HYDROLOGY AND WATER RESOURCES IN ARIZONA AND THE SOUTHWEST, VOLUME 8, p. 137-145.
Proceedings of the 1978 meetings of the Arizona Section of the American Water Resources Association and the Hydrology Section of the Arizona Academy of Science, held in Flagstaff, Arizona, April 14-15.

THE EFFECTS ON WATER QUALITY BY MINING ACTIVITY IN THE MIAMI, ARIZONA REGION

by

Don W. Young and Robin B. Clark

ABSTRACT

Intensive strip and leach mining activity within a confined region usually causes environmental impacts both on the land and on water quality. Adverse water quality effects could be realized long after any mining activity has ceased due to the continuous leaching by precipitation of contaminants from spoils piles and leach dumps. The Miami, Arizona region is unique in its surface and subsurface hydrology. Two unconnected aquifers underlay the region with both serving as domestic (private and municipal) and industrial (mining) supply sources. The shallow floodplain alluvial aquifer is hydraulically connected to surface drainage from mine tailings and leach dumps. Several wells drawing from this aquifer have been abandoned as a municipal supply source due to severe water quality degradation. Water quality in these wells varies directly with precipitation indicating a correlation between surface drainage over and through tailings and leach piles. Expansion of spoils dumps into natural recharge pathways of the deeper Gila Conglomerate aquifer has raised concern that this aquifer may also be subjected to a long term influx of mine pollutants. Questions have also been raised concerning the potential effects of a proposed in situ leaching operation on the water quality of the conglomerate aquifer.

PHYSIOGRAPHIC SETTING

The Miami-Claypool area lies in the southern portion (Township 1N, Range 15E) of Gila County, Arizona, approximately 96 miles due east of Phoenix, Arizona (see Figure 1). The region is historically made up of copper mining communities such as the Town of Miami (population 3,394), which date back to the late 1800's.

The project area lies in the basin and range province, in the physiographic unit of Arizona described by geographers as the mountain region. The Miami-Claypool area is located at approximately 3,400 feet above mean sea level in a northeast-trending trough of the Pinal Mountain range. The highest point in the range, Pinal Peak (7,848 ft.), lies 10 miles to the south, and the towns are enclosed by stream-dissected mountainous topography on all sides. The topographic configuration of the northerly side of the Miami-Claypool valley has been modified by extensive mining operations and their consequent tailings dumps and leach piles on the slopes. Slope modification as a result of tailings accumulation is shown in Figure 2.

Surface water drainage on the surrounding watersheds is typified by a high density of well-incised first, second, and third order channels which carry runoff into Bloody Tanks Wash. Slopes of the tailings which form much of the northerly runoff-bearing surface of the Bloody Tanks Wash watershed are deeply incised and virtually devoid of vegetation.

The region is underlain by two aquifers (Shallow Floodplain Alluvial and Gila Conglomerate) which historically, and at present, serve as the principal sources of municipal, industrial and private domestic water. No other viable aquifers are known within the substrata of the region.

DESCRIPTION OF IN SITU LEACHING PROJECT

In situ leaching is conceptually a simple process. By way of example, an ore body lying beneath the surface is penetrated by two or more cased and cemented wells. Leach solution (in this case 2-4 percent sulfuric acid) is pumped down an injection well where

The authors are respectively, Hydrologist III and Natural Resource Manager II, Arizona State Land Department, Water Rights Division, Phoenix, Arizona.

it is forced under high pressure through the ore body dissolving out the mineral desired. The leachate containing the dissolved mineral is then pumped out of the other recovery well(s) to the surface where the mineral is extracted employing one of several electrochemical techniques. The leachate is then returned to the injection well to begin the cycle again (see Figures 3 and 4). Sometimes explosive and/or hydrofracturing techniques are employed to "rubbleize" the ore body prior to leach solution injection, to open up fractures through which the solution can more easily flow.

GEOLOGIC STRUCTURE AND GENERAL GEOLOGY

The geologic structure of the project area reflects a system of northwest-trending mountain ranges and faults. There are also numerous faults showing a northeasterly trend. Surface water drainage patterns exhibit a strong fault alignment.

The Miami Fault (Figure 2) divides two major structural blocks: the Globe Valley block to the east, and the Inspiration block to the west of the northeast-trending fault line. Both blocks are dissected by intersecting faults and contacts, many of which are expressed on the surface, and can be delineated on satellite and high altitude aircraft imagery.

The two major rock units in the project area are the Pinal Schist (p€pi) and the Gila Conglomerate (Qtg). The Pinal Schist, which forms the basement of the area, is of Lower Precambrian age, related in time sequence to the Vishnu Schist formation of the Grand Canyon. Outcrops of Pinal Schist and Schultze Granite make up the dominant rock type exposed in the Pinal Mountains to Sleeping Beauty Peak area. The Gila Conglomerate is an extensive valley fill material of late Pliocene to Pleistocene age, made up of poorly sorted alluvium of Pinal Schist origin. The upper Gila Conglomerate contains materials from other local granitics uncovered by erosion. Exploration drilling in the Bloody Tanks Wash area has shown the Gila Conglomerate to exceed 4,000 feet in thickness (Peterson, 1962).

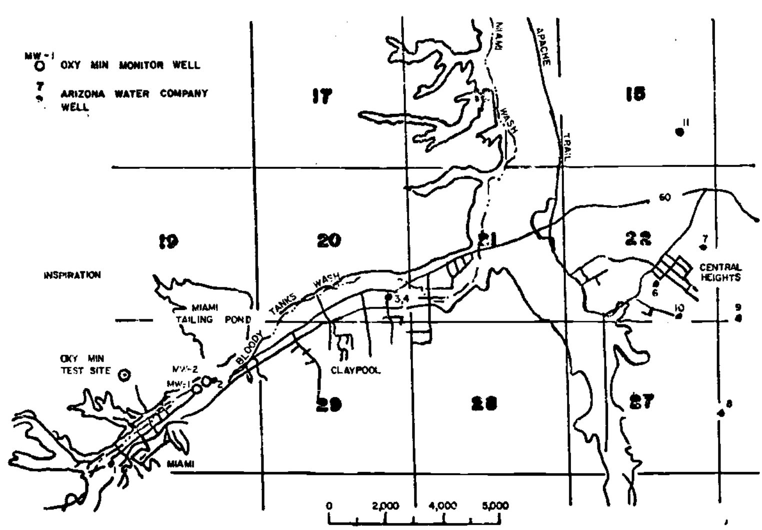


Figure 1: MAP OF MIAMI-CLAYPOOL AREA, ARIZONA

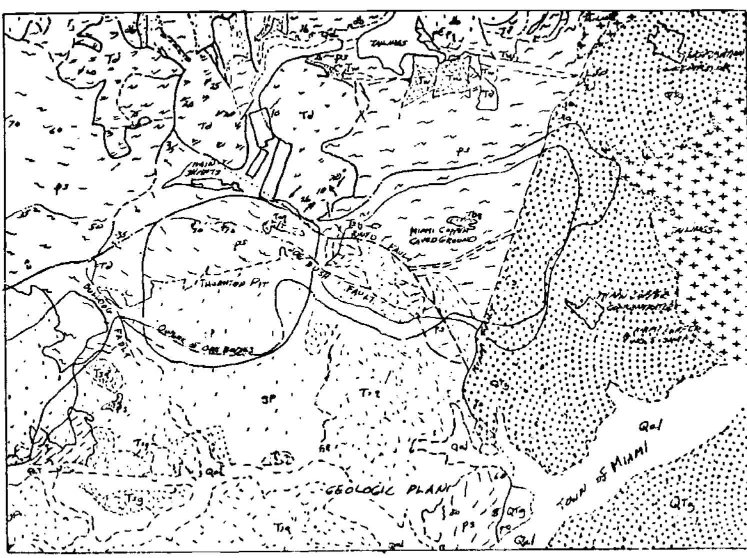
The Gila Conglomerate rests on basement which is cut by considerable faulting and fracturing, and was degraded by vigorous erosion prior to deposition of the conglomerate. Faulting continued during the deposition of conglomerate, with evidence of displacement and deformation in most exposures.

Alluvium in the area is made up largely of detritus from the Gila Conglomerate, with contributions from local granitic porphyry and mineralized schist. Recent erosional activity is cutting through these alluvial deposits to the deeper Gila Conglomerate. This sequence is well exposed along Bloody Tanks Wash, which drains the project area into Pinal Creek (Peterson, 1962).

The primary materials of the Conglomerate are diorite, schist, and quartzite fragments averaging less than one foot in diameter, but with some occurrence of boulders of 10-20 feet.

The Gila Conglomerate is cut by many small faults, striking in varied directions, which are a result of compaction of the formation. Faulting in the Gila Conglomerate is significant in its effects of impeding and directing flow of groundwater.

Groundwater occurring in the Gila Conglomerate aquifer is a product of precipitation runoff, mainly in spring and early summer, from the surrounding mountain watershed. The igneous-metamorphic rock complex of the Pinal Mountains is nearly impermeable, allowing movement of groundwater only in fractured areas. The conglomerate fill is reported in USGS research to be sufficiently "tight" in some locations as to deliver almost no flow to wells penetrating the formation (Hazen and Turner, 1946).



EXPLANATION

Alluvium, Qal; talus, Qt; basalt, QTb; Gila conglomerate, QTg; dacite, Td; Whitetail conglomerate, Tw; diabase, db; Naco limestone, Pn; Escabrosa limestone, Me; Martin limestone, Dm; Troy Quartzite, Єt; basalt, pЄb; Mescal limestone, pЄm; Dripping Spring quartzite, Barner conglomerate at the base, pЄds; Pioneer formation, Scanlan conglomerate at the base, pЄps; Ruin granite, pЄrg; and Pinal schist, pЄpi

FIGURE 2: GENERAL GEOLOGIC PLAN OF THE MIAMI-CLAYPOOL AREA SHOWING MAJOR FAULTING AND ENCROACHMENT OF TAILINGS ONTO THE EXPOSED GILA CONGLOMERATE (from Reed, 1975).

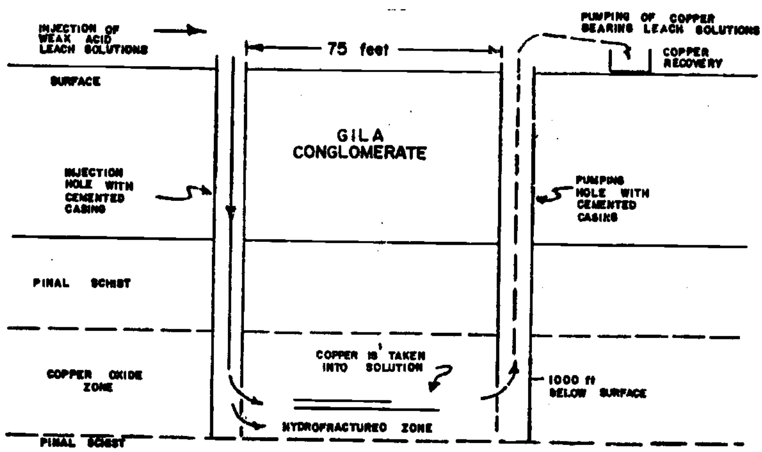


Figure 3; SCHEMATIC REPRESENTATION OF IN SITU MINING

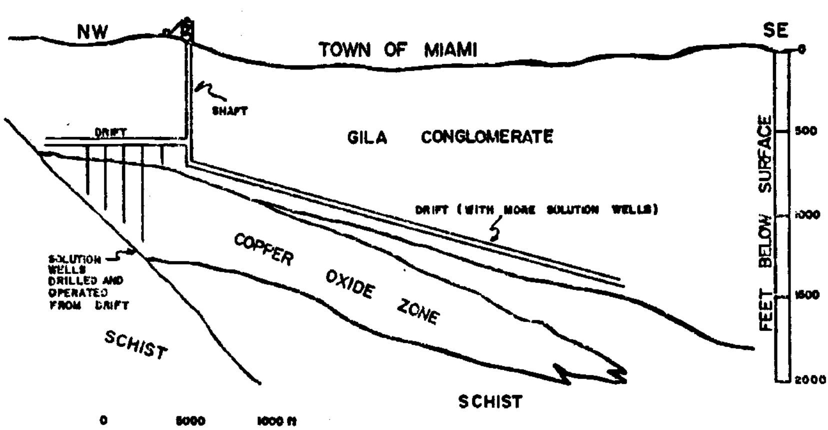


Figure 4: VERTICAL CROSS-SECTION THROUGH VAN DYKE COPPER ORE DEPOSIT. FULL SCALE PRODUCTION BY OCCIDENTAL MINERALS CORPORATION, DENVER, COLORADO CONSISTS OF SINKING A VERTICAL SHAFT OUTSIDE THE TOWN LIMITS AND DRIFTING HORIZONTALLY BELOW THE TOWN AND IMMEDIATELY ABOVE THE ORE BODY. THE ACID INJECTION AND RECOVERY WELLS WILL BE DRILLED AND OPERATED FROM THE UNDERGROUND DRIFTS

It is unlikely that there is direct hydrologic connection between the fault zones in the Pinal Schist and Schultze Granite formations and the Gila Conglomerate aquifers. Further, the major fault zones, with their associated clay formations, may form a nearly impervious barrier to underflow of water.

HYDROGEOLOGY OF THE MIAMI-CLAYPOOL AREA

Based on an aquifer pump test performed on Arizona Water Company Well No. 6, a drawdown curve was plotted which yielded an estimated K (hydraulic conductivity) for the Gila Conglomerate aquifer of 0.75 gallons per day per square foot (gpd/sq. ft.). This value is in agreement with the report written by Harshbarger (1976) who estimated a K value of 1.0 gpd/sq. ft., or less, and indicates that on the average the conglomerate aquifer is consolidated and tight.

This estimate of low hydraulic conductivity is further supported by the theory that minor fractures within the Gila Conglomerate and the Pinal Schist are effectively forced closed at the depths we are considering (1900-2000 feet) by the sheer weight of rock above. According to the equation for fluid velocity between parallel plates

$$V = \frac{\Delta p}{\Delta L} \frac{b^2}{3\mu} \quad \text{(Rouse, 1950)},$$

where $\Delta p/\Delta L$ is the pressure gradient, 2b is the width of fracture and μ is fluid viscosity, it follows that as b becomes smaller the flow velocity through the fracture is reduced by the square of the size reduction (holding all other variables constant). Since hydraulic conductivity K=V/I, and quantity Q = KIA, where I is the gradient and A the area, it stands that if K decreases with depth, the possible quantity Q of leachate that could be forced any substantial distance through minor fault lines is greatly limited.

Pressures due to hydostatic loading could be 150-200 pounds per cubic foot per foot of depth, thereby effectively reducing b by several orders of magnitude due to distortion of the rock itself. Proper placement of collection/monitor wells in the operations phase of in situ leaching will effectively prevent escape of leachate from the hydrofractured ore body, since the K of this zone would be greater than that of the surrounding base rock.

However, well logs indicate that the conglomerate is not homogeneous (nor isotrophic) throughout its entire depth and that several semi-perched water lenses occur at varying depths throughout. These lenses are probably connected by natural recharge pathways to the surface water system of the surrounding watershed, and since the conglomerate does outcrop in the vicinity of existing and proposed mining activity it is of the utmost importance that this aquifer be adequately monitored.

WATER QUALITY ANALYSES OF THE MIAMI-CLAYPOOL AREA

Considerable amounts of water quality data for the Miami/Globe region were obtained from various sources (USGS, State Health Department, Arizona Water Company, Arizona Water Commission, Occidental Corporation, and Arizona State Land Department). These data were evaluated from two perspectives: 1) the spatial distribution of ground water quality within the region, and 2) the temporal migration of groundwater pollution within the region.

Two water quality monitoring wells (MW-1 and MW-2) were established by Oxymin in the shallow alluvial aquifer underlying Bloody Tanks Wash. These wells, both 101 feet deep and 40 and 55 feet depth to water, respectively, are located 2500 feet down gradient from the in situ leaching site, and slightly up gradient from Arizona Water Company well number 2 (see Figure 1). Monitor wells MW-1 and MW-2 have been sampled on a weekly basis from May 14, 1976 up to and continuing through the present time. These samples were analyzed by BC Laboratories of Bakersfield, California, an independent testing facility. These data are considered representative of the present water quality within the shallow alluvial aquifer when compared to chemical analyses from Arizona Water Company wells numbers 1, 2, 3 and 4. According to State Land Department records, these wells draw from the shallow alluvial aquifer underlying the region.

On May 11, 1976, the Arizona Department of Health Services conducted an investigation of point pollution sources along a reach of Bloody Tanks Wash from above the Oxhide Mine to the highway bridge below the Bluebird Mine. These data appear to be the only surface water quality information available for Bloody Tanks Wash; however, it was sufficient for comparison of surface and groundwater conditions.

A trilinear plot of cations and anions of the aforementioned well and surface water analyses provides evidence that the waters of the shallow alluvial aquifer throughout the area are common with surface water flowing in Bloody Tanks Wash.

Arizona Water Company wells numbers 8, 10, 11, and 12 plot considerably differently on trilinear paper and show agreement with Harbarger (1976) that the water in the Gila Conglomerate, from which these wells draw, is a sodium-bicarbonate type, as opposed to a calcium-sulfate type found in the shallow alluvial aquifer.

Plots of selected ions ($SO_4^=$, $NO_3^=$, Cl^-, K^+, Na^+, Cu^{++}, and pH) from MW-1 and MW-2 over the period of time from 5/19/76 to 8/26/77 show severe fluctuations in concentrations and correspondence between the highs and lows of the various chemical species. An attempt was made to correlate quality parameters of the shallow alluvial aquifer with discharge in Bloody Tanks Wash.

No stream discharge data is available for Bloody Tanks Wash, so local monthly precipitation records were obtained from Miami Copper Company, an official Weather Service gaging station. A plot of these data, when compared with the ion concentration data above, indicates that the high chemical concentration peaks correspond to periods of high rainfall (and therefore, assumed high stream flow) with an approximate forty (40) day lag, which is a realistic delay considering the composition of the alluvium and well depths. This would substantiate that surface runoff from the considerable amount of leaching dumps and mine tailings in the area (Figure 2) is infiltrating directly into the shallow alluvial aquifer, and is appearing approximately 40 days later in the wells.

Although historic groundwater quality data is fragmented, examination of Arizona Water Company wells and other analyses covering the period from August 1949 to present (Tables 1 and 2) indicates a trend toward poorer water quality possibly due in part to the substantial increase in surface mine tailings and leach piles over which surface water must flow prior to reaching the streambed and/or to direct point source pollution from tailing ponds and other sources. The chemical content of the waters of Bloody Tanks Wash and the shallow alluvial aquifer is indicative of what one would expect to be associated with mine wastes.

DATE	8-9 1949 2/	7-31 1956 2/	3-20 1961 1/	8-9 1962 1/	5-21 1964 2/	10-23 1964 1/	2-4 1966 2/	4-2 1969 2/	2-9 1976 1/3/
Ca	75	156	238	85	236	160	169	472	
Mg	23	68	42	14	0	34	7	59	
Na			40	25	30	65	159	33	
Cl			35	16	26	55	24	12	21
HCO_3	88	83			98		68	34	
CO_3	0	0			0		0	0	
SO_4	210	540	660	230	450	355	680	1490	148
F	.5	.6	1.12	0.6	0.6	0.5	0.5	0.7	1.1
NO_3			28	11		60		1	3.0
SiO_3	17.3	27.0			23		10		
Fe		0.5	.245	.15	0	.05	0	0	1.1
Mn			.06	.05					.75
Cu	5.0			1.8		.05			1.98
Cr						.01			.01
As						.01			
TDS	450.0	918	1113	478	863	930	1118	2101	
P-Alk	0.0	0.0	0	0	0	8	0	0	
M-Alk	72.0	68.0	48	44	80	140	56	28	
C-Hard	187.0	390.0			590		422	1181	
Mg-Hard	95.0	280.0			0		28	243	
Total Hard	282.0	670.0	670	270	590	500	450	1424	210
pH	6.45	6.3			6.3		6.5	5.8	7.1
Lab No.	73563	127846			109403		110342	114153	1784

TABLE 1. -- SUMMARY OF CHEMICAL ANALYSES FOR ARIZONA WATER COMPANY WELL NO. 1 (All constituents in milligrams per liter)

1/ Arizona State Health Laboratory

2/ Arizona Testing Laboratories

3/ Rainwater Entering Well

DATE	7-31 1956 2/	8-16 1961 1/	8-21 1962 1/	6-21 1963 2/	10-23 1964 1/
Ca	142	122	67	82	114
Mg	25	21	11	9	20
Na		40	21	34	57
Cl	32	33	12	22	31
HCO_3	98			68	
CO_3	0			0	
SO_4	430	335	183	220	280
F	0.2	.48	0.4	0.2	0.4
NO_3		31	8		37
SiO_3	34			26	
Fe	.05	.05	0.1	0	0.8
Mn		.05	.05		
Cu					0.05
Cr					.01
As					.01
TDS	814	709	417	461	675
P-Alk	0.0	0	0	0	2
M-Alk	80	92	38	56	118
Ca-Hard	354			204	
Mg-Hard	104			36	
Total Hard	458	395	215	240	370
pH	7.6			6.6	
Lab No.	127848		572	108541	

TABLE 2.--SUMMARY OF CHEMICAL ANALYSES FOR ARIZONA WATER COMPANY WELL NO. 2
(All constituents in milligrams per liter)

1/ Arizona State Health Laboratory
2/ Arizona Testing Laboratories

Waters drawn from the alluvial aquifer by Arizona Water Company well numbers 3 and 4 greatly exceed U.S. Public Health (USPH) drinking water standards and are usable for domestic purposes only when mixed with waters drawn from the Gila Conglomerate aquifer, or with waters imported from elsewhere. Wells number 1 and 2 have been abandoned for municipal supply purposes due to high pollutant levels.

Analysis of chemical and well log data for Arizona Water Company well numbers 6, 7, 8, 9, 10, 11 and 12 indicates these wells all draw from the Gila Conglomerate aquifer and produce between 40-110 gpm. Although water quality varies somewhat from well to well, it is generally much better water than that found in the shallow alluvial aquifer. There is insufficient data at this time to effect thorough spatial and temporal distribution analyses of water quality; however, it is suspected that the Gila Conglomerate aquifer is also being affected to some extent by surface mine waste discharges entering natural recharge zones. This is reinforced by the fact that mine tailings dumps are situated directly over portions of the outcropped conglomerate as shown in Figure 2.

Some leakage between the shallow floodplain aquifer and the conglomerate aquifer may also be occurring at various points of their contact, and/or a combination of water from these two aquifers may be entering wells having perforations spanning both strata or where cascading is occurring down well casings. Further data collection and analysis would be required to substantiate this. Also, recharge of water along Russel Gulch from the Solitude tailings pond to the conglomerate may be occurring.

Potentially the Gila Conglomerate aquifer has, and will continue to have, increasingly greater importance with respect to the continued viability of the region from the standpoint of municipal supply than does the shallow alluvial aquifer. The Gila Conglomerate aquifer remains the primary source of municipal water supply for the region and its protection must be assured at all cost to maintain the continued viability of the region.

However, there would obviously be a long term residual water quality impact due to the continued leaching of pollutants from mine spoils by surface water even if all mining activity in the area was discontinued. This impact would diminish over time (probably exponentially) to some indeterminate level, whereupon a leveling off of pollutant input would be experienced.

Conversely, increased mining activity, or an expansion of mines in the region, could effect a spatial and temporal increase in pollutant influx levels. Spatial expansion of pollutants would be bounded only by the expansion limitations of the mines themselves. Temporal migration of pollutants from spoils and leach dumps to the groundwater would be limited by a variety of variables, such as meteorological conditions, hydraulic and chemical character of the dumps, and stabilization practices of the spoils piles, to name a few.

CONCLUSIONS AND RECOMMENDATIONS

1) The waters of the shallow floodplain aquifer are chronically chemically polluted and exceed USPH drinking water standards. If the trend continues, the aquifer will eventually be totally abandoned as a domestic water source unless an investigation indicates large point source pollution influxes which can be controlled, thereby upgrading the water quality in Bloody Tanks Wash and the shallow alluvial aquifer.

2) As indicated, the Gila Conglomerate and Pinal Schist strata are highly faulted throughout the region. It is conceivably possible that acid leachate could escape from the ore body and bypass the collection and monitor wells through major fractures in the Pinal Schist and Gila Conglomerate. Any leakage which did or could occur during the early phases of Oxymin's in situ leaching project would be insignificant in amount, and any acid leachate contacting the conglomerate aquifer would be instantly neutralized due to the carbonate nature of the consolidating media. The injection, collection and monitoring wells, and the sealing thereof from overlying strata, as practiced by Occidental appear to be adequate for protection against undetected leakage from the leached ore body.

In situ leaching appears to be a viable alternative to cave block, open pit and surface leaching methods, if properly planned and the necessary safeguards established. It is conceivable that if in-place leach mining had been developed and utilized 60 or 70 years ago, much of the physiographic, ecologic, and hydrologic degradation now apparent in numerous mining regions throughout the state would have been limited.

3) In general, the historic surface and underground mining activity within the Miami region has contributed, and in all probability will continue to contribute, to water quality degradation in both the floodplain and Gila Conglomerate aquifers. Some degradation may also be associated with natural leaching phenomenom from the variety of mineral ore-deposits underlying the region.

4) Small mining communities such as the Town of Miami typically have an interwoven socio-economic interdependence with large corporate mining activity. Historically, such communities were formed and remain viable as a direct result of the mines. If the mines permanently cease operations, then generally the towns either die, or desperately struggle, more often unsuccessfully, to adopt a new economic base.

The town of Miami, Arizona is faced with an ever decreasing potable water supply problem due to quality degradation. Fortunately, the town is experiencing an almost static growth rate thereby predicating a need for increased supply. Alternatives for additional water supply have been investigated, including importation, treatment and additional well fields; however, the rate base of the privately owned water company which supplies the area would not, at present, support the required capital expenditure to effect an alternative. Cooperative effort among the mines, the town of Miami and the Arizona Water Company could provide the required socio-economic impetus to develop a new viable water supply source for the town.

REFERENCE MATERIAL

Chow, Vente, Handbook of Applied Hydrology, McGraw Hill Book Company, New York, N.Y., 1964

Daugherty, Robert L. & Joseph B. Franzini, Fluid Mechanics with Engineering Applications. McGraw Hill Book Company, New York, N. Y. 1977

Davis, Stanley N. & Roger J. M. DeWeist, Hydrogeology, John Wiley and Sons, Inc., New York, N. Y. 1966

Hazen, G. E. and S. F. Turner, Geology and Ground-water Resources of the Upper Pinal Creek Area, Arizona. U. S. Geological Survey, Open File Report, Tucson, 1946

Peterson, Nels P., Geology and Ore Deposits of the Globe-Miami District, Arizona. U. S. Geological Survey, Professional Paper 342, Washington, 1962

"Quality of Arizona Domestic Waters", Report No. 217, University of Arizona, Agricultural Experiment Station, Tucson, Arizona, November 1963

Quarterly Reports, "Groundwater Monitoring" (with associated analyses) from Clyde R. Caviness, Occidental Mineral Corporation to Miami Town Council, 7/19/76, 11/3/76, 3/25/77, 8/11/77

Reed, E. F. and W. W. Simmons, "Geological Notes on the Miami Inspiration Mine", 13th Field Conference Proceedings of New Mexico Geological Society, 1975

Report, "Hydrogeological Conditions and Aquifer Quality of Bloody Tanks Aquifer, Miami, Arizona", Harshbarger and Associates, Tucson, Arizona, March 11, 1976

Report, "Bloody Tanks Wash", Bureau of Water Quality Control, Department of Health Services, Phoenix, Arizona, May 11, 1976 (unpublished)

Report, "Geohydrology of Globe-Cutter Groundwater Basin for the City of Globe", Water Resources Associates, Inc., Scottsdale, Arizona, January 24, 1975

Rouse, Hunter (Editor), Engineering Hydraulics, John Wiley and Sons, Inc., New York, N. Y. 1950

Telephone conversation with Mr. David Rabb, Mining Engineer, Arizona Bureau of Mines, October 4, 1977

Tilley, Spencer R. and Carol L. Hicks, Geology of the Porphyry Copper Deposits - Southwestern North America, The University of Arizona Press, Tucson, Arizona, 1966

U. S. Bureau of Mines, Mineral Facts and Problems - 1970 Edition, Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 1970

U. S. Bureau of Mines, The Mineral Industry of Arizona, 1969

U. S. Department of Interior, Minerals Year Book Vol. II, Area Reports: Domestic, 1973

U. S. G. S., "Geology and Ground-water Resources of the Upper Pinal Creek Area, Arizona", Open File Report, December, 1946