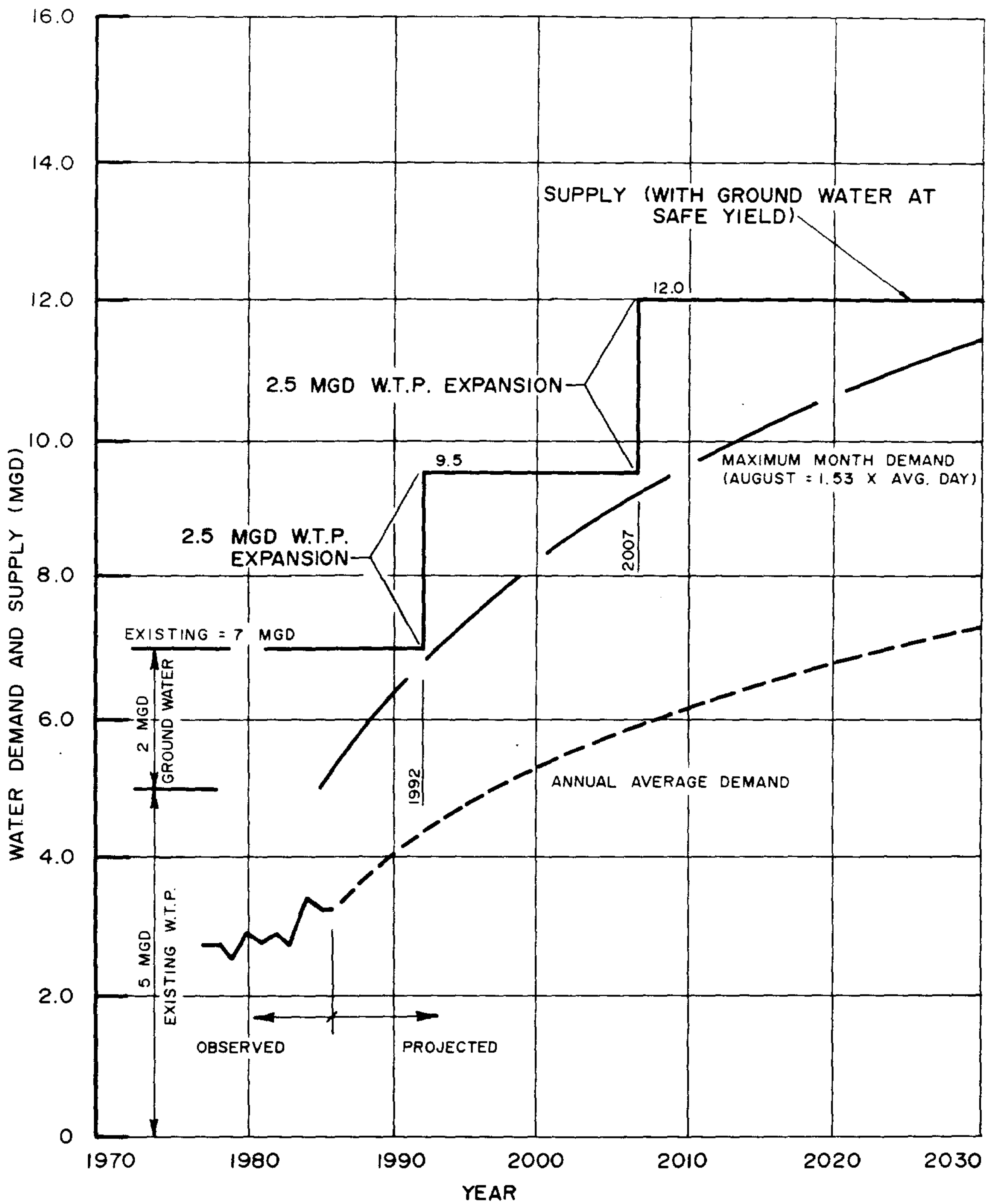

Figure 6
Supply/Demand Relationship
Without ASR--One Alternative

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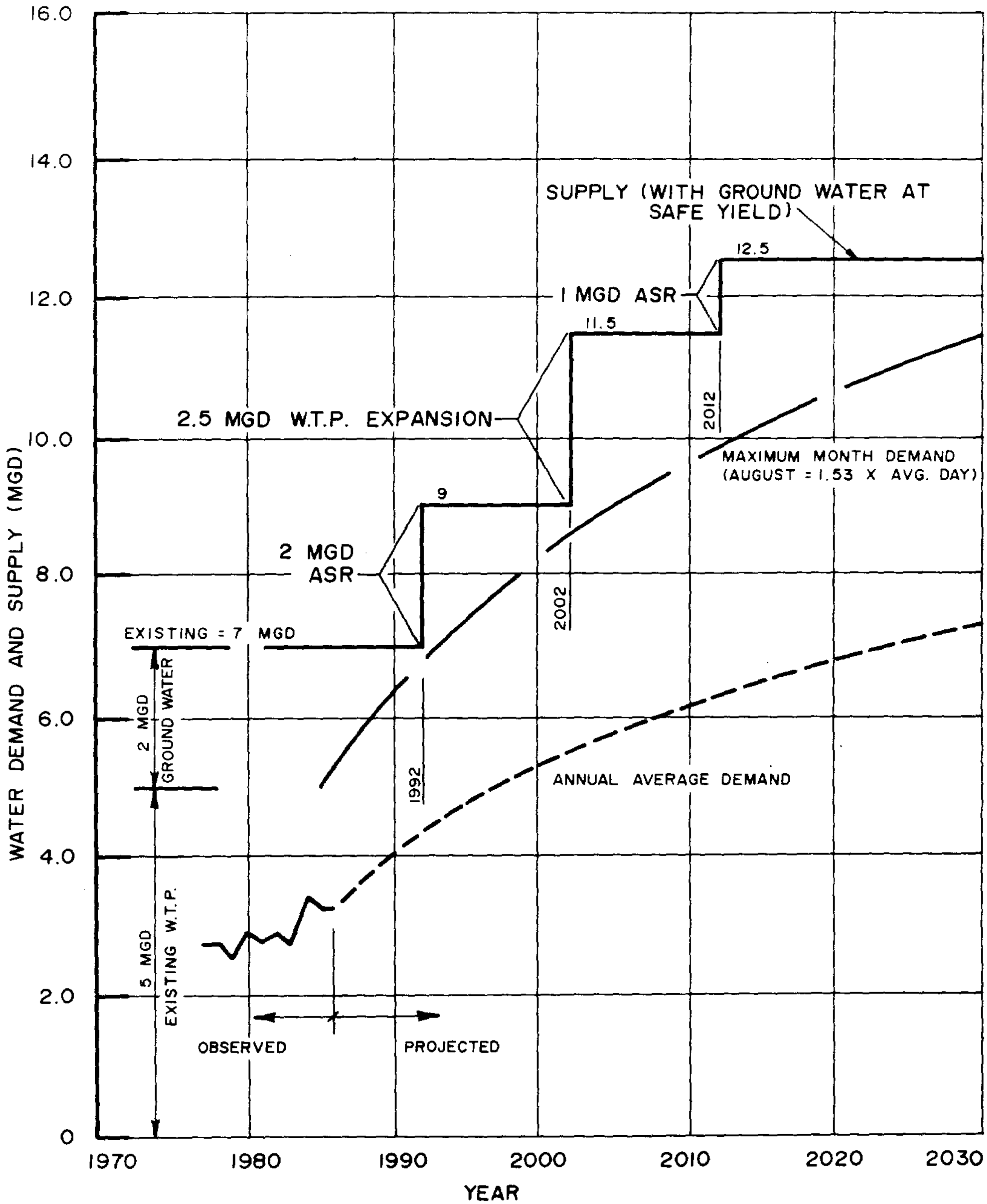

Figure 7
Supply/Demand Relationship
With ASR--One Alternative

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Geology

Geologists divide the aquifer into the following layers in descending order based on differences in the geologic formations:

Upper Trinity Aquifer (nearest ground surface)

- Upper member of Glen Rose Limestone

Middle Trinity Aquifer

- Lower member of Glen Rose Limestone
- Hensell Sand
- Cow Creek Limestone

Lower Trinity Aquifer

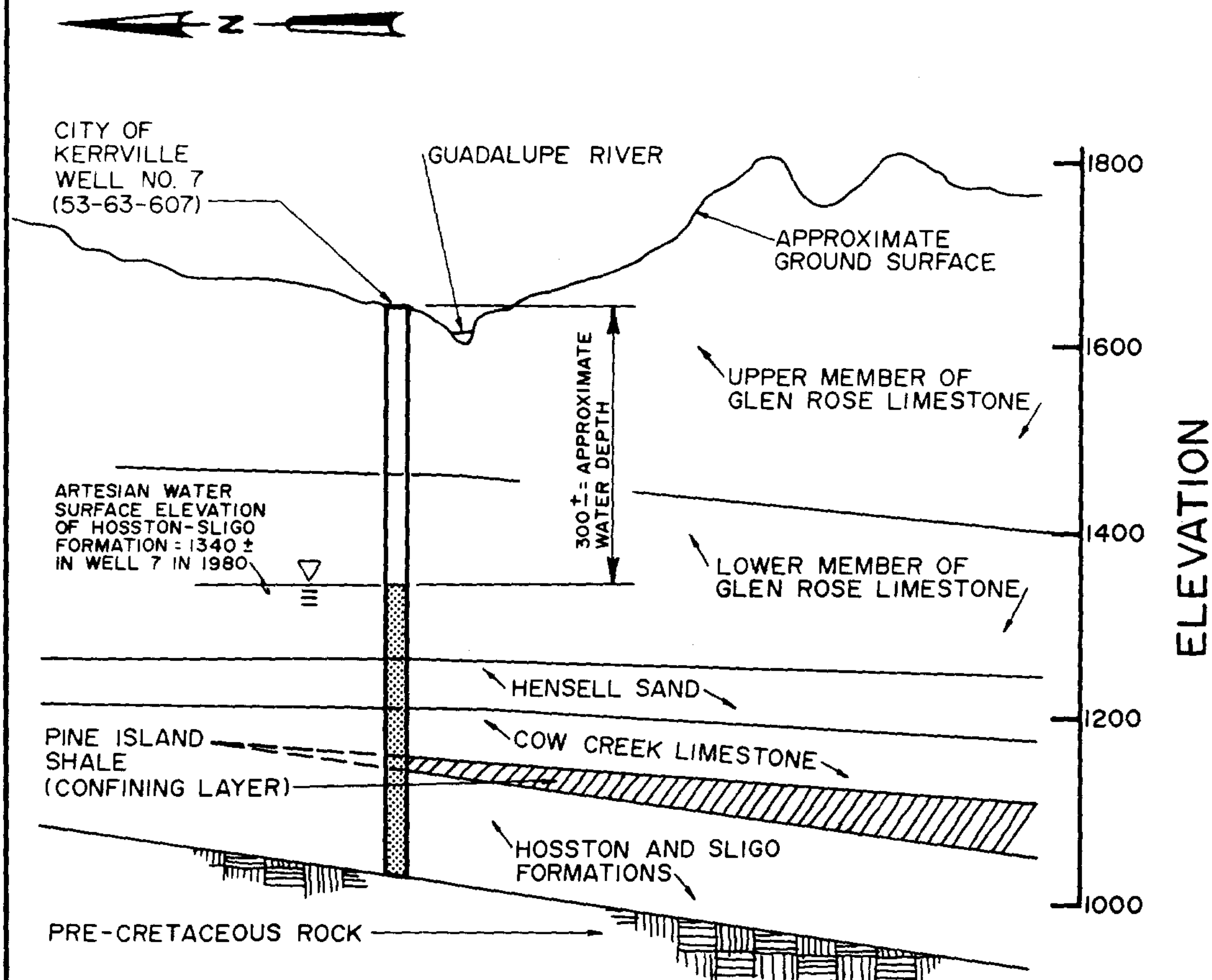
- Pine Island member of Pearsall Formation
- Sligo Limestone member of Travis Peak Formation
- Hosston Sand member of Travis Peak Formation

A cross-sectional view of these formations is shown in Figure 8. The major water yielding formation in the Kerrville area is the Hosston-Sligo formation. Although in some areas the two layers are distinct, in the Kerrville area they are undifferentiated and therefore referred to by geologists as the "Hosston and Sligo formations" or "Hosston-Sligo Formation." Since the Hosston-Sligo has water of better overall quality and produces higher yields than the other formations, it is used for municipal purposes in Kerrville and Bandera and for irrigation in a few other places.

However, since it is deeper (about 600 feet from ground surface to bottom of well) and therefore more costly to drill into than the shallower formations, most small domestic and commercial wells in the Kerrville area draw water from the Lower Member of the Glen Rose Limestone, at about 300 to 500 feet below ground surface. Quality is fairly good, and although yields are lower than from the Hosston-Sligo--typically 20 to 100 gpm versus 500 to 900 gpm--the yields are sufficient for individual residence purposes. The shallower Upper Member of the Glen Rose Limestone is generally not used except for limited domestic and livestock purposes, due to low yields and poor chemical quality.[3]

The Cow Creek Limestone is separated from the Hosston-Sligo formation by the Pine Island Shale, which is impermeable and

[3] Ibid.



SOURCES: 1) TEXAS WATER DEVELOPMENT BOARD, "GROUND WATER RESOURCES OF KERR COUNTY, TEXAS," REPORT 102, NOVEMBER 1969
2) WATER LEVEL FILES OF THE TEXAS WATER DEVELOPMENT BOARD

Figure 8
Approximate Geologic Cross Section

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therefore confines the water in the underlying Hosston-Sligo. This results in an artesian water surface in Hosston-Sligo wells which is currently about 200 feet above the level of the Pine Island Shale (Figure 8). It also serves as a hydraulic barrier between the two formations with the possible exception of some leakage where faulting occurs and also through the open hole section of Well 8, which penetrates both the Cow Creek and Hosston-Sligo formations.[4] The Pine Island Shale is believed to "pinch-out," or end, toward the north part of Kerrville since it grows gradually thinner moving in a northerly direction (Figure 8). However, there is not enough subsurface geologic information in the area to confirm the exact extent of the formation north of the Guadalupe River.

The Hosston-Sligo formation is thus confined with relatively impermeable barriers both top and bottom--the Pine Island Shale above and the pre-Cretaceous rock below.

Average thickness and general description of the materials comprising each geologic formation are summarized as follows[5]:

Formation Name	Average Thickness in Kerrville Area, Feet	Primary Materials
Upper Member of Glen Rose Limestone	130	Fossiliferous limestone, shale, and marl
Lower Member of Glen Rose Limestone	210	Fossiliferous limestone, dolomite, marl and shale
Hensell Sand	55	Conglomerate, shale, sand, dolomite and marl
Cow Creek Limestone	35	Sandy limestone
Pine Island Shale	18	Shale with some sand and limestone
Hosston-Sligo Formation	75	Conglomerate, sand, and shale

Recharge and Ground Water Movement

Recharge to the Trinity Group aquifer occurs primarily by direct infiltration of rainfall plus overland flow of water

[4] Ibid.
[5] Ibid, and William F. Guyton and Associates, "Report on Groundwater Conditions in the Kerrville Area," December 1983.

across areas where the water bearing formations outcrop (appear at the surface). For wells in the Kerrville area this recharge occurs about 20 miles to the north and northeast in Gillespie County. The Glen Rose Limestone and the Hensell Sand receive the greatest amount of this direct recharge. The lower formations--Cow Creek Limestone and Hosston-Sligo formation--are thought to be recharged by vertical leakage from the overlying Glen Rose Limestone in addition to direct infiltration.[6]

Ground water in Kerr County is slowly moving in a general south and southeast direction. Where water is withdrawn by pumping, this general flow trend can be reversed, with water flowing toward the center of pumping. Although there is considerable ground water discharging to the Guadalupe River in the Kerrville area through springs and seeps, this is from the shallow formations, not the Hosston-Sligo formation which is of interest in this study. The water level in the Hosston-Sligo is nearly 300 feet below river level (Figure 8).

The ability of an aquifer to transmit water is a key element in ASR studies, since an ASR well must be able to accept and yield sufficient quantities of recharge water to make the investment in construction and operation worthwhile. A measure of the ability of an aquifer to transmit water is its transmissivity. Transmissivity is defined as the quantity of water that will flow through a vertical strip of the aquifer one unit wide and extending the full saturated height of the aquifer under a unit hydraulic head. In English units, the quantity is usually expressed in cubic feet per day, and the unit width and saturated thickness in feet. In general, experience with operational ASR facilities and results of other test programs suggest that suitable storage zones are characterized by a transmissivity greater than 2,000 ft^2/day. Transmissivities of Kerrville wells producing from the Hosston-Sligo formation range, with one exception, from 2000 to 3300 and average 2900 ft^2/day. This is not particularly transmissive by comparison with some other aquifers like the Edwards at San Antonio, but the Hosston-Sligo formation does qualify as a feasible ASR development candidate on this criterion.

Pumping tests by William F. Guyton & Associates in 1973 and by the USGS in the 1940's and 1950's on eight City wells indicate that water flows fairly freely in the City wellfield area, but transmissivity in the aquifer beyond the immediate Kerrville area is considerably lower. This could be due to lower overall permeability of surrounding water-bearing beds and/or to hydraulic formations such as

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[6] Ibid.

impermeable barriers or faulting.[7] In any case, the net effect is a productive ground water "bowl" beneath Kerrville which does not draw down quickly in a given well under short-term pumping conditions. However, with continued long-term significant pumping, large drawdowns over the entire wellfield occur since the surrounding water-bearing formation beyond Kerrville cannot fill the "bowl" fast enough to equalize the drawdown throughout the formation.

Well Records

Locations of recorded wells within a 2-mile radius of the UGRA plant are shown in Figure 9. Wells developed in the Hosston-Sligo formation are typically about 600 feet deep in the Kerrville area, as shown in Table 4. The City of Kerrville has drilled 13 municipal wells into the formation, with 11 currently in use. The wells, averaging 12-inch in diameter, produce from 200 to 900 gallons per minute (gpm), with the yield averaging 560 gpm.

Other private or commercial wells listed in Table 4 are developed in the Lower Member of the Glen Rose Limestone, with a couple of wells in the Upper Member of the Glen Rose. These typically bottom out at elevation 1200 to 1300, which is 50 to 150 feet above the top of the Hosston-Sligo, but separated hydraulically from it by the Pine Island Shale confining layer. Production of these private wells is much lower than City wells, and ranges from 20 to 100 gpm.

3.3 PUMPAGE AND WATER LEVELS

Pumpage by the City of Kerrville has increased steadily over the years from an initial 1941 annual average rate of 0.5 mgd to a 1980 rate of 2.8 mgd. The rate of increase has been nearly constant, and equates to a 4.5 percent annual growth rate in water use.

Long-term drawdowns in City wells from 1944 (first year of recorded levels) to 1980 have been on the order of 250 feet, as illustrated below by the records of three selected City wells:

City Well Number	Drawdown, Feet
Period 1944 to 1960	
4	85

[7]William F. Guyton & Associates, "Report on Ground-Water in the Kerrville Area," December 1973.

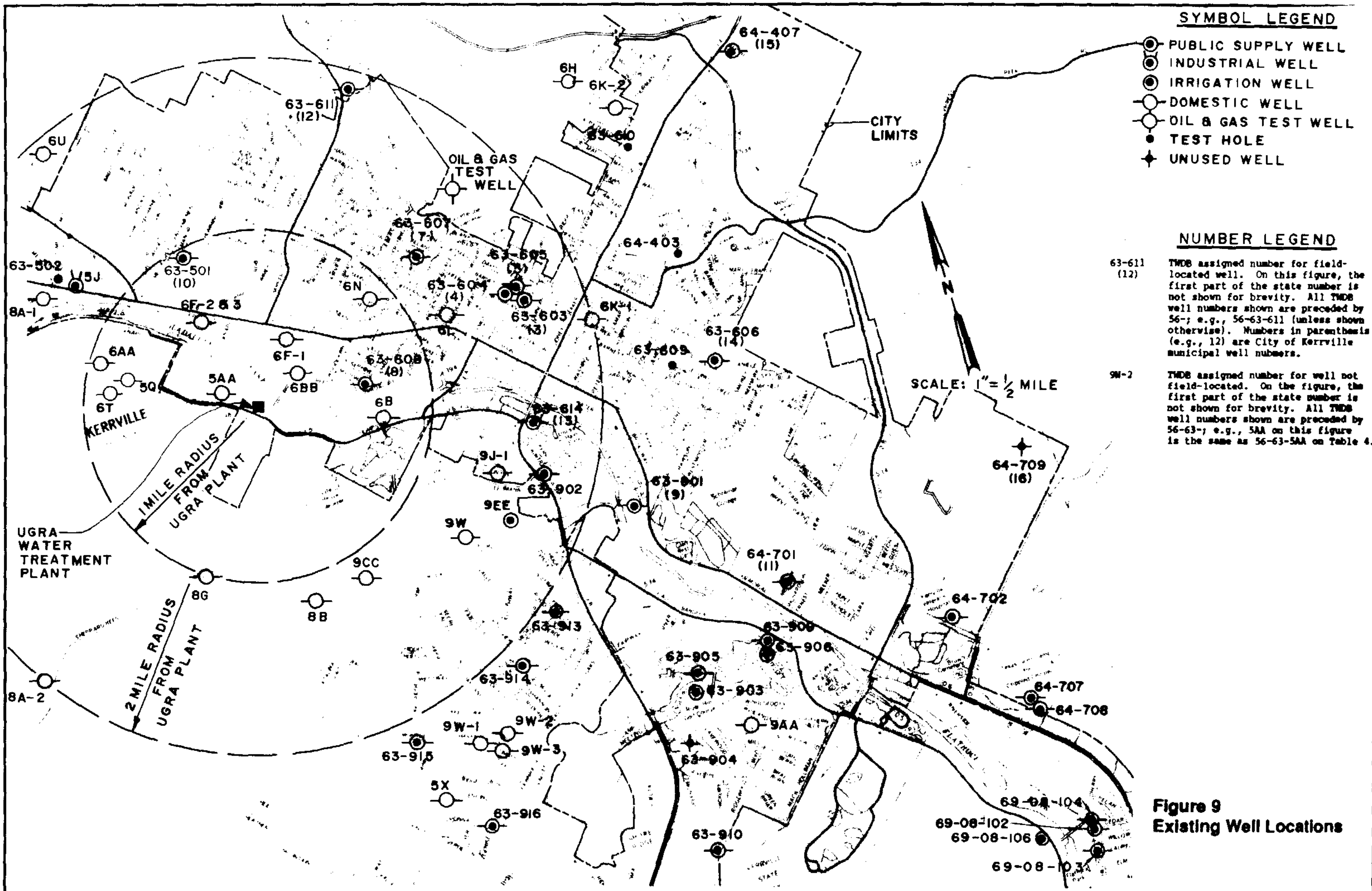

Figure 9
Existing Well Locations

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Table 4
WELL RECORDS

State Well No.[1]	Owner[1]	Dia. (Inch)[1]	Depth (ft)[1,2] Hole	Depth (ft)[1,2] Casing	Land Surf. Elevation	Hosston-Sligo Formation[1] Top of Formation Elevation	Hosston-Sligo Formation[1] Bottom of Formation Elevation	Hosston-Sligo Formation[1] Thickness (ft)	Pump Rate (gpm)[3]	Specific Capacity (gpm/ft)[3]	Transmissivity (ft^2/day)[3]	Coefficient of Storage[4]	TDS (ppm)	Logging Data[1] Drillers	Logging Data[1] Electric	Logging Data[1] Gamma	Comments
Wells Within 2-Mile Radius of UGRA Plant																	
56-63-603	City of Kerrville #3	10	667	498	1652	1145	--	--	500	16	2940	5×10^{-5}	610	.		.	
56-63-604	City of Kerrville #4	10	606	470	1653	--	--	--	525	22	3208	5×10^{-5}	580	.			
56-63-605	City of Kerrville #5	10	600	470	1656	--	--	--	700	15	3142	--	540	.			
56-63-607	City of Kerrville #7	13	634	530	1640	1145	1030	115	850	16	3316	2×10^{-5}	540		.		
56-63-608	City of Kerrville #8	20	619	440	1632	--	--	--	900	17	3102	7.4×10^{-5}	600		.		
56-63-501	City of Kerrville #10	12	620	513	1674	--	--	--	740	19	3262	--	560			.	
56-63-611	City of Kerrville #12	12	610	540	1695	1145	1090	55	500	10	--	--	540	.	.		
56-63-614	City of Kerrville #13	12	603	532	1620	1135	--	--	450	2.5	2139	--	550	.	.		
56-63-902	Kerrville South #2	8	583	--	1640	--	--	--	--	--	--	--	--				
56-63-502	Antler HHS	9	657	657	1700	1160	1070	90	--	--	--	--	--				
56-63-5AA	Roland Schellhase	7	350	316	±1660	--	--	--	*	--	--	--	--	.			
56-63-5Q	John R. Banister	6-5/8	410	410	±1700	--	--	--	*	--	--	--	--	.			
56-63-6AA	Betty Fritz	5-1/2	512	490	±1700	--	--	--	*	--	--	--	--	.			
56-63-6B	Graddy A. West	±6	400	314	±1700	--	--	--	*	--	--	--	--	.			
56-63-6BB	Michael Coffee	4	321	316	±1650	--	--	--	*	--	--	--	--	.			
56-63-6F-1	Pure Milk Co.	5-1/2	260	260	±1650	--	--	--	*	--	--	--	--	.			
56-63-6F-2	Jerry Hare	5-1/2	320	290	±1660	--	--	--	*	--	--	--	--	.			
56-63-6F-3	Lee Joy	5-1/2	340	290	±1660	--	--	--	*	--	--	--	--	.			
56-63-6K-1	L.P. Moore Plumbing Co.	4-1/2	380	380	±1650	--	--	--	*	--	--	--	--	.			
56-63-6L	Colorama TV	5-1/2	300	250	±1640	--	--	--	*	--	--	--	--	.			
56-63-6N	LaFayette Reed	4-1/2	420	420	±1660	--	--	--	*	--	--	--	--	.			
56-63-6T	Wayne Winfield	6-5/8	420	420	±1800	--	--	--	*	--	--	--	--	.			
56-63-6U	Robert Bowie	6-5/8	350	350	±1740	--	--	--	*	--	--	--	--	.			
56-63-8A-1	W.L. King	5-1/2	257	257	±1650	--	--	--	*	--	--	--	--	.			
56-63-8A-2	Lauerne Harris	5-1/2	570	300	±1925	--	--	--	*	--	--	--	--	.			
56-63-8B	Morris Harris	5-1/2	405	405	±1925	--	--	--	*	--	--	--	--	.			
56-63-8G	Douglas L. Arnold	5	579	560	±1900	--	--	--	*	--	--	--	--	.			
56-63-9CC	LaVern D. Harris	6-5/8	106	106	±1800	--	--	--	*	--	--	--	--	.			
56-63-9EE	L.D. Brinkman Corp.	8-5/8	520	422	±1700	--	--	--	*	--	--	--	--	.			
56-63-9J-1	Kerrville South	8-5/8	640	640	±1700	--	--	--	*	--	--	--	--	.			
56-63-9W	Frank Feguson	5-1/2	440	440	±1700	--	--	--	*	--	--	--	--	.			
Other City of Kerrville Wells																	
56-63-901	City of Kerrville #9	10	625	500	1608	1135	--	--	470	9	2005	3×10^{-5}	550	.	.		
56-63-701	City of Kerrville #11	12	638	528	1600	--	--	--	820	10	2941	--	610	.			
56-63-606	City of Kerrville #14	12	665	95	1670	1155	1075	80	500	7.4	--	--	610-660		.		
56-64-407	City of Kerrville #15	12	620	541	1710	1160	1120	40	198	4.8	194	--	590	.	.		
69-08-101	City of Kerrville Airprt	10	647	551	1581	--	--	--	85	0.34	--	--	560				
(56-64-403)	City of Kerrville	--	604	--	1654	1150	1085	65	--	--	--	--	--	.	.		Test Hole
(56-63-609)	City of Kerrville	--	601	--	1631	1160	1080	80	--	--	--	--	--		.		Test Hole
(56-63-610)	City of Kerrville	--	641	--	1722	1170	1120	50	--	--	--	--	--		.		Test Hole

Sources: [1]Texas Water Development Board, well schedule forms with attached logs.
[2]Texas Water Development Board, "Report 102, Groundwater Resources of Kerr County, Texas," November 1969, 2nd printing, November 1975.
[3]William F. Guyton and Associates, "Report on Groundwater Conditions in the Kerrville Area," December 1973.
[4]Texas Department of Water Resources, "Report 273, Groundwater Availability of the Lower Cretaceous Formations in the Hill Country of South-Central Texas," January 1983.
*These domestic wells do not have reliable recorded pumpage rates. However, on those wells where pumpage was estimated by the driller, the range was 20 - 100 gpm.

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City Well Number	Drawdown, Feet
Period 1960 to 1980	
4	174
8	121
10	192
Total 1944 to 1980	
4	259

The drawdown rate averaged about 5 feet per year before 1960, and almost 9 feet per year after 1960. In 1944 the water level was about 80 feet below ground surface at well 4 near the center of the City. The level had declined to about 340 feet below grade by 1980 due to continued and increasing pumpage. Starting in 1981 with the switch to river water as the primary City source, this long-term decline was halted and water levels rose about 50 feet between 1980 and 1986. As shown in Figure 2, annual average well water levels have remained fairly constant since 1983 with pumpage levels holding at about 0.5 mgd. This is a considerable reduction from the pumpage rate of 2.7 mgd in the four years preceding the switch to surface water.

Seasonal fluctuations in water levels of City wells have been considerable in the past due to low pumpage in the winter and peak pumpage in the summer. Monthly readings of selected City wells for 1980 are shown below:

1980 Water Surface Elevations in City Wells

Month	No. 4	No. 10	No. 14
JAN	1337	1301	1249
FEB	1332	1303	1270
MAR	1318	1324	1270
APR	N.A.	1301	1245
MAY	1342	1301	1275
JUN	N.A.	N.A.	N.A.
JUL	1272	1266	1168
AUG	1272	1182	1164
SEP	1295	1280	1221
OCT	1344	1294	1247

NOV	1300	1268	1233
DEC	1302	1280	1270
Annual Average	1311	1288	1237
Annual Fluctuation, Feet	72	142	111

N.A.=Data not available

Fluctuations range from 72 to 142 feet in the three wells selected for analysis. The month of lowest water level has typically been August. This would be expected due to highest demand occurring in this month. The month of highest water level varies by well but falls within the October to May cooler season. Generally the drop below the annual mean water level is considerably greater than the winter rise above the mean. For instance, in well 14, the drop below the annual mean was 73 feet in 1980 while the rise above the mean was only 38 feet.

3.4 WATER QUALITY CONSIDERATIONS

The ASR program for UGRA will consist of storing treated water underground and recovering the water for use with no retreatment except wellhead chlorination. In order to implement a successful program, a year-round treated water supply will be required with a relatively low concentration of total dissolved solids (TDS). Also, the ground water formation receiving the recharge water should have a background TDS concentration of less than about 4,000 mg/l. Since some of the native ground water blends with the recovered recharge water, ground water with TDS greater than about 4000 mg/l may cause the blended recovered water to exceed desirable levels of 1000 mg/l by state standards.

As shown in Table 1 of Chapter 2, the TDS of treated Guadalupe River water is in the 220 to 260 mg/l range which is well below the 1000 mg/l limit. Ground water in the proposed storage zone exhibits TDS values of around 540 to 710 mg/l (Table 2). Therefore high TDS problems are not expected in Kerrville as is sometimes the case with both surface and ground water in other parts of the state.

An additional factor to be explored during Phase Two testing of a prototype ASR well is potential chemical interaction of the recharge water with subsurface rocks and soil. Changing the existing chemical balance in the storage zone might cause precipitation of salts or swelling of clays, both of which pose potential clogging problems, or sand production from dissolution of calcareous material in the sandstone. Tests on native soil/rock and recharge water samples will be conducted in Phase Two to determine whether any chemical interaction problems are evident and how these may be controlled. However, on the basis of the existing data, there does not appear to be any significant cause for concern on this issue since water from both sources is fairly similar in quality.

3.5 RECHARGE AND RECOVERY RATES

An appraisal was made of the ability of the Hosston-Sligo formation to accept recharge at the rates proposed herein. The concern is whether the formation will accept recharge water fast enough and has sufficient volume to avoid "overtopping", or discharge to seeps and springs near the ground surface.

An actual field recharge test by the U.S.G.S. in 1955 offers some insight into this question. Water was recharged into a City well for 48 hours at 400gpm, increasing to 500 gpm for another 24 hours. Rise in well water level was measured and extrapolated for other recharge rates and durations of up to 1 year of continuous recharge.

Based on the U.S.G.S. data, a water level rise of about 40' is calculated as a conservative value for a 350 gpm rate of recharge per well over 8 months' time. Additional rise would occur due to the concurrent operation of other recharge wells. However, this additional rise diminishes with distance from other recharge wells. For instance, a second recharge well located 3000' away from the first recharge well, and operating at the same 350 gpm, would result in an additional 17' of rise in the first well. The rise in water levels at recharge wells would be reversed during the summer months when the recharged water is recovered from the ASR wells.

This 40 to 60 feet of annual water level rise at recharge wells is considered minimal and acceptable in the Hosston-Sligo formation since water levels have fallen about 250 feet from equilibrium levels in the 1940's prior to pumping. In other words, there is more than enough storage volume in the formation for recharge in the amounts proposed, as well as considerable extra storage volume for above-average natural recharge in wet years. This conclusion will be field-verified during the Phase Two testing of a prototype ASR well.

3.6 PRELIMINARY ASR OPERATIONS PLAN

As presented in Section 3.1 of this chapter, ASR is proposed as one of three sources for a conjunctive use water supply plan. ASR wells could be used in tandem with existing City wells and the UGRA water treatment plant. Such a system provides maximum flexibility and redundancy in the event of emergencies or planned outages for maintenance purposes. The water treatment plant would continue to be used for "base load" supply throughout the year, while existing wells and added ASR wells would provide peaking capacity when demand exceeds the treatment plant capacity. It is proposed to limit City well pumpage to a yearly safe yield of 0.5 to 0.6 mgd. This leaves a reserve of stored ground water for future emergencies or droughts, although at lower ground-water levels than have occurred historically. With ASR wells, this reserve can be augmented.

Although several alternative combinations of treatment plant additions and ASR wells could be considered, one preliminary alternative was presented in Figure 7. Additional combinations will be considered during Phase Two studies. The month-by-month operation of all three sources used in the development of Figure 7 is presented below for illustration of the general analysis approach as it may apply in 1995:

ILLUSTRATIVE EXAMPLE
OF COMBINED WATER SOURCES
FOR YEAR 1995

		Supply, mgd			
Month	Projected Demand, mgd	City Wells	W.T.P.	ASR Recovery	ASR Recharge From W.T.P.
JAN	3.4	0.1	3.3	0	1.2
FEB	3.4	0.1	3.3	0	1.2
MAR	3.9	0.3	3.6	0	0.9
APR	4.5	0.3	4.2	0	0.3
MAY	4.5	0.4	4.1	0	0.4
JUN	5.4	0.4	4.5	0.5	0
JUL	7.0	1.9	4.5	0.6	0
AUG	7.2	2.0	4.5	0.7	0
SEP	5.6	0.4	4.5	0.7	0
OCT	4.4	0.3	4.1	0	0.4
NOV	3.7	0.3	3.5	0	1.0
DEC	3.4	0.1	3.3	0	1.2
Year	4.70 mgd	0.55 mgd		75 MG	198 MG

Note: W.T.P.=water treatment plant

The assumptions used in developing this operation plan are as follows:

- City wells are operated at an annual average of 0.5 to 0.6 mgd, which would keep ground water levels at their present stage on a long-term average basis. Winter month withdrawals are based on historic operations since 1981. The August maximum flow was then calculated to not exceed the 0.55 mgd annual target pumpage.

- The water treatment plant is operated all year at a constant 4.5 mgd. Whatever amount remains after satisfying the monthly demand is recharged through ASR wells (see last column on right). 4.5 mgd was chosen by the plant operator as an achievable year-round target rate. It was set at about 10 percent below actual maximum capacity of 5.0 mgd to allow for downtime (averaging 9 days per year since 1981) and seasonal flowrate reductions to cope with changes in turbidity and temperature. In practice, the plant might actually run at 5 mgd for several months and at lesser rates during other months to achieve an annual average rate of about 4.5 mgd.

Note that in the selected year--1995--more water is recharged (198 MG) than is recovered (75 MG). This is a common characteristic of ASR facilities in the first few years of operation. Net storage is experienced in early years, followed by net withdrawals in the final years before another supply expansion is constructed. The goal is to achieve an approximate net balance of storage and withdrawals over the period between expansions--in this example, between 1992 and 2002.

Chapter 4
AQUIFER STORAGE RECOVERY TEST PROGRAM

4.1 PROPOSED LOCATION

Consideration was given to several alternative locations for ASR testing facilities within the Kerrville area. Among the principal criteria for site selection were the following:

- Accessibility to drilling equipment for test and monitor wells
- Ease of water disposal at rates up to 1000 gpm
- Adequate transmission capacity to convey water to and from the site
- Suitable hydrogeologic location
- Minimum risk resulting from potentially irreversible adverse effects upon the geologic formation surrounding the test well
- Proximity of operating staff and laboratory to assist with intensive data collection and analysis during testing
- Proximity of wells producing from the Hosston-Sligo formation

Two locations appeared reasonably suitable based upon these criteria: City of Kerrville Well No. 7, and the UGRA water treatment plant.

CH2M HILL recommends that the UGRA site be selected for ASR testing. This site offers the best likelihood of successfully demonstrating ASR feasibility during Phase 2, while minimizing any risk to the City of Kerrville's existing water supply facilities.

The principal advantage of Well No. 7 is that it is already constructed and is currently not in use. However considerable further investment may be necessary to line the casing to prevent aquifer plugging from rust particles. Furthermore there is some technical risk that geochemical reactions occurring during ASR operations may cause the formation in the vicinity of the ASR well to plug. While the ASR test program would be designed to minimize this risk, it would be better to risk a separate test well than a 13-inch diameter production well that constitutes a part of the City's existing investment in water supply facilities.

If Phase 2 results prove successful, then Well No. 7 would be an excellent candidate for conversion to ASR operation in 1992. Other City wells may also be suitable for future ASR operation based upon their design and location within the service area. In particular, wells located near the eastern and western extremities of the distribution system would be helpful in maintaining adequate pressures in these areas during times of peak demand.

4.2 CONCEPTUAL DESIGN OF FACILITIES

Test facilities should be designed to demonstrate not only that ASR operations are feasible, but also to show how and why they work. The resulting data will provide a firm basis for efficient design of expanded ASR facilities and also for response to questions that may be raised during permitting of additional ASR production wells.

To achieve these objectives it will be necessary to construct three wells in the following sequence:

PZ-1	Production Zone Monitor Well
C-1	Cow Creek Formation Monitor Well
R-1	Aquifer Storage Recovery Well

These wells would be located as shown on Figure 10. Ground elevation at the UGRA site is assumed to be ±1635 ft msl. Based upon this the wells would be designed as shown in Figure 11 and constructed as follows:

Production Zone Monitor Well, PZ-1

The first well would be constructed as a 6-inch monitor well approximately 565 feet deep, with open-hole construction through the full thickness of the Hosston-Sligo formation, which constitutes the proposed ASR storage zone. The hole would be continuously cored from the top of the Cow Creek formation at an estimated depth of 420 feet, to 100 feet into the pre-Cretaceous bedrock at an estimated depth of 665 feet. The construction sequence is suggested as follows:

- Drill 18-inch hole to 50 feet
- Set and cement 50 feet of 12-inch surface casing
- Drill 6-inch hole to 420 feet
- Obtain continuous wireline cores (4-inch) to top of Hosston-Sligo formation at 490 feet
- Obtain geophysical logs
- Ream hole to 12-inch diameter to 490 feet

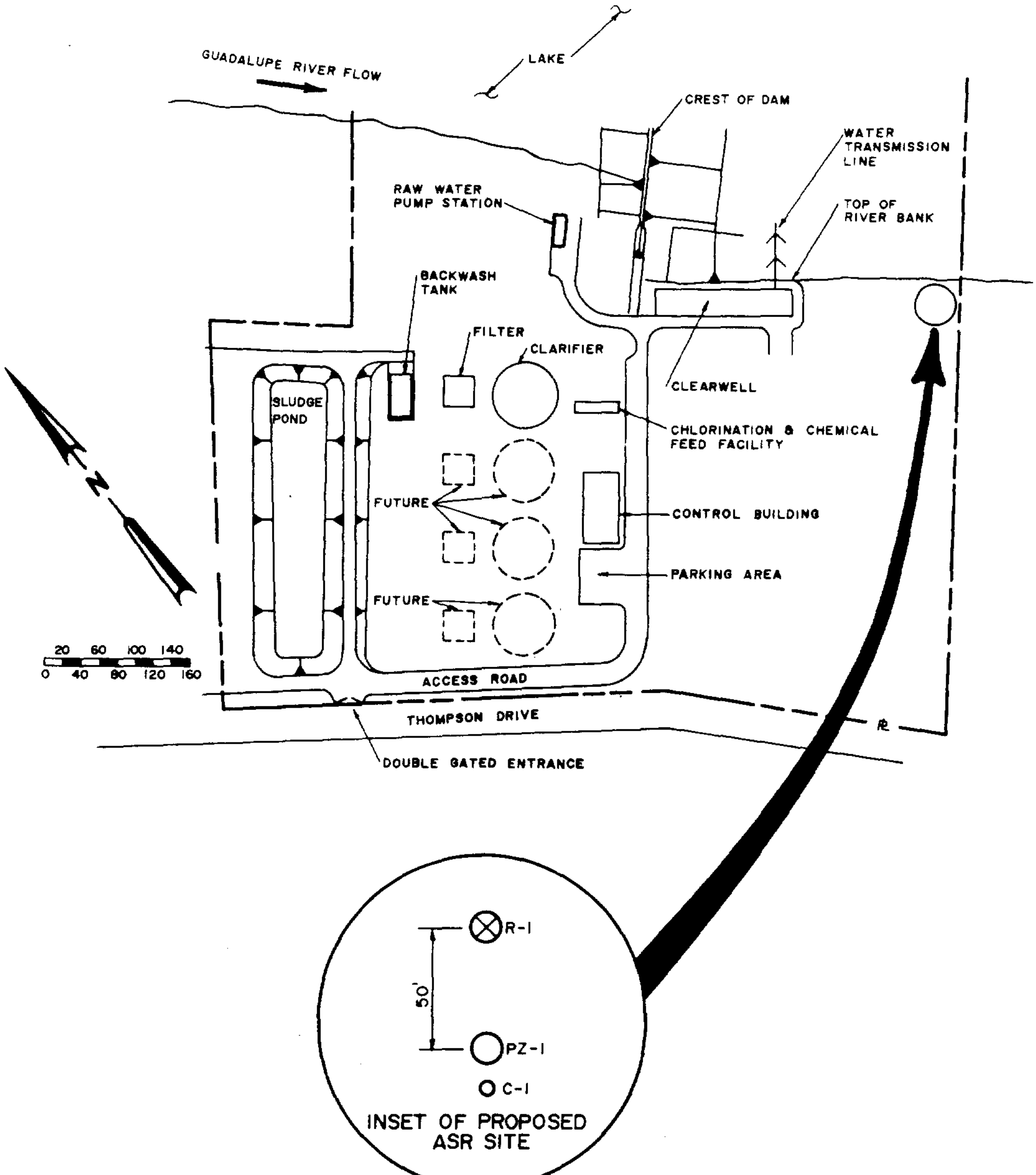

Figure 10
Proposed ASR Site Plan

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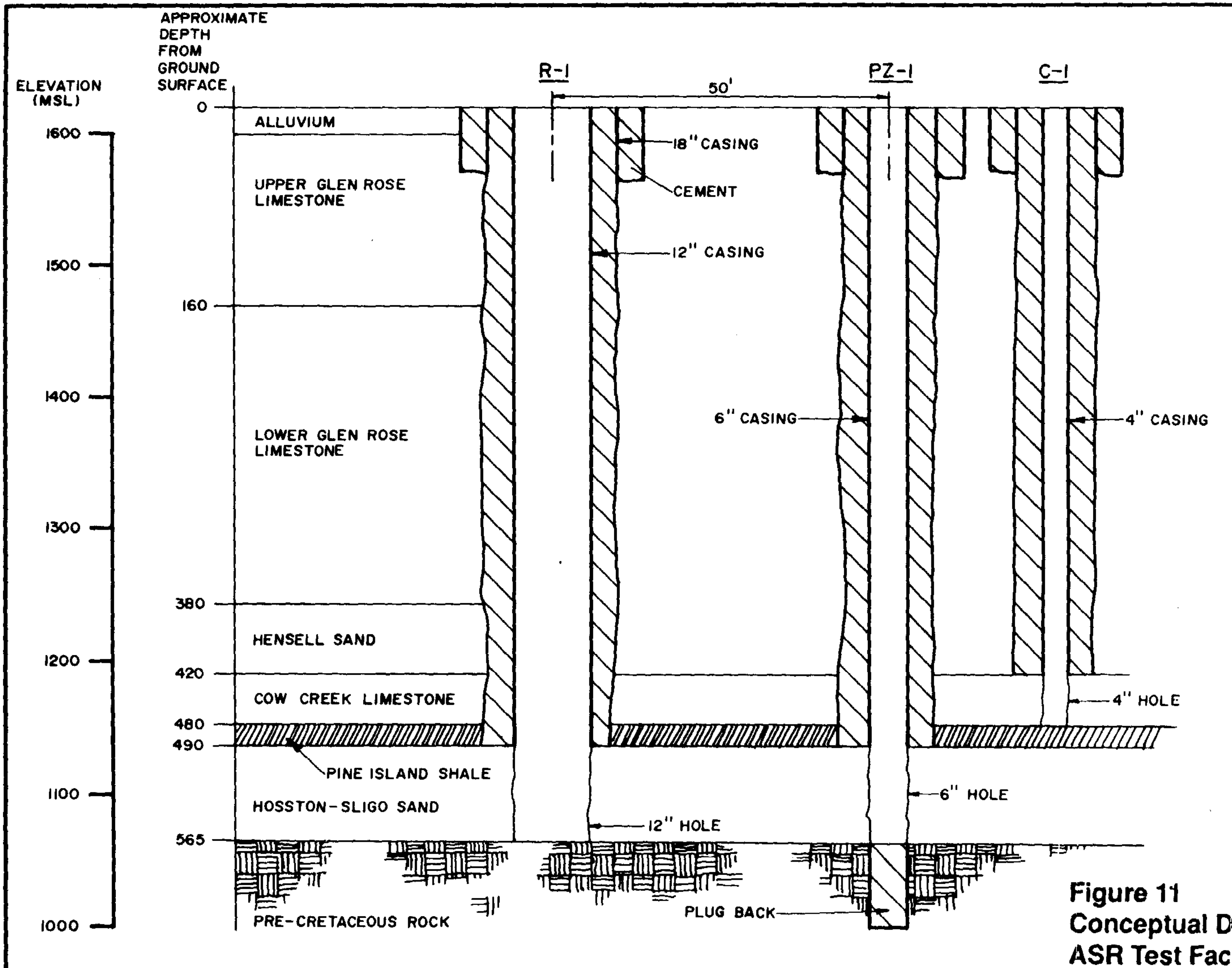

Figure 11
Conceptual Design of ASR Test Facility

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- Set and cement 490 feet of 6-inch steel casing
- Obtain continuous cores to 665 feet
- Conduct 8-hour pump test
- Obtain geophysical logs
- Plug back well to base of Hosston-Sligo formation at 565 feet and develop well
- Conduct 8-hour pump test

Monitor Well PZ-1 will be located at a distance of about 50 feet from Well R-1, the production well, and will monitor changes in water level during recharge and recovery operations. It will also monitor changes in water quality that indicate lateral movement of stored water from Well R-1.

Cow Creek Formation Monitor Well, C-1

Well C-1 will provide data on water levels in the Cow Creek formation, and whether they are affected directly or indirectly by ASR operations in the underlying Hosston-Sligo formation. Since this zone is utilized for water supply purposes by some of the adjacent private wells, it is necessary to assess potential impacts on water levels during both recharge and recovery. The construction sequence suggested for this 4-inch monitor well is as follows:

- Drill 10-inch hole to 420 feet
- Set and cement 420 feet of 4-inch casing
- Drill 4-inch hole to base of Cow Creek formation at 480 feet
- Develop well with air

Aquifer Storage Recovery Well, R-1

The final well to be constructed would be the ASR well, in order to receive the full benefit of data collected during construction of the monitor wells. This will be a 12-inch well, constructed as follows:

- Drill 24-inch hole to 50 feet
- Set and cement 50 feet of 18-inch surface casing
- Drill nominal 18-inch hole to top of Hosston-Sligo formation at 490 feet

- Set and cement 490 feet of 12-inch fiberglass casing
- Drill nominal 12-inch hole to base of Hosston-Sligo formation at 565 feet
- Develop well
- Obtain geophysical logs in this well and also Wells PZ-1, and C-1
- Acidize with 15000 gallons hydrochloric acid
- Conduct a 48-hour pump test, monitoring water levels in all wells and also monitoring water quality
- Obtain caliper log following acidization and pump test
- Equip wellhead for ASR operations

Core Analyses

Continuous cores of formation materials from well PZ-1 will be analyzed at a qualified core laboratory to estimate permeability, porosity, mineral and clay composition, cation exchange capacity and other tests designed to determine whether or not adverse geochemical effects may occur during ASR operations that would possibly plug the formation or cause it to become unconsolidated. A series of laboratory column tests will be conducted using selected cores to verify laboratory results under simulated field conditions. If laboratory analyses and column tests indicate the possibility of adverse geochemical reactions, additional column tests will be conducted to evaluate the effectiveness of alternative pretreatment measures in the ASR well prior to ASR operations in order to control plugging or prevent loss of consolidation. Due to the similarity in water quality between recharge water and native groundwater, adverse geochemical reactions are considered unlikely.

Wellhead Facilities

Piping, valves and other fittings will be required to convey water to and from the ASR well. The exact point of connection to existing piping will need to be established. However it should be possible to recharge by gravity from the adjacent clearwell and to utilize the same piping for recovery to the clearwell. Valves will be required to control borehole pressure during recharge, and probably to control flow rate during recovery. Flowmeters will be required for both recharge and recovery. Piping will be necessary to convey water from the well to the plant influent or to the Guadalupe River during initial tests, well development and acidization, and also during times of well maintenance. Since the site is fenced already, it should not be necessary to construct a wellhouse. Electrical supply will be required at the ASR well. Telemetry may be added at a later date to facilitate routine operations, if desired. All wellheads should be at least two feet above the 100-year flood level.

4.3 ASR TESTING

Upon completion of construction activities for the wells and wellhead facilities, a series of ASR test cycles will be conducted. Table 5 shows a preliminary plan for these cycles, to be adjusted as necessary following well completion to meet system operational needs.

Assumed recovery rate is 500 gallons per minute (gpm). This is within an expected range of 450 to 900 gpm based upon typical yields of the City's existing wells (average 560 gpm). Assumed recharge rate is 300 gpm, representing an average of higher initial recharge rates declining with time as water levels rise in the aquifer.

Table 5 shows a testing period of seven months during which four cycles would be conducted. These would provide data to estimate long-term recharge and recovery flow rates, expected trends and variations in water levels, changes in water quality with successive cycles, effect of storage time on recovery efficiency, and other factors. Cycle 5 would be a test operational cycle with a duration of one year, conducted under normal operational conditions. During Cycle 5, approximately 307 acre feet of water would be recharged and 202 acre feet recovered. The remaining 105 acre feet would be left in storage to raise water levels in the aquifer and thereby provide a reservoir of treated water for future recovery during droughts, emergencies, or periods when peak demand exceeds the design capacity of water treatment facilities.

An interim final report would be prepared upon completion of Cycle 4. The final report would be prepared upon completion of Cycle 5.

It is anticipated that during well construction and testing, monthly measurements of water levels in selected wells will be conducted in the vicinity of the test site. This will supplement ongoing monthly water level measurements of a larger regional area, and will help to assess the direction and rate of movement of water stored at the ASR well site.

Table 5
PRELIMINARY AQUIFER STORAGE RECOVERY TESTING PLAN

Cycle No.	Volume (million gallons) Recharge	Recovery	Approximate Duration (days) Recharge	Storage	Recovery	Total	Cumulative
1	5	10	12	0	14	26	26
2	10	10	23	0	14	37	63
3	10	10	23	7	14	44	107
4	25	25	58	21	35	114	221
5*	100	66	233	40	92	365	586

*Cycle 5 is a test operational cycle with a one-year duration. Assuming recharge rates averaging 300 gpm and recovery rates averaging 500 gpm, 100 million gallons (307 acre feet) would be stored, 66 million gallons (202 acre feet) recovered to meet peak demands, and 105 acre feet left in storage to raise aquifer water levels.

4.4 MONITOR WELLS AND DATA COLLECTION

Data collection during well construction and testing is fairly intensive. Major areas of data collection include the following:

- Regional water levels - Monthly measurements of water levels in selected wells for a period of about one year during construction and testing.
- Recharge well water quality - Primary and secondary inorganic and bacteriological standards, prior to ASR operations.
- UGRA treated water quality - Primary and secondary standards (inorganics and organics), during or before Cycle 1.
- Monitor well water quality - Background primary and secondary standards (inorganics) in PZ-1 and C-1 before ASR operations.
- ASR cycles - Sampling and analyses at the beginning and end of recharge and recovery periods for parameters listed on Table 6, with daily and weekly analyses for a much smaller number of indicator parameters selected during initial testing.
- Flow rates, pressures, and water levels in ASR test and monitor wells at the site, measured daily during ASR testing.
- Supplemental data collection - Issues to be addressed include coliform bacteria counts during recharge and recovery, trihalomethane concentrations, and any other items that may arise.

4.5 SCHEDULE

The test program will require approximately 30 months to complete, including one year for Cycle 5. A tentative schedule is as follows:

	Month
Preparation of plans and specifications	0-4
Contractor selection	5-6
Construction of wells and piping	6-10
ASR Cycles 1-4	10-16
Interim report	18
ASR Cycle 5	16-28
Final report	30

Table 6
WATER QUALITY MONITORING PARAMETERS DURING ASR TESTING

Primary and Secondary Inorganics
Total Hardness
Non-carbonate Hardness
Alkalinity
Conductivity
Temperature
pH
pHs
Eh
Calcium
Magnesium
Sodium
Potassium
Sulfate
Fluoride
Chloride
Total Dissolved Solids
Total Organic Carbon
Color
Turbidity
Silica
Iron
Color
Dissolved Oxygen
Carbon Dioxide
Trihalomethane
Priority Pollutants, primary and secondary organics
Coliforms

Permitting activities and meetings with regulatory agencies would be conducted prior to beginning construction and upon completion of the interim and final reports. The objective is to have a fully permitted and operational ASR well soon after completion of Phase Two activities.

If Phase Two begins during June 1988, the interim report would be issued in December 1989. Cycle 5 would begin in October 1989, which is a logical time to begin a 12-month operational cycle. Phase Two would be completed upon issuance of the final report in December 1990. Operational permitting should be completed during early 1991. Among other things, this schedule assumes the availability of water for recharge at rates up to about 700 gpm (1 mgd) during summer 1989.

Chapter 5
LEGAL ISSUES AND ESTIMATED COSTS

5.1 PERMITTING

The only permit required for an ASR well at Kerrville, is a Class V Underground Injection Control (UIC) permit from the Texas Water Commission (TWC). TWC representatives indicate that this would be a straightforward and relatively simple procedure if treated drinking water is the fluid being recharged into the aquifer.[1] Monitoring of the water prior to injection would likely be required as a permit condition, probably on a quarterly basis similar to the routine checks currently made on well water and UGRA plant water. No special reviews or hearings are expected. This permit will be applied for as a first step of the Phase Two well testing program, if authorized.

Although a specific permit is not required, the Texas Department of Health is empowered to review and approve all municipal water supply systems or modifications thereto. Since the proposed ASR well(s) would be part of the public drinking water supply for Kerrville, plans of the ASR well and its interconnection to the transmission/distribution system would need to be submitted for approval. This would also be undertaken during the Phase Two well testing program prior to well construction.

5.2 WATER RIGHTS

A water right permit must be obtained from the Texas Water Commission in order to divert surface water which is considered the property of the state. As discussed in Chapter 2, the Upper Guadalupe River Authority already has a water right to divert Guadalupe River water to its water treatment plant. However, as demands increase, an amended water right must be sought to provide for larger river diversions, whether the additional capacity will come from a water treatment plant expansion or from ASR wells on the discharge side of the plant. A water right amendment for increased diversions is currently being pursued by the Upper Guadalupe River Authority.

A separate legal issue is how to maintain the sole rights to the recharged water. Although recharged water in operating ASR wells in other parts of the country typically only travels a few hundred feet from the well before it is recovered, the possibility exists that someone else overlying the recharge zone could tap this source with a new

[1] Telephone conversation with Brad Cross, TWC, November 16, 1987.

well. No deep wells are known to exist in the vicinity of the Kerrville water system where ASR wells would be placed. However, new wells could be drilled in the future by an entity with the means and need for a large production well, such as an industry or commercial establishment with high water use. Since Texas ground water law follows the English common law rule of "absolute ownership," the owner of land overlying a ground water aquifer--including a recharge zone--has the right to pump all the water he can from beneath his land.

The following approaches have been used in various parts of the country to apportion and protect ground water resources, one or more of which could be used to safeguard the right to the proposed recharge water in Kerrville:

- Special legislation to cover the specific ASR project.
- Creating a new ground water district under existing legislation, such as Chapter 52 of the State Water Code.
- New legislation setting up a statewide permitting system for ground water (this is the current approach in Arizona).
- Adjudication in the courts of conflicting ground water claims after competing claims develop and cannot be resolved by the involved parties (this is the current approach in California).
- Passage of an ordinance by the City of Kerrville prohibiting drilling of new wells into the recharge area without prior approval by the City.
- Purchase of the "water right" from overlying landowners.

A more detailed analysis of these options will be conducted by legal counsel during the next testing phase of an ASR program. However, initial cursory evaluation of these options reveals the following points:

- <u>Special legislation for this project</u>--this may be a good option since it can be tailored specifically for this project as merely an amendment to UGRA's enabling legislation. Since the new authority sought would be only underground water storage and recovery rights which would not affect current land or water use, significant opposition to the legislation would not be expected.

- New ground water district--this may not provide full protection and creates another overlapping unit of government.

- Statewide permitting system--although Arizona successfully converted to this system recently, there is no current indication that the Texas Legislature would be considering this issue in the foreseeable future, since it would be a radical change from the current practice used for over a hundred years. There is no groundswell of public support for such a measure, which would be required for the Legislature to act favorably on such an issue.

- Adjudication--this is expensive and has the additional disadvantage that the courts could ultimately find that if no protective action was originally taken by the recharger, the recharger has no special interest in, nor claim on the water.

- City ordinance--this may be possible, since Kerrville might be able to exercise its home rule provision relating to protection of water supplies. However, it may require exercise of Kerrville's condemnation authority.

- "Groundwater right" purchase--this is feasible and currently being pursued in some West Texas locations. A public entity (UGRA or Kerrville) could buy the raw land overlying a recharge zone, or condemn it as a last resort. If the land is already occupied (likely in this case), the recharger could purchase only the right to use water below a specified elevation. This would in no way affect current use of the land or private wells, since no surface construction would be involved and since current landowners with wells do not draw from the deeper aquifer to be recharged.

  A variation of this approach would be to purchase an easement for subsurface storage of water and the sole right of recovering it. This could be potentially easier and less expensive than purchase of the groundwater right.

Additional studies during the next phase of investigation will further explore these approaches, but it appears at this time that protection of the recharged water can likely be achieved under one of three mechanisms mentioned--special legislation, Kerrville ordinance, or ground water right/easement purchase.

The direction of recent water rights legislation and court rulings in California and Arizona, and consumptive use permitting in Florida, suggests that ASR may best be viewed as a "storage" alternative rather than a surface water diversion or a groundwater withdrawal. Once the water user has established his right to the water diverted or withdrawn, and stores it underground, it is his to recover in the future. Purchase of property or groundwater rights/easements, or passage of local or state laws may be practical ways of asserting these rights, which may not yet be well established with sufficient clarity to meet ASR program needs.

5.3 PRELIMINARY ECONOMIC ASSESSMENT

Total cost for the Phase 2 ASR test program is expected to be in the range of $490,000 to $660,000 comprised as follows:

Well construction	$200,000 - $250,000
Wellhead facilities construction	$40,000 - $60,000
Engineering Design/Investigations	$190,000 - $250,000
ASR testing	$50,000 - $80,000
Regulatory and Permitting	$10,000 - $20,000
TOTAL	$490,000 - $660,000

A reasonable estimate for budgeting purposes is $600,000. This estimate does not include legal consultation, which is assumed to be paid under separate contract between UGRA and its attorney.

This cost range reflects several opportunities that would need to be addressed prior to or during the early design tasks of Phase 2. In particular, opportunities may exist to enter into a cooperative agreement between UGRA and the Texas Water Development Board under which the state would provide both geophysical logging and coring services. Furthermore, an arrangement between UGRA and the University of Texas Bureau of Economic Geology may facilitate cost-effective core laboratory analysis in Austin. If a real reduction in program costs can be achieved through such arrangements without substantially delaying the program or increasing costs in other tasks, then such arrangements would be beneficial in building a broader base of understanding among regulatory agencies and others regarding the UGRA aquifer storage recovery program.

These Phase 2 costs would be distributed over a period of 30 months, approximately as follows:

Year 1 - 70%
Year 2 - 20%
Year 3 - 10%
(six months)

Depending upon when the Phase 2 project is initiated, these costs may be distributed more evenly over three fiscal years.

Assuming successful completion of Phase 2 in 1990, UGRA will have one operational ASR well with a recovery capacity estimated at about 0.7 mgd. Future ASR wells would be added as needed to meet community needs. Tentatively it is anticipated that future wells would be added in 1992, to increase ASR capacity to 2 mgd, and during 2012. In 2002, the water treatment plant would be expanded by 2.5 mgd to a capacity of 7.5 mgd. Unit costs for future ASR wells should be substantially lower than for the initial well, since ASR feasibility investigations will have been completed. Future ASR well installations should cost about $200,000 each in 1988 dollars.

A preliminary time schedule of the costs to UGRA for an ASR program is summarized as follows:

Phase 2	1988 - 1990	$ 600,000	Including 1 ASR well
Phase 3	1992	$ 200,000	1 ASR well
	2002	$2,000,000	Plant
	2012	$ 200,000	ASR well
	Total	$3,000,000	(1988 dollars)

By comparison, an order-of-magnitude estimated cost for a two-phase 5 mgd plant expansion in 1992 and 2007 (2.5 mgd in each phase) is $3.9 million. Construction cost for a potential offstream reservoir would depend upon its design storage volume and other factors, and is not included in this estimate.

Assuming an interest rate of 8%, an inflation rate of 5%, and omitting consideration of offstream reservoir construction costs, the present worth in 1988 dollars (indicated by the abbreviation "PW") of the two alternative approaches is as follows:

Conventional (5 mgd plant expansion) - $2,980,000 PW
ASR (2.5 mgd plant expansion + ASR) - $2,260,000 PW

ASR could thus save around $720,000 in present worth costs--or about 25 percent--compared to the conventional approach. Costs savings could, in fact, be in the millions of dollars if ASR storage can be used in lieu of, or to defer, construction of an off-channel reservoir in Kerrville.

Note that the present worth values--the amount of money to be deposited in an interest-bearing account today, that would pay for future expenditures--will vary somewhat depending on the interest rate and inflation rate selected. The opinions of cost shown, and any resulting conclusions on project financial or economic feasibility or funding requirements, have been prepared for guidance in project evaluation and implementation from the information available at the time the opinion was prepared. The final costs of the project and resulting feasibility will depend on actual labor and material costs, competitive market conditions, actual site conditions, final project scope, implementation schedule, continuity of personnel and engineering, and other variable factors. As a result, the final project costs will vary from the opinions of cost presented herein. Because of these factors, project feasibility, risks, and funding needs must be carefully reviewed prior to making specific financial decisions or establishing project budgets to help ensure proper project evaluation and adequate funding.

In addition to the apparent economic advantages of the ASR approach, there is the additional possibility of financing the program from normal operating revenues rather than from the issuance of bonds. An offsetting factor is that there is a somewhat greater element of risk with the ASR approach than with the conventional approach. We believe that the risk is small; however, until the Phase 2 test program is completed, ASR feasibility at this site cannot be confirmed. Fortunately UGRA has sufficient time to confirm ASR feasibility before design of the 1992 plant expansion has to begin. Assuming ASR feasibility is confirmed, UGRA and the residents of Kerrville will benefit from a savings in water facilities construction costs of at least 25 percent, while also restoring groundwater levels, and deferring the need for off-channel reservoir construction.