CITY OF PHOENIX

CAVE CREEK RECHARGE

PROJECT: TECHNICAL ASPECTS

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CITY OF PHOENIX
CAVE CREEK RECHARGE
PROJECT: TECHNICAL ASPECTS

For presentation at the Second
Symposium on Artificial Recharge.

Tempe, Arizona

2 May 1985

Offices In Tucson and Phoenix, Arizona
Engineering · Planning · Surveying · Landscape Architecture · Hydrology

INTRODUCTION

In January of 1984, the City of Phoenix contracted the services of Cella Barr Associates to investigate various techniques of recharging excess CAP water in a ten mile stretch between the Granite Reef Aqueduct and the Arizona Canal.

The availability of CAP water presented our municipality with the challenge of finding an appropriate means of storing the water until needed.

The city does not have a suitable conveyance and distribution system with adequate capacity to deliver to its customers the amount of CAP water contracted, even though enough buyers were at hand and treatment capabilities were to be completed by delivery time.

The space available for underground storage of the water was limited by the fact that the City of Phoenix wanted to retain primary access. This imposed a very difficult restriction.

There was also a time constraint, the City wanted to have an adequate recharging operating system within a period of two years, and the water was to be recharged during the period of low demand in the winter months to be recovered by pumping during the high demand period in summer.

Last, but not least, was the economic factor. The City needed a cost-effective system which would not impose an excessive cost burden for the supply and marketing of this water to its customers.

For all these reasons, the City determined to take an engineering approach to the recharge of the excess CAP water.

Cella Barr planned a systematic, step wise approach in solving the possible problems that could arise in the study and design of this recharge system.

Although, groundwater recharge has been practiced extensively both in the United States and abroad for agriculture, salinity control and urban supply, it has not been frequently used intensively or in the magnitude of that desired by the City of Phoenix. Present projections call for the injection of 55,000 acre-feet of CAP water to an aquifer system each year.

Local conditions are different for each region and area and these have to be addressed individually to accomplish an adequate and efficient recharge system.

The feasibility study completed in 1984 considered various influential factors.

We looked at the local geology in the Cave Creek area to try to establish the common and the unique physical characteristic of the various lithologic units which are pertinent to the behavior of the aquifer or aquifers of the system. This was accomplished by an examination of all the published and unpublished reports of this area and by a thorough compilation and examination of all the lithologic information available from the wells of the study area and its surrounding region.

We examined the local groundwater hydrology to try to determine the type of aquifer system that is present in the Cave Creek area and to evaluate its capacity potential and possible response to the additional CAP water. We investigated the types of aquifers: confined, semi-confined, unconfined, perched; that could be expected, and where in the stratigraphic section could they be located. The various aquifer parameters were estimated using several techniques in order to attempt to predict both the areal and local transmissive and storage properties of the different hydrogeologic units. The average yield of production wells in the area, as well as the water table declines were established by statistical data obtainable.

The possible contribution or influence of the surface run off for the recharge process was investigated.

The quality of the groundwater in this area was determined from available data and the mean and range of concentration of the major and influential components was established. This was important in order to determine the background, or baseline, concentrations for comparison with the injected CAP waters. It showed if any areas had any higher than standard permissible composition, and of which components; and defined regional concentration zonation patterns and gradients.

The various methods of recharge:

a) deep well injection

b) surface impoundment by using constructed infiltration basins or utilizing available stream channel space

c) and combination of all, were evaluated by using the local geologic and hydrologic conditions determined by this study and taking into account the time, space and economic limitations.

The surface land ownership as well as the location of landfills was examined to evaluate possible permissible site for infiltration basins.

The history of subsidence effects from the pumping of groundwater from this area was briefly surveyed to establish if major problems existed and if they did, could they pose a problem or a benefit to the infiltration basins.

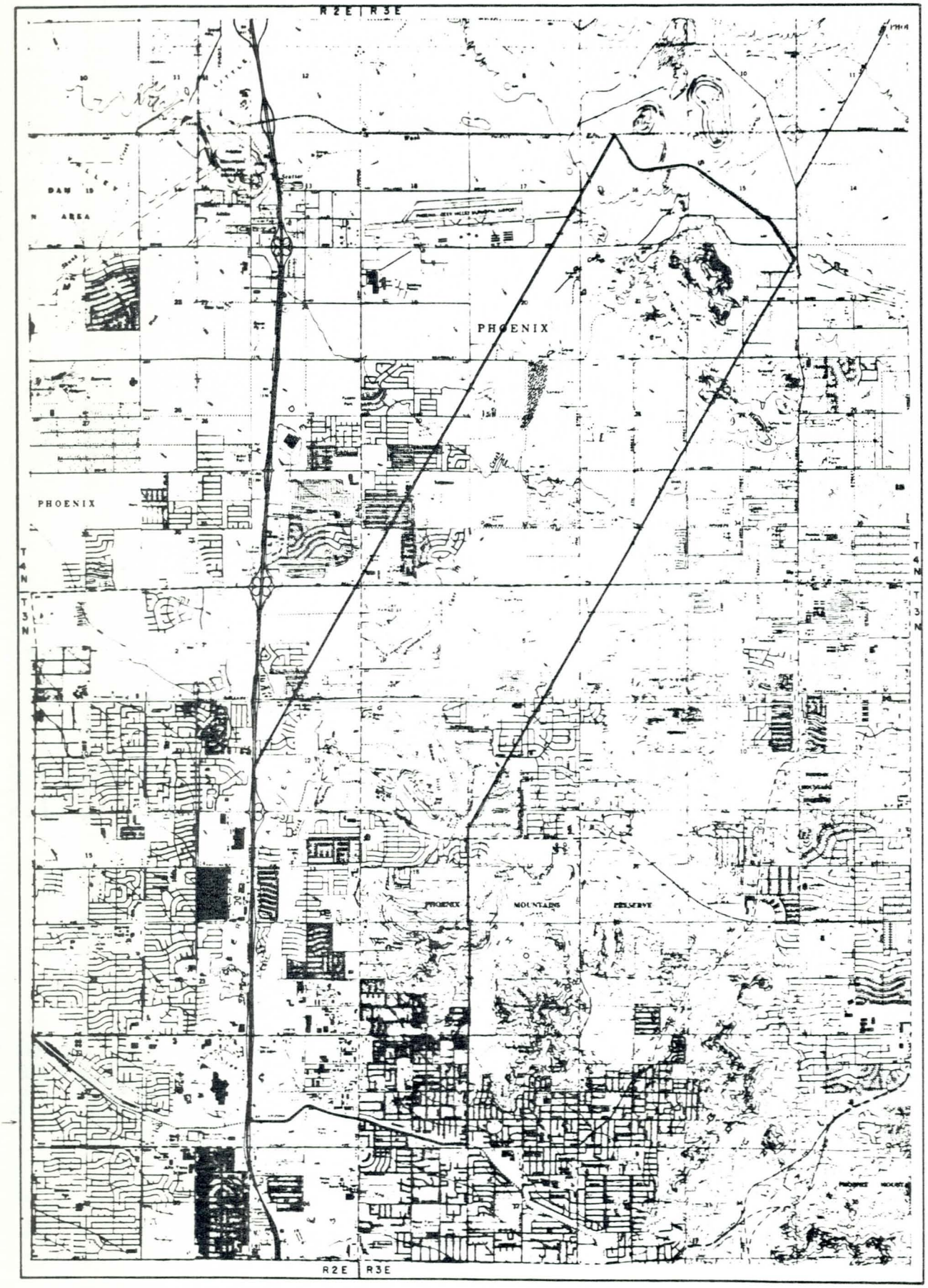
A case history survey of similar groundwater recharge projects in the United States was undertaken in order to examine the design and procedures used by others that may be applicable to the Cave Creek situation. As a result of this study members of the CBA technical team accompanied by Mr. Bill Chase of the City of Phoenix Managers Office inspected the facilities of the Hueco Bolson Recharge Project of the City of El Paso, Texas. Geologic and hydrologic conditions in the Cave Creek area are in many ways similar to those of the El Paso project.

LOCATION

The project area is located in the northern part of the City of Phoenix, just east of Interstate Highway 10 and occupies approximately 20 square miles (Figure 1).

During the initial stages of this project, it became apparent that, to provide an accurate picture of the local aquifer system, the area under investigation would have to be expanded.

This is the total area shown on this illustration and has a surface extension of approximately 90 square miles. We will refer to this as the "study area" or Cave Creek area.



EXPLANATION

—— Denotes study area boundary

(1225) Contour interval is 5 feet and multiples thereof

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FIGURE 1

Topographic Map of the Cave Creek Study Area

GEOLOGY

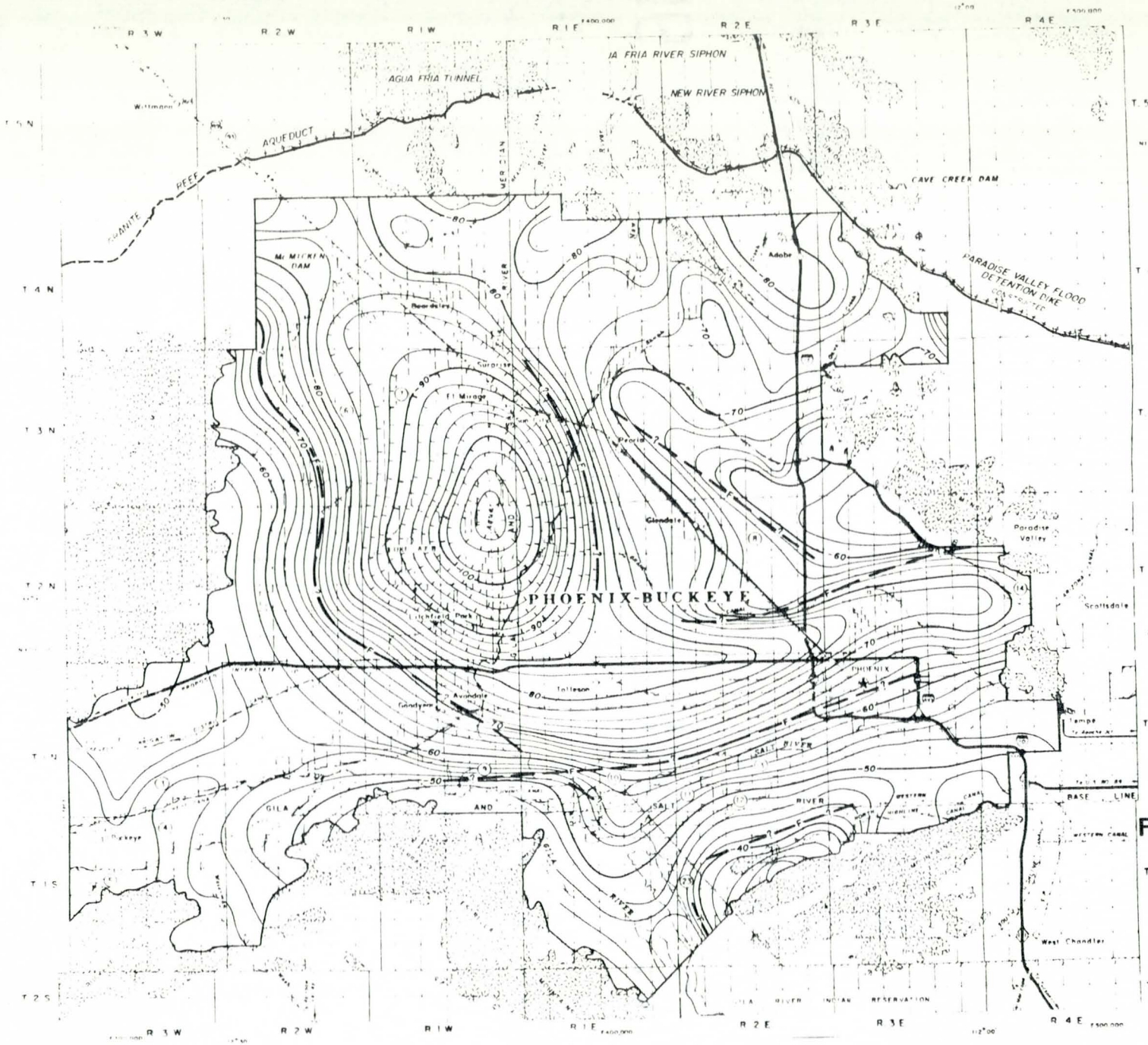
The "study area" is situated within the southern Basin and Range physiographic province. It is part of the eastern Lower Aqua Fria Basin, also recognized as the Phoenix - Buckeye subarea, a part of the West Salt River Valley Active Management Area. It is bounded by the Union Hills to the east, the Phoenix Mountains to the southeast, the White Tank Mountains to the west and the Hieroglyphic and New River Mountains to the north.

Rocks of Precambrian age crop out in all of the bounding mountain ranges. These units are predominently schist of the Pinal group and granites and gneisses equivalent to the Ruin granite of 1.4 by B.P. These rocks constitute the most extensive hydrologic bedrock units which form the floor and walls of the basin containing the aquifer system of the Cave Creek area. The configuration of the Phoenix - Buckeye basin is as indicated by the Bouguer Anomaly map (Figure 2).

The strong north-northwest late Tertiary Basin and Range structural direction dominates the northern part of the basin while the southern part has an anomalous east-northeast trend following a common Laramide age structural grain parallel to the Ray lineament and clearly expressed in this area by the strike of the South Mountains. The Cave Creek area is in the southeast corner of this basin north of the east-northeast structure.

This basin as most, in the Basin and Range province of the Western Corolillera, formed during the Mid to Late Cenozoic tensional structural event. Mid Tertiary (25-15 m.y.B.P.) extensional tectonics following the development of metamorphic core complexes produced extensive low angle normal faults, or detachment faults as shown here for the Whipple Detachment fault in the Whipple Mountains. Brittle fracturing in the upper plate of these faults generated listric normal faults which triggered the formation of numerous basins. Growth of these basins continued during the late Tertiary tensional event between 15-6 m.y.B.P. by high angle normal faulting and the generation of horts and graben.

Erosion of the ranges into the basins created during this tectonic event of Tertiary age produced the sedimentation of the geologic units that constitute the aquifers of this region. Each phase of the tectonic evolution is reflected in the physical character of the corresponding unit and consequently in the hydraulic properties of the aquifers. These units range from the poorly sorted coarse grain, high energy fanglomerates with high permeability and storage, to the very fine grained, low energy lacustrine sediments with good storage capabilities, but poor transmissive properties. Contemporaneous volcanic activity, predominantly andesitic to basaltic as well a the formation of salt deposits, although more areally restricted are important modifiers for the local groundwater hydrology and could be very important, as we shall see later in the case of the Cave Creek area.



EXPLANATION

AUTHORIZED FEATURES

- Open Aqueduct
- Tunnel
- Bridge

UNDER CONSTRUCTION FEATURES

- Dike
- Open Aqueduct
- Siphon

Indian reservation boundaries

Reservation boundaries

Water service organizations and boundaries

(1) Roosevelt Irrigation District
(4) Buckeye Water Conservation and Drainage District
(5) South Side Irrigation District
(6) Maricopa County Municipal Water Conservation District No 1
(7) Mc Micken Irrigation District
(8) Salt River Project Agricultural Improvement and Power District
(9) St Johns Irrigation District
(10) New State Irrigation and Drainage District
(11) Peninsula Ditch Company
(12) Leon Irrigation District (Inactive)
(13) Maricopa Garden Farms (Inactive)
(14) Arcadia Water Company
(21) Gila River Indian Reservation Miscellaneous Irrigation

Rock areas, essentially nonwater bearing

Subarea boundary

-80 Gravity contours, dashed where inferred, contour interval 2 milligals

F Inferred basement fault from gravity configuration

Earth fissures, as of 1964

NOTES

This map based on data developed from a cooperative program between the Bureau of Reclamation with the U.S. Geological Survey, resulting in "Geophysical Investigation Map GP-615" published in 1968

Arizona state plane coordinates, central zone

Figure 2

SCALE OF MILES

12-20-78	REVISED AQUEDUCT ALINEMENT

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

CENTRAL ARIZONA PROJECT—ARIZONA

BOUGUER ANOMALY

PHOENIX—BUCKEYE SUBAREA

GEOLOGY ____ SUBMITTED ____
TRACED ____ RECOMMENDED ____
CHECKED ____ APPROVED ____

PHOENIX, ARIZONA JULY 1, 1972 SHEET 3 OF 7

344-314-1260

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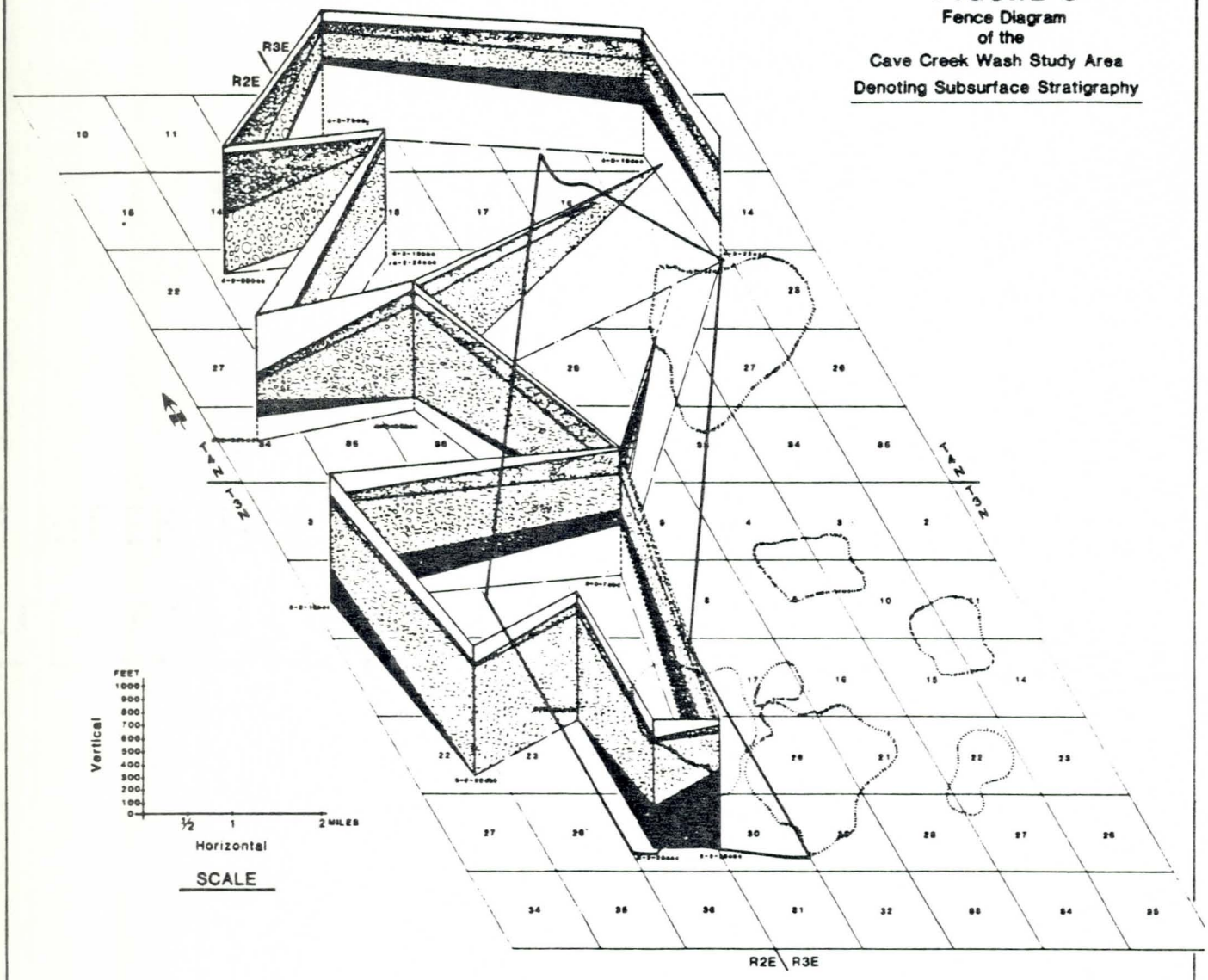
The aquifer system for the study area is hosted in three major units which reflect the three last phases of the Basin and Range tectonic event in this area. Up the section these are the Lower Conglomeratic Sand and Gravel Unit, the Middle Fine Grained Unit and the Upper Alluvial Unit. The areal distribution of these units is shown in Figure 3.

The age of these sediments is Late Miocene to Recent. In the study area the maximum thickness of this whole section is 1,600 feet.

The examination of 107 lithologic logs from the study area showed the principal geohydrologic characteristics of the three units. These are shown on Table I.

FIGURE 3

Fence Diagram of the Cave Creek Wash Study Area Denoting Subsurface Stratigraphy



EXPLANATION

- Denotes study area boundary
- Upper Sand and Gravel Unit
- Sticky Brown Clay Layer, Denotes Top of the Middle Fine-Grained Unit
- Middle Fine-Grained Unit
- Lower Conglomerate Unit
- Denotes correlation between units, dashed (---) where inferred
- Denotes generalized mountainous areas
- (example) Denotes legal description of well's location

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TABLE I

STRATIGRAPHIC UNITS HOSTING THE AQUIFERS OF THE CAVE CREEK AREA.

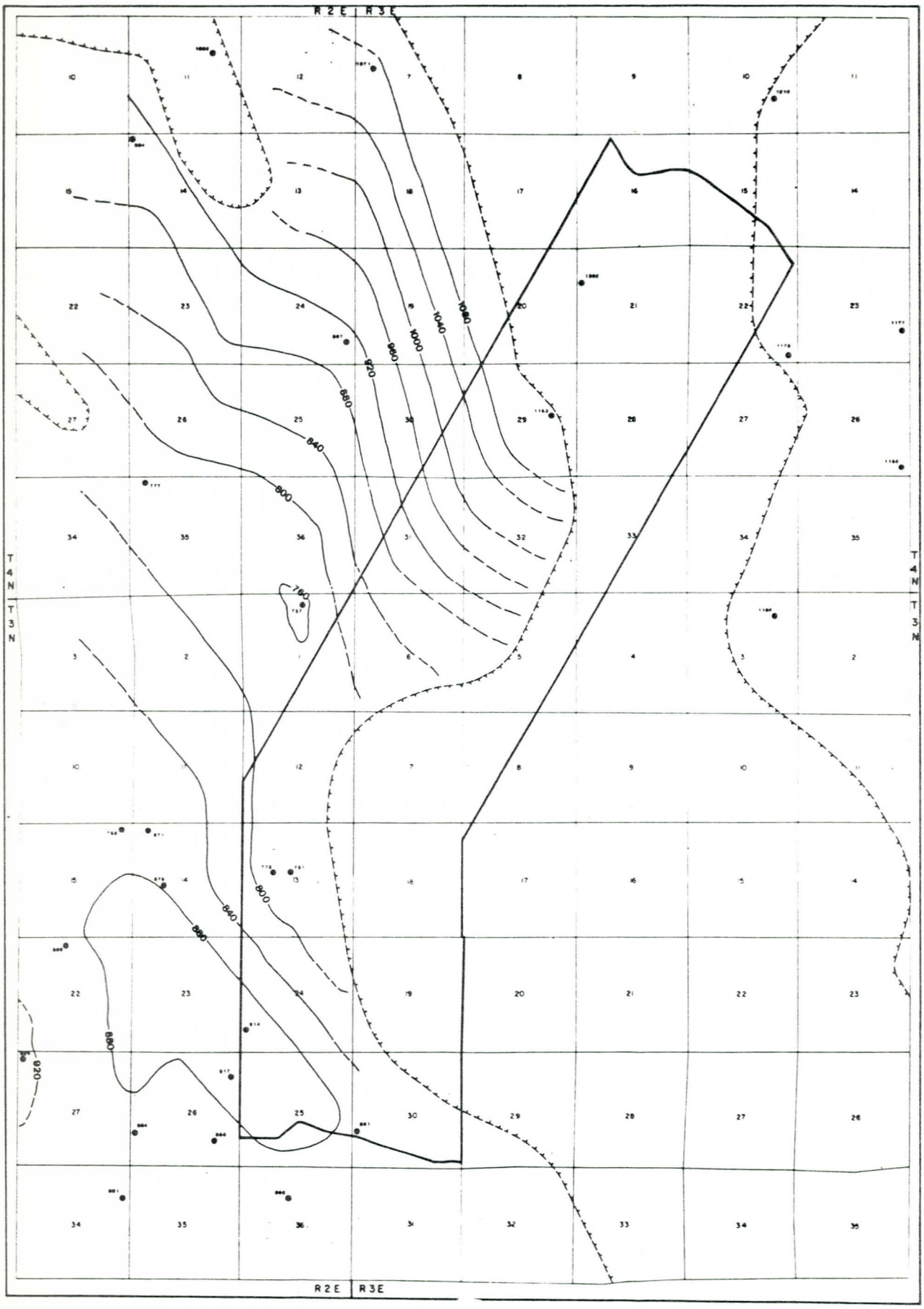
UNIT	PREDOMINANT LITHOLOGY	AGE	TYPE	MEAN THICKNESS(ft)	TYPES OF AQUIFERS
Upper Alluvial Unit	Unconsolidated sands and gravels	Pleistocene	Alluvial	130	Unconfined Perched
Middle Fine-Grained Unit	Clays, silts evaporites	Pliocene-Pleistocene	Lacustrine	590	Semi-confined to confined
Lower Conglomerate Sand and Gravel	consolidated sands and gravels, basalts in upper section	Miocene-Pliocene	Fanglomerate	Unknown	Confined

HYDROLOGY

Numerous wells have been drilled in this area and are in use for urban and industrial needs. The movement of groundwater in the study area is towards a trough in its central part, with a limited zone of outflow to the west (Figure 4).

Groundwater table decline averaged 4.9 ft/yr. from 1945 to 1983. The present rate is 1.9 ft/yr.

Mean and range values for the transmissivity, specific capacity and specific yields for the Cave Creek study area are shown in Table II.



EXPLANATION

- Denotes study area boundary
- —800— Water table elevation, contour interval is 40 feet (dashed where uncertain)
- Well location, number indicates 1982-83 water level measurement
- Denotes approximate boundary of aquifer

(Data obtained from ARIZONA DEPARTMENT of WATER RESOURCES/BASIC DATA and U.S. GEOLOGICAL SURVEY.)

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FIGURE 4

Water Table Elevation Contours for the Cave Creek Study Area

TABLE II

STUDY AREA

Aquifer Parameter	Mean	Range
Transmissivity (gpd/ft)	30,000	5,000 - 100,000
Specific Capacity (gpm/ft)	17.8	0.7 - 72
Specific Yield	0.09	0.5 - 0.16

PROJECT AREA

Transmissivity (gpd/ft)	68,000	5,400 - 144,000
Specific Capacity (gpm/ft)	34	2.6 - 72
Specific Yield	0.10	0.5 - 0.15

WATER QUALITY

The quality of the groundwater encountered at any location within the Salt River Basin depends primarily on the subsurface lithology and the physico chemical conditions prevalent in the aquifer in the immediate vicinity of the well. The most common problems encountered locally include large concentrations of fluoride and nitrate, hardness and total dissolved solids. Within the Cave Creek area, however, the overall quality consideratios center around high levels of nitrate and hardness.

The contribution of these two components to the groundwater produced can be reduced or even eliminated by isolating the donating aquifers in the wells. This is common practice in new City of Phoenix wells. We will be recharging into an aquifer that do not contain high concentration of either one.

The concentration mean and range for some of the more pertinent groundwater components of the study area and a comparison with the expected CAP water are contained in Table III.

TABLE III

CONCENTRATION OF SOME OF THE GROUNDWATER COMPONENTS OF THE CAVE CREEK AREA AND OF EXPECTED CAP WATER

(All concentrations are in mg/l)

Component	CAP Water	CAVE CREEK GROUNDWATER Concentration Mean	Concentration Range	Standard Deviation
Total Dissolved Solids	696	587	235- 1245	244
Nitrate	0.7	9.1	0.9- 19.0	5.3
Hardness	335	247	60- 548	123
Sulfate	310	56	8- 247	49
Sodium	110	60	30- 289	43
Turbidity*	2.0	0.15	0.08- 0.27	0.05
pH	7.8	8.0	7.7- 8.2	0.2

* In NTU Units

SELECTION OF RECHARGE METHOD

A detailed technical and economic examination of the three most commonly used methods of artificial recharge was undertaken to determine the favorability of using one or a combination of them. These methods are:

1) streambed recharge
2) infiltration basins (Figure 5)
3) injection wells

Of prime consideration was the problem of what will happen to the recharged water once it left the surface, that is the problem of control of the water. The time and cost of construction and operation were also important determinant factors.

A comparison of the major advantages and disadvantages of the three methodologies is shown on Table IV.

The results of the economic study indicated that the total cost per acre-foot recoverable for each of the methods was relatively close.

These are in 1984 dollars:

$115/acre-foot for the streambed recharge
$118/acre-foot for the infiltration basin
$116/acre-foot for the injection well

A decision on which method to employ was then based on technical considerations and land availability.

For the latter, and if we assume a realistic hydraulic loading rate of 245 feet/year, the area required for infiltration basins to recharge 55,000 acre-feet/year would be 225 acres. This would be land in a well developed urban area.

For the case of streambed recharge, a retaining structure such as a dam would have to be constructed on Cave Creek.

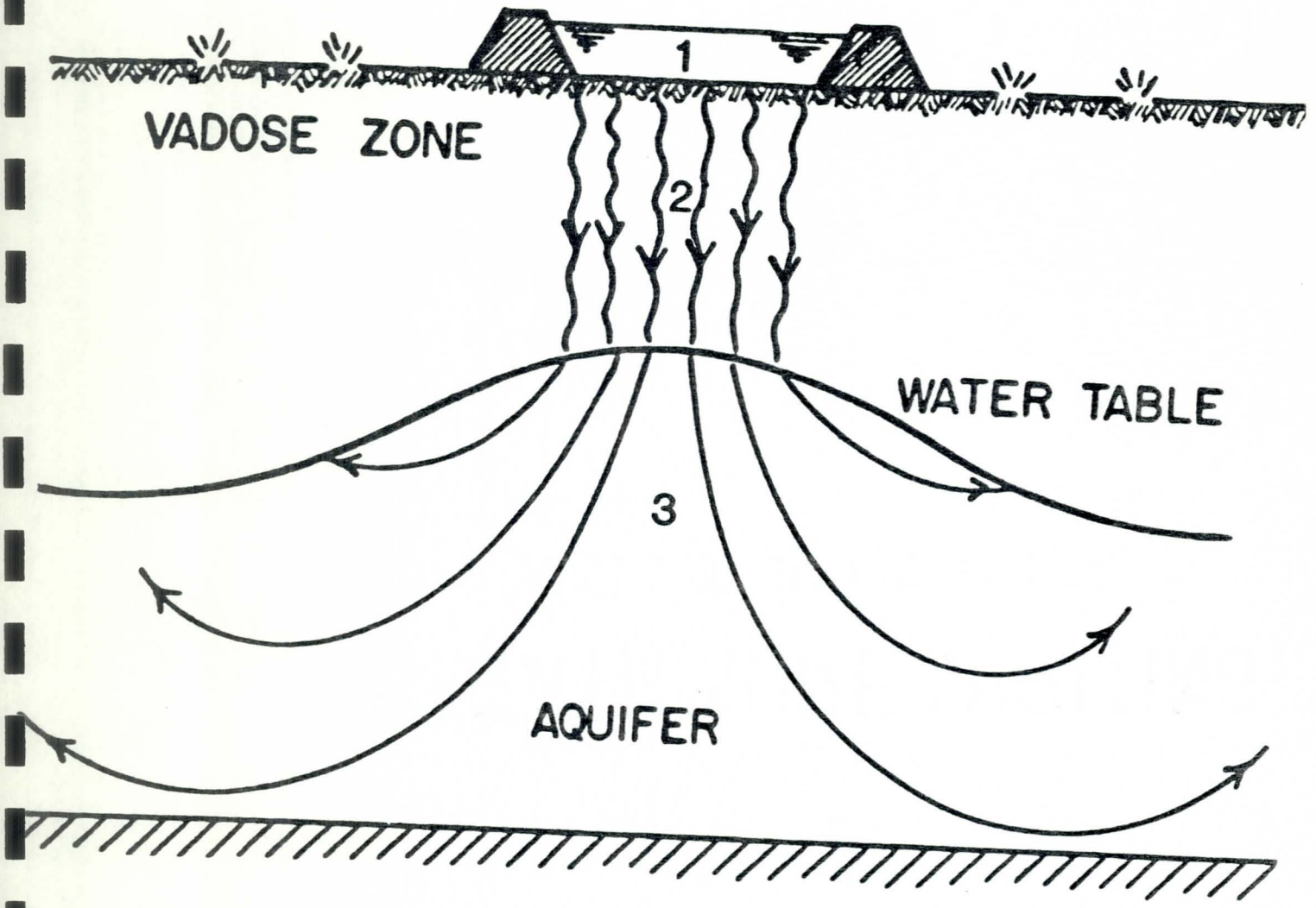
The rate of recharge using infiltration basins is considerably slow through the transmission zone and for both this method and the streambed recharge the water will go directly to the unconfined aquifer that in this area has the water quality problems previously mentioned. In addition, you loose control due to the presence of clay lenses in the lithologic sequence and permanent quantities are also lost to rewetting of clays and evapotranspiration.

By using injection wells the water can be recharged very rapidly and there is fairly good control of where the water is going. Most important the injection wells are also production wells.

After careful examination of all the local conditions, a decision was taken to use deep well injection.

A pilot study using one injection well in the project area was recommended and this phase is in progress at present.

The Three Processes Involved In Recharging Surface Water to the Groundwater System



(Taken from Bouwer, 1978)

Schematic of groundwater recharge system showing: 1) infiltration basin, 2) wetted zone, 3) groundwater mound and flow lines within the aquifer.

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Figure 5

TABLE IV

COMPARISON OF THE ADVANTAGES AND DISADVANTAGES OF THE THREE MOST COMMONLY USED METHODS OF ARTIFICIAL GROUND WATER RECHARGE, FOR THE CAVE CREEK AREA.

ADVANTAGES

Streambed Recharge	Infiltration Basins	Well Injection
1- Small capital investment	1- Low initial start-up costs	1- Water losses are low (90-95% recovery)
2- Minimal maintenance cost	2- Low maintenance costs	2- Very little property need be acquired
3- Lack of significant water quality problems	3- Loss severe water quality constraints	3- The recharge wells can be production wells.
	4- Recovery using shallow wells	4- The recharge wells can be constructed in urban areas.
		5- Cycling time to clean the wells is minimal

DISADVANTAGES

1- Loss of water to wetting of clays	1- Requires considerable land	1- The injected water must be of adequate quality
2- Environmental control problems	2- Basin clogging with fines	2- Organic slimes may clog the well.
3- Creating a shallow perched aquifer	3- Flooding of gravel operations	3- Air bublles may reduce effective permeability.
4- Increased seepage through landfills which would contaminate the recharge water.	4- Possible formation of perched aquifer	4- Chemical precipitates may obstruct.
5- Flooding of sand and gravel operations.	5- Insect infetation	
	6- Water losses to evaporation, transpiraton and clay absorbtion.	

THE PILOT STUDY

Geology

The recharge well to be used in the pilot study is City of Phoenix well number 274 located on Section 24 T3NR2E. For those of you from the Phoenix area or familiar with our city, it is located less than one mile northeast of the Metro Center Mall. It is in the floodplain of Cave Creek.

This well has been recently completed and equipped. An 18 inch pilot hole was drilled to 1,549 feet and the hole reamed to 28 inches to a depth of 1,390 feet. Screen has been set from 960 feet to 1,390 feet or a thickness of 430 feet. This interval hosts a confined aquifer as we shall see.

Figures 6 and 7 show the reverse circulation rig used in the drilling of well number 274.

The stratigraphy intersected by the drilling is as follows:

0 - 380'	The Upper Alluvial Unit: unconsolidated sand and gravels.
380' - 760'	The upper member of the Middle Fine Grained unit predominently clay, silt and silty sand with minor gravel.
760' - 960'	The lower member of the Middle Fine Grained unit: predominently clays, silt and evaporites.
960' - 1390'	Basalt, vesicular, fractured overlying andesite tuffs that grade into bentonitic clays down the section.
1390' - 1540'	Clays, bentonitic, that grade into a medium to coarse sand at the base.
1540' - 1549'	Pinal schist/Precambrian in age, mostly chloritic and the floor of the basin in this area.

The water table was intersected at 350 feet.

The aquifer to be recharged consists predominantly of fractured basalt in this area. The basalt which grades down section into andesites with some interbedded clays rests here in the clastic sediments of the Lower Conglomeratic Sandstone and Gravel Unit, but also laterally interfingers with the clastic sediments of this Lower Unit in other parts of the Cave Creek area. The basalt has adequate primary porosity and permeability, especially in the uppermost flow units where it is scoracious. Also, it's secondary or open fracture permeability is favorable for transmission.

Observation Well

To assist in determining the local aquifer parameters from a pumping test and principally to observe the transient effects of the injection an observation well will be constructed adjacent to the recharge well.

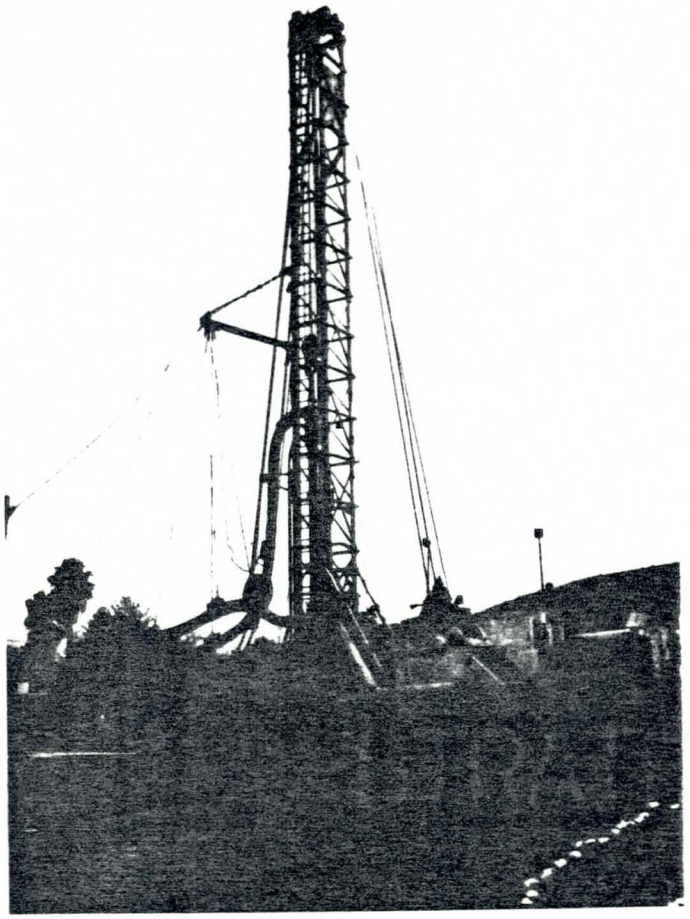

Figure 6 - Reverse circulation rig drilling. City of Phoenix Well Number 274 that will be used for recharge.

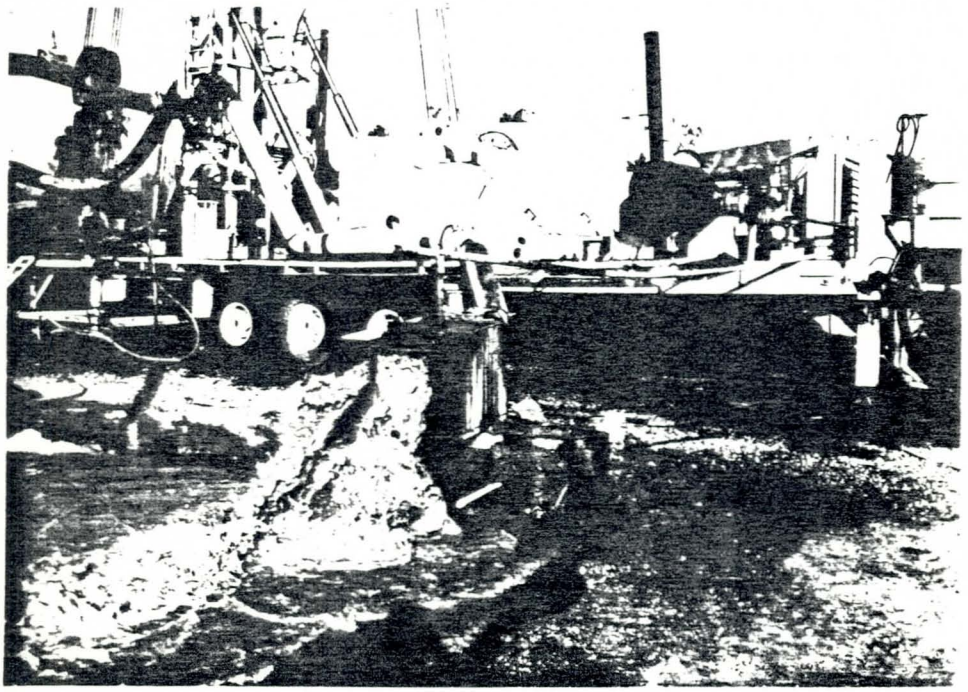

Figure 7 - Wedge sampler used to collect rotary cuttings for the City of Phoenix Well Number 274

The design of the observation well proceeded through several stages.

The first design consisted of several observation wells set radially from the injection well.

One alternative consisted of a "Cluster" of four wells, one fully screened well and three with piezometers set at three different depths.

Another design consisted of two wells one fully screened well, the other well with a set of "four nested" piezometers placed at various depths in the various hydrogeologic units.

Economic considerations did not permit the use of these multi-well design, so we first looked for alternate injection sites, where a usable City of Phoenix production well could be used for recharge and such that another well was located a reasonable distance away to be used as an observation well.

Such a setting appeared to be present at the Deer Valley Filtration Plant. However, on site inspection revealed that the separation between the possible recharge well and the well that could be used for observation was in excess of 1,000 feet (Figure 8).

A simple recharge time - well separation study was carried out using a simple Theis analysis.

Various magnitudes of the transmissivity and storativity used for these computations were based on lithologic analysis of the wells in the area. We considered a rise of 15 feet to be the minimum permissible deflection of the piezometric level that could be reliably detected over local background noise, due to seasonal fluctuation, changes in the pumping regimes, etc.

As you can see from Figures 9 and 10, it would take 1.8 years or 3.6 years to observe this deflection at 1,000 feet so the time involved in the injection would be excessive and the amount of water to be injected would be too costly.

A decision was then taken to use a single observation well located between 50 and 100 feet from City of Phoenix Well #274.

This will be sealed above the basalt and will be screened from 960 to 1,390 feet (Figure 11).

Pumping Test

A continuous recorder observation station will be installed in City of Phoenix well #274 to monitor the water level changes. This information will give background data of the local fluctuations to assist in interpreting the build-up during the recharge.

EXPLANATION

- ⊙ CITY OF PHOENIX WELL
- ● ABANDONED & BURIED WELL

SCALE: 1:24,000

Figure 8

LOCATION OF WELLS IN THE CHOLLA STREET AND DEER VALLEY PLANT SITES

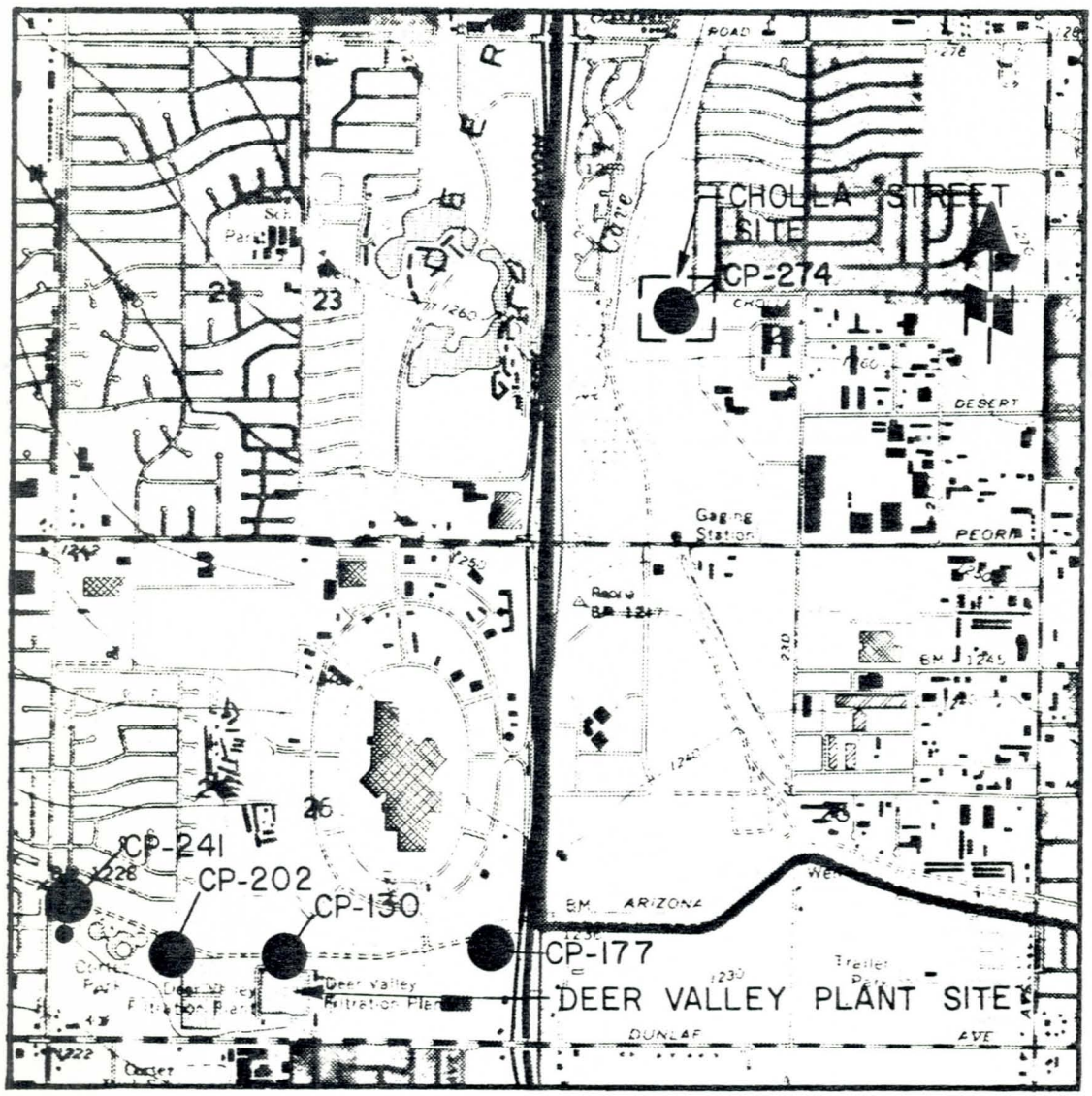

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Figure 9

RECHARGE

TIME VS. OBSERVATION

WELL DISTANCE

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(602) 242-2999

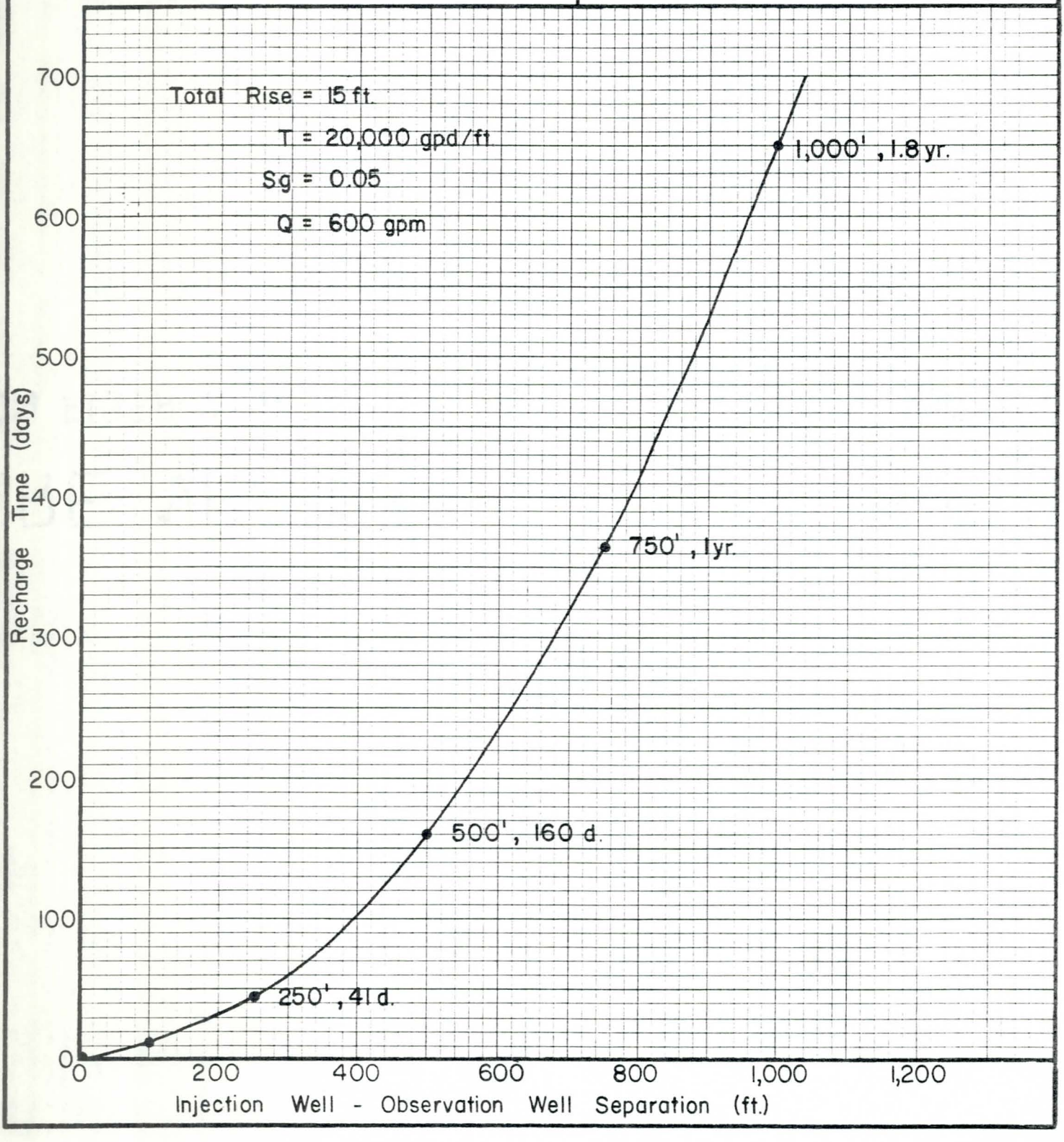

Figure 10

RECHARGE
TIME VS. OBSERVATION
WELL DISTANCE

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5062 N. 19th Avenue,
Phoenix, Arizona 85015
(602) 242-2999

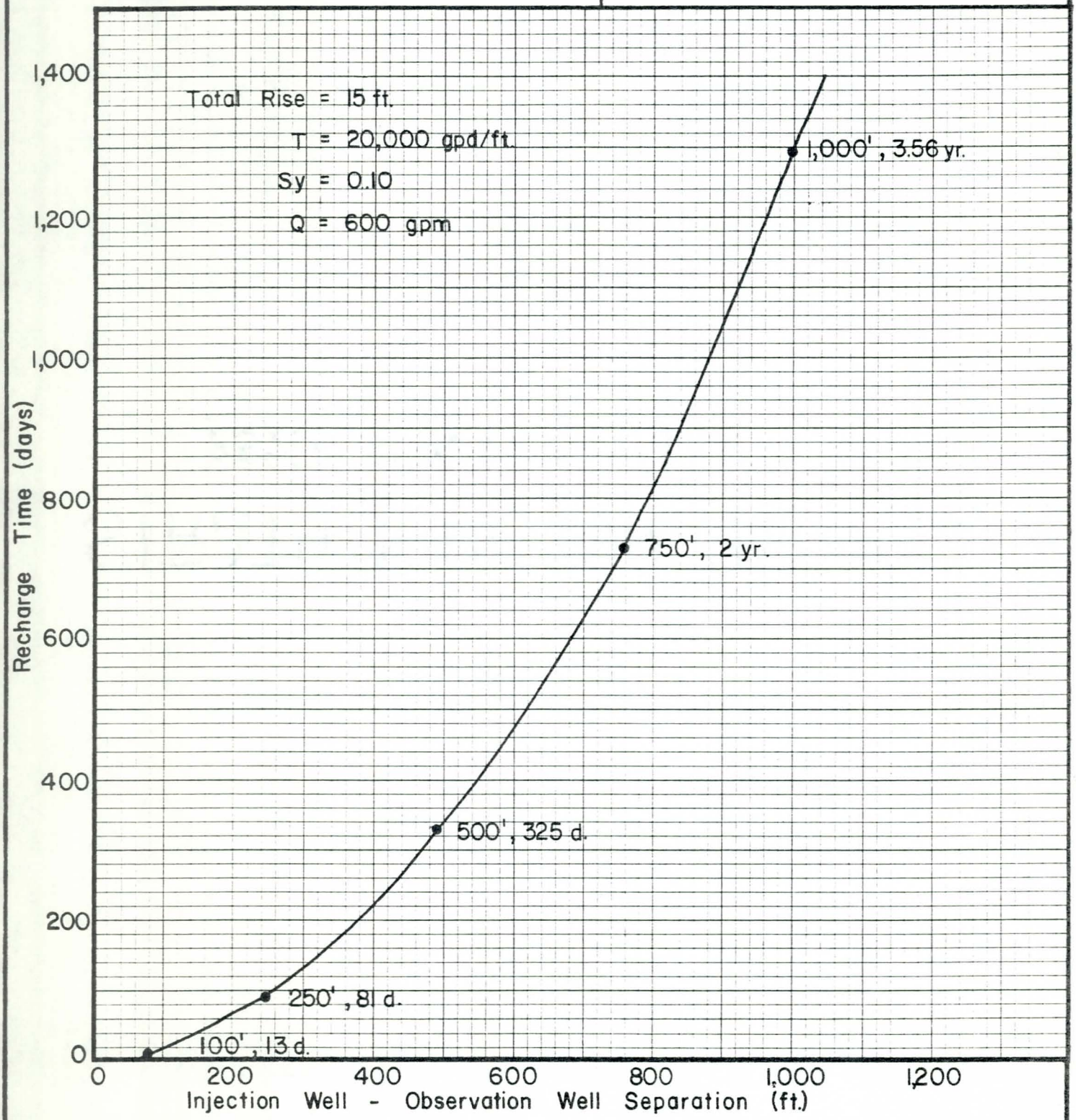
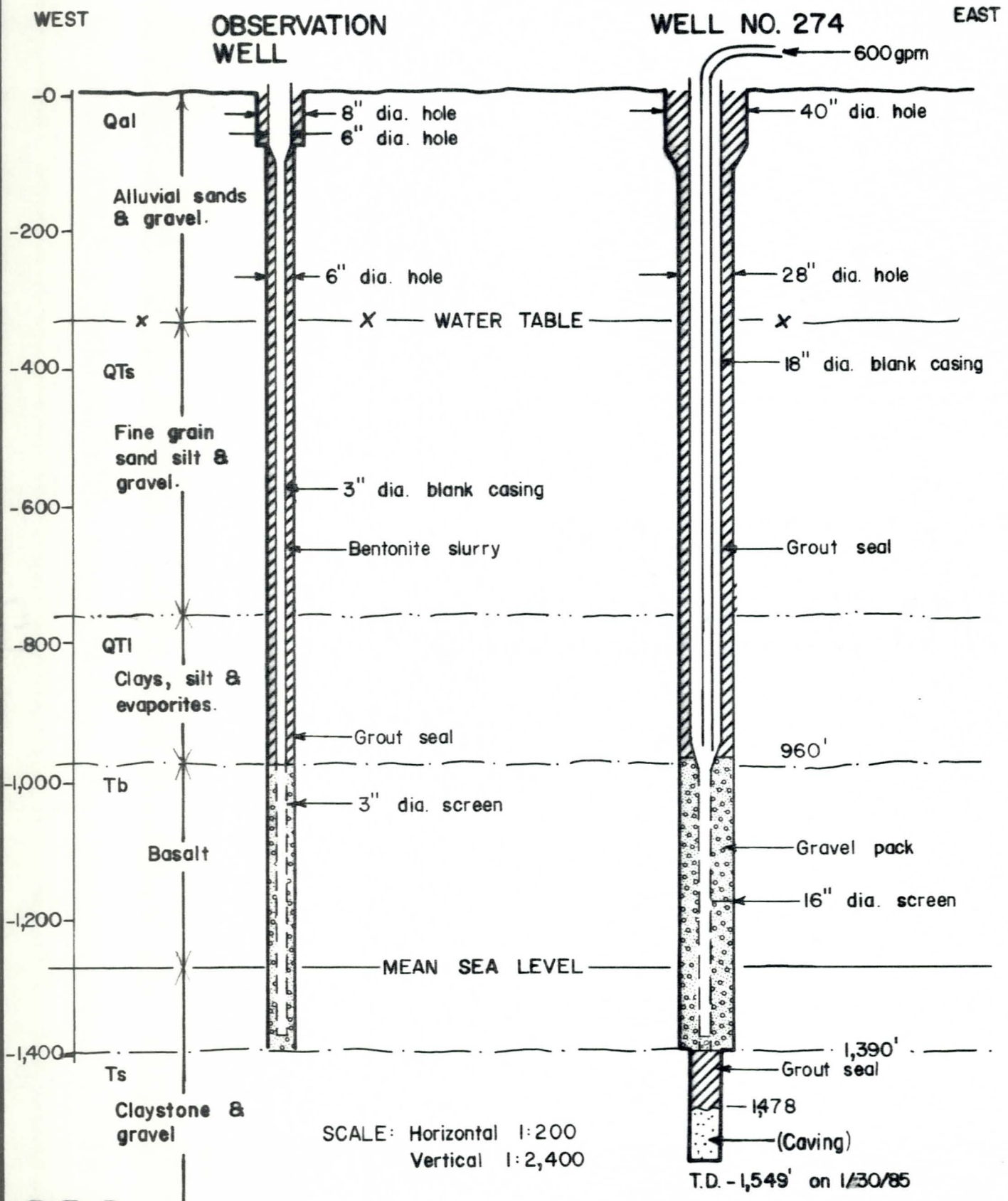


FIGURE: 11
CITY OF PHOENIX
CAVE CREEK RECHARGE PROJECT



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A continuous rate pumping test will be carried out at the completion of the observation well to establish the local transmissivity and storativity values of the aquifer. This will also assist in estimating the rate of recharge, which in similar situations, like in the Hueco Bolson Project, should be about one half of the production rate of the well.

Water Quality Monitoring

A restricted groundwater sampling survey of wells in the vicinity of the recharge well will be undertaken before the recharge starts. This survey will establish the local background of the water quality in the area of influence of the injection.

Samples will also be taken during the period of recharge and during the recovery period to study any possible effects in the composition of the waters and of physico chemical parameters, such as the temperature, the pH, the Eh and conductivity.

Modeling

All the hydrologic and geologic data acquired to this point will be utilized for numerical model simulation to calculate the expected impacts on the local aquifer.

The results of the modeling will be useful for planning subsequent phases of the project and securing the necessary permits.

INJECTION TECHNIQUE

Since the main problem of artificial recharge by deep injection wells has been the generation of a zone of reduced permeability around the well due to:

a. introduction of fine particles into the formation,
b. introduction of organic matter and bacteria,
c. introduction of air.

Measures will be taken to avoid or minimize these:

The recharged water will be filtered, it will be treated, at least chlorinated, and the problem of air entrainment will be minimized by employing a system similar to that being used successfully in the City of El Paso recharge project.

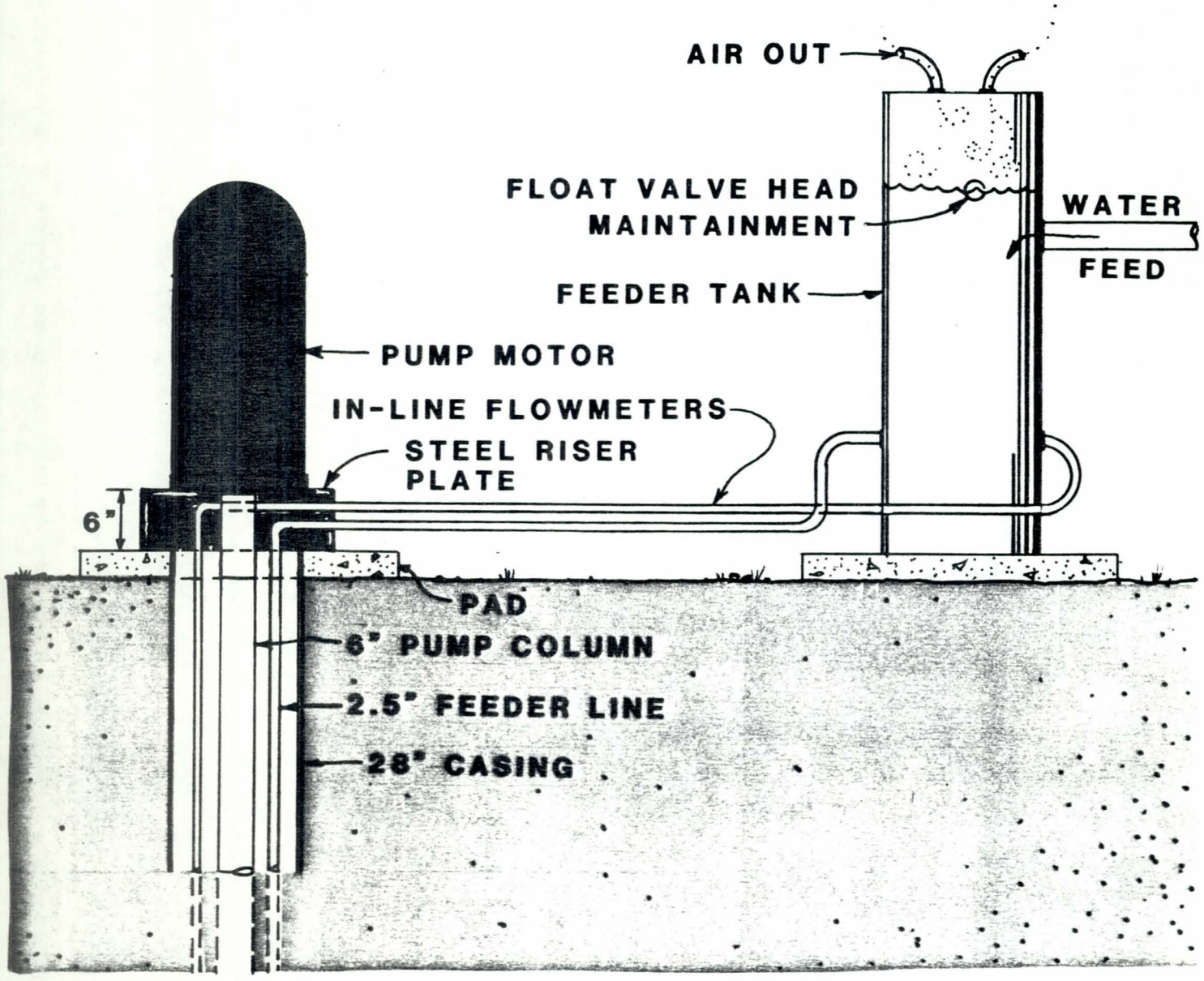
The main feature in this system is the double injection pipes with a maximum diameter of 2.5 inches (Figure 12).

The Recharge rate is now estimated at 600 gpm, but will be determined more accurately at the completion of the Pilot Phase.

CAVE CREEK RECHARGE PROJECT

CITY OF PHOENIX

TENTATIVE INJECTION SYSTEM DESIGN



Equip Well With A Piezomeric Water Level Sensor, Connected To A Recorder.

Figure 12

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FINAL PHASE

If the pilot phase is successful the plan calls for the utilization of a well field consisting of 57 injection wells. Each well will recharge approximately 965 acre-feet per year for a total of 55,000 acre-feet. These injection rates take into account periodic maintenance and repairs.