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WATER DEVELOPMENT CORPORATION

HYDROGEOLOGY OF ANDERSON MINE AREA, ARIZONA

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CONTENTS

CONTENTS
(continued)

TABLES

FIGURES

PLATES
(in pocket)

HYDROGEOLOGY OF ANDERSON MINE AREA, ARIZONA

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CONCLUSIONS

1. The two aquifers of major significance within the mine area are the Sandstone and conglomerate unit and the Barren sand unit. The fine-grained lacustrine sediments are saturated, where below the water-table-piezometric surface, but will drain slowly. The principal component of ground-water movement in these fine-grained sediments would be along fault zones where the sediments are competent enough to reflect fracturing. The direction of ground-water movement in the mine area is northwestward. Movement through all of the units is strongly controlled by faulting. Within the Sandstone and conglomerate unit the zones of higher permeability are along the faults and related fractures. Within the Barren sand the zones of higher permeability appear to be within fault blocks. Maximum transmissibility for the fractured portion of the Sandstone and conglomerate amount to approximately 4,000 gpd/ft (gallons per day per foot of aquifer width) in the vicinity of Well AM-28. This is considered to be a short-term maximum value and will decrease substantially with prolonged pumping or increased discharge. Transmissibility of the relatively undisturbed portions of the Sandstone and conglomerate is considered to be of the order of 200 gpd/ft. The transmissibility of the Barren sand in the zone of higher permeability extending northwestward from Well DC-5 is in the range of 500 gpd/ft In the zone of lower permeability along the northeastern part of the mine

area, transmissibility is considered to be of the order of 100 gpd/ft or less.

2. Recharge to the Sandstone and conglomerate unit is considered to occur locally from a recharge area of about two square miles, as discussed in Chapter 5 of this report. Estimated recharge to this aquifer system is considered to be in the range of 5 to 6 acre-feet per year, equivalent to an average throughflow rate of 3 to 4 gpm (gallons per minute). Recharge to the Barren sand unit is considered to be equal to throughflow, which was computed to be of the order of 3-1/2 to 4 gpm.

3. Ground water in the Sandstone and conglomerate and in the Barren sand gradually migrates downward into the underlying volcanics and is discharged northwestward via faults in the volcanics. The test conducted on Well AM-1007 indicates that throughflow along this particular fault is in the range of 4 to 9 gpm.

4. Ground water in the Sandstone and conglomerate, lacustrine sediments, and the Barren sand will drain into the pit as excavation proceeds downward and exposes the saturated portions of these units. Theoretical calculations based on the assumption that all three units are exposed simultaneously across the entire pit at Coordinate 1,205,000 N indicates that total inflows would amount to 170 gpm from the Sandstone and conglomerate, 90 gpm from the lacustrine sediments, and 60 gpm from the Barren sand. These figures are considered to represent maximums.

5. Well AM-28 could be utilized to assist in draining the Sandstone and conglomerate and is considered to be capable of producing about 100 gpm until pit excavation intersects the water table in the Sandstone and conglomerate northwest of the well. Calculations were made of the effect of operating four hypothetical wells along the southern rim of the pit to reduce artesian pressure head on the Barren sand. According to the calculations the wells could produce at a rate of about 50 gpm each (total of 200 gpm) for only about 60 days, following which the discharge would decline to only about one gpm per well. It was concluded that the feasibility of constructing and operating drainage wells for depressurizing the Barren sand was not acceptable and that construction is not warranted.

6. The area lying between Fault 1878 and the East Boundary Fault (see Pl. 1) has been examined for the occurrence of ground water and found to be barren. Fifty test holes have been drilled in the area, one as deep as 319 feet, and all were dry. Twenty-six of the holes encountered the Tertiary volcanic rocks.

7. Well AM-1007 located on a water-bearing fault in the volcanics northwest of the mine area will serve as an excellent water-level and water-quality monitor well. Sites for additional monitor wells are discussed in this report.

8. Natural discharge of ground water from the hydrogeologic unit that will be affected by the mining operation is to the Santa Maria River along faults in the volcanics and is considered to be about 8 gpm or less. The mining operation will intercept this discharge and there will be effectively no ground water discharge to the river during the life of the mine. The possibility of reverse movement along the faults, from the river to the pit while mining is in progress, is considered to be negligible. Several years after mining ceases, natural discharge will resume at about the same rate as before. The possibility of major changes in chemical quality of the throughflowing ground water, as between current conditions and several years after mining is completed, is considered to be negligible.

based on what

INTRODUCTION

As a part of the ongoing investigations of the Anderson Mine area by Union Minerals, Water Development Corporation has been conducting investigations of the ground-water hydrology of the region since late in 1976. The initial work was related to locating and developing a firm water supply of 1,000 gpm for mill and mine operation. It was determined that the ground-water system within the mine and mill area was not capable of yielding the needed 1,000 gpm. Likewise, the alluvium along the Santa Maria River directly north of the mine area was found not to be capable of producing an adequate water supply. Accordingly, the area of investigation was expanded. Two possible areas for water development were identified, one in the southwestern half of Sec. 16, T. 11 N., R. 10 W., and the other along the Santa Maria River about 6 miles west of the mine area.

Attention was then directed to evaluating the hydrogeology of the mine area in greater detail. One objective was to evaluate drainage of ground water into the mine pit after it has been excavated below the water table. Another objective was to develop a better understanding of the possibility of communication in either direction between ground water in the mine area and ground water in the alluvium of the Santa Maria River. A series of aquifer tests was planned. Small diameter wells were constructed for water production. Several observation wells were established either by casing or cleaning out existing drill holes or by drilling and casing new holes. The work of conducting the aquifer tests began about the middle of November 1978 and was completed by the middle of February 1979.

This report was prepared and is submitted as a report primarily on the results of the aquifer tests in the mine area. In order that the report be complete , it repeats to a certain extent information contained in preceding reports about the regional and local topography, local geology and structure, occurrence and chemical quality of the ground water, and environmental aspects of the local hydrogeology as they might be affected by the mining operation.

Reports prepared and submitted previously are listed as follows:

June 1977: Progress report, exploration for water supply, Anderson Mine area, Ariz.;

July 1977: revised March 1978: Surface-water hydrology of Bill Williams River system, Ariz.;

February 1978: Ground-water hydrology of Anderson Mine area, Ariz.;

September 1978: Interim report on hydrogeology of Anderson Mine area, Ariz.

TOPOGRAPHY

Regional Drainage

The Anderson Mine area lies within the drainage basin of the Santa Maria River, which rises a short distance west of the town of Prescott and flows southwestward and thence westward toward the Colorado River. About 13 miles west of the mine area the south-flowing Big Sandy River joins the Santa Maria River and the combined streams become the Bill Williams River. A flood-control structure known as Alamo Dam was constructed on the Bill Williams River in the mid-1960's about 7 miles downstream from the confluence of the Santa Maria and Big Sandy Rivers. A permanent recreation lake is maintained behind the dam. From Alamo Dam the Bill Williams River flows almost directly westward and joins the Colorado River in Lake Havasu a short distance upstream from Parker Dam.

The Anderson Mine area is in the northern portion of the Date Creek Basin that is drained by three west-flowing streams, all of which flow only for brief periods following rainstorms. The northernmost of these is the Santa Maria River, at the northern edge of the valley. South of this is Date Creek, which flows parallel with the Santa Maria River through most of its course and enters the Santa Maria River about 2-1/2 miles upstream from the confluence of the Big Sandy and Santa Maria Rivers. South of Date Creek is Bullard Wash, which also flows westward and enters the Bill Williams River about 4 miles downstream from the confluence of the Big Sandy and Santa Maria Rivers.

Of the three westward-flowing streams in the Date Creek Basin, the Santa Maria River has cut the deepest. Elevations in line from north to south passing through the Anderson Mine area are as follows:

Place	Location (Sec.-Twp.-Rg.)	Elevation (ft/msl)
North edge of valley	35-12N-10W	2,630 ±
Santa Maria River channel	35-12N-10W	1,510 ±
Anderson Mine	11-11N-10W	1,910 ±
Drainage divide	23-11N-10W	2,400 ±
Date Creek channel	35-10N-10W	1,970 ±
Drainage divide	35-10N-10W	2,180 ±
Bullard Wash channel	2-9N-10W	2,160 ±
South edge of valley	14-9N-10W	2,300 ±

Local Drainage in Mine Area

The Santa Maria River has eroded a deep gash along the northern edge of Date Creek Basin. In the Anderson Mine area the distance southward from the Santa Maria River to the topographic divide is about 3 miles. Stream courses which rise along the northern side of this divide follow northwestward courses to the Santa Maria River and have eroded the terrain into relatively deep, narrow canyons separated by steep hills. The general gradient from the divide along stream courses to the Santa Maria River is about 300 feet per mile, equivalent to a grade of about 6 percent.

SUMMARY OF GEOLOGY

Plate 1 is a map which shows the surface geology and structure in the Anderson Mine area, as mapped by personnel of Union Minerals. Also shown on Plate 1 is some structure mapped by Urangesellschaft U. S. A., Inc. personnel. The formational units are discussed by age beginning with the oldest and progressing to the youngest. In the following discussion the quoted excerpts are from ~~Hill (1977)~~. 1/
Anderson Mine Geology Report, Minerals Exploration CO, Aug 1977

Crystalline Intrusive Rocks (Jurassic)

"In the extreme northeast portion of the claims group the Santa Maria River and its tributaries have cut into a crystalline basement complex. These rocks are low in quartz content but are granitic. This granitic rock is purplish-gray in color, medium to coarse crystalline to pegmatitic and is intruded by veins of quartz and plagioclase feldspar with large crystals of horneblende and black biotite. A sample of the crystalline basement complex has been dated ..... by the K-Ar method to be Jurassic (157.5 ± 3 my)."

Felsic to Intermediate Volcanics (Tertiary)

"Unconformably overlying the crystalline basement or in fault contact with it is a series of felsic to intermediate volcanics. This series includes intrusive necks, flows, lahar breccias and tuffs. These volcanic rocks appear to be rhyolitic to andesitic in composition and are generally white to light gray in color."

The thickness of these rocks is not known. Where exposed they are above the water table/piezometric surface and are dry. Field observation indicates the permeability to be negligible, with northwestern movement of ground water through them mainly along faults.

1/ See "References Cited" at end of report.

Volcaniclastic Sediments (Tertiary)

> "Interbedded with and unconformably overlying the felsic to intermediate volcanics are tuffs, ashes, and volcaniclastic sediments. All of these appear to be of felsic to intermediate composition and are, therefore, believed to be contemporaneous with the felsic to intermediate volcanics. However, deposition of this unit continued after the felsic to intermediate volcanic activity ceased, as they are also interbedded with the overlying andesitic volcanics.
>
> "The most complete section of this unit in the area is located in the northeast portion of the claims group. Here the basal part of the section is composed of white felsic to intermediate tuffs, thin ash flows or volcaniclastic sediments, lahar breccias and volcanic bombs. Volcaniclastic sediments increase upward in the section and the color changes from white to yellow to tan. These sediments include felsic volcanic material and arkosic sandstone.
>
> "Many aspects of these sediments (crossbedding, thin continuous beds, etc.) lead to the conclusion that they were deposited in a lake bed ancestral to the overlying lacustrine sediments."

The upper surface of these beds dips southward. The thickness ranges from a few feet to about 600 feet. Where exposed they are above the water table/piezometric surface and are dry. Field observation indicates the permeability to be negligible.

Andesitic Volcanics (Tertiary)

> "A series of andesitic volcanic flows uncomformably overlies the felsic to intermediate volcanics or the volcaniclastic sediments. Reyner (1956) described the unit as fine-grained, vesicular augite andesite locally containing calcite-filled amygdules. The flows are generally purple, red brown,

> "gray brown or gray. In several areas of outcrop they are interbedded by volcaniclastic sediments composed of felsic volcanic pebbles and arkosic sands. The andesitic flows have been considered "basement" at Anderson Mine, as no mineralization has been observed in or below them. Before deposition of the lacustrine sediments, erosion and faulting developed a complex paleotopography and locally thick red brown paleosols on the top of the andesitic volcanics."

The upper surface of the andesitic volcanics dips southwards. The thickness ranges from a few feet to about 500 feet. Test drilling in the andesitic volcanics indicates that they are non-water-bearing except possibly along some of the faults.

Lacustrine Sediments (Miocene)

> "The lacustrine sediments overlie the andesitic volcanics over most of the Anderson Mine property. However, to the east-central they overlie the volcaniclastic sediments and further to the east they onlap the felsic to intermediate volcanics. One drill hole, AM-341 (SE$\frac{1}{4}$ Sec. 10, T. 11 N., R. 10 W.), encountered the felsic to intermediate volcanics or the tuffaceous part of the volcaniclastic sediments immediately below the lacustrine sediments.

> "Evidence now suggests that deposition of the lacustrine sediments occurred in a restricted basin.... Therefore, these sediments represent time-transgressive facies deposited within a narrow, probably shallow, basinal feature. This type of depositional environment exhibits complex relationships between individual facies; lensing out, vertical and horizontal gradation, interfingering, etc.

> "Ljung et al (1976) simplify these complexities by dividing the lake bed sequence into four (4) subunits: 1) a basal coarse clastic unit, 2) a mudstone-siltstone unit containing intercalated carbonaceous zones, 3) a succession of interbedded limestones, silicified limestones, cherts, mudstones and siltstones, and 4) a

> "thin, fissile, fossiliferous marker bed which has been designated the top of the lacustrine unit.
>
> "The lake sediments include green siltstones and mudstones, white calcareous siltstones, and silty limestone or calcareous tuffaceous material. Much of this material is silicified to varying extents and was derived in part, from volcanic ashes and tuffs common throughout the lake beds. Also present in the lacustrine sequence are zones of carbonaceous siltstone and lignitic material. Along the southern boundary with Urangesellschaft, drill holes encounter the basal arkosic sandstone. To the south and southwest the "typical" lakebeds interfinger with and eventually are replaced by a thick, medium to coarse-grained, arkosic sandstone unit."

The lacustrine sediments lie on the south-dipping Tertiary volcanic sequence and dip southward. From a thin sequence along the lake bed-volcanic contact, the thickness increases southward to a maximum of about 350 feet. The permeability of the lake bed sequence in its entirety is extremely low. Beneath the water table/piezometric surface the lake beds are saturated and drain extremely slowly. Where penetrated by a drill hole and saturated, the coarser facies will yield water slowly into the hole. Maximum movement of ground water in the lacustrine sediments is expected to occur in zones which are competent enough to reflect fracturing caused by faulting.

Barren Sand (Miocene)

called the barren sand

A subunit of the lacustrine sequence is a sandstone bed about in the middle of the sequence. It is more easily identifiable in drill holes within the Urangesellschaft claim area to the south. At Well DC-5 (5/1648 on Plate 1) the thickness encountered is approximately 100 feet. This subunit of the lacustrine sequence pinches or lenses out approximately along the line of Coordindate 1,205,600 N (see Pl. 1). In the southern portion of the Union Minerals claim area the thickness of the Barren sand encountered in drill holes is of the order of 30 to 50 feet.

The Barren sand is one of two water-bearing units within the claim areas. Well DC-5 serves as the water supply for drilling holes in the Urangesellschaft claim area. This well has produced 40 gpm with a specific capacity of 0.77 gpm per foot of drawdown after five days of pumping at the 40 gpm rate. The water in the unit is under artesian pressure and, at Well DC-5, has a pressure head in the range of 450 to 500 feet above the depth at which it was encountered when drilled. Figure 1 is a sketch which shows in a general way the influence of geology upon development of the artesian head. Northward the artesian head decreases. The Barren sand is reported to pinch or lens out to the southeast in the Urangesellschaft claim area.

Sandstone and Conglomerate (Miocene)

This unit is identified on the map (see Pl. 1) as Lower Conglomerate (Tmc).

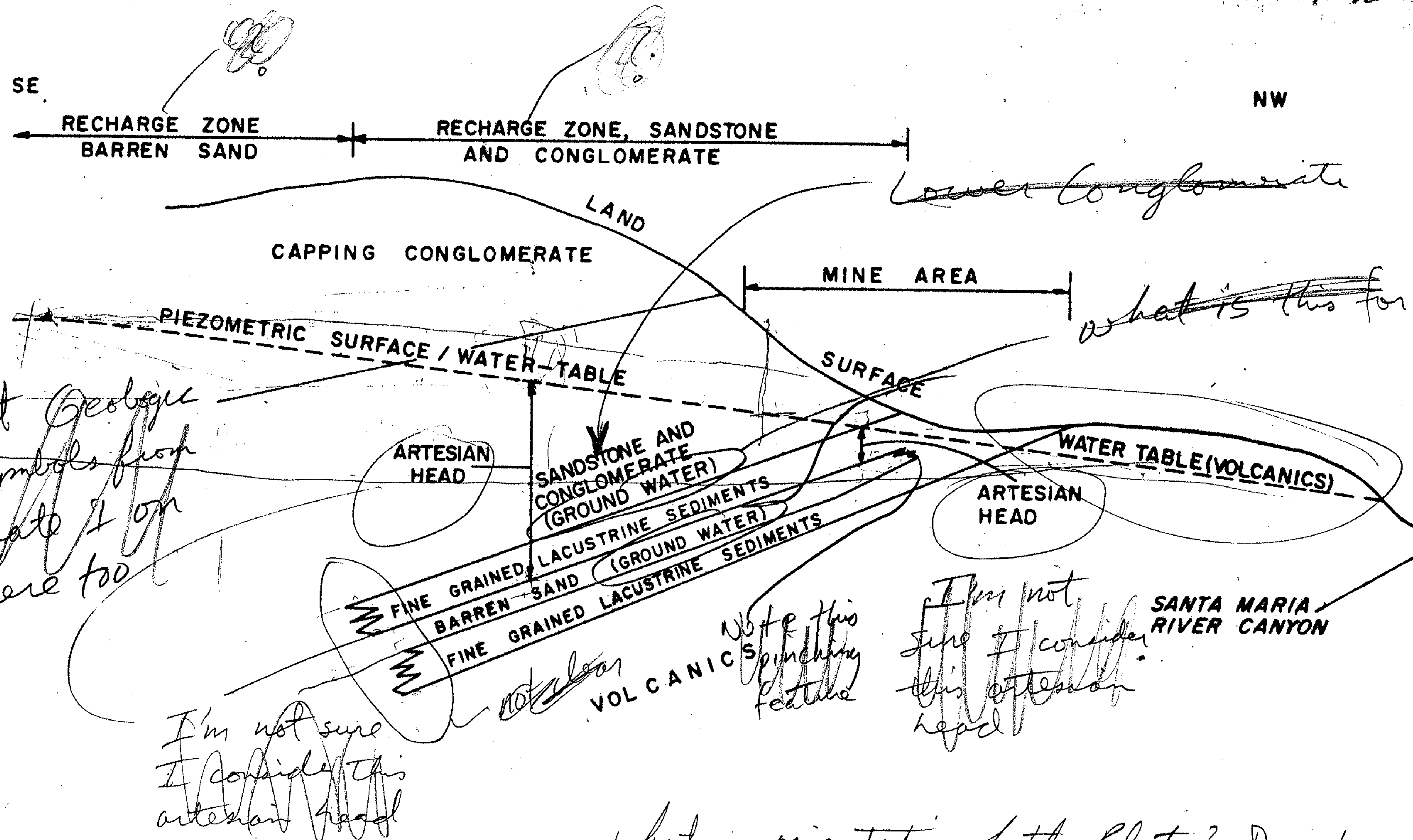
> "Immediately above the lacustrine sediments a tan to brown siltstone usually is present. This siltstone grades upward into arkosic sandstones and then into the conglomerate. The unit is composed primarily of arkosic sands and granitic and metamorphic clasts. Minor amounts of rhyolitic and andesitic volcanic materials are present throughout the unit. The sandstone and conglomerate may either be locally well cemented by calcite or relatively unindurated. To the southwest where the lake beds interfinger with sandstones the lower conglomerate is indistinguishable from these sandstones."

This unit dips southward. Within the northern part of the claim area it has been removed by erosion. Along the southern edge of the claim area it has been incised by stream erosion and, between stream courses, stands as steep slopes with cliffs along canyons in places. The thickness of the unit is in the range of 150 to 350 feet.

The Sandstone and conglomerate unit is the second of the two water-bearing units within the claim area, for the lower part is saturated. Well AM-28 (28/1794 on map, Pl. 1) is the source of water for drilling holes in the claim area. On test, the well yielded an average of 89 gpm with a specific capacity of 2.06 gpm per foot of drawdown after 28 hours of pumping at the 89 gpm rate. Additional information is contained in a subsequent part of this report ("Results from aquifer tests").

Basalt (Miocene)

> "Basaltic volcanic flows unconformably overlie the conglomerate forming erosionally resistant caps on many of the mesas and eroding cliffs.



what is orientation of the Plate? Due to wide variability in the area I recommend that a rough key map be added

FIGURE I.-- SKETCH SHOWING APPROXIMATE RELATIONS BETWEEN OCCURRENCE OF GROUND WATER AND GENERAL GEOLOGY OF MINE AREA. (NOT TO SCALE, EFFECT OF FAULTING NOT SHOWN)

> "Ljung et al (1976) describes the basalt as "black fine-grained to aphanitic, containing calcite-filled amygdules, and commonly jointed parallel to the flow surface". The basalt attains a maximum thickness of 120 feet southeast of Flat Top Mesa and thins to the east where eventually it is no longer present. At least two flows are present in the western portion of the property. To the northeast of Flat Top Mesa (NE$\frac{1}{4}$ Sec. 9, T. 11 N., R. 10 W.) several dikes, possibly basaltic, have been noted. These dikes cut the felsic to intermediate and andesitic volcanics, however, no direct pipe has been observed to the basaltic flows from these dikes. Wes Pierce (1977 a) of the Arizona Bureau of Mines, reports that a sample of basalt taken at Anderson Mine near AM-368 (SE$\frac{1}{4}$ Sec. 10, T. 11 N., R. 10 W.) has been dated by Paul Damon of the University of Arizona, using the Potassium Argon Method, as being 13 or 14 million years old or Miocene age."

The basalt lies above the water table within the claim area and is not water bearing.

Capping Conglomerate (Quaternary-Tertiary)

> "The upper conglomerate unconformably overlies either the basaltic volcanics or the lower conglomerate. This unit is composed of cobbles and boulders of felsic to mafic volcanics, and granite and metamorphics in a matrix of medium to coarse-grained arkosic sandstone. The unit is weakly to moderately indurated and is locally well cemented by calcite."

The maximum thickness of the Capping conglomerate in the mining claim area is about 120 feet. The unit lies above the water table within the claim area and is not water bearing.

Alluvium (Quaternary)

Along the Santa Maria River

The alluvium along the Santa Maria River (see Pl. 1) has been well sorted by river flows and consists mainly of unconsolidated sand with beds and lenses of gravel, silt, or clay. Test drilling in the alluvium along the river in Sec. 3, T. 11 N., R. 10 W., yielded the following data:

Hole No.	Depth (ft)	Depth to Bedrock (ft)	Saturated Thickness (ft)
1	57	57 +	33
2	27	27	8
3	30	30 +	-
4	61	61	33 ±

West of R. 10 W. the river valley widens and deepens and the saturated thickness of the alluvium increases.

Within Claim Area

> "Unconsolidated sands and gravels are present in most of the drainages at Anderson Mine. At least one older alluvial terrace is present in the northeast portion of the claims group. Remnants of several older alluvial deposits are present along some of the deeper drainages. Most of these older alluvial deposits have well developed caliche zones within them."

Within the claim area the thickness of alluvium ranges from a few inches to a maximum of about 15 feet in pockets. The water table is below the bottom of the alluvium except in a few small seepage areas along stream channels between the mine area and the river.

Geologic History

"At the end of the Oligocene, Basin and Range block, transform, and normal faulting began. The lacustrine sediments have been dated paleontologically as Miocene and a geochemical date of Miocene (13 - 14 M. Y.) had been obtained for the basalt. Thus, lake beds are probably early or middle Miocene. During this time volcanism was waining, however, ashes and tuffs would still have been common.

"Drill hole data from the Anderson Mine and regional geologic information leads to the conclusion that deposition of the lacustrine sediments occurred in a very restricted area. To the north of Anderson Mine in Section 4, T. 11 N., R. 10 W, the basalt caps Hill 2826 and is underlain by the lower conglomerate. This in turn rests unconformably on the "basement volcanics". Two possibilities arise: 1) the lake beds were never deposited here, or 2) they were deposited and subsequently eroded. Since the lake beds are thinning rapidly northward, it is felt that the lake beds were never deposited here. The intertongueing and interfingering of the "typical" lake beds with clastic siltstones and medium to coarse grained sandstones to the southwest and south limits the lake in this direction. The relationship of coarse-grained lithologies in this direction and lack of them to the north in the "typical" lake bed sequence implies that the sediments source was from the west or south. Urangesellschaft drilling has traced the lake beds and mineralization to the southeast. It appears that the lacustrine sediments were deposited in an area less than three miles wide and only about five or six miles long. The lake trended roughly northwest-southeast, generally parallel to the dominate Post-Oligocene faulting trend of the area. One further lithologic implication is of interest. The northern and northeastern margin of the lake was probably the Black "

"Mountains, however, they must have been topographically lower, only a slight bit above the lake beds, as there are no coarse clastics in the lake sediments along this margin.

"The lower conglomerate overlying the lake beds attests to the continuation of basin and range faulting and development. Erosion from nearby sources, possibly from the north or northeast, is indicated. Near the end of Miocene the basaltic volcanics flowed across the area, possibly marking the passage of the East Pacific Rise beneath the area. Normal faulting continued and the upper conglomerate was deposited. Its very coarse texture implies very near sediment sources and a very high energy environment of deposition. The inclusion of fresh basaltic boulders suggest the source was to the north and that the transporting agent may have been the Santa Maria River.

Structure

"The Anderson Mine Property is located in the Basin and Range Physiographic Province and exhibits the general structrual pattern common to the province. Parallel to subparallel fault blocks with usually normal bounding faults predominate. These faults are often rotational or hinged and may have experienced some longitudinal movement. While much of the basin and range faulting is on the magnitude of thousands of feet of displacement, displacement along faults at Anderson Mine are measured in tens and hundreds of feet.

"At Anderson Mine faulting was active prior to and during the deposition of the Miocene section (lake beds, lower conglomerate and basalt). The general 5^{o} to 15^{o} (dip) to the south appears to be the result of the recurrent nature of the faulting and may be in part the result of fault hinging and rotation of fault blocks. Drag folds are common "along many of the faults and in these areas dips may surpass 20^{o}. Many of the onlap, pinchout and lens relationships in the lake beds are probably due to or related to recurrent faulting.

"The recurrent and hinging nature of the faulting makes it extremely difficult to predict how a specific fault will affect the individual units along it. At one point along a fault there may be only a few feet of vertical displacement while two hundred feet beyond that point portions of the section may be displaced several tens of feet. Many of the faults that displace the lake beds show diminished or no movement in the basalt and most of the faults die out before or in the upper conglomerate.

"Three major faults, the East Boundary Fault System, Fault 1878, and the West Boundary Fault Sys- are present in the area. In addition to these are many parallel faults which have less displacement than the major faults. All of these faults trend between N30^{o}W and N55^{o}W. Another set of faults trending more westerly (N65^{o}W) are present at least in the south-central portion of the property. A set of faults trending northeast has been conjectured by Urangesellschaft but has not been observed in the field.

"The West Boundary Fault System includes at least two distinct normal faults. Movement on these faults is down to the southwest. Vertical offset of the volcanic basement across the two faults is approximately 400 feet. Another fault is indicated to the southwest which vertically offsets the volcanic basement about 250 feet. While total vertical offset of the basement volcanics across the West Boundary Fault System is over 700 feet, vertical offset of the basalt is less than 200 feet.

"Fault 1878 in the east-central portion of the properties exhibits 200 feet of vertical displacement near the boundary with Urangesellschaft. To the northwest along the fault displacement appears to decrease and movements appear to be distributed across a zone of faults. The movement along this normal fault has been down to the southwest. Along "the zone of faults, movement (while generally down to the southwest) has produced horst and graben features.

"The East Boundary Fault System consists of several large faults along the eastern and northern portion of the properties. These faults are beyond the limits of mineralization and therefore, very little is known about them. In general they are downthrown to the southwest and several of them probably have displacements approaching a thousand feet."

OCCURRENCE OF GROUND WATER

Sources of Data

Drill Holes

More than 1,000 exploration holes have been drilled within the claim area and within the Urangesellschaft claim area to the south. The general procedure followed was to start the initial drilling of each hole with air. If and when water was encountered the method of drilling was switched to a combination of air and foam to remove cuttings from the hole. In some holes, generally in the Urangesellschaft area, either the depths were too great or more water was encountered than could be handled with air and foam, and it became necessary to complete the drilling with a conventional fluid of drilling mud and water.

Drilling has been done within the claim areas since prior to 1976. During the early phases of drilling only general information was collected on the occurrence of ground water in drill holes and the results of test drilling indicated that ground water occurred only in the area southwest of Fault 1878. During the period March thru May 1979, 50 additional test wells were drilled in the area between the East Boundary Fault and Fault 1878. Pertinent data for these test holes are given in Table 1 and locations are shown on Plate 1. Results of this recent test drilling confirm the lack of occurrence of ground water in this general area. For example, none of the 50 holes encountered ground water and 26 of the holes were drilled into the volcanics. The deepest hole was drilled to a depth of 319 feet.

In early 1977 a field survey was made of all drill holes that were still open (a few had been cased) and the depth to fluid level in each hole (if any) was measured. These data were plotted on a coordinate grid as shown on Plate 2. Also shown on Plate 2 are data for the wells drilled for the aquifer tests discussed in this report. where is the data compilation for Plate 2

The bore-hole fluid level data range in reliability from excellent for the holes that had been cased with perforated pipe and cleaned out with air to poor for those holes that had been drilled in the lower portion with mud, had not been cased nor cleaned out with air, and for which data were not clear as to the water-producing unit. Two holes in particular provided accurate data for they had been converted to water wells to supply water for the drilling rigs. These wells are DC-5 (Urangesellschaft water well) which produces water from the Barren sand, and AM-28 (Union Minerals water well) which produces water from the Sandstone and conglomerate unit.

TABLE 1

DATA FOR HOLES DRILLED NORTHEAST OF FAULT 1878

(All holes were drilled and logged by Dames and Moore. No ground water was encountered in any of the holes. Locations are shown on Plate 1.)

Hole No.	Depth (ft)	Collar Elevation	Bottom Elevation	Formation at Land Surface	Formation at Hole Bottom
225-B	95	1,934	1,839	Tml	Tml
227-B	100	1,942	1,842	Tml	Tml
232-B	100	2,002	1,902	Tmc	Tml
249-B	95	1,975	1,880	Tml	Tml
961-B	60	1,941	1,881	Tml	Tml
962-B	95	1,941	1,846	Tml	Tml
963-C	76	1,870	1,794	Qal	Tvs (tuff)
964-C	84	1,852	1,768	Qal	Tvs (ss/cg)
966-C	104.5	1,838	1,734	Tml	Tvs (ss/cg)
968-C	217	1,930	1,713	Tml	Tvs (ss/cg)
969-C	170	1,837	1,667	Tml	Tvs (tuff)
970	80	1,814	1,734	Qal	Tvs (ss/cg)
971-C	83	1,814	1,731	Qal	Tvs (tuff)
972-C	101	1,949	1,848	Tml	Tml
973	319	1,960	1,641	Tmc	Tvs (ss/cg)
974	218	1,961	1,743	Qal	Tvs (tuff)
975	200	1,873	1,673	Tml	Tvs (ss/cg)
976	28.5	1,922	1,894	Tml	Tml
977	19.5	1,954	1,934	Tml	Tml
978	23.5	1,963	1,939	Tmc	Tml
979	6	1,966	1,960	Tml	Tml
980	17.5	1,965	1,947	Tml	Tml
981	55.5	1,844	1,788	Qal	Tvs (tuff)
982	75.5	1,892	1,816	Qal	Tvs (tuff)
983	45.5	1,910	1,864	Tml	Tvs (tuff)
984-C	38.2	1,814	1,776	Qal	Tvs (ss/cg)
985	27.5	1,884	1,856	Qal	Tml
986	45.3	1,916	1,871	Qal	Tml
987-C	75.8	1,923	1,847	Qal	Tml
988	50.5	1,860	1,810	Qal	Tml

TABLE 1
(continued)
DATA FOR HOLES DRILLED NORTHEAST OF FAULT 1878

Hole No.	Depth (ft)	Collar Elevation	Bottom Elevation	Formation at Land Surface	Formation at Hole Bottom
989	90.5	1,899	1,809	Qal	Tvs (tuff)
990	16.5	1,946	1,930	Qal	Qal
991-C	190.25	1,985	1,795	Tvf	Tvf
992-C	130	1,945	1,815	Tvf	Tvf
993-C	129	1,938	1,809	Tvf	Tvf
994-C	160	2,004	1,844	Tvf	Tvf
995-C	99.5	1,960	1,860	Tml	Tvf
996-C	101	1,940	1,839	Tml	Tml
997-C	274	1,940	1,666	Tml	Tva
998-C	150	1,990	1,840	Tml	Tvs (ss/cg)
999-C	167	1,892	1,725	Tml	Tvs (ss/cg)
1012	65	1,858	1,793	Qal	Tvs (tuff)
1013-B	150	2,000	1,850	Tml	Tvs (tuff)
1014	55	2,032	1,977	Tml	Tvs (tuff)
1015	35	2,014	1,979	Qal	Tml
1016	40	2,021	1,981	Qal	Tml
1017	85	2,031	1,946	Tmc	Tml
1019	80	2,012	1,932	Tmc	Tml
1021	50	1,966	1,916	Tml	Tml
1022-C	50	1,973	1,923	Tml	Tml

Several attempts were made with only partial success to contour the borehole fluid level data. Problems inherent in contouring the data include the multi-aquifer nature of the system in a portion of the area, caved or plugged holes, and mudded up holes. In spite of the shortcomings of the borehole fluid level data, they did provide useful information. First, the data review indicated that the only two water-bearing units of consequence are the Barren sand and the Sandstone and conglomerate. Second, the relation between faults and fluid-level elevations indicated that the faults excercise primary control over ground-water movement. Within blocks between faults and along faults the fluid-level gradient is generally downward to the northwest, parallel with the fault pattern. As the faulting is generally downstepped to the southwest, the fluid levels in each successive fault block are lower southwestward. Thus, if one were to plot a profile of fluid levels along a line across the mine area from northeast to southwest, the gradient would be downward to the southwest in a series of steps. However, the actual direction of ground-water movement within the claim area appears to be northwestward. Within the Sandstone and conglomerate, permeability is greater along the northwest trending fault zones than within blocks undisturbed by faulting, and therefore the northwestward ground-water movement is facilitated and southwestward movement is impeded by the massive unfractured blocks between faults. Within the Barren sand, faulting that completely or partially offsets the unit, placing it in contact with fine-grained lacustrine sediments, would impede southwestward movement. Within this unit the zones of greater permeability appear to be those northwest-southeast trending blocks between faults.

Production Water Wells

Early in 1978 plans were made to construct six small diameter test production water wells and a series of satellite observation wells with the objective of conducting aquifer performance tests. The wells were completed and aquifer tests were begun in November 1978. Subsequent to beginning the aquifer tests, a six-inch test well and several observation wells were also drilled in the volcanics north of the mine area. Testing of all wells, including AM-28 and DC-5, continued into February 1979. The results obtained from the testing are discussed in the following chapter of this report.

Chemical Quality

The February 1978 report contained analyses of all water samples available as of the data of preparation. Table 2 contains data from water samples collected since February 1978.

Water from the Sandstone and conglomerate unit within the claim area is typified by the analysis from Well AM-28. The water is low in total dissolved solids (200$\pm$ mg/l (milligrams per liter)) and relatively low in all constituents. Nitrate content is in the range of 15 to 20 mg/l. Water from the Barren sand is typified by the analysis from Well DC-5. The total dissolved solids content of this water is in the range of 650$\pm$ mg/l, about three times greater than in water from the Sandstone and conglomerate. Although the calcium and magnesium content is low, the bicarbonate content is higher and the pH is high (8.7 to 8.9). The sodium, chloride, and fluoride content is signicicantly higher than in water from the Sandstone and conglomerate. Discussion of the analyses of the water from the other wells that were tested is given in the discussion of results from aquifer testing.

The analyses from Well AM-28 indicate that water in the Sandstone and conglomerate unit has dissolved little soluble material from the formation. This suggests several things including the following: 1) the formation contains little soluble material; 2) movement of water through the formation is fairly free, and the ground water is not stagnant in the formation; and 3) the low total dissolved solids content and the relatively high nitrate content imply a local source of recharge rather than a far distant recharge source. In Sec. 16, T.11 N., R.10 W., a short distance westward from the Urangesellschaft claim area and southwestward from the Union Minerals claim area (see Pl. 1), where the Barren sand, lacustrine sequence, and Sandstone and conglomerate merge by facies changes into one general unit there is ground water in the sequence considered stratigraphically equivalent to the Sandstone and conglomerate. Analyses of this water exhibit characteristics between water from the Barren sand and water from the Sandstone and conglomerate.

also Figure 1

The analyses of water from the Barren sand indicate possibly longer contact time in the formation, more likelihood of soluble materials in the formation (especially from the lake bed sequence), and likelihood of a recharge area farther from the claim areas than for water in the Sandstone and conglomerate.

The three analyses from the volcanics well (No. 1007, see Table 2) indicate the water produced more closely resembles Barren sand water than Sandstone and conglomerate water, but as pumping progressed there was a slight shift toward Sandstone and conglomerate water. This

TABLE 2

ANALYSES OF WATER SAMPLES

(Analyzed by the Anaconda Company (An) and B C Laboratories (BC). All constituents in milligrams per liter except specific conductance (micromhos @ 25°C), water sample temperature (°F), and pH.)

Well No.	(B-11-10) 2 ccb	(B-11-10) 9 dbc	AM-660	AM-660	AM-660	AM-28
Laboratory	BC	BC	An	An	BC	An
Date sampled	09-25-78	09-26-78	11-28-78	11-28-78	11-28-78	12-06-78
Hour sampled	-	-	09:30	16:50	16:00	12:50
Calcium (Ca)	22	19	21	20.8	16	26.5
Magnesium (Mg)	3.4	17.4	13.5	13.6	13.7	15.3
Sodium (Na)	120	122	30.1	29.9	29	14.6
Potassium (K)	7.8	2.7	3.2	3.2	4.2	2.36
Hydroxide (OH)	-	-	0	0	-	0
Carbonate (CO_3)	43.5	46.9	0	0	0	0
Bicarbonate (HCO_3)	254.7	255.5	161	161	148.1	152
Chloride (Cl)	15.6	42.5	15.3	15.3	15.2	10.3
Sulfate (SO_4)	33	36	14.4	12.3	9	5.3
Nitrate (NO_3)	2.7	3.1	-	-	21.7	-
Fluoride (F)	1.5	2.7	-	-	1.0	-
Total Copper (Cu) TR 1/	-	-	.004	.005	-	.002
Total Iron (Fe)	-	-	.056	.054	-	.039
Molybdenum (Mo) TR	-	-	< .01	< .01	-	< .01
Selenium (Se) TR	-	-	< .01	< .01	-	< .01
Total Vanadium (V) TR	-	-	< .05	< .05	-	< .05
Total dissolved solids						
Calculated	-	-	259	257	-	227
At 180°F	463	473	-	-	240	-
Specific conductance	580	670	335	335	260	291
Temperature	80	84	78	76	76	70
pH	8.5	8.3	8.12	8.04	7.8	7.93

1/ Total recoverable unles otherwise noted; includes dissolved and suspended.

TABLE 2
(continued)
ANALYSES OF WATER SAMPLES

Well No.	AM-28	AM-28	AM-933	AM-933	AM-933	AM-556
Laboratory	An	BC	An	An	BC	An
Date sampled	12-07-78	12-07-78	12-09-78	12-10-78	12-10-78	01-04-79
Hour sampled	10:30	14:00	14:00	16:00	16:00	10:50
Calcium (Ca)	26.5	21	3.2	3.2	2.0	4.8
Magnesium (Mg)	15.0	14.5	1.7	1.5	.63	3.6
Sodium (Na)	14.6	17	85	154	150	156
Potassium (K)	2.44	3.3	2.43	2.75	4.2	3.21
Hydroxide (OH)	0	-	0	0	-	0
Carbonate (CO_3)	0	0	0	0	23.9	0
Bicarbonate (HCO_3)	152	146.4	198	320	259.9	250
Chloride (Cl)	10.3	10.6	16.5	40.5	41.4	60
Sulfate (SO_4)	6.6	8	13.6	15.8	25	62.9
Nitrate (NO_3)	-	18.6	-	-	3.1	-
Fluoride (F)	-	.76	-	-	3.8	1.45
Total Copper (Cu) TR	.002	-	.021	.005	-	.008 2/
Total Iron (Fe)	.023	-	.10	.063	-	.014
Molybdenum (Mo) TR	< .01	-	< .01	< .01	-	.20
Selenium (Se) TR	< .01	-	< .01	< .01	-	.02 2/
Total Vanadium (V) TR	< .05	-	.07	.07	-	0.10 2/
Total dissolved solids						
Calculated	228	-	321	538	-	542
At 180°F	-	217	-	-	443	-
Specific conductance	291	290	395	645	630	635
Temperature	74	74	88	88	88	78
pH	7.93	7.8	8.85	8.39	8.3	8.31

2/ Dissolved only.

TABLE 2
(continued)
ANALYSES OF WATER SAMPLES

Well No.	AM-556	AM-659	AM-659	AM-659	DC-5	DC-5
Laboratory	BC	An	An	BC	An	An
Date sampled	01-04-79	01-05-79	01-05-79	01-05-79	01-12-79	01-17-79
Hour sampled	10:50	15:20	16:10	15:20	14:00	12:00
Calcium (Ca)	3.3	4.8	4.8	5.6	1.6	1.6
Magnesium (Mg)	.91	3.9	3.9	.99	.5	.5
Sodium (Na)	162	130	165	140	200	203
Potassium (K)	3.3	2.43	2.72	3.7	3.48	1.87
Hydroxide (OH)	-	0	0	-	0	0
Carbonate (CO_3)	0	0	0	0	0	0
Bicarbonate (HCO_3)	244.3	323	402	333.5	445	445
Chloride (Cl)	68	16.5	22	14.9	30.5	30.5
Sulfate (SO_4)	62	11.9	13.6	25	25.9	25.1
Nitrate (NO_3)	2.2	-	-	1.3	.71	.93
Fluoride (F)	1.4	1.55	2.45	1.6	4.30	4.30
Total Copper (Cu) TR	-	.012 2/	.016 2/	-	.031	.002
Total Iron (Fe)	-	.03	.03	-	.012	.007
Molybdenum (Mo) TR	-	.12	.16	-	< .01	< .01
Selenium (Se) TR	-	< .01 2/	.01 2/	-	< .01	< .01
Total Vanadium (V) TR	-	.05 2/	.11 2/	-	< .05	< .05
Total dissolved solids						
Calculated	-	494	617	-	712	713
At 180°F	450	-	-	413	-	-
Specific conductance	670	500	645	550	775	775
Temperature	78	-	88	-	95	95
pH	8.1	8.23	8.18	8.0	8.69	8.69

2/ Dissolved only.

TABLE 2
(continued)
ANALYSES OF WATER SAMPLES

Well No.	AM-960	AM-960	AM-1007	AM-1007	AM-1007
Laboratory	An	An	An	An	An
Date sampled	01-30-79	01-31-79	02-07-79	02-08-79	02-09-79
Hour sampled	11:24	07:50	11:32	13:30	13:00
Calcium (Ca)	29.7	28.9	26.9	26.5	26.1
Magnesium (Mg)	26.7	26.7	24.5	24.3	25.5
Sodium (Na)	43.8	40.6	102	93	91
Potassium (K)	3.85	3.85	4.02	3.07	3.63
Hydroxide (OH)	0	0	0	0	0
Carbonate (CO_3)	0	0	0	0	0
Bicarbonate (HCO_3)	292	292	427	408	414
Chloride (Cl)	11.5	11.5	1.0	2.0	1.0
Sulfate (SO_4)	9.1	7.0	20.6	18.5	18.9
Nitrate (NO_3)	19.9	21.7	.62	5.8	6.6
Fluoride (F)	.74	.76	1.77	1.70	1.53
Total Copper (Cu) TR	.011	< .001	.003	.005	.006
Total Iron (Fe)	.006	.005	.027	.026	.017
Molybdenum (Mo) TR	< .01	< .01	< .01	< .01	< .01
Selenium (Se) TR	< .01	< .01	< .01	< .01	< .01
Total Vanadium (V) TR	< .05	< .05	< .05	< .05	< .05
Total dissolved solids					
Calculated	438	434	608	584	589
At 180°F	-	-	-	-	-
Specific conductance	450	450	720	690	600
Temperature	82	82	80	80	81
pH	7.93	7.95	8.18	8.36	7.72

water could be either a mixture of Sandstone and conglomerate water and Barren sand water, or it could be Sandstone and conglomerate water which has picked up additional dissolved solids (primarily sodium and bicarbonate) while migrating through the lacustrine sediments.

Approximate Limits of Hydrogeologic Unit

The hydrogeologic unit related to mining within the claim area and relating to the effects of mining is considered to be a parallelogram aligned northwestward along faults. As no ground water has been encountered northeast of Fault 1878, this fault is considered to be the northeastern limit of the hydrologic unit.

The southwestern limit of the parallelogram is considered to be along an imaginary line trending northwest in the vicinity of holes DC-133, DC-136, and DC-126 (see Pl. 1). Ground water occurring southwest of this line is believed to continue moving northwestward along structural features including the West Boundary Fault and it is considered that water in this zone would be unaffected by mining operations.

The northwestern limit of the parallelogram is considered to be along the Santa Maria River where it bends southward and thence northwestward in the vicinity of Coordinates N 1,209,000 and E 82,000 (see Pl. 1). This is the zone of natural discharge from the hydrogeologic unit.

The southeastern portion of the parallelogram is the recharge area. The southeastern limit is not precisely known owing to paucity of drill-hole data, but cannot be farther southeast than the vicinity of Sec. 4, T. 10 N., R. 9 W., where the water-bearing sediments are cut off by volcanic rocks of the Black Mountains.

The width of the parallelogram is less than one mile. The length is about 7-1/2 miles.

Direction of Ground-Water Movement

Regional

There are few wells in Date Creek Basin. Data for elevations of water levels in wells and for elevations of water issuing from Grapevine Springs (Secs. 21, 22, and 23, T. 11 N., R. 11 W.) indicate that the regional direction of ground-water movement in the basin is northwestward.

Within Mine Area

The data for water-level elevations within the mining claim areas of Union Minerals and Urangesellschaft U.S.A. (see Pls. 1 and 2) indicate that the direction of ground-water movement is northwestward. Further discussion of the direction of ground-water movement within the claim areas is given elsewhere in this chapter and in the next chapter of this report.

Natural Discharge

Regional

There is practically no withdrawal of ground water from the Date Creek Basin and the basin is considered to be in dynamic equilibrium. Therefore, one method for estimating natural discharge is to evaluate the recharge.

According to Busby (1966), annual runoff in the portion of southwestern Arizona that includes the Date Creek Basin is 0.1 inch of depth. Annual rainfall at Alamo Dam is about 8 inches in an average year (Wolcott and others, 1956, p. 308). Thus, slightly more than one percent of the rainfall becomes runoff on the average, and the other 99 percent is consumed by direct evaporation and replenishment of soil moisture. The soil moisture is continuously depleted by native vegetative cover.

Of the runoff, not more than 50 percent sinks deeply enough into the ground to escape capillary upward pull in the zone of soil moisture, and hence recharges the ground-water system (Coates and Cushman, 1955, p. 28).

The area of Date Creek Basin and tributary washes, excluding the drainage area of Bullard Wash, is 270 square miles (Halpenny and Clark, 1978, p. 5-1; 310 - 40 = 270). The drainage area of Bullard Wash is 275 square miles (ibid, p. 7-1). It is considered, therefore, that the annual ground-water discharge from Date Creek Basin into the Santa Maria River upstream from the confluence with the Big Sandy River is about 1,450 acre-feet per year. (545 sq mi x 640 ac/sq mi x 0.1 in/yr x .5 ÷ 12 in/ft = 1,453 ac-ft).

Within Mine Area

The data collected from the Anderson Mine area indicate that the avenues of natural discharge of ground water from the hydrologic unit is northwestward along faults that cut the sequence of Tertiary volcanics northwest of the mine area. No seeps have been observed within the mine area at the exposed contact between the Sandstone and conglomerate and the lacustrine sediments. This absence of seeps (ground-water discharge) at the surface contact indicates that ground-water in the Sandstone and conglomerate is percolating downward through the lacustrine sediments into faults in the underlying volcanics. Owing to the low permeability of the bulk of the lacustrine sediments most of this downward movement is considered to be along faults and fractures in the lacustrine sediments.

The Barren sand, although confined in the Urangesellschaft claim area and the southern portion of the mine area, has a piezometric-surface elevation in the order of 100 feet lower than the water-level elevation in Sandstone and conglomerate wells a short distance to the north. Data discussed in a subsequent section of this report indicate that the bulk of the Barren sand ground water is moving northwestward toward the cluster of structural features in the vicinity of AM-659, AM-138, and AM-443 (see Pl. 1). The possibility exists that some of the Sandstone and conglomerate water to the north at a higher elevation could be draining into this northwest trending Barren sand ground-water low. Pressure head on the Barren sand at DC-5 is 450 to 500 feet and in the vicinity of AM-659 and AM-138 is in the range of 280 feet. Thus, as the Barren sand water moves northwestward the artesian head decreases. Farther northwest, the Barren sand pinches or lenses out into the lacustrine sediments or against the volcanics, and the pressure head drops to zero. Ground water in the Barren sand also eventually finds its way into structural features in the volcanics.

Sources of Recharge, Local Hydrogeologic Unit

Sandstone and Conglomerate

The principal source of recharge to the Sandstone and conglomerate unit is considered to be primarily downward percolation from occasional storm runoff in stream courses that extend northwestward from the drainage divide to the northern limit of outcrop of the unit. Some percolation from direct runoff may enter the unit along fractures and faults.

The principal recharge area is considered to be no larger than two square miles and occurs in the zone marked on the sketch (Fig. 1) as "Recharge zone, Sandstone and conglomerate". Utilizing the same data that were applied to the Date Creek Basin, the average annual recharge to the Sandstone and conglomerate within the local hydrogeologic unit is about 3.3 gpm (5.3 ac-ft/yr).

(2 sq mi x 640 ac/sq mi x 0.1 in/yr x 0.5 ÷ 12 in/ft = 5.3 ac-ft/yr)

Barren Sand

Recharge to the Barren sand in the hydrologic unit under discussion is considered to be from the southeast. The source of recharge is infiltration from desert washes during runoff events and possibly mountain front recharge from a portion of the Black Mountains. Owing to lack of drill hole data in the southeastern part of the parallelogram that comprises the hydrogeologic unit and lack of knowledge of the location of the ground-water divide between the Santa Maria River and Date Creek, a reasonable estimate of the areal extent of the Barren sand recharge area cannot be made.

The throughflow in the Barren sand is equivalent to the annual recharge and the annual discharge because the unit is in dynamic equilibrium. The general direction of Barren sand ground-water movement through the hydrogeologic unit is northwest. In the area under discussion (from Fault 1878 southwest to the vicinity of holes DC-133, DC-136, and DC-126) the width of the Barren sand (normal to flow direction) is about 4,200 feet. As discussed in a subsequent section of this report the zone of higher transmissibility for the Barren sand is in the southwestern portion of the hydrogeologic unit extending northwestward from the vicinity of Well DC-5. Transmissibility in this area is in the range of 500 gpd/ft and the width of the zone is estimated to be about 2,000 feet. The zone of lower transmissibility is in the northeastern portion of the hydrogeologic unit and is about 100 gpd/ft based on data from the test on Well AM-933. Width of this zone is about 2,200 feet.

Based on piezometric data for Wells DC-5 and AM-659 the hydraulic gradient on the Barren sand amounts to 0.0043 feet per foot. Using the relation

$$Q = TIL$$

where

Q = throughflow in gallons per day
T = transmissibility in gallons per day per foot
I = hydraulic gradient in feet per foot
L = length width of section normal to flow direction

the computation for the 2,000-foot section with a transmissibility of 500 gpd/ft is as follows:

$$
\begin{aligned}
Q &= 500 \times 0.0043 \times 2{,}000 \\
&= 4{,}300 \text{ gpd} \\
&= 3.0 \text{ gpm}
\end{aligned}
$$

and the computation for the 2,200-foot section with a transmissibility of 100 gpd/ft is as follows:

$$
\begin{aligned}
Q &= 100 \times 0.0043 \times 2{,}200 \\
&= 946 \text{ gpd} \\
&= 0.7 \text{ gpm}
\end{aligned}
$$

Accordingly, throughflow through the Barren sand is considered to be about 3-1/2 to 4 gpm.

RESULTS FROM AQUIFER TESTS

Well Construction and Testing Procedures

Sandstone and Conglomerate - Barren Sand Sequence

Six new six-inch diameter test wells were drilled for test purposes in the Sandstone and conglomerate-Barren sand sequence. These are AM-439, AM-556, AM-659, AM-660, AM-933, and AM-960. In addition to the six new wells constructed for testing, existing supply wells AM-28 and DC-5 (Urangesellschaft) were also utilized for testing purposes. Drill-hole data for these holes are shown on two maps (Pls. 1 and 2) and in Table 3. Depths cased varied widely depending upon location in the geologic section and ranged from 188 to 750 feet. None of the wells were gravel packed. The general procedure followed in installing casing was that the depth to the uppermost perforations corresponded to the depth at which water was first encountered. Again depending upon location within the geologic section the depth at which water was first encountered could be in either the Sandstone and conglomerate or the Barren sand or in the lacustrine sediments between these two units. Casing installed in AM-933 was 6.249-inch ID steel casing with 1/8-inch by 9-inch torch cut slots. Casing installed in the remaining five new test wells was 5.76 inch ID PVC casing with 1/8-inch by 3-inch machine cut slots. Open area for both the steel and PVC casing amounts to 4.5 square inches per linear foot. All test wells were washed and cleaned prior to testing.

A total of 12 small diameter observation wells were utilized for observation purposes during the tests. Several of these were old exploration holes which were washed out and cased. The remainder of the observation wells were new holes which were drilled, washed, and cased specifically for the testing program. Casing installed in these holes consisted of either 2-inch ID or 3.5-inch ID steel casing or 4-inch ID PVC. Procedure for selecting depths at which to perforate the observation wells was similar to that used for the pumped wells. Perforations in the steel casing were 1/8-inch by 9-inch torch cut slots with 2.25 square inches of opening per linear foot of perforated casing. Perforations in the one observation well cased with PVC casing were made with a hacksaw.

The tests were conducted with submersible pumps ranging in size from three to ten horsepower. The discharge line assembly for all tests was equipped with a flow meter for measuring discharge rates, a gate valve for controlling flow rates, and a pressure gage for monitoring back pressure on the flow meter and pump.

when recorded

Lost - all of this data taken on ~~b~~ road program

TABLE 3

DRILL HOLE DATA

Hole No.	Collar Elevation (ft/msl)	Depth to Fluid Level (ft)	Elevation of Fluid Level (ft/msl)	Elevation of Base of Sandstone and Conglomerate (ft/msl)	Elevation of Top of Barren Sand (ft/msl)	Elevation of Base of Barren Sand (ft/msl)	Elevation of Top of Basement Volcanics (ft/msl)
AM-22C	1,954	178	1,776	1,644	1,409 +	1,364	1,259
AM-23	1,988	250	1,738	1,643	1,478 -	?	1,453
AM-28	1,852	70	1,782	1,627	1,402 ±	1,377 ±	1,337
AM-28C	1,853	-	-	-	-	-	-
AM-110C	1,845	-	-	-	-	-	-
AM-129	1,869	231	1,638	1,654	1,468 ±	1,454 ±	1,454
AM-134	2,008	277	1,731	1,643	1,533 ±	1,518 ±	1,503
AM-135C	1,994	147	1,847	1,657 ±	1,509	1,499 ±	1,500
AM-137	1,924	178	1,746	1,594	NE	-	1,444
AM-138	1,822	176	1,646	1,577	NE ?	-	1,387
AM-139	1,801	35	1,766	1,586	NE	-	1,421
AM-145	1,767	75	1,892	-	NE	-	1,647
AM-155	2,068	337	1,731	1,553	1,478 ±	1,423 ±	1,363
AM-167	2,004	308	1,696	1,629	1,404	1,339 ±	1,314 ±
AM-170C	1,797	82	1,715	-	NE		1,677
AM-177	2,014	209	1,805	1,659	1,374 ±	1,364 ±	1,364
AM-180	2,060	266	1,794	1,680	1,450	1,410	1,335
AM-182	2,082	278	1,804	1,616	1,452	1,422	1,336
AM-183	2,051	267	1,784	1,651	1,451	1,381	1,281
AM-306C	1,755	35	1,720	-	NE	-	1,718
AM-320	1,825	110	1,715	-	NE	-	1,575
AM-321	1,786	75	1,711	-	NE	-	1,586
AM-324C	1,837	-	-	-	-	-	-
AM-325	1,820	100	1,720	1,800	1,605 ±	1,590 ±	1,550
AM-326	1,817	100	1,717	1,777	NE	-	1,602
AM-334	1,844	115	1,729	1,674	NE	-	1,529
AM-335	1,854	110	1,744	1,639	NE	-	1,539
AM-336C	1,836	96	1,740	1,746 +	NE	-	1,581
AM-350	1,869	65	1,804	1,569 -	1,499 ±	1,449 ±	1,379 ±
AM-371	2,008	266	1,742	1,648	NE	-	1,553
AM-372	1,996	245	1,751	1,641	NE	-	1,486
AM-378	1,948	212	1,736	1,643	NE	-	1,443
AM-379	1,974	231	1,743	1,634	NE	-	1,439
AM-380	1,983	267	1,716	1,678	NE	-	1,499
AM-384	1,937	238	1,699	1,632	1,467 ±	1,437 ±	1,392
AM-385	1,911	168	1,743	1,661	1,471 ±	1,444 ±	1,444
AM-402	1,857	140	1,717	1,677	NE	-	1,587
AM-403	1,893	144	1,749	1,578	1,463 ±	1,453 ±	1,453
AM-405	1,906	148	1,758	1,566	NE	-	1,431
AM-406	1,918	321	1,597	1,578	NE	-	1,438
AM-417	1,984	361	1,623	1,509	1,364 ±	1,349 ±	1,349
AM-419	1,940	318	1,622	1,480	1,350 ±	1,320 ±	1,320
AM-422C	1,915	262	1,653	1,570	1,335 ±	1,315	1,245
AM-423	1,902	256	1,646	1,512	1,347	1,312	1,272
AM-424	1,899	304	1,595	1,519	1,374	1,349	1,324
AM-426	2,035	251	1,784	1,670	1,480	1,405	1,345
AM-427C	2,078	260	1,818	1,643	1,388	1,343	1,343
AM-437	1,894	126	1,768	1,629	1,414	1,364	1,254
AM-439	1,867	104	1,763	1,627	1,407	1,357	1,337
AM-440	1,900	167	1,733	1,630	1,450 ±	1,430 ±	1,350
AM-441	1,891	134	1,757	1,626	1,431 ±	1,420 ±	1,346
AM-442	1,891	151	1,740	1,596	1,436	1,406	1,341
AM-443	1,807	50	1,757	1,607	1,397	1,357	1,297
AM-444C	1,874	217	1,657	1,635	1,419	1,374	1,306
AM-446	1,984	220	1,764	1,534	1,404	1,324	1,219
AM-448	1,930	159	1,771	1,615	1,405	1,360	1,215
AM-507	2,011	465	1,546	?	?	?	531
AM-516	2,014	470	1,544	1,345	?	?	555
AM-520	2,040	485	1,555	825	?	?	540
AM-525	1,839	90	1,749	1,709	1,619 ±	1,579 ±	1,519
AM-556	1,847	94	1,753	1,780	1,582 ±	1,547 ±	1,536
AM-659	1,830	192	1,638	1,570	1,355 ±	1,325 ±	1,245
AM-660	1,925	125	1,800	1,660	1,490 ±	1,470 ±	1,470
AM-707	2,060 T	414	1,646	1,555	1,380	1,335	-
AM-866	1,900	101	1,799	1,600	-	-	1,475
AM-874	1,829	73	1,756	-	-	-	-
AM-931	2,020	367	1,653	1,480	1,340	1,295	1,230
AM-933	1,998	328	1,670	1,448	1,383	1,318	1,263
AM-945	1,888	242	1,646	1,583	1,288 ±	1,258 ±	1,228
AM-960	1,960 T	192	1,768	1,590	1,380 ±	1,300	-
DC-5	1,990	342	1,648	-	1,200	1,120 ±	-
DC-71	2,097	523	1,574	-	-	-	-
DC-126	1,951	319	1,632	-	-	-	-
DC-129	1,983	382	1,601	-	-	-	-
DC-133	1,952	337	1,615	-	-	-	-
DC-136	1,977	350	1,627	-	-	-	-

NE: Not encountered.
T: Elevation from topo.

Volcanics

In addition to the previously discussed wells and observation holes, other holes were drilled in the volcanics along the northwestward trending fault in NW$\frac{1}{4}$ Sec. 10 (see Pl. 1). The objective of drilling the volcanic wells was to determine the potential ground-water production from the fault zone and to establish a monitor well for future use. A total of 12 exploration holes were drilled using air so that the depth at which water was encountered could be determined and quantities of water could be estimated by blowing the hole with the rig compressor. Six of the holes were dry or did not encounter measurable amounts of water, and were not cased. The locations of the six cased holes are shown on the map (Pl. 1) and pertinent data on all of the holes are shown in Table 4. Coordinates and additional data for the six cased holes are shown in Table 5. Casing used in observation wells was 2 or 2.5-inch galvanized pipe with torch-cut slots. Casing used in the production well (AM-1007) was six-inch steel pipe with 1/8-inch by 3-inch saw cut slots. Total open area was nine square inches per linear foot of casing.

The testing procedure on volcanic production Well AM-1007 was the same as that for the other wells, a submersible pump with the discharge line equipped with a flow meter and a gate valve. Observation wells utilized during the test were those that were cased, AM-1000, AM-1002, AM-1009, AM-1010, and AM-1011.

Aquifer Tests

Water levels were measured in many observation wells throughout the testing. Plates 3 and 4 are hydrographs of water levels measured during the period November 13, 1978, through January 22, 1979. All water levels are shown except those made in the pumped wells during pumping. Inclusion of those data would have required separate graphs at a smaller scale to illustrate the substantial drawdowns in the pumped wells.

Work done since January 22 included testing Well AM-960 and the volcanic well, AM-1007. Data on declines caused by pumping AM-960 and AM-1007 are given in the detailed discussions of the tests in a subsequent part of this chapter.

Discussion of the individual tests is given by pumped wells in the following pages, with the tests related to the Sandstone and conglomerate first (28, 439, 660, and 960), the Barren sand next (556, 659, 933, and DC-5), and the volcanic test last (1007).

TABLE 4

TEST HOLES DRILLED IN TERTIARY VOLCANICS

Hole No.	Depth Drilled (ft)	Estimated Discharge With Compressor (gpm)	Remarks
AM-1000	165	10 to 25	Hit fault at approximately 115 feet. Cased to total depth. Perforated from 102 to 165 feet.
AM-1001	165	0	1/ Damp from 25 feet to bottom. No water could be produced.
AM-1002	137	50 to 100	Hit fault at approximately 120 feet. Cased to total depth. Perforated 100 to 137 feet.
AM-1003	165	0	1/ Damp from 25 feet to bottom. No water could be produced.
AM-1004	245	0	1/ Damp from 195 to 245 feet. No water could be produced.
AM-1005	160	0	1/ Damp from 60 to 160 feet. No water could be produced
AM-1006	320	< 1	1/ Damp from 60 to 320 feet. Estimated discharge 1 to 2 pints per minute.
AM-1007	200	50 to 100	Hit fault at approximately 120 feet. Cased to total depth. Perforated from 100 to 200 feet.
AM-1008	230	0	Dry hole. Not even damp.
AM-1009	200	30 to 50	Hit fault at approximately 175 feet. Cased to total depth. Perforated from 100 to 200 feet.
AM-1010	200	1 to 3	Cased to total depth. Perforated from 100 to 200 feet.
AM-1011	165	0.5 to 2	Cased to total depth. Perforated from 80 to 165 feet.

1/ The holes were drilled with air. Dry cuttings were blown out as dust. Cuttings from below the water table were blown out with accompanying water. Cuttings from moist zones were described from field observation as "damp".

TABLE 5

DRILL HOLE DATA, VOLCANIC WELLS

Hole No.	Elevation of Land Surface (ft/msl)	Depth to Fluid Level (ft)	Elevation of Fluid Level (ft/msl)	Coordinates N	Coordinates E
AM-1000	1,635	102	1,533	1,208,361	84,944
AM-1002	1,638	104	1,534	1,208,283	85,032
AM-1007	1,638	104	1,534	1,208,288	85,025
AM-1009	1,665	132	1,533	1,208,288	85,129
AM-1010	1,631	74	1,557	1,208,492	84,832
AM-1011	1,628	64	1,564	1,208,499	84,846

AM-28

AM-28 is the existing supply well used for drilling water. The hole was originally drilled as an exploration hole and penetrated Sandstone and conglomerate from land surface to 225 feet, lacustrine sediments from 225 to 450 feet, approximately 25 feet of Barren sand in the depth range of 450 to 475 feet, and lacustrine sediments from 475 to 515 feet. The hole was completed and cased to a depth of 200 feet with five-inch PVC casing perforated from 60 to 200 feet. Perforations are 1/8-inch by 3-inch cuts with 4.5 square inches of opening per linear foot of casing. AM-28 has been sounded and is open to cased depth but is plugged below that depth.

Observation wells near AM-28 include AM-350 located 260 feet east and south, AM-874 located 510 feet northwest, AM-866 located 340 feet north, and AM-660 located 410 feet northeast. AM-350 was drilled to a total depth of 490 feet and cased to 240 feet with perforations extending from 50 feet to the bottom of the casing. The section encountered consisted of Sandstone and conglomerate from land surface to 300 feet, lacustrine sediments from 300 to 370 feet, approximately 50 feet of Barren sand in the depth range of 370 to 420 feet and lacustrine sediments from 420 to 490 feet which were underlain by volcanics. AM-350 was sounded during the test period and is only open to a depth of 96.2 feet. It is considered likely that the hole has been partially filled as a result of surface water overtopping the casing. The well is in the bed of a wash that occasionally carries flood runoff.

AM-874 penetrated the Sandstone and conglomerate from land surface to a depth of 125 feet and lacustrine sediments from 125 to 350 feet. Casing is reported to extend to 180 to 200 feet with perforations starting at 50 feet. Pertinent data for AM-660 and AM-866 are given in the discussion on the AM-660 test.

AM-28 was tested for 28 hours with a 10 horsepower submersible set at 173 feet during the period December 6-7, 1978. Initial static water level was 57.9 feet and the final pumping water level was 101.1 feet. With the exception of the first few minutes of pumping the discharge was maintained at 89 gpm throughout the test. This is the highest yield obtained from any of the Sandstone and conglomerate wells. Specific capacity at the end of pumping was 2.06 gpm/ft of drawdown. Semi-log and log-log plots of the data obtained from AM-28 give transmissibility values ranging from 2,000 to 5,000 gpd/ft.

Observation wells AM-350, AM-660, and AM-866 all showed a response to pumping with the maximum decline amounting to 2.3 feet in

AM-350. Semi-log plots for these three wells show a continuing curvature downward with time and the log-log plots show a continuing departure from the type curve with time. Using the late data gives transmissibility values ranging from 11,000 gpd/ft for AM-350 to 16,000 gpd/ft for AM-660. Distance-drawdown plots at 300, 700, 1,200, and 1,680 minutes after pumping started give transmissibility values of 16,000, 15,000, 14,000, and 8,500 gpd/ft respectively. Thus, the general shape of the curves plus the distance-drawdown data show that with increasing time transmissibility values are still decreasing fairly rapidly. For the vicinity of AM-660 and AM-866 we believe that the results of the AM-660 test are more indicative of actual transmissibility values in this direction. For the vicinity of AM-28 the transmissibility value is in the range of 4,000 gpd/ft after 28 hours of pumping at 89 gpm. With prolonged pumping or a greater discharge, a lower value would prevail because data show that the transmissibility was decreasing with time. Short-term storage coefficients determined from the test data were generally in the 10^{-3} to 10^{-4} Range.

AM-336 C, AM-556, AM-874, and AM-525 were all affected slightly by pumping AM-28. The magnitude of this effect is best described in terms of changes in recovery or decline rates. All of these wells showed a net rise in water level from before the time AM-28 was turned on until after it was turned off. Prior to the test of AM-28, AM-336 C showed a recovery rate of approximately 0.4375 ft/day. The effect of pumping AM-28 was to reduce this recovery rate to approximately 0.2125 ft/day. AM-556 was similarily affected, the pre-test recovery trend changing from 0.2690 ft/day to 0.1875 ft/day. AM-874 showed a pre-test recovery rate of 0.3750 ft/day which reversed to a decline rate of 0.15 ft/day prior to shut off of AM-28. Sufficient data were not obtained to develop rates of change for AM-525.

AM-439

Well AM-439 was reported drilled to a total depth of 660 feet. The units encountered at this location include 240 feet of Sandstone and conglomerate, from land surface to a depth of 240 feet; 220 feet of the lacustrine sediments, from a depth of 240 to 460 feet below land surface; 50 feet of Barren sand from 460 to 510 below land surface; 90 feet of lower lacustrine sediments from 510 to 600 feet below land surface and 60 feet of andesite from 600 feet below land surface to the total depth.

AM-439 is reported to be cased with PVC to 520 feet. Sounding of AM-439 indicates the well bore is open only to a depth of 379 feet. The casing record indicates the well is perforated from 140 to 240 feet below land surface and from 420 to 520 feet below land surface. A video film of the well indicates perforations from approximately 77 feet below land surface to

200 feet, and a break in the casing at 235 feet. Material brought into the break by the camera caused sufficient turbidity so that filming of the remainder of the hole was not possible.

On December 11, 1978 an attempt was made to obtain preliminary pumping data on AM-439, in order to pick a discharge at which to conduct a test. A ten-horsepower submersible pump was set at a depth of 210 feet, which allowed for only 105 feet of drawdown. This shallow setting was selected in order to keep the pump above the casing break at 235 feet. However, sufficient material was produced through the break to lock the pump approximately three minutes after the pump was turned on. No water samples were obtained owing to the brief period of operation before the pump stopped. No additional attempts were made to test this well due to the condition of the casing.

Static water levels in this well have been 105 $\pm$ 1 foot throughout the period October 1978 through January 1979.

AM-660

AM-660 was drilled to a total depth of 523 feet. The transition from Sandstone and conglomerate to lacustrine sediments was gradual at this site, occurring in the depth range of 220 to 265 feet. Lacustrine sediments extended from 265 feet to 435 feet, underlain by approximately 20 feet of Barren sand (?) which in turn was underlain by volcanics. There was also a barren zone in the depth range of 365 to 385 feet which was a green to dark green siltstone. The hole was cased to a depth of 188 feet with perforations extending from 60 to 180 feet. Sounding subsequent to testing indicates that the hole is actually open to a depth of 212 feet. The static water level in AM-660 is in the range of 127 feet, which gives a saturated thickness of 53 feet of Sandstone and conglomerate open to the perforated section of the well bore plus an additional 24 feet in the open hole below the casing.

AM-866, located 200 feet west, is the closest observation well to AM-660. Total depth drilled for AM-866 was 457 feet and cased depth is 400 feet. Precise data on casing perforations are not available but it is believed they extend from 50 feet below land surface to total cased depth. The base of the Sandstone and conglomerate unit was encountered at a depth of 250 to 270 feet and the remaining 130 to 150 feet of material open to the well bore consists of lacustrine sediments. Static water level in AM-866 is in the range of 101 feet giving a combined saturated thickness of 299 feet of Sandstone and conglomerate and lacustrine sediments open to the well bore.

AM-660 was tested on November 28, 1978 with a three horse-power submersible pump set at 173 feet. Total pumping period amounted to 9.5 hours. Initial static water level was 127.3 feet and the discharge was maintained at about 15 gpm during the bulk of the test. The discharge started declining during about the last 45 minutes of pumping and could not be maintained at 15 gpm even with the gate valve wide open. Accordingly, the test was terminated. Final pumping water level was 165.2 feet giving a drawdown of 37.9 feet. The discharge at time of shutoff amounted to 14.5 gpm. Specific capacity at this time was 0.38 gpm/ft of drawdown and was still decreasing. Analysis of the drawdown and recovery data for AM-660 indicates transmissibility values in the range of 100 to 350 gpd/ft.

Based on the water-level data and hydrographs (see Pl. 3) pumping AM-660 had a definite effect on AM-866 and AM-874. The hydrographs also indicate a slight effect on AM-556, AM-525, and AM-336C, as their recovery rates were dampened while pumping AM-660. Slight effects were also noticed on AM-350 and AM-28. Total water-level decline in AM-866 as a result of pumping AM-660 amounted to 0.36 foot. This occurred within 150 minutes after pumping started and remained essentially constant during the remainder of the test. Plotting and analysis of the drawdown and recovery data for AM-866 gives transmissibility values in the range of 12,000 to 22,000 gpd/ft which are extremely high and are not considered to be valid. Problems inherent in the above analysis include the partially penetrating nature of AM-660 versus the fully penetrating nature of AM-866 including the lacustrine sediments penetrated, the relatively brief time period during which it was possible to maintain a constant discharge, the low rate of discharge, and relatively small amount of drawdown with resultant lack of stress on the aquifer system.

Total water-level decline in AM-874, located 500 feet west of AM-660, as a result of pumping AM-660 amounted to 0.76 foot and the decline was continuous throughout the test. At the AM-874 site the base of the Sandstone and conglomerate is at a depth of 125 feet. The casing is reported to extend to a depth of 180 to 200 feet, perforated from 50 feet to total depth. Saturated thickness of the Sandstone and conglomerate would be in the range of 50 feet. Analysis of the available data for AM-874 indicate a transmissibility value in the range of 1,300 gpd/ft. Due to the brief period of pumping and inability to maintain a constant discharge with increasing drawdown at AM-660, it is considered that the true transmissibility is somewhat less than 1,300 gpd/ft in the AM-874 area. In addition, the observed drawdown in AM-874 is less than the true drawdown during the pumping period due to the recharge event that was occurring prior to, during, and after the AM-660 test. The hydrograph (Pl. 3) shows that water levels were rising during the period, especially in AM-336C, AM-525, AM-556, and AM-874. The period was one of heavy storms and runoff.

In summary, we consider that the real transmissibility value for the Sandstone and conglomerate unit in the vicinity of AM-660 and AM-866 is in the order of magnitude indicated by the drawdown and recovery data for AM-660, in the range of 100 to 350 gpd/ft.

A water sample was collected from AM-660 during the test (see Table 1). Results of the analysis show that the water produced is essentially identical to the water produced by AM-28.

AM-960

Well AM-960 is reported drilled to a total depth of 600 feet. The section penetrated at this location includes 370 feet of the upper and lower conglomerate units, 210 feet of the lacustrine sediments from a depth of 370 to 580 feet below land surface, and approximately 20 feet of the Barren sand from 580 to 600 feet below land surface.

AM-960 was cased to a depth of 600 feet and the perforated interval is from 360 to 600 feet. Down-hole video film of AM-960 indicates a casing break at 119 feet below land surface and another at 379 feet. At the lower break, movement of the camera going past the break brought in sufficient formation material to prohibit the filming of the remainder of the hole. While perforations are reported to start at 360 feet below land surface, the video film indicates no perforations to 380 feet, which creates some doubt as to the accuracy of the casing record, and also indicates that the Sandstone and conglomerate is blanked off. Sounding of AM-960 indicates the well is open to a depth of 593 feet.

Testing of AM-960 began on January 30, 1979, and continued for a total of 21 hours. The discharge was maintained at a rate of 12 gpm for a period of 5 hours, at which point it was increased to 15 gpm for the remainder of the test.

Static water level at the beginning of the test was 192.1 feet, and has been in this range $\pm$ 1 foot throughout the period August 1978 through January 1979. After 5 hours of pumping, the pumping water level was 258.4 feet (drawdown of 66.3 feet), giving a specific capacity of 0.18 gpm/ft of drawdown. During the remaining 16 hours of pumping the discharge was increased to 15 gpm, and the final pumping water level was 276.4 feet (84.3 feet of drawdown), and the final specific capacity was also 0.18 gpm/ft of drawdown.

Observation wells monitored during the testing of AM-960 included Wells AM-22C, AM-437, AM-439, and AM-945. Well AM-22C, located 250 feet northwest of AM-920, is reported drilled to a depth of 780 feet, and cased to a depth of 690 feet. However, sounding of this well indicates it is open only to a depth of 475 feet. The section penetrated at this location includes 310 feet of the Capping and lower conglomerate, from 0 to 310 feet below land surface; 45 feet of Barren sand from 545 to 590 feet below land surface; 95 feet of lower lacustrine sediments from 590 to 685 feet below land surface; and 95 feet of andesite from 685 to 780 feet below land surface. The casing in AM-22C is reported perforated from 490 to 690 feet below land surface. As mentioned above this well is open only to a depth of 475 feet, leaving only blank casing from this depth to land surface, and no real communication with any of the units penetrated. Static water levels have been in the range of 178 feet throughout the testing program.

Well AM-437 located 600 feet northwest of AM-960 is reported drilled to a total depth of 660 feet. The section penetrated at this location includes 265 feet of the Capping and lower conglomerate from 0 to 265 feet below land surface; 215 feet of lacustrine sediments from 265 to 480 feet below land surface; 50 feet of Barren sand from 480 to 530 feet below land surface; 110 feet of lower lacustrine sediments from 530 to 640 feet below land surface; and 20 feet of andesite from 640 to 660 feet below land surface. AM-437 is reported cased to a depth of 320 feet and perforated from 120 to 260 feet. Sounding of AM-437 indicated the well is cased to 280 feet and open to a depth of 307 feet. Thus, the well is open to the lower conglomerate unit and 42 feet of lacustrine sediments. Static water level in this well for the length of the testing program was in the range of 128 feet.

AM-945 located 410 feet west of AM-960 is reported drilled to a depth of 660 feet below land surface. The section penetrated at this location includes 305 feet of Capping and lower conglomerate from 0 to 305 feet below land surface; 295 feet of lacustrine sediments from 305 to 600 feet below land surface; 30 feet of Barren sand from 600 to 630 feet, and 30 feet of lower lacustrine sediments. The well is cased to a depth of 630 feet and perforated from 480 to 630 feet. Sounding of AM-945 indicates a total depth of 614 feet leaving 120 feet of lacustrine sediments and 14 feet of Barren sand open to the well bore. Well AM-439, which was also monitored during the test on AM-960, is described in a separate section of this report.

During the testing of AM-960 none of the above observation wells showed any response to pumping. As mentioned earlier the video films of AM-960 indicate the saturated section of Sandstone and conglomerate is not perforated. Temperature of the ground water produced while pumping AM-960 was 82°F. Although the total dissolved solids content (see Table 1) is more than twice that for AM-28 the water resembles the Sandstone and conglomerate type of water more than the Barren sand type. The high water level elevation, similar to that for AM-437 and AM-439, also indicates Sandstone and conglomerate conditions. Sandstone and conglomerate water, in order to be produced, would have to move vertically downward from the base of the unit and enter the well bore through the casing break at a depth of 379 feet. Some of the production may also have been from the upper lacustrine sediments which could explain the higher mineral content. All of the data indicate that AM-960 is not open to the Barren sand.

In view of the physical condition of AM-960, aquifer characteristics for the Sandstone and conglomerate at this site cannot be determined. The lack of response in AM-22C is attributed to the fact that the Sandstone and conglomerate is blanked off in this well. The lack of response in AM-437 and AM-439 would indicate tight conditions in the direction of these wells and little or no hydrologic communication via faults or fractures.

AM-556

AM-556 was drilled to a total depth of 360 feet and cased to a depth of 315 feet. The section penetrated at this site consisted of Sandstone and conglomerate from land surface to a depth of 60 feet, lacustrine sediments from 60 to 265 feet, approximately 35 feet of Barren sand in the depth range of 265 to 300 feet, and 55 feet of the lower lacustrine sediments which is underlain by volcanics. Perforations in the casing extend from depths of 110 to 180 feet and 265 to 315 feet. The static water level in AM-556 prior to preliminary pumping was generally in the range of 94 feet. Thus, the Sandstone and conglomerate unit at this site is dry and sections open to the perforated casing include 70 feet of the upper lacustrine sediments, approximately 35 feet of Barren sand and 15 feet of the lower lacustrine sediments.

AM-336C, located 280 feet west and slightly north of AM-556, and AM-525, located 340 feet east and slightly north of AM-556 are the two closest observation wells. AM-336C was drilled to a total depth of 255 feet. The Sandstone and conglomerate unit extended to a depth of 90 feet and lacustrine sediments extended from this depth to 255 feet where volcanics were encountered. Casing was installed to a depth of 240 feet, perforated from 140 to 240 feet. Static water levels in this hole have generally been in the range of 94 to 96 feet. The Sandstone and conglomerate unit is dry and perforations are opposite the lacustrine sediments.

AM-525 was drilled to a depth of 357 feet, encountering volcanics at a depth of 320 feet. The section penetrated included Sandstone and conglomerate from land surface to 130 feet, lacustrine sediments from 130 to 220 feet, approximately 40 feet of Barren sand in the depth range of 220 to 260 feet, underlain by 60 feet of lacustrine sediments. Casing was installed to a depth of 340 feet, perforated from 60 to 180 feet. Static water level in AM-525 is about 90 feet. Perforations are opposite 40 feet of saturated Sandstone and conglomerate and 50 feet of lacustrine sediments.

AM-556 was tested briefly on January 4, 1979 after 13 minutes of preliminary pumping on the previous day. Static water level at the beginning of the test was 92.1 feet, and the pump was set at 260 feet. After 25 minutes of pumping the pumping water level was at 249.7 feet and still dropping rapidly, thus it was necessary to terminate the test. An attempt was made during the pumping period to restrict and control the flow rate but the back pressure was excessive. Discharge at the time of shutoff was 55 gpm. Specific capacity was 0.35 gpm/ft of drawdown and still decreasing. Analysis of the recovery data for AM-556 indicates a transmissibility value in the range of 150 gpd/ft. The water level data shown on Plate 3 indicate that the two brief pumping periods in AM-556 affected water levels in AM-874, AM-525, and AM-336C and possibly AM-28 and AM-350. However, the data are insufficient for analysis.

During the preliminary pumping of AM-556 the casing moved down the hole about 10 feet. The relative shallow depth of AM-556 plus potential casing problems precluded additional testing with a deeper pump setting.

A water sample was collected from AM-556 (see Table 1) just before it was necessary to terminate pumping. The water is a sodium bicarbonate type and resembles Barren sand water more than Sandstone and conglomerate water. The chloride and sulfate values are considerably higher than any previously determined. Temperature of the ground water produced was not obtained.

AM-659

Total depth drilled at AM-659 was 660 feet and the section penetrated included Sandstone and conglomerate from land surface to 260 feet, lacustrine sediments from 260 to 475 feet, approximately 30 feet of Barren sand in the depth range of 475 to 505 feet, and lacustrine sediments from 505 to 585 feet which were underlain by volcanics. Casing was set to a depth of 400 feet with perforations extending from 200 to 280 feet, opposite 60 feet of Sandstone and conglomerate plus 20 feet of lacustrine sediments, and from 360 to 400 feet, opposite 40 feet of lacustrine sediments. During the course of field work, prior to testing, it was observed that the casing in AM-659 had slipped down the hole into the open hole below the bottom of the casing. The casing was not anchored at land surface and storm runoff which overtopped the casing probably contributed to the slippage. Slippage amounted to approximately 73 feet, thus at the time of testing all perforations were opposite lacustrine sediments. The initial static water level measured in AM-659 was 192 feet indicating that about 69 feet of the Sandstone and conglomerate unit may be saturated at this site.

The two observation wells nearest AM-659 are AM-138, located 170 feet north and slightly east, and AM-443 located 380 feet north and slightly east. AM-138 was drilled to a total depth of 468 feet and may have encountered the Barren sand at a depth of 455 feet. Depth to the base of the Sandstone and conglomerate unit is 245 feet with lacustrine sediments extending from this depth to the Barren sand(?) at 455 feet. Casing was reported installed to a depth of 400 feet, perforated from a depth of 120 to 280 feet. Initial static water level in this hole was 176 feet indicating that 69 feet of Sandstone and conglomerate is saturated and open to the perforated casing at this site. Perforations are also located opposite 35 feet of lacustrine sediments. The testing of DC-5, described later in this section of the report, and the response observed in AM-138 while pumping DC-5 indicates that the Barren sand unit exists at the AM-138 site and is open to the bore hole. The water level elevation for AM-138 also indicates it is a Barren sand well.

AM-443 was drilled to a depth of 520 feet and cased to a depth of 280 feet with perforations extending from 60 to 200 feet. The section encountered at this site includes Sandstone and conglomerate from land surface to 200 feet; lacustrine sediments from 200 to 410 feet; Barren sand from 410 to 450 feet; lacustrine sediments from 450 to 510 feet; and volcanics from 510 to 520 feet. The perforated section of casing in this hole is opposite the Sandstone and conglomerate. Initial static water level was 48 feet indicating that 152 feet of Sandstone and conglomerate is saturated at this site.

AM-659 was tested on January 5, 1979 with a 10 horsepower submersible set at a depth of 386 feet. Static water level at the beginning of testing was 191.4 feet. The initial pumping period was for 25 minutes at a discharge of about 10 gpm. Drawdown during the period amounted to 75.2 feet giving a specific capacity of 0.13 gpm/ft of drawdown. The pump was shut off for 38 minutes while rewiring and then turned back on at a discharge rate in the range of 40 gpm. The pump operated for 11 minutes and then locked up. Pumping water level at the time pumping stopped was 333.9 feet and the discharge was 38 gpm. Specific capacity at that time was 0.27

gpm/ft of drawdown and decreasing rapidly. Water produced during the brief interval of pumping was quite dirty. Subsequent pulling and examination of the pump showed that the impellers were locked up with organic material and pieces of plastic shavings. The well is in the bed of a wash. Runoff in the wash in December 1978 entered the well and apparently carried with it twigs, leaves, and other debris.

The short-term specific capacity data show that AM-659 is capable of producing very little water in its present condition. In view of the problems with casing slippage and pump blockage, additional testing of AM-659 is not considered warranted. The pumping period was too short to obtain water levels in nearby observation wells.

Two water samples were collected from AM-659, one 21 minutes after pumping at the 10 gpm rate, and one just prior to pump failure while pumping at 38 gpm. Both samples are a sodium bicarbonate type of water similar in character to the Barren sand water. The sample collected at the higher discharge rate more closely resembles Barren sand water. Fluoride content at the 10 gpm rate was 1.55 mg/l and at the 38 gpm rate was 2.45 mg/l. Water temperature was not measured at the 10 gpm rate. At the 38 gpm rate temperature of the water produced was 88° F after seven minutes of pumping. As mentioned earlier, the casing has slipped downward in this hole so that at the time of testing all perforations were opposite lacustrine sediments. Ground water in the lacustrine sediments could be expected to be similar in quality to Barren sand water, especially if the piezometric level of the Barren sand at a given location was higher than the base of the overlying Sandstone and conglomerate unit. If the piezometric surface at a given location was lower than the base of the Sandstone and conglomerate and the Sandstone and conglomerate was saturated, water produced from the lacustrine sediments could be a mixture of the two types of water.

AM-933

Total depth drilled and cased at AM-933 was 755 and 750 feet, respectively. The base of the Sandstone and conglomerate unit was at a depth of 550 feet and 45 feet of Barren sand was encountered between depths of 635 to 680 feet. Casing perforations start at 488 feet, which is approximately the depth at which ground water was first encountered in the Sandstone and conglomerate, and extend to 750 feet. Thus, approximately 62 feet of saturated Sandstone and conglomerate and 45 feet of Barren sand are open to the well bore. In addition 85 feet of the upper lacustrine sediments, 55 feet of the lower lacustrine sediments and 15 feet of volcanics are also open to the well bore. Static water levels observed in

AM-933 prior to testing ranged from about 327 to 338 feet. As ground water was not encountered during drilling until a depth of approximately 488 feet, this subsequent rise in water level is attributed to the pressure head on the Barren sand.

AM-931 and AM-707 are the two closest observation wells to AM-933, with AM-931 located 160 feet southeast of AM-933 and AM-707 located 240 feet south and west of AM-933. AM-931 was drilled to a depth of 810 feet and cased to 798 feet with perforations extending from 598 feet to total depth of the casing. The base of the Sandstone and conglomerate unit is at a depth of 540 feet and apparently no ground water was encountered in this unit at this location. The section perforated and open to the well bore consists of 82 feet of the upper lacustrine sediments, 45 feet of the Barren sand, 65 feet of the lower lacustrine sediments and 8 feet of volcanics. Static water levels observed in AM-931 prior to testing AM-933 were in the range of 366 to 367 feet and are considered to represent the piezometric surface of the Barren sand.

AM-707 was drilled to 820 feet and cased to 777 feet with perforations extending from 577 feet to the bottom of the casing. Base of the Sandstone and conglomerate was encountered at a depth of 505 feet and the unit was also apparently dry at this site. Lacustrine sediments extended from 505 to 795 feet and are underlain by volcanics. Two barren zones were encountered in the lacustrine sediments. One was a brown siltstone between depths of 555 to 580 feet and the other was a brown sandstone between depths of 725 to 780 feet. The section perforated and open to the well bore in AM-707 includes the lacustrine sediments, the upper barren zone, and essentially all of the lower barren zone.

AM-933 was tested with a 7.5 horsepower submersible pump set at a depth of 617 feet on December 9-10, 1978. The well was pumped for a total of 29 hours. The first two hours of pumping was at a rate of 16 gpm and the remaining 27 hours was at a rate of 20 gpm. Average weighted discharge during the test was 19.7 gpm. During about the last two hours of pumping the rate of pumping water level decline began to increase rapidly and during the final few minutes of pumping a discharge rate of 20 gpm could not be maintained due to excessive lift. Consequently the test was terminated. Static water level at the beginning of pumping was 338.10 feet. The last pumping water level measured while still at a rate of 20 gpm (30 minutes before shutoff) was 519.6 feet, giving a drawdown of 181.5 feet. Specific capacity at this time amounted to 0.11 gpm/ft of drawdown and was still decreasing.

During the test on AM-933 there was a very small water level decline observed in AM-707 that could possibly be attributed to operating AM-933. A fair response was observed in AM-931 however, and this data plus the data from AM-933 was examined by plotting on semi-log and log-log graphs. The drawdown data from AM-933 at the 20 gpm rate during the period from about 120 minutes after pumping started to about 400 minutes after pumping started indicate a transmissibility value in the range of 60 gpd/ft. From about 400 minutes to about 1,600 minutes after pumping started there was a flattening trend in the drawdown data indicating a higher apparent transmissibility. As mentioned earlier there was an increase in the rate of decline during about the last two hours of pumping. The drawdown trend shown during the last two hours is steeper than that for the period from 120 to 400 minutes indicating a transmissibility value of something less than 60 gpd/ft.

The flattening trend observed in the range of 400 to 1,600 minutes after pumping started began when the pumping water level reached 490 feet and ended when the pumping water level was slightly greater than 510 feet. The depth of 490 feet corresponds closely to the approximate depth at which water was encountered in the Sandstone and conglomerate. Thus, the drawdown data indicate that in the initial stage of pumping most of the production was from the head on the Barren sand. Some of the production was from the Sandstone and conglomerate as a result of water having moved upward for several months from the Barren sand into the Sandstone and conglomerate unit. Once the top of the saturated portion of Sandstone and conglomerate was reached this unit temporarily contributed sufficient additional water to slow the rate of decline. Once the pumping water level was lowered through a little over 20 feet of Sandstone and conglomerate its ability to offset the previous rate of decline was apparently exceeded. At the time pumping was stopped the pumping water level was 520.4 feet; the discharge was less than 20 gpm and the discharge drawdown relationship was still deteriorating. Thus, by reducing the pressure head on the Barren sand 182.3 feet and by lowering the pumping water level through 32 feet (approximately 50 percent of the saturated thickness) of the Sandstone and conglomerate AM-933 is capable of producing something less than 20 gpm.

Water samples collected from AM-933 149 minutes after pumping started, and at the end of the pumping, tend to support the above interpretation (see Table 1). Based on analyses for AM-28 (Sandstone and conglomerate water) and DC-5 (Barren sand water) the first sample collected indicates a mixture of the two waters and the last sample collected is more similar to the Barren sand water produced by DC-5. The last sample collected indicates that at that time the proportion of the water being contributed by the Sandstone and conglomerate unit was decreasing. During the time interval between collection of the two samples there was a substantial increase in conductivity, total dissolved solids, sodium, and bicarbonate. Temperature of the water produced was 88°F, higher than water from AM-28 and approaching the water temperature from DC-5.

The flattening trend in the rate of decline in AM-933, when the pumping water level reached the upper portion of saturated Sandstone and conglomerate, was also observed in AM-931. Prior to this the drawdown data for AM-931 indicated a transmissibility value in the range of 970 gpd/ft. This would correspond to the time period when most of the production from AM-933 was from the head on the Barren sand. When the deterioration of the discharge-drawdown relationship began in AM-933 it was not possible to continue pumping at a controlled rate for a sufficient period of time for the new steeper drawdown trend to be reflected in AM-931. Thus, the actual transmissibility value in the direction of AM-931 is unknown but would be something less than the above value of 970 gpd/ft. As the Sandstone and conglomerate unit was dry at the AM-931 site the transmissibility value under discussion is for the Barren sand. Correction for the proportion of Sandstone and conglomerate water produced by AM-933 would lower the actual tranmissibility an additional amount. The coefficient of storage determined from the data for AM-931 is in the 10^{-4} range.

As mentioned earlier, the Barren sand piezometric surface in AM-707 appeared to respond very little to withdrawal of Barren sand water from AM-933. Possible reasons for this would include plugging of the Barren sand aquifer in AM-707 or offsetting of the Barren sand by a structural feature between the two wells. As the piezometric surface in AM-707 responded to the intermittent operation of DC-5 located 1,430 feet southwest, the well is definitely in communication with the Barren sand and cannot be considered plugged. Based on the Barren sand contacts picked for AM-933 and AM-931, both are at essentially the same elevation and the unit is described as a brown sandstone in both of these holes. Both of the barren zones in AM-707 are offset in terms of elevation from the Barren sand in the other two wells and there may be a small structural feature between AM-933 and AM-707. If so, this would delay or restrict the response in AM-707 while pumping AM-933.

DC-5

Well DC-5 is the existing water-supply well for Urangesellschaft U.S.A., Inc. The hole was originally drilled to a depth of 1,040 feet encountering an estimated 10 gpm of water in the Sandstone and conglomerate at a depth of 500 to 580 feet and an estimated 80 to 100 gpm in the Barren sand in the depth range of 800 to 860 feet. The hole was cased to a depth of 950 feet with steel casing with perforations extending from 750 to 950 feet. Static water level in this well on December 1, 1976 was 328 feet indicating a pressure head on the Barren sand at this location in the range of 450 to 500 feet.

Prior to and during the initial phases of testing described in this report, Urangesellschaft was completing their most recent phase of drilling. Based on data furnished by Urangesellschaft personnel related to the on-off operation of DC-5 and water-level measurements collected by both Urangesellschaft and Minerals personnel, it was apparent that DC-5 was affecting water levels in some of the Minerals wells. Accordingly, permission was requested, and received, from Urangesellschaft to run a five day aquifer performance test on DC-5.

Following removal of the existing pump and installation of a 10-horsepower submersible set at 638 feet, DC-5 was pumped for five consecutive days beginning on Janaury 12, 1979. Average discharge during the test was 40 gpm. Initial static water level was 341.5 feet and the final pumping water level was 393.6 feet. Drawdown amounted to 52.1 feet giving a specific capacity of 0.77 gpm/ft of drawdown.

Observation wells which responded to pumping from DC-5 included AM-138, AM-659, AM-945, AM-933, AM-931, and AM-707, with the most significant response occurring in AM-945 (see Pl. 4). The response observed in AM-931 was slight and the response observed in AM-659 was similar to that of a plugged well. As mentioned earlier AM-659 is open only to the lacustrine sediments. Thus, the response is delayed and restricted to some extent. Observation wells, their distances from DC-5, and maximum declines attributable to pumping DC-5 are tabulated below:

Well No.	Distance From DC-5 (ft)	Decline Caused by Pumping DC-5 (ft)
AM-707	1,430	7.28
AM-945	1,470	17.84
AM-933	1,660	4.45
AM-931	1,680	0.94
AM-659	2,330	3.04
AM-138	2,430	7.70

With the exception of AM-931 all of the data for the above wells, and DC-5, were plotted and examined on semi-log and log-log plots. Minimum values of transmissibility were in the range of 500 gpd/ft for DC-5, AM-945 and AM-138. Maximum values were in the range of 1,000 to 1,500 gpd/ft for wells AM-707, AM-933 and AM-659. DC-5, AM-945, and AM-138 are in a general northwest alignment that roughly parallels the predominant structural trend in the area .

The response observed in AM-945 and AM-138 indicates excellent communication between DC-5 and these two wells in a northwest-southeast direction, and it is considered that the transmissibility value in the range of 500 gpd obtained from these three wells is more representative of the actual value for the Barren sand. The coefficient of storage is in the range of 10^{-4}.

The delayed rate of drawdown versus time for AM-659 results in an unusually high transmissibility value for AM-659. Am-707 and AM-933 are located northeast of DC-5, normal to the predominant structural trend and it is considered that movement of ground water across structural features is somewhat restricted, affecting free communication, delaying drawdown and recovery and hence, resulting in anomalously high transmissibility values. Additional factors which could affect observed responses in observation wells would include changes in lithology and thickening or thinning of the more productive section. The Barren sand appears to be a highly compartmentalized aquifer as a result of the structure. Maximum communication within the unit is considered to be parallel to the structure along more or less continuous sections of the unit not completely offset by faulting. Transmissibility values determined in a direction parallel with the structure are those most indicative of the ability of the unit to transmit ground water.

Although the Barren sand is an artesian system with a substantial head, with the exception of AM-960, water-level elevations in those wells known to penetrate and be open to the Barren sand are lower than those in Sandstone and conglomerate holes immediately to the north (see Pl. 1). The general direction of movement of ground water appears to be to the northwest parallel to the predominant structural trend with a relatively flat hydraulic gradient.

Examination of the water-level data on Plate 3 indicates that AM-439, AM-437, AM-22C, and AM-960 may have responded very slightly to pumping DC-5. The indicated response, if real, indicates very restricted communication between these wells and DC-5.

AM-1007

AM-1007 and the surrounding observation wells, AM-1000, AM-1002, AM-1009, AM-1010, and AM-1011 are all completed in volcanic rocks. Details on depth drilled, depth cased, etc., are given in Tables 4 and 5 of this report.

The initial test on AM-1007 was started on February 7, 1979 and continued for 28.75 hours at an average rate of 35 gpm. The initial static water level was 107.22 feet and the final pumping water level was 120.82 feet. Drawdown in AM-1007 amounted to 13.60 feet and the specific capacity at the end of pumping was 2.57 gpm/ft of drawdown. The decline in AM-1002 located 8.9 feet south of AM-1007 was 13.58 feet at the end of pumping. The decline in AM-1009 located 115 feet south and east was 13.19 feet and the decline in AM-1000 located 109.5 feet north and west was 13.03 feet. Observation Wells AM-1010 and AM-1011 located 281 and 277 feet north and west of AM-1007 respectively, showed no water level changes that could be attributed to pumping AM-1007. The water level in AM-1011 on January 29, 1979 was 43.48 feet. During the period prior to pumping AM-1007 the water level was declining in this hole. The decline continued during and after pumping with no acceleration visible during the pumping period. The water level in AM-1010 was rising during the pre-pumping period, started declining just prior to pumping, and continued declining after pumping stopped.

Observation well AM-1010 encountered a fault at a depth of 50 feet which was blown with air at an estimated one to three gpm. The recovery observed in this well was probably a result of producing the one to three gpm, or from blowing the hole during drilling before it was cased. Observation well AM-1011 produced an estimated one-half to two gpm during drilling but was not blown before casing was set. A residual head of fluid may have been left in this hole which is bleeding off very slowly. The water level in AM-1011 appears to be trending toward stabilization in the depth range of 80 to 85 feet. AM-1010 is located only 15 feet from AM-1011 and it is possible that the present decline observed in AM-1010 is the result of very slow drainage to the lower water surface in AM-1011.

The almost identical decline in the pumped well and observation wells that responded demonstrates the hydrologic character of the "aquifer" system in the volcanics. Ground water occurs only along the open portion of the fault or fracture system. Observation wells along the same fault or fracture system where it is open respond almost immediately and in essentially the same amounts as in the pumped well. Observation wells not on that particular fault or fracture system do not respond, attesting to the dense nature of the undisturbed volcanics and apparent lack of communication between faults or fracture systems.

The fault encountered in AM-1007 was at a depth of 120 feet below land surface and it was considered desirable to pull the pumping water level down to and through the fault plane. Extrapolation of water-level declines at the 35 gpm rate indicated that this might take two days or longer. Accordingly, the test was terminated so as to install a larger 10 horsepower pump.

Recovery measurements were made on the wells for a total of 21.25 hours while changing pumps. Recovery in AM-1007 during this period amounted to 3.40 feet leaving a residual drawdown of 10.20 feet. Recovery in AM-1002, AM-1000, and AM-1009 amounted to 3.50, 3.04, and 3.24 feet respectively, leaving residual drawdowns in these wells of 10.08, 9.99, and 9.95 feet.

The amount of throughflow in the fracture system was estimated using the drawdown and recovery data from the test of February 7 and 8. The water produced during pumping was partly withdrawn from storage and partly by interception of throughflow. During recovery all the water was derived by interception of throughflow. During the pumping period the well produced 60,367 gallons (metered) in 1,725 minutes. Average drawdown in the four wells was 13.35 feet. During recovery the water level rose an average of 3.30 feet in the four wells during 1,275 minutes, at an average rate of 0.00259 foot per minute. The average rate of throughflow was computed and found to be 8.8 gpm.

Testing was resumed at 12:00 hours on February 9, using the 10-horsepower unit, and producing water at a rate of 75 gpm. A short-circuit developed in the wiring system after 324 minutes of pumping, and the pump stopped. The pumping water level had just declined to the fault plane at the time of pump failure. After discussion with Union Minerals personnel a decision was made not to attempt another test of the well.

The water levels in the four observation wells behaved the same as in the first test, declining and recovering nearly in unison. Drawdown and recovery data in AM-1007 for both tests are shown on Figure 2.

The amount of throughflow was computed and found to be 4.5 gpm. Computation of coefficients of transmissibility and storage was considered inappropriate and meaningless because the system is not remotely related to a homogeneous aquifer of infinite areal extent and of constant thickness.

Giving consideration to the fact that as a general rule fracture systems and fault systems become tighter with depth (Davis & Turk, 1964) it is likely that all of the throughflow was intercepted during pumping and that little or none continued to move northwestward along the fracture. Accordingly, the throughflow along this fracture system from the mine area toward the Santa Maria River is considered to be in the range of 4 to 9 gpm, with the more likely value to be of the order of 4 to 5 gpm.

The likelihood of developing part of the mine water supply by drilling a well that intercepts the fracture at a depth of several hundred feet is considered negligible.

Water samples were collected from AM-1007 at the beginning and end of the 35 gpm test and at the beginning of the 75 gpm test. During the 35 gpm test the ground-water temperature was in the range of 80 to 81°F and the conductivity ranged from 600 to 650 micromhos per square centimeter. At the 75 gpm rate the ground-water temperature was 81°F and

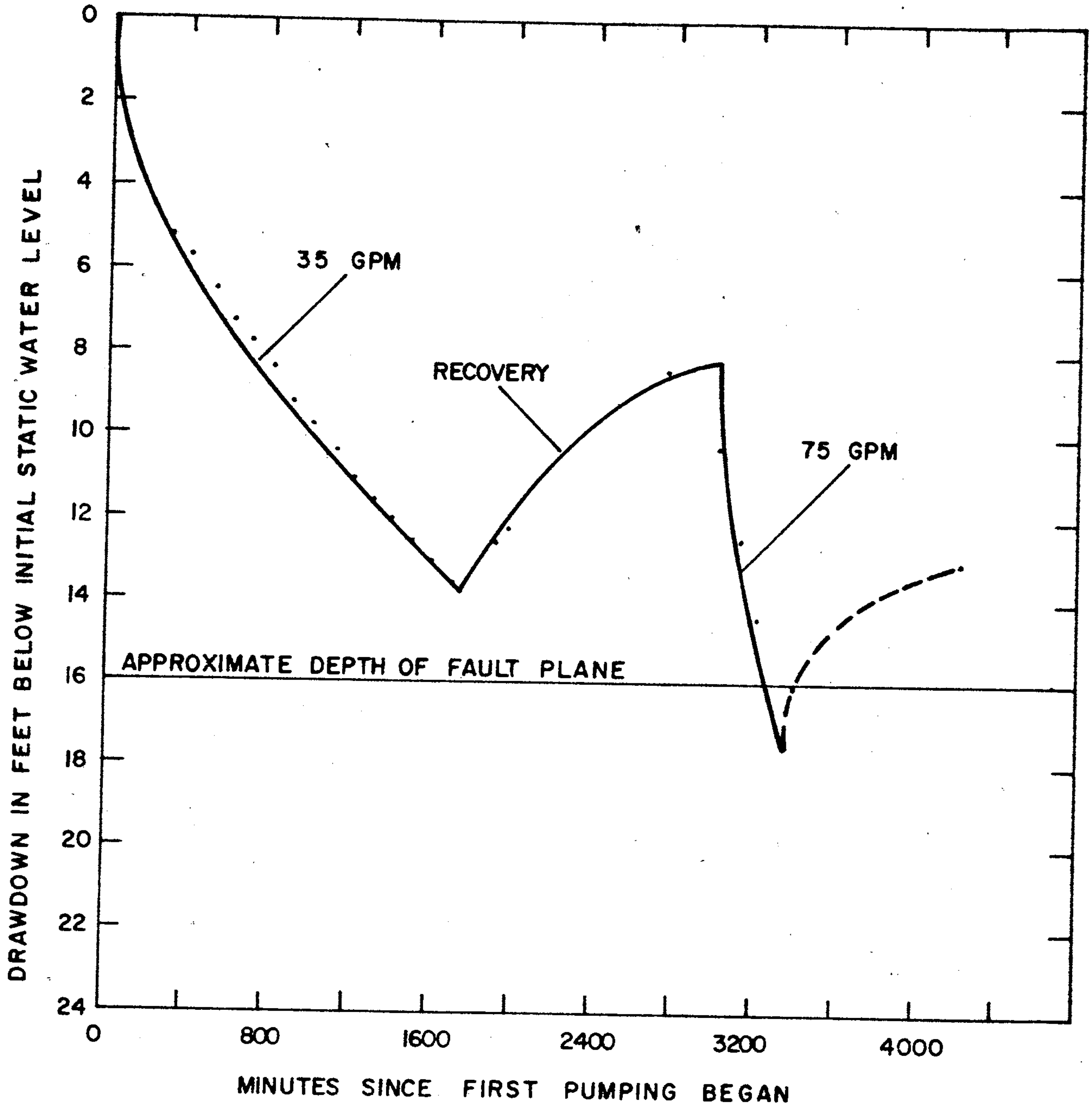


FIGURE 2.--HYDROGRAPH OF WATER LEVELS IN AM-1007 IN TERTIARY VOLCANICS DURING AQUIFER TEST FEBRUARY 7 TO 9, 1979.

the conductivity ranged from 625 to 670 micromhos per square centimeter. The water produced during both tests had a sulphur odor. Results of the chemical analyses (see Table 1) show that the ground water occurring along the fault in the vicinity of Am-1007 is a sodium bicarbonate water. The sodium content is about half that for the water from DC-5 and the bicarbonate content is a little greater. The fluoride content for the three samples ranged from 1.53 mg/l to 1.77 mg/l.

AM-1007 will serve as an excellent water-level and quality-of-water monitor well.

EFFECT OF PIT EXCAVATION

Mine Drainage

Initial pit excavation will be in the northern portion of the proposed mine area where the lacustrine sediments are exposed at land surface and are dry. As mining progresses southward within the hydrogeologic unit previously described, the water table will be intersected in the lacustrine sediments and in the Sandstone and conglomerate. These units will begin to drain water into the pit excavation. With additional southward extension of the excavation and increasing depth the Barren sand will also be intersected and start contributing water to the pit excavation.

Owing to the fault pattern little water will be diverted into the pit excavation from the northeast or southwest. As a matter of fact, drilling on the northeast side of Fault 1878 has demonstrated that ground water does not exist in this area. This fault essentially bounds the pit on the northeast side in the vicinity of Coordinate 1,205,000 N. The strong influence that faulting has in controlling the movement of ground water indicates that in the area southwest of the pit excavation ground water will continue moving northwest along the fault trends and will be affected little, if any, by the pit. Thus, ground water that will be intercepted and drained into the pit area consists essentially of ground water that is presently moving through, and in storage, within the actual proposed pit area and to the southeast.

Sandstone and Conglomerate

Calculations related to inflow from the Sandstone and conglomerate were made based on the "line sink" method using a transmissibility of 200 gpd/ft and a drainage coefficient of 0.05. The calculations assume a simplified mining plan that advances uniformly from north to south across the full length of the pit reaching Coordinate 1,205,000 N after 36 months of mining and that the base of the saturated Sandstone and conglomerate is exposed simultaneously across the full length of the pit. Drainage time was estimated as 18 months. Thickness of saturated Sandstone and conglomerate along Coordinate 1,205,000 N ranges from 100 feet along the east side of the pit to a maximum of 180 feet in the western portion. Based on these thicknesses the calculations indicate that drainage inflow rates would range from 0.022 gpm/ft in the eastern portion to 0.027 gpm/ft in the central portion, to a maximum of 0.040 gpm/ft in the western portion of the pit excavation where maximum thickness of saturated Sandstone and conglomerate exists. Total drainage discharge across the entire pit under these conditions would amount to about 120 gpm. If the Sandstone and conglomerate had a uniform saturated thickness of 180 feet across the entire pit length the total drainage rate would amount to 170 gpm. As the assumption is made that the entire section of Sandstone and conglomerate is breached simultaneously and the saturated thickness approaches the maximum for the pit area the 170 gpm is considered to represent a maximum average rate of inflow to the pit from the Sandstone and conglomerate. With time as the pit progresses southward and the drainage cone expands southward the drainage rate will decrease.

Lacustrine Sediments

Calculations related to anticipated rate of drainage from the lacustrine sediments were based on the same assumptions as used for the Sandstone and conglomerate with the exception that the transmissibility value used was 10 gpd/ft and the coefficient of drainage was estimated to be 0.20. Saturated thickness of the lacustrine sediments at Coordinate 1,205,000 N ranges from 110 feet along the east side to 200 feet along the west side. Calculated drainage rates under these conditions range from 0.011 gpm/ft in the eastern portion, to 0.018 gpm/ft in the central portion, to a maximum of 0.021 gpm/ft in the western portion. Total average drainage across the pit length under these conditions would amount to about 75 gpm. With a uniform saturated thickness of 200 feet across the entire pit width the lacustrine sediments would drain at an average rate in the range of 90 gpm.

Barren Sand

In general initial inflow from the Barren sand will begin about the time the bottom of the pit approaches Coordinate 1,205,000 N. Most of the drill holes north of this coordinate encountered little, if any, Barren sand, particularly in the western portion of the pit area. Wells AM-525 and AM-556 located about 525 to 550 feet north of this coordinate in the eastern portion of the pit area encountered 40 and 35 feet of Barren sand respectively. Results of the test on AM-556 indicate that the Barren sand in this vicinity yields little water. Thus, from a practical standpoint and for the purpose of the calculations it is assumed that on an average basis Barren sand inflow will begin when the bottom of the pit excavation reaches Coordinate 1,205,000 N.

As with the Sandstone and conglomerate and the lacustrine sediments the assumption is made that the Barren sand is exposed simultaneously along the entire pit length. Calculations of drainage into the pit, however, are based on the new hydraulic gradients that would be established with exposure of the Barren sand. For the eastern portion (low transmissibility zone) of the pit the new hydraulic gradient was determined by using the present piezometric level in Well AM-931 and an average elevation of 1,500 feet for the Barren sand top along Coordinate 1,205,000 N. For the western portion (high transmissibility zone) the new hydraulic gradient was based on the present piezometric level in DC-5 and the elevation of the top of the Barren sand at Well AM-659. Results of these calculations indicate that in the eastern 2,700 feet of the open-pit drainage from the Barren sand would amount to 0.001 gpm/ft and in the western 1,550 feet of the pit 0.035 gpm/ft. Total inflow from the Barren sand would be in the range of 60 gpm.

In summary, based on the assumption that the Sandstone and conglomerate and the lacustrine sediments were excavated simultaneously to the top of the Barren sand along Coordinate 1,205,000 N calculated maximum drainage rates would be as follows:

Unit	Drainage (gpm)
Sandstone and conglomerate	170
Lacustrine sediments	90
Barren sand	60
Total	320

In actuality the units cannot be exposed simultaneously across the entire pit width. Shorter segments of each unit will be exposed in shorter time periods. Under these conditions greater inflows per unit of length exposed can be expected but the total flow from a given unit would be less than shown above.

Dewatering Wells

The possibility of partially draining the Sandstone and conglomerate and depressurizing the Barren sand by use of drainage wells was examined. Of the two water-bearing units, the effects of natural drainage into the pit may be more troublesome with water from the Barren sand than from the Sandstone and conglomerate. Comparing the two units, the Barren sand is less consolidated and the water it contains along the southern edge of the pit is under artesian pressure. Offsetting this is the fact that when the Barren sand is first encountered at its northern extremity it will be under substantially less pressure and possibly under water table conditions. Once drainage begins from this unit at a rate in excess of its natural discharge, pressures to the south will begin to decrease. Owing to the consolidated character of the Sandstone and conglomerate, water seeping into the pit along the southern perimeter is considered not likely to cause severe problems even along faults.

Sandstone and Conglomerate

If it were desired to pump some of the water from the Sandstone and conglomerate by using dewatering wells rather than let it all drain into the pit by gravity, it would be possible to produce water from the Sandstone and conglomerate by using Well AM-28 for a few years during the initial stages of mining. After it becomes necessary to destroy Well AM-28, a replacement could be constructed at or near the intersection of Coordinates E 90,000 and N 1,204,000. At the beginning of pumping the yield from AM-28 could be as much as 100 gpm. This pumping rate can probably be maintained until mining intersects the water table in the Sandstone and conglomerate northwest of AM-28.

Barren Sand

The effects of operating four hypothetical dewatering wells, tapping the Barren sand, located at intervals of 800 feet on a line close to and parallel with the southern crest of the pit were calculated. The westernmost well would be in the vicinity of Coordinate E 85,700 and the easternmost, E 88,000. These would need to be within the Urangesellschaft claim area.

Calculations were made to evaluate the effects of pumping 50 gpm from each well for 1,100 days (about 3 years). The calculations indicate that at the wells the combined drawdown effects would bring the pumping water level to the top of the Barren sand within about 60 days and that the assumed production rate of 50 gpm per well could not be sustained. Well discharges will gradually decline after the pumping water levels decline below the top of the Barren sand at the wells. However, holding the pumping water level at the line of wells at the top of the Barren sand will cause extremely steep gradients to develop from Wells AM-659 and AM-933 to the line of wells. For example, after pumping for 60 days from the four dewatering wells at a combined discharge of 200 gpm, the computed gradients from AM-659 to the dewatering wells would be of the order of 1,700 feet per mile to the nearest well and 570 feet per mile to the farthest well. From AM-933 the gradients would be of the order of 1,425 feet per mile to the nearest dewatering well and 765 feet per mile to the farthest well. Water level declines caused by pumping the four hypothetical wells for 60 days would be about 171 feet at AM-659 and about 58 feet at AM-933.

Continued pumping at the hypothetical dewatering wells at reduced rates would continue to remove artesian pressure head at Wells 659 and AM-933. However, given the reduced rates of pumpage after about 60 days of operation, the reduction in head will be relatively small and the expense of operation of the drainage wells may not be warranted. Also, the time frame required to remove all artesian head from these points will not be realistic in terms of the planned mining operation.

Consideration was given to constructing and operating two short-lived dewatering wells for reducing the artesian head on the Barren sand near AM-659 and AM-933 more rapidly than can be done with a line of four wells beyond the rim of the pit. The data from the tests of AM-933 indicate that the yield of a well in this area would be so low that the cone of depression would have little areal extent. Definitive data on the productivity of the Barren sand at the AM-659 site could not be obtained.

Possibility of Inflow to Pit from Santa Maria River

The deepest part of the pit, at an elevation of 1,300 feet, is not far from the fault zone along which Well AM-1007 is situated. The possibility of movement of water from the Santa Maria River along this fault zone to the deepest part of the pit was examined. The elevation of the top of the alluvium along the bed of the Santa Maria River opposite this fault trend is about 1,460 feet. The distance from the river to the deep part of the pit is about 7,800 feet. Thus, the gradient from the river to the point ultimately could be 108 feet per mile.

At AM-1007 the elevation of the water surface in the well is 1,534 feet. The distance to the river is about 2,300 feet, giving an average gradient toward the river along the fault of 170 feet per mile. This gradient is an average of open zones along the fault with gradients substantially lower than the average and tight zones along the fault with gradients substantially higher than the average, possibly in the range of two to three times the average. Under these conditions it is considered doubtful that a reverse gradient of 108 feet per mile could induce any measurable inflow to the pit area along the fault extending from AM-1007 to the river.

faults

HYDROGEOLOGIC CONDITIONS AFTER COMPLETION OF MINING

Recovery of Water Levels

After mining ceases, many years will pass before water levels recover to the presently prevailing level. In a homogeneous aquifer of infinite areal extent, the length of time required for water levels to recover from a pumping regime is theoretically the same as the time occupied by pumping. This situation does not prevail at Anderson Mine. The mining operation will effectively drain much of the ground water now stored in the Sandstone and conglomerate within the hydrogeologic unit. Owing to the low rate of recharge, many years must elapse before ground water will accumulate in the unit to the extent that existed before mining began. The Barren sand can be expected to recover sooner from mine drainage because it is not likely to be drained entirely as a result of mining operation; the northwestward gradient will be steepened along the southern edge of the pit but some water will remain in the unit farther southeast. The rate of recovery of pre-mining piezometric head will depend on the length of the mine life, and is not expected to occur for several years after mining ceases, but will eventually occur.

What does this due to surface wells in Chane

Possible Changes in Recharge System

The situation at the end of mining is shown on Plate 10 of the January 17, 1979, Dames and Moore report, "Design Report, Proposed Mill Waste Management Facilities". A large part of the pit will be backfilled against the southwest, south, and southeast sides. The rest of the pit will be partially backfilled, enough that natural runoff can enter the pit at natural grade at the upstream end and leave at natural grade at the northwestern, downstream end. The material used for this backfill will be excavated overburden. This material will consist mainly of blocks and fragments of the Capping conglomerate and the Sandstone and conglomerate, with lesser amounts of lacustrine sediments and some fragments of basalt. This material will, in general, be considerably more permeable than when in place originally because of fragmentation from excavation, transport to storage, and reuse for backfill. Accordingly, the percolation from stream runoff and from direct rainfall on the material can be expected to be substantially greater than in the same material in the original state. The increase in recharge owing to these changes in this relatively small area cannot be predicted. However, the increased recharge resulting from this fragmentation will offset to a certain extent the anticipated slow recovery to pre-mining levels of the ground water within the affected hydrogeologic unit.

Consideration was given to the possibility that the ground water accumulated in this reworked material after full ground-water recovery could become highly mineralized by dissolving calcium carbonate or other slightly soluble constituents from the reworked mass of rock fragments. A slight increase in hardness can be anticipated. However, the natural water in the Sandstone and conglomerate (total dissolved solids of about 200 mg/l) and in the Barren sand (total dissolved solids of about 650 mg/l) is relatively low in calcium and magnesium and could absorb substantial amounts before it becomes as hard as the ground water in the Santa Cruz Valley now produced for municipal use by the city of Tucson, for example. There is no likelihood of substantial increases in sodium or chloride because those substances are not present in the conglomerates and only slightly in the limited amount of lacustrine sediments that might be included during backfilling.

Natural Discharge

Natural discharge will resume northwestward from the mine area after ground-water levels have returned to pre-mining levels. As stated in preceding parts of this report, many years will elapse before this situation occurs. The level at which natural discharge resumes cannot rise higher after mining ceases than before mining began because the through flow will recover to the same rate as before. The mining operation cannot permanently affect the natural balance between ground-water recharge, throughflow, and ground-water discharge within the mining permit area.

Environmental Monitoring for Ground-Water Quality

North of the mine area volcanics crop out and ground-water discharge from the mine area moves northwestward through the volcanics along fault zones. Therefore, monitor wells for ground-water quality must be located along faults that cut the Tertiary volcanics. Encountering water by drilling along faults is difficult and it may be necessary to drill several holes at a site before a usable monitor well can be established. For example, test drilling in December 1978 and January 1979 in the vicinity of Coordinates E 85, 060 and N 1, 208, 330 resulted in six dry holes and six that encountered water and were cased. This drilling was along faults that cut the volcanics. The test production water well completed here (AM-1007, see Pl. 1) will be maintained as a water quality monitoring well.

There are three other sites along fault trends within or close to the mine area that are recommended for a monitor well, as follows:

Coordinate E	Coordinate N
87,680	1,207,350
88,630	1,207,930
89,620	1,207,790

Two other areas that are along faults southwestward and northeastward from any effects of mining are as follows:

Coordinate E	Coordinate N	Remarks
85,920 1/	1,205,930	Consider constructing a monitor well for base-line data.
92,480	1,208,210	

1/ This site is within the pit near the southwest corner.

Potential for Water Recapture if Necessary

In the unlikely event that the quality of water naturally discharging from the mine area becomes changed in some manner as a result of mine activities, recapture would be feasible through pumping from monitor wells. All of the ground water leaving the area is directed through one or more fault systems and none can escape directly through the unfractured rocks of the Tertiary volcanics. Each monitor well will be pumped as a part of the development of the well after drilling has been completed, as an assurance that the well actually can be used to monitor natural discharge of ground water. Thus, the monitor wells all will be capable of being pumped to recapture water if such becomes necessary. Union Minerals has proven its ability to find and construct monitor wells within the volcanics as monitor well AM-1007 attests.

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