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Vol. 8 Book 19

TOMBSTONE MINING DISTRICT Cochise Co., AZ

AZ Dept. of Environmental Quality - App. for GWQPP

Aug. 3, 1988

APPLICATION FOR A GROUND WATER QUALITY PROTECTION PERMIT

Arizona Department of Environmental Quality
Office of Waste and Water Quality Management, Water Permit Unit
2005 N. Central Avenue
Phoenix, Arizona 85004
(602) 257-2270

A. Facility Name: Grand Central Leaching Facility

B. Name, Title, Address and Telephone Number of Contact Person for Facility:

Name: Gary Lindroos

Title: Facility Manager

Mailing Address: P.O.Box 370, Tombstone, AZ 85638

Telephone Number: 602-457-2282

C. Application signature and certification:

"I certify under penalty of law that I have personally examined and am familiar with the information submitted in this document and all attachments and that, based on my inquiry of these individuals immediately responsible for obtaining the information, I believe that the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibilities of fine and imprisonment."

Gary Lindroos
Type or print name

Facility Manager
Title

Gary Lindroos
Signature

3 August 1988
Date

GEOCHEMICAL ENGINEERING INCORPORATED

JIM V. ROUSE
V.P. GEOHYDROLOGY

BOX 260572
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LAKEWOOD, COLORADO 80228
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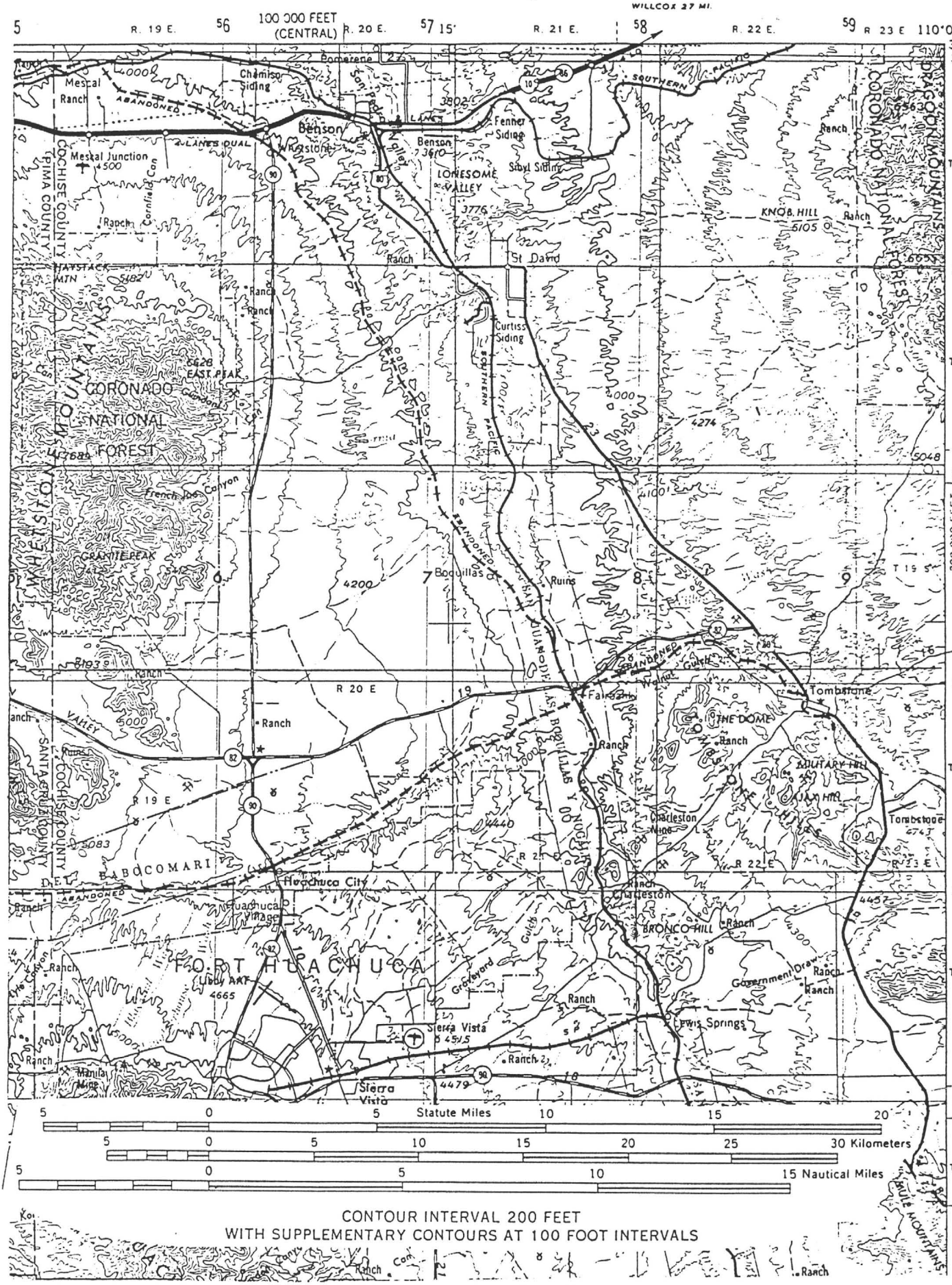
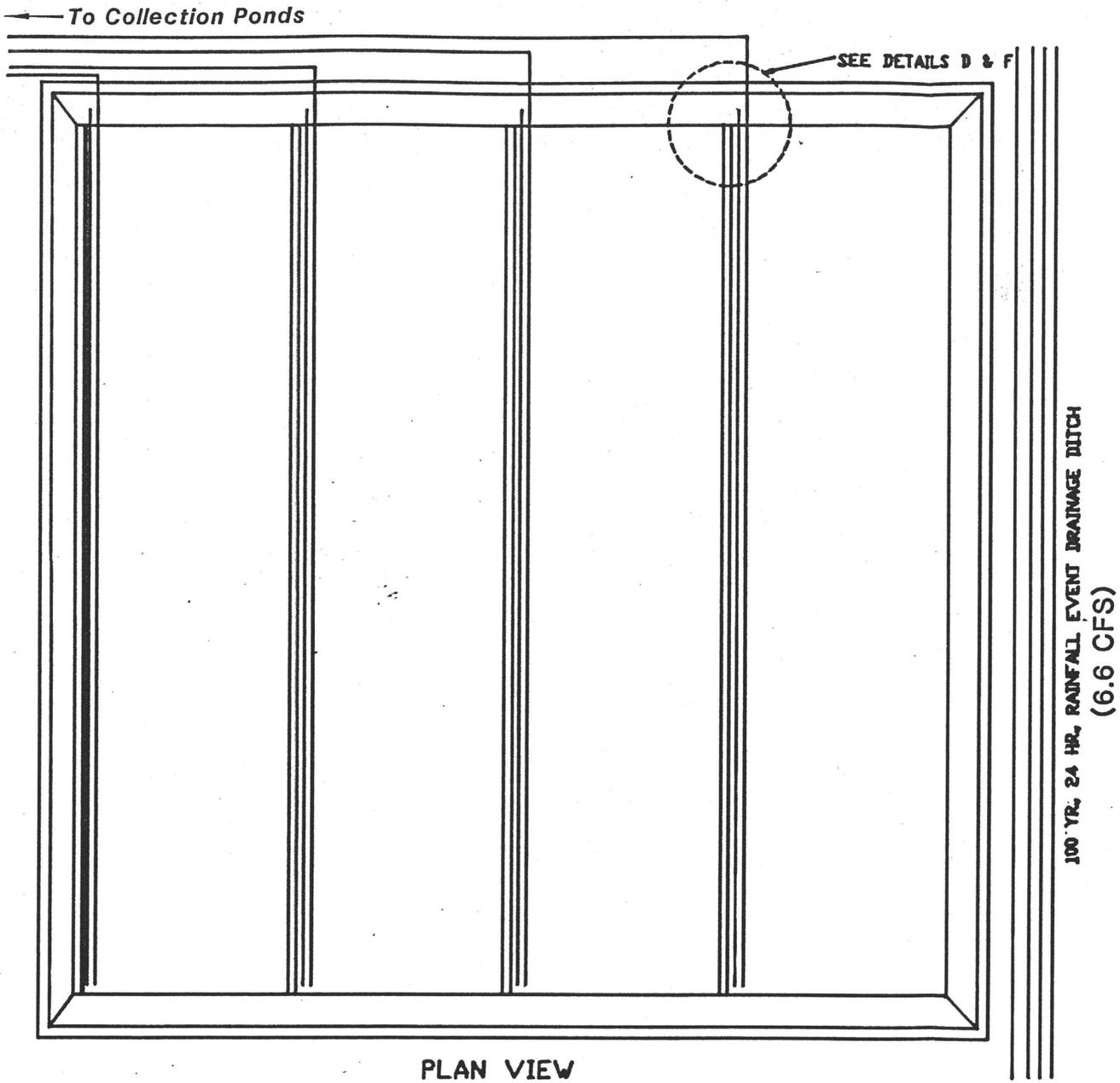
SECTION 2



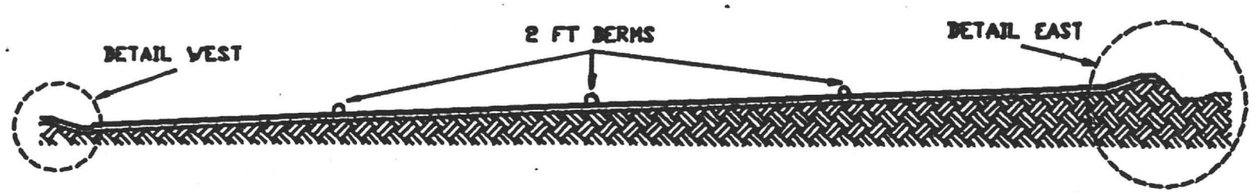
CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS

Fig. 2-1 Location Map

LEACH PAD CONSTRUCTION



PLAN VIEW



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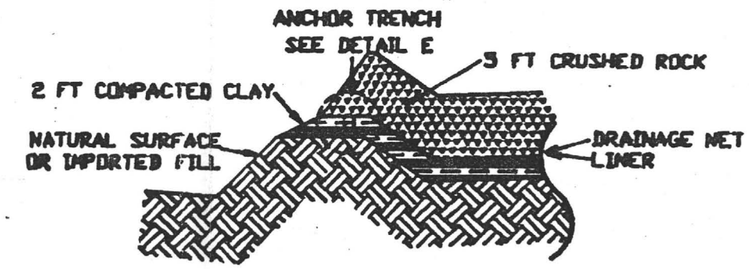
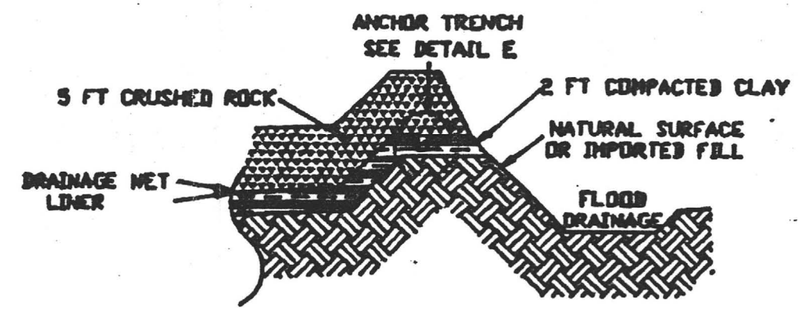


DETAIL WEST



DETAIL EAST

Figure 2-2
PBR Minerals, Inc.

TITLE: Leach Pad Construction
PROJECT: Grand Central Leach Facility
DATE: August, 1988
SCALE: 1 INCH = 60 FEET
DESIGNED BY: Dustin Escabuie, Sr.
DRAWN BY: CHARLOU CORPORATION

PREGNANT & BARREN SOLUTION PONDS IDENTICAL

Grand Central Leach Facility
PBR Minerals, Inc.
Tombstone, Arizona

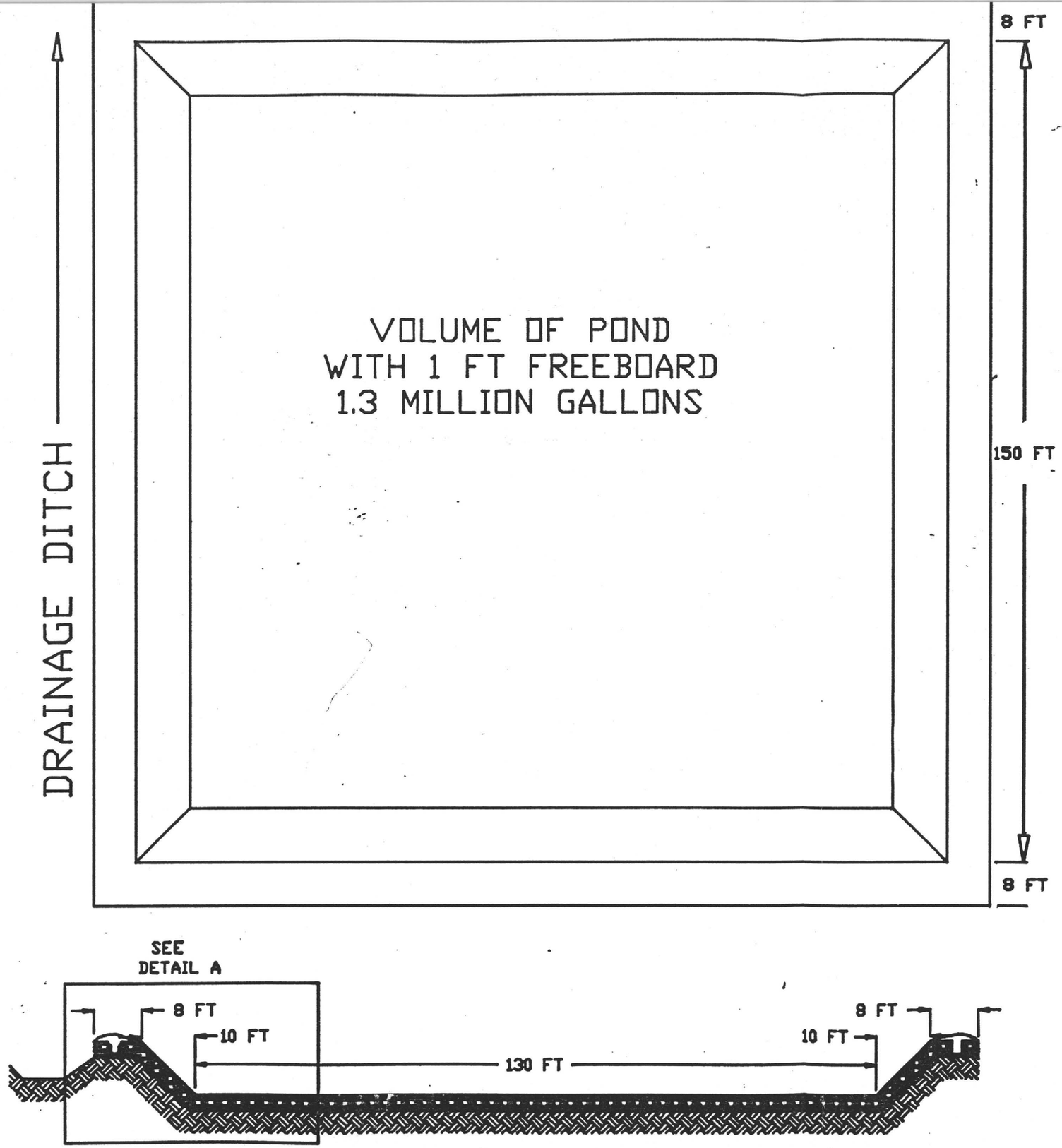
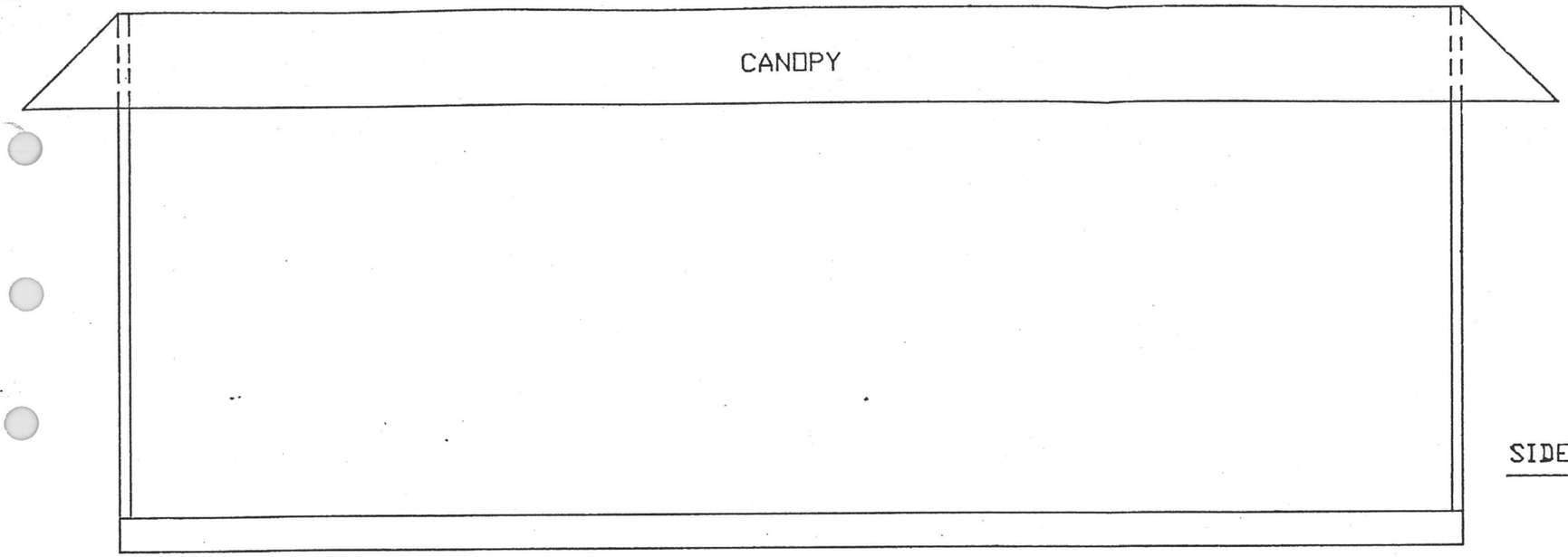
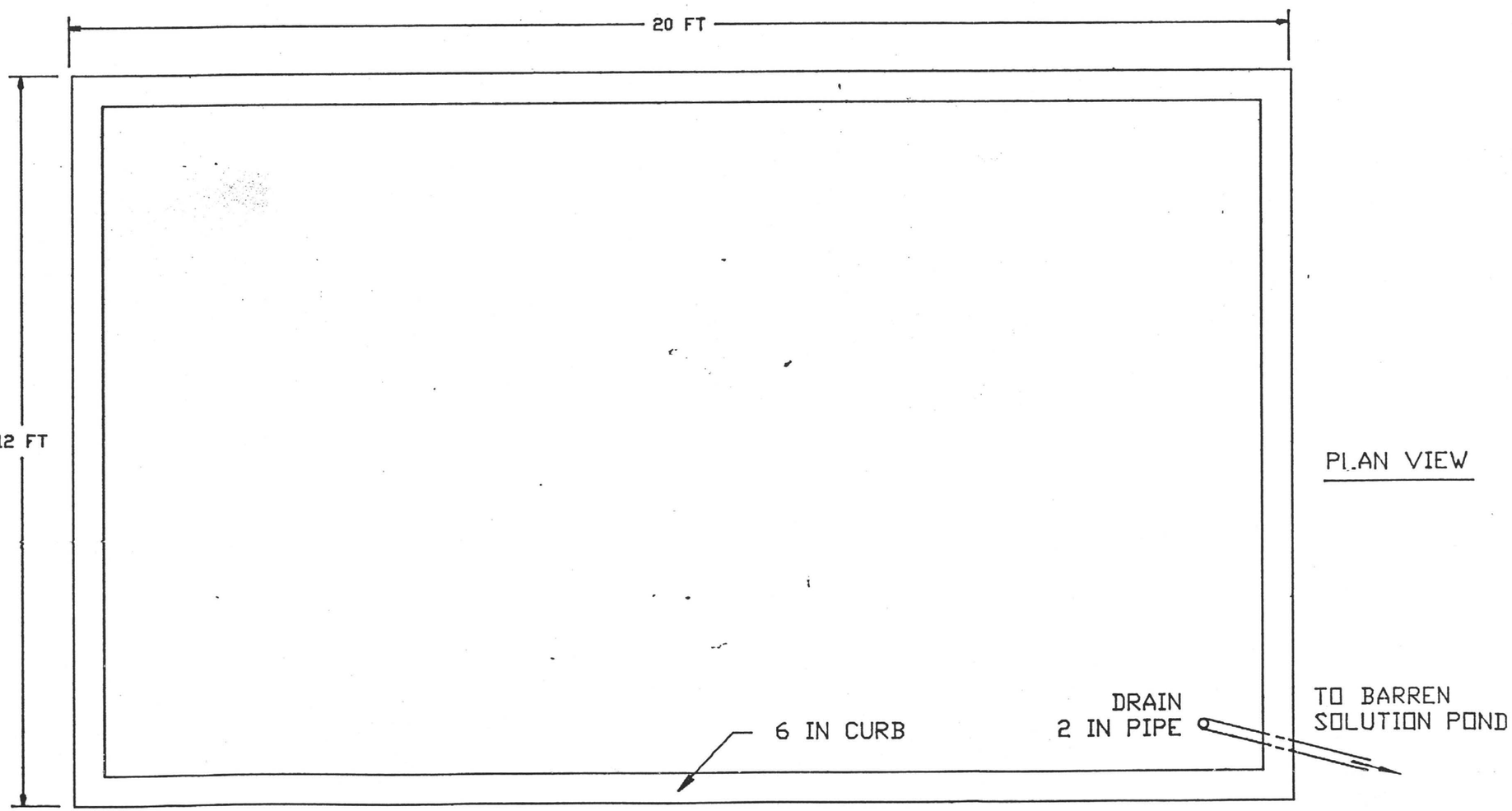


Figure 2-3



CYANIDE STORAGE AREA

SIDE VIEW



PLAN VIEW

Figure 2-4
PBR Minerals, Inc.

TITLE: Cyanide Storage Area
PROJECT: Grand Central Leach Facility
DATE: August, 1988
SCALE: 1 INCH = 2 FEET
DESIGNED BY: Dustin Escapule, Sr.
DRAWN BY: CHARLOU CORPORATION

CYANIDE MIX AREA

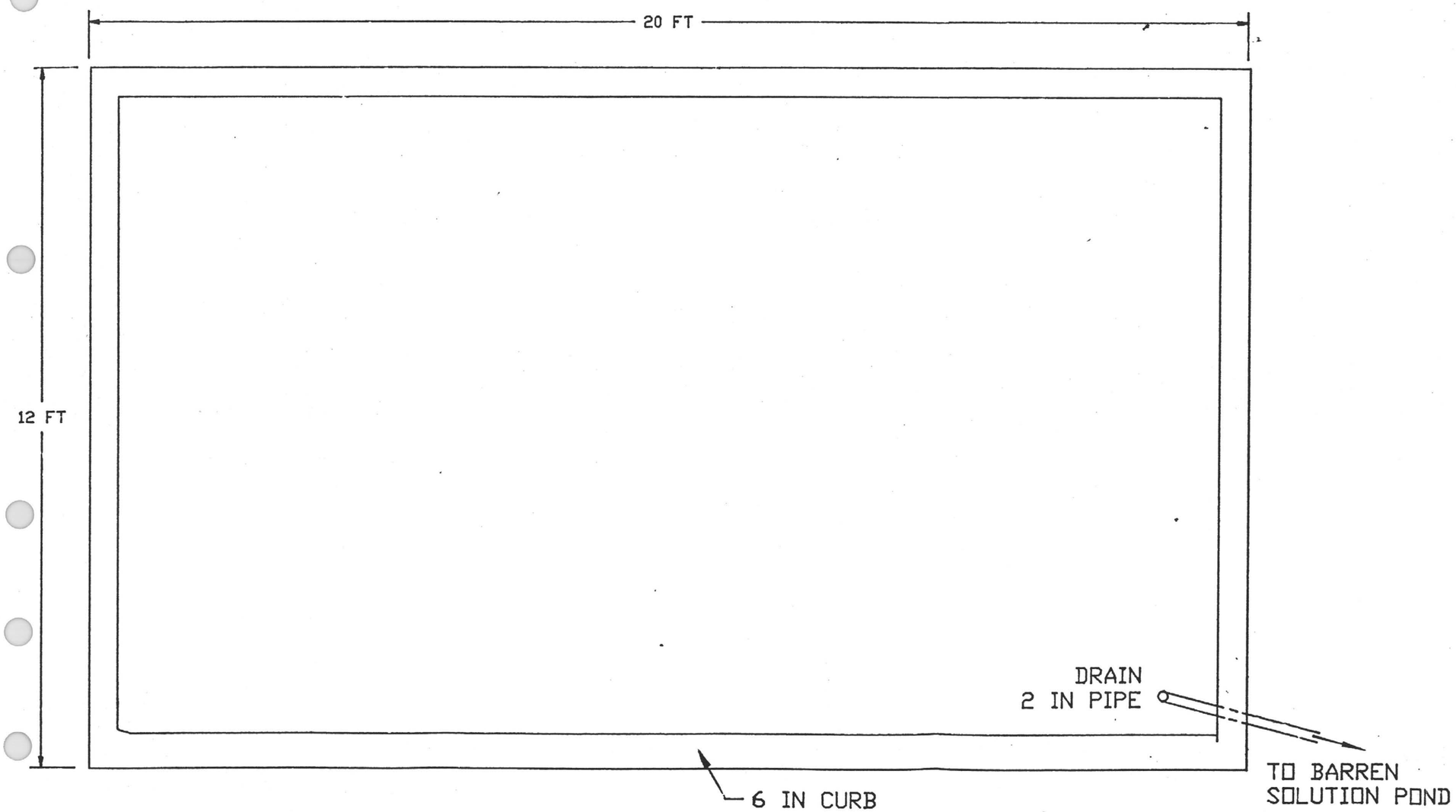


Figure 2-5
PBR Minerals, Inc.

TITLE:	Cyanide Mix Area
PROJECT:	Grand Central Leach Facility
DATE:	August, 1988
SCALE:	1 INCH = 2 FEET
DESIGNED BY:	Dustin Escapule, S
DRAWN BY:	CHARLOU CORPORATIO

CYANIDE CAN
RINSE AREA

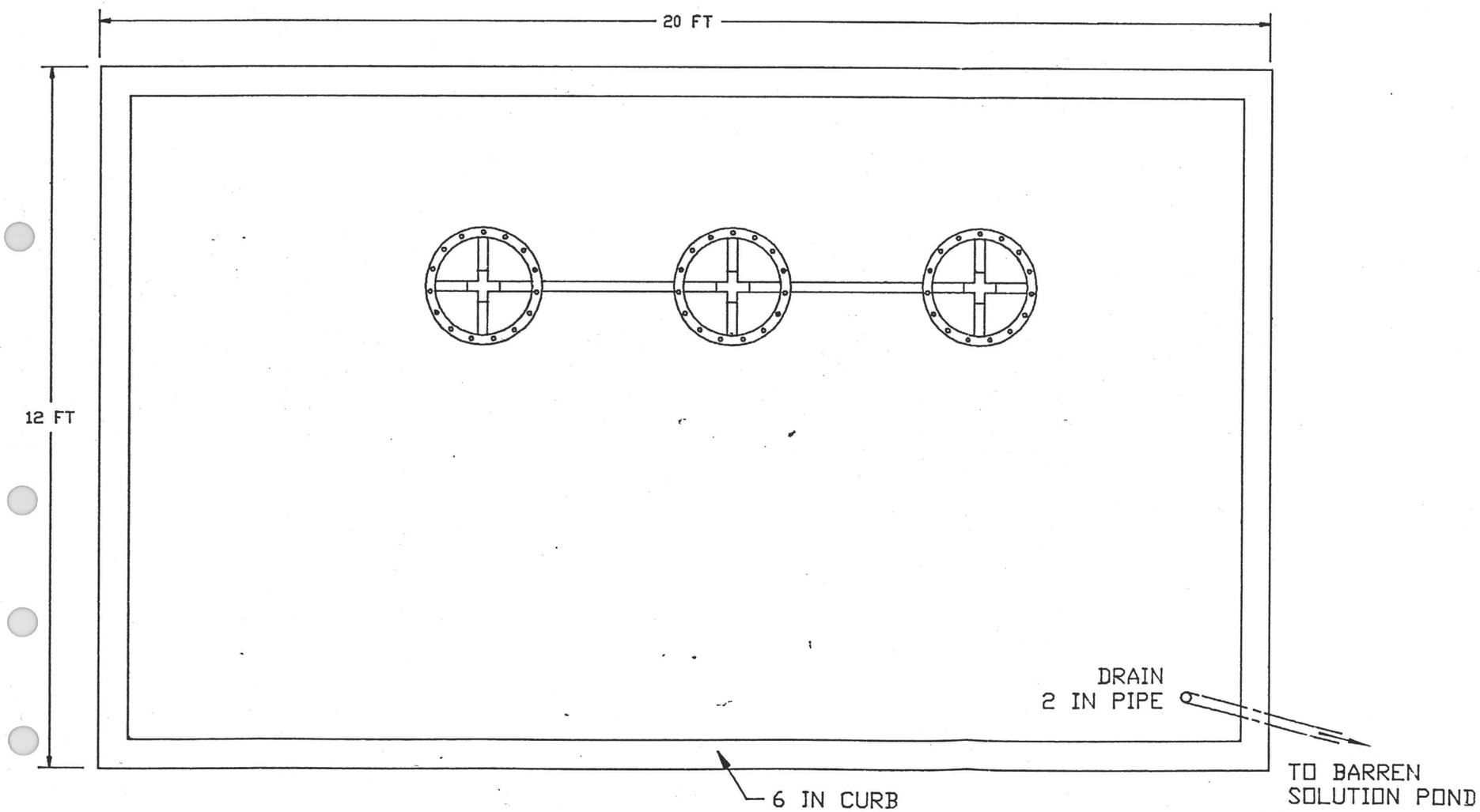
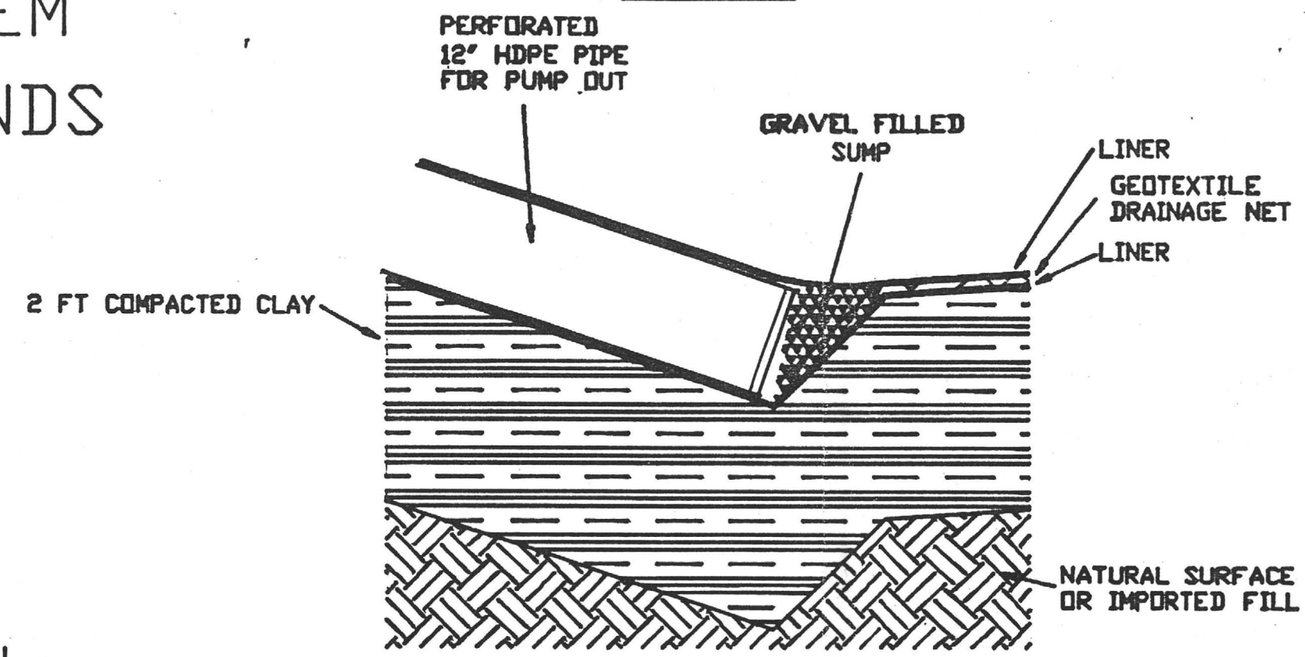


Figure 2-6
PBR Minerals, Inc.

TITLE: Cyanide Can Rinse Area
PROJECT: Grand Central Leach Facility
DATE: August, 1988
SCALE: 1 INCH = 2 FEET
DESIGNED BY: Dustin Escapule, Sr.
DRAWN BY: CHARLOU CORPORATION

DETAIL A
LEAK DETECTION SYSTEM
BARREN & PREGNANT PONDS

DETAIL



X-SECTION

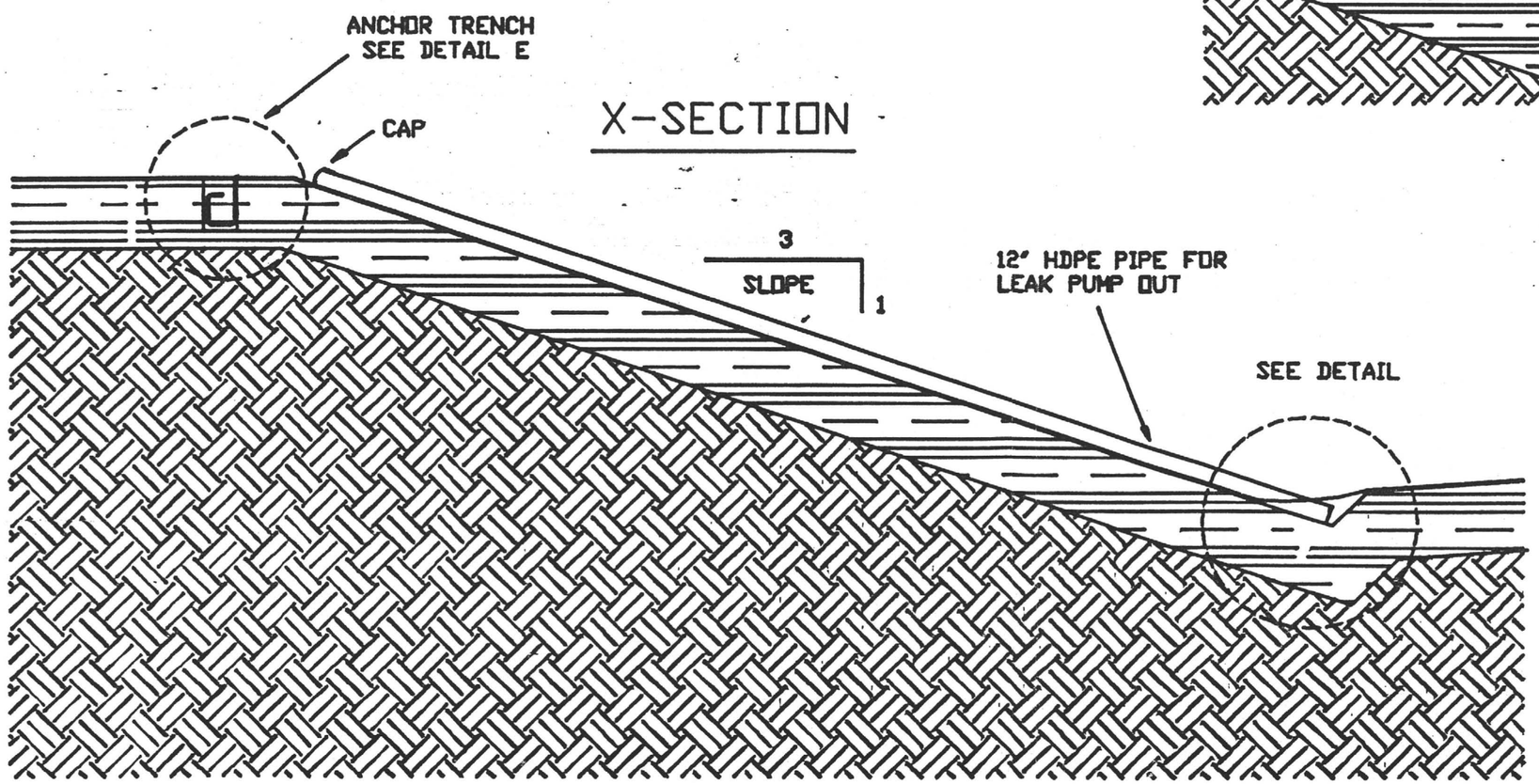
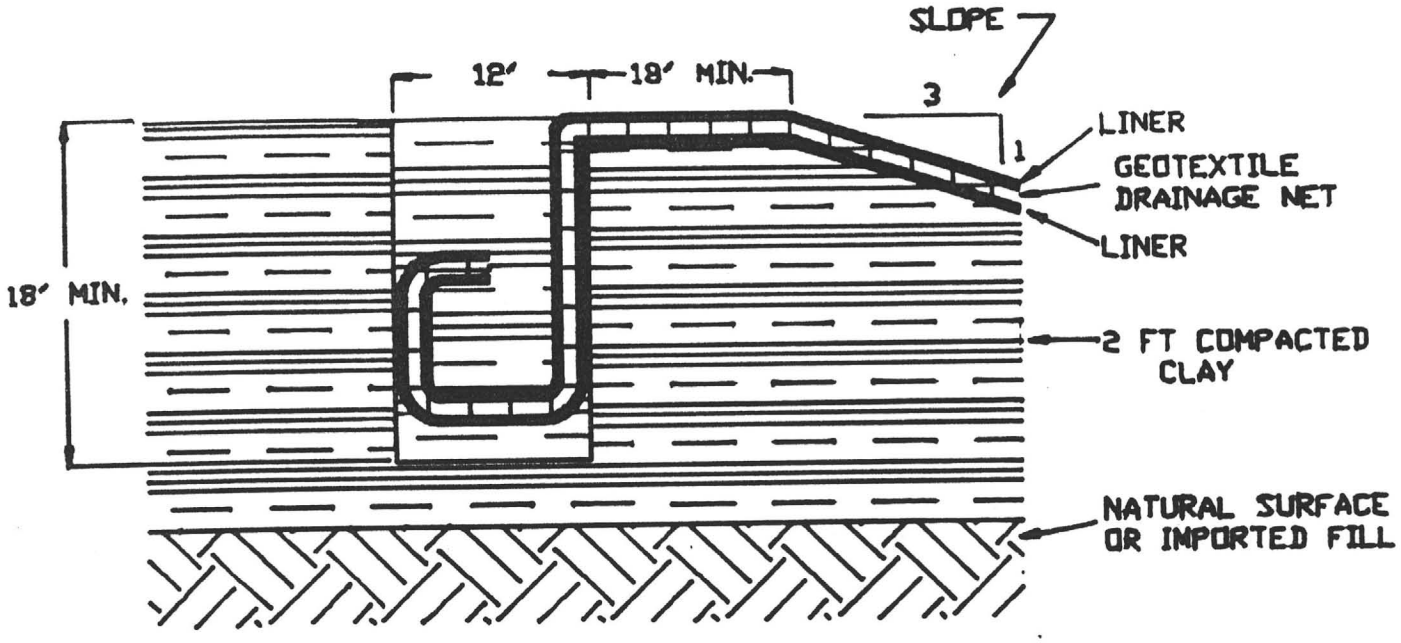


Figure 2-7
PBR Minerals, Inc.

TITLE:	Leak Detection System Barren & Pregnant Ponds
PROJECT:	Grand Central Leach Facility
DATE:	August, 1988
SCALE:	1 INCH = 4 FEET
DESIGNED BY:	Dustin Escapule, Sr.
DRAWN BY:	CHARLOU CORPORTATION

DETAIL B
ANCHOR TRENCH
FOR POND LINERS



TYPICAL
X-SECTION

Figure 2-8
PBR Minerals, Inc.

TITLE:	Anchor Trench for Pond Liners
PROJECT:	Grand Central Leach Facility
DATE:	August, 1988
SCALE:	1 INCH = 1 FOOT
DESIGNED BY:	Dustin Escapule, Sr.
DRAWN BY:	CHARLOU CORPORATION

DETAIL C
BOOT PIPE PENETRATION FOR PAD EFFLUENT

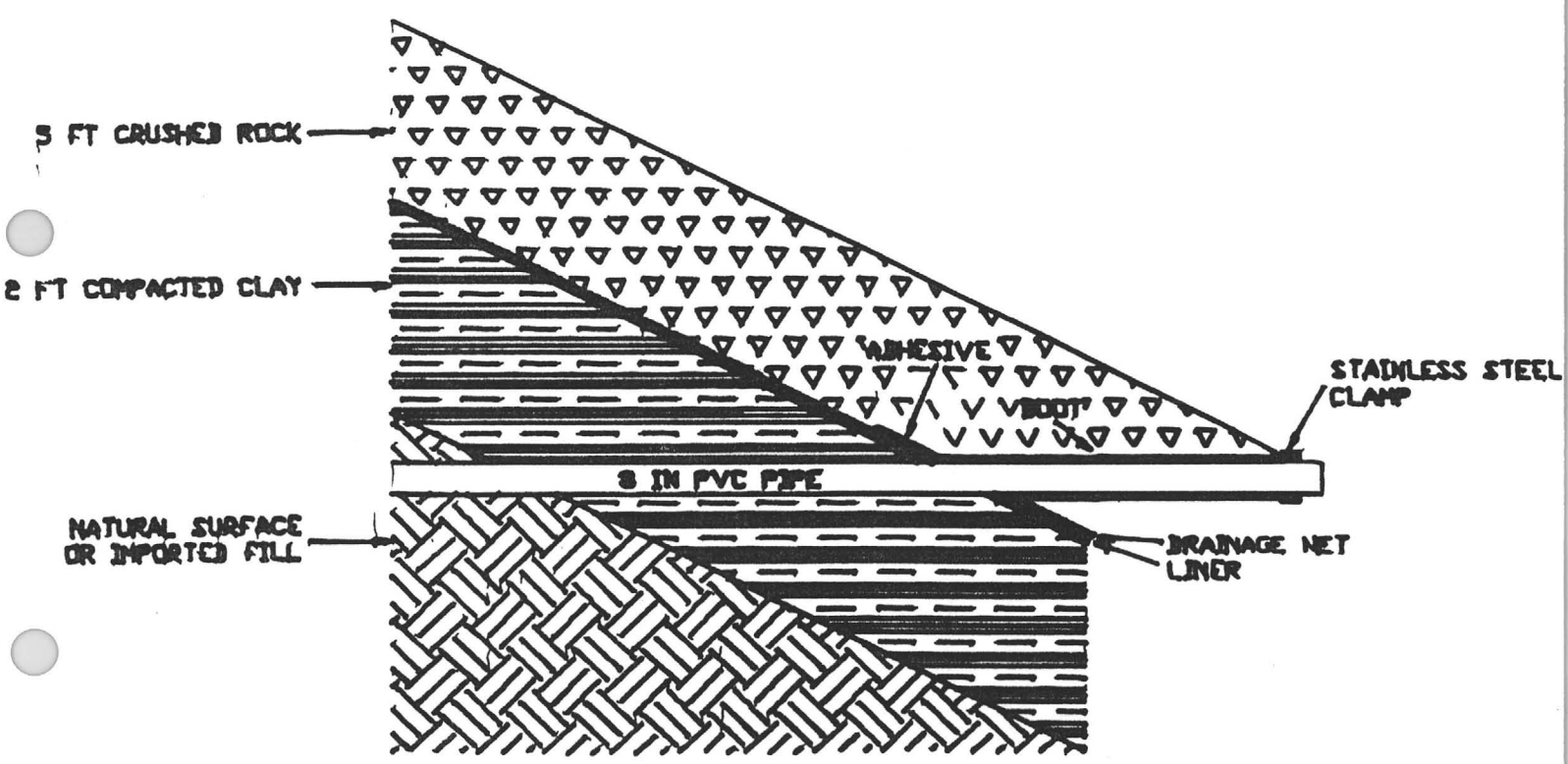


Figure 2-9
PBR Minerals, Inc.

TITLE:	Boot Pipe Penetration
PROJECT:	Grand Central Leach Fac.
DATE:	August, 1988
SCALE:	1 INCH = 2 FEET
DESIGNED BY:	Justin Escabuie
DRAWN BY:	CHARLON CORPORATION

DETAIL D
LEAK DETECTION SYSTEM
LEACH PAD

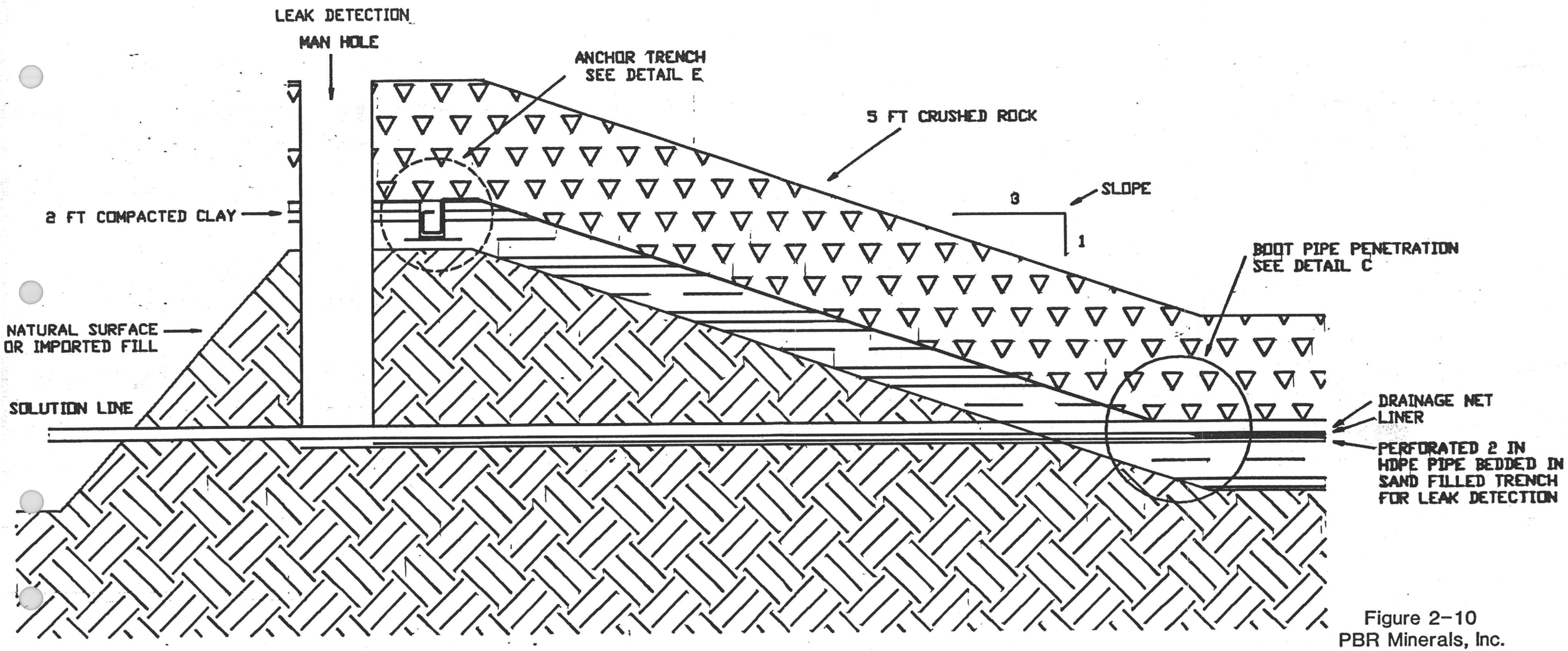


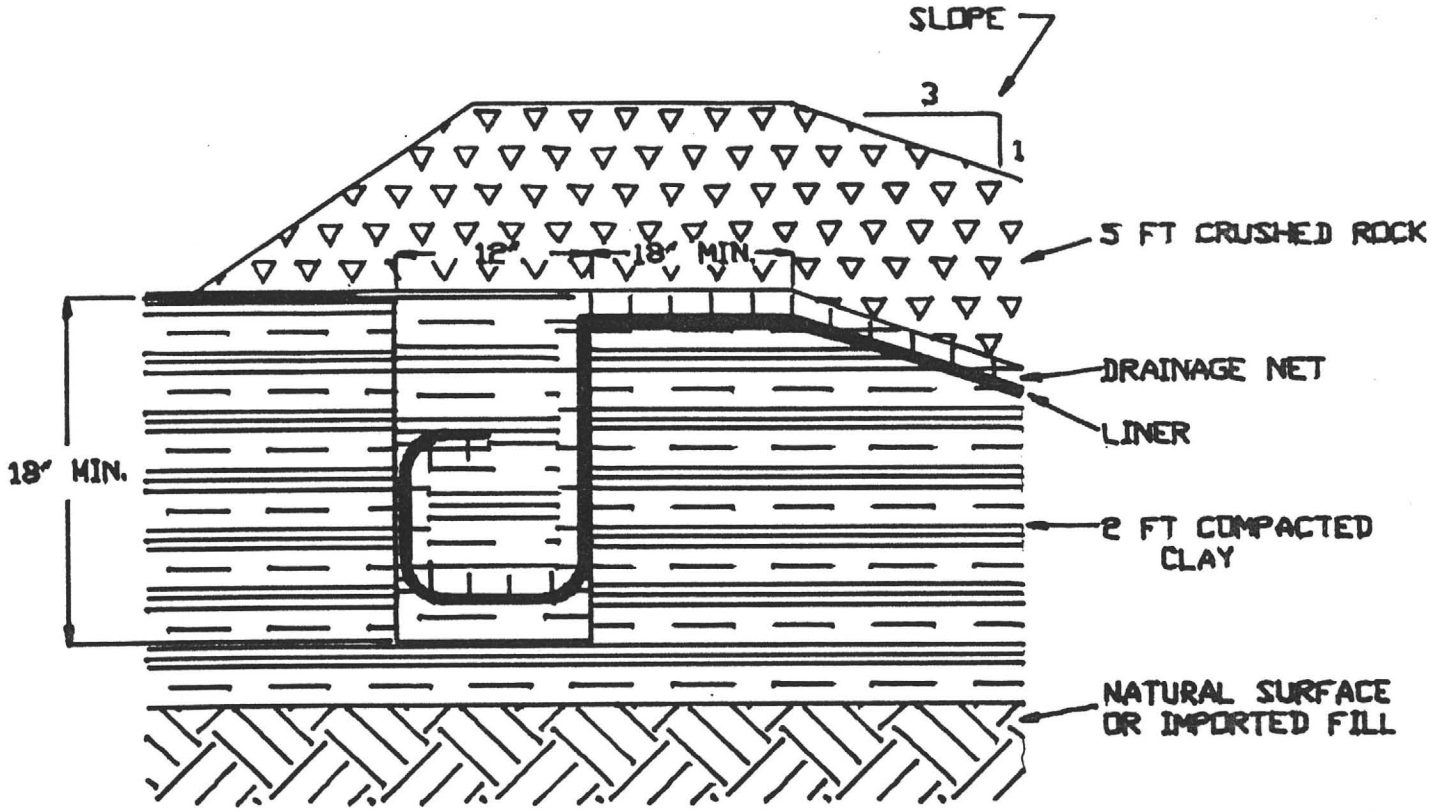
Figure 2-10
PBR Minerals, Inc.

X-SECTION

THRU NORTH SIDE OF PAD

TITLE: Leak Detection System, Leach Pad
PROJECT: Grand Central Leach Facility
DATE: August, 1988
SCALE: 1 INCH = 4 FEET
DESIGNED BY: Dustin Escapule, Sr.
DRAWN BY: CHARLOU CORPORTATION

DETAIL E
ANCHOR TRENCH
FOR PAD LINER



TYPICAL
X-SECTION

Figure 2-11
PBR Minerals, Inc.

TITLE:	Anchor Trench for Pad Liner
PROJECT:	Grand Central Leach Facility
DATE:	August, 1988
SCALE:	1 INCH = 1 FOOT
DESIGNED BY:	Dustin Escapule, Sr.
DRAWN BY:	CHARLOU CORPORATION

DETAIL F
LEAK DETECTION SYSTEM
LEACH PAD

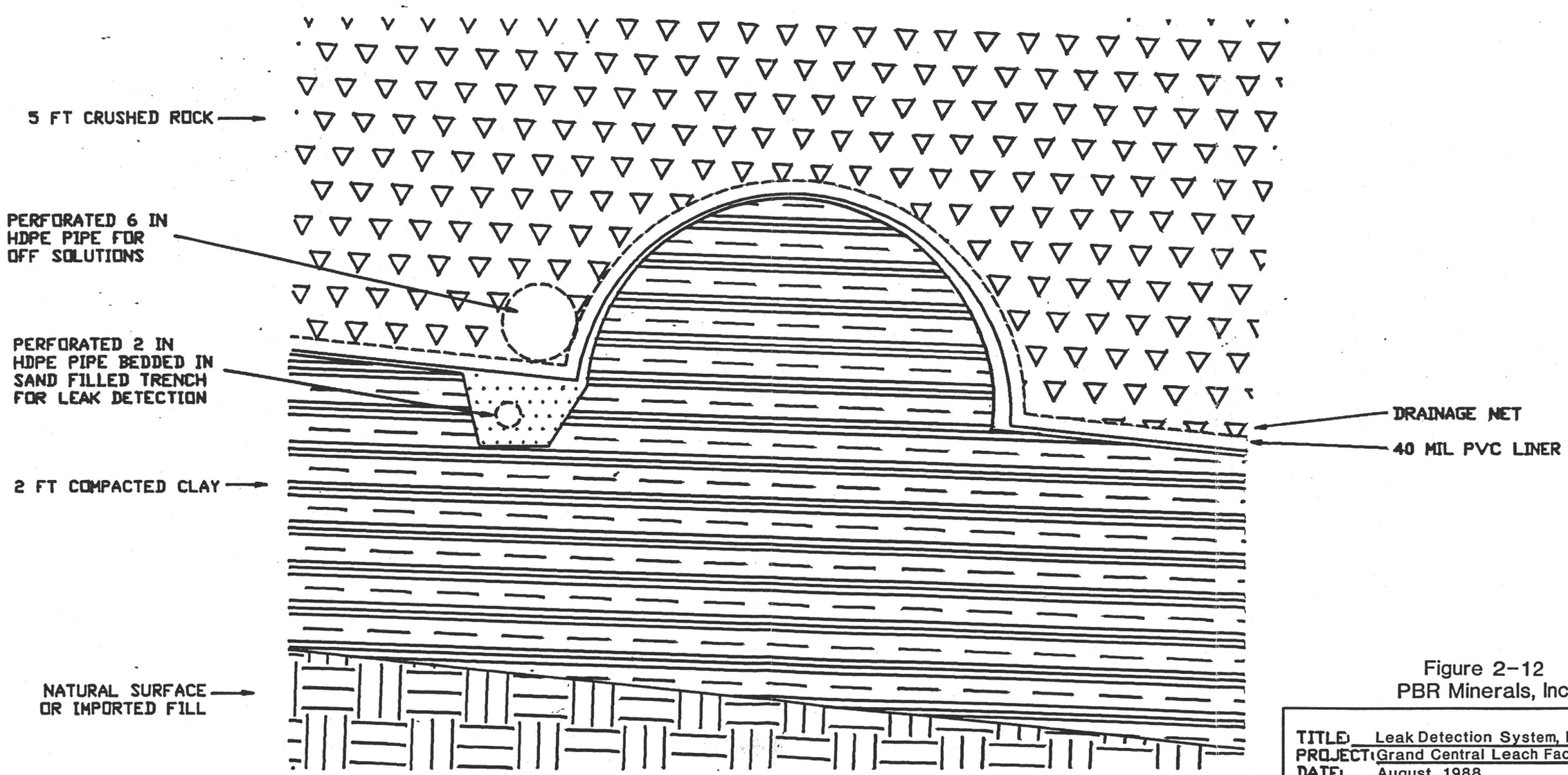


Figure 2-12
PBR Minerals, Inc.

TYPICAL X-SECTION THRU BERM

TITLE: Leak Detection System, Leach Pad
PROJECT: Grand Central Leach Facility
DATE: August, 1988
SCALE: 1 INCH = 4 FEET
DESIGNED BY: Dustin Escapule, Sr.
DRAWN BY: CHARLOU CORPORTATION

SECTION 3

3.0 SUMMARY OF DISPOSAL ACTIVITY

At present, there are no waste-disposal activities at the proposed PBR Minerals heap-leach site. Present PBR Minerals activities center on the clean up of soil contamination from the actions of the former site occupant, together with washing of cyanide-bearing tailings from a past leaching facility in an area north of the proposed PBR heap leach.

3.1 Waste Characteristics

No data exists on actual waste characteristics, since operations are not yet in effect. In an effort to provide data on potential trace-element mobilization associated with the proposed leaching, a synthetic leach solution and leached tailings were created in the laboratory from a sample of the PBR ore and water from the existing PBR Well #2, treated with lime and cyanide in the anticipated reagent dosage. This material was then assayed, and used in the conduct of geochemical attenuation tests. The results of those tests are summarized in Section 3.3, and detailed in Appendix 1. Waste material will consist of spent crushed ore which has been treated by chemical or biological means to degrade remaining cyanide residue. The spent ore will be disposed onto a clay-lined spent-ore disposal area, with runoff from the area contained and used in the process plant. In addition barren or pregnant solution containing low levels of cyanide and trace metals in an alkaline solution will be generated, but will be recycled with no disposal. All solutions will be retained in double-lined ponds with an additional earthern subliner capable of attenuating contaminant migration, as is described in Section 3.3.

The spent ore will consist of existing leached, agglomerated material, and of natural ore, which will be agglomerated. Residual cyanide concentrations will be less than 0.2 mg/kg free cyanide, and will be achieved by a combination of rinsing with clean water, followed by treatment with chemical oxidants, and/or biodegradation. The rock will be slightly alkaline, as a result of the natural presence of limestone and the addition of lime. The acid-neutralizing potential will exceed the acid-forming potential, with the result that the material will be geochemically stable and will not change significantly with time.

The spent ore will be biologically inactive. While it is anticipated that a part of the cyanide degradation will be achieved by means of bioremediation, this will be achieved by means of natural strains of soil bacteria common to the area. No data exist on the radiological characteristics of the spent ore; however, it is not anticipated that the ore contains elevated radiochemical levels. The geochemical conditions, such as pH, oxyhydroxide content, etc., in the spent ore are such as to minimize the potential migration of any radionuclides present in the spent ore.

The barren and pregnant solutions will be composed of sodium bicarbonate type alkaline aqueous solutions prepared by mixing natural

ground water from present Well #2 and the proposed pumped monitor well with lime and sodium cyanide. As the solutions are recirculated, they will become elevated in major ions, with a significant concentration of calcium sulfate (gypsum) derived from lime addition and the dissolution of sulfide reaction products. Calcium and sulfate concentrations are anticipated to be as high high as 1,500 and 2,000 mg/l, respectively.

Tests which were conducted with the synthetic heap leach solution show that the liquid solutions will contain relatively low concentrations of trace or toxic metals. The synthetic heap leach solution contained arsenic at close to the Primary Drinking Water Standard, with less than 10 times that of the cadmium standard. The mercury and silver concentrations of the leach solution were 24 and 41 times the Primary Drinking Water Standard, respectively. Silver, however, will be recovered during processing. All other metals were within the Primary Drinking Water Standard in the synthetic heap leach liquor.

3.2 Waste Disposal Rates and Volumes

Mining activities and resultant heap leaching will be conducted on a round-the-clock basis, 365 days per year. It is anticipated that the mining will produce 350,000 tons of ore per year which will be placed on low-permeability pads, leached for the time period required to mobilize the precious metals and then rinsed and neutralized prior to decommissioning. Solution will be circulated through the system at a rate of 600 gpm. Solution flow measurement will be by means of flow meters and pump-capacity ratings.

3.3 Waste Discharge Mitigation

The PBR Minerals proposed heap-leach facility consists of multiple lines of defense to assure that contamination of the ground-water resource shall not occur. The entire process operation area shall be guarded by run-on protection capable of handling overland flow produced by a 100-year, 24-hour rainfall event. The process facility building will include a 6-inch curb, with floor drains leading to the process barren pond. Reagent storage areas will be under roof, with reagent mix areas on liners draining to the barren pond. Empty reagent containers will be triple rinsed with well water. Rinse water will drain to the barren pond.

The barren and pregnant ponds shall each consist of double liners of synthetic membrance, separated by a geotextile drain layer. The geotextile drain is sloped to a sump equipped with a HDPE pipe to provide for leak detection, and capable of allowing the removal of collected leakage (Detail A). The heap leach pad is underlain by a synthetic membrane liner, protected by a drainage net and a 5-foot layer of crushed rock.

The barren and pregnant ponds and the heap leach pad are all, in turn, underlain by a 2-foot fill layer of clay which will be mined from an adjacent site, imported, and placed as an engineered fill. This material will serve as further protection against solution leakage. This protection will be afforded not only as a result of the low permeability of the clay, but also as a result of its ability to attenuate and retard the movement of contaminants, through natural geochemical processes.

To quantify the ability of the clay liner material to attenuate such contaminant migration, a sequential batch test was conducted, using a sample of the proposed liner material. This test was conducted in accordance with the sequential batch test procedure outlined by Houle and Long (1980). The liquid used in the test consisted of a synthetic pregnant solution generated by reacting a sodium cyanide solution of Well #2 water with typical ore. The test procedure and results are discussed in detail in Appendix 1. The clay liner material was shown to be rich (46%) in calcite, with most (75%) of the clay a mixed-layer Illite/Smectite. The clay material had a cation-exchange capacity of 14.7 meg/100 g, with almost 40 meg/100 g of exchangeable calcium.

Further protection is provided by the extensive thickness of unsaturated rock between the land surface and the water table. While no wells exist at the proposed heap-leach facility, hydrogeologic data (see Chapter 5) indicates there should be more than 500 feet of unsaturated bedrock between the leach facility and the water table.

As is described in Section 3.4, there is no monitoring system at the heap-leach site. It is proposed that a pumped monitoring well be utilized to assure detection and capture of any contaminants which may reach the water table. As is described in Chapter 8, such a well could also serve as a remedial facility in the unlikely event that ground-water contamination occur.

3.4 Existing Monitoring Program

At present, no monitoring facilities exist in the immediate vicinity of the proposed heap-leach facility. PBR Minerals does monitor their 3 water-supply wells in the vicinity of the existing facility, as well as the Town of Tombstone Well #1. This monitoring is described and data presented in Chapter 5.

SECTION 4

4.0 ENVIRONMENTAL SETTING

The PBR facility is located immediately south of the town of Tombstone, Arizona, in a portion of the Sonorian Desert. The general environmental setting is described in the following portion.

4.1 Land Use

The PBR Minerals facility is located on the south side of the Town of Tombstone, approximately 75 miles southeast of Tucson and 25 southeast of Bisbee, Arizona, in the southwest quarter of Cochise County. The region is semiarid, and is used primarily for stock grazing, mining and recreational and tourism activities. Access is provided by means of Interstate Highway 10 to Benson and U.S. Highway 80 from Benson to Tombstone. The regional area is further accessed by means of various gravel roads, with unimproved ranch and mining roads generally passable, and providing access to nearly all sites. Figure 2-1 provides general information on site location, while Plate II-1 provides land-ownership information adjacent to the PBR Minerals Facility.

Vegetation in the area consists of predominately desert shrubs and scattered clumps of grasses. Within the San Pedro River basin, creosote bush, tarbush, mortonia and whitethorn are common, with several varieties of grama, curly mosquite and tobosa grass near the mountain front. Mesquite and paloverde are common along the dry stream channels, while ocotillo, yucca and agave occasionally occur with the grasses (Hollyday, 1963).

Recreational and tourism activities developed largely due to the historic mining development which has occurred within and adjacent to the town of Tombstone. Tourism is assuming an increasing importance within the town. Mining activities are generally perceived as consistent with such historical tourism activities.

4.2 Climate

Tombstone, situated at an elevation of between 4,500 and 4,600 feet, has a semiarid climate, with moderate winters and hot summers. Average maximum temperature is 76°, while the average minimum is 49° (Hollyday, 1963). Recorded extremes are a high of 110° and a low of 9°. Average annual precipitation at Tombstone over a 65-year period of record is less than 13 inches, with extremes of 7 and 28 inches. Precipitation is bimodal, with approximately 70% of the precipitation coming during intense convective storms during the July, August and September monsoonal season. The remaining precipitation is distributed during the winter months, and is more general and gentle in nature.

Because of the semiarid nature of the area, evaporation and evapotransporation is extreme, greatly exceeding the precipitation during

the year. Table 4-1 provides monthly and annual data on precipitation, lake evaporation and net evaporation. This is illustrated in Figure 4-1, which shows an average net evaporation for all months. Such semiarid conditions, with a net evaporation in all months, allow for the conduct of zero-discharge milling operations, with a bleed stream in the form of the water incorporated into the interstitial voids of waste material.

Table 4-1
TOMBSTONE, ARIZONA
EVAPORATION/PRECIPITATION

Month	Avg. Precip.	Avg. Lake Evap.	Net Evaporation
January	0.84	2.40	1.56
February	0.55	3.00	2.45
March	0.7	4.80	4.10
April	0.25	6.36	6.11
May	0.17	8.16	7.99
June	0.46	8.55	8.09
July	3.51	6.15	2.64
August	3.23	5.40	2.17
September	1.08	5.55	4.47
October	0.85	4.80	3.95
November	0.48	3.12	2.64
December	0.69	2.40	1.71
SUM	12.81	60.69	47.88

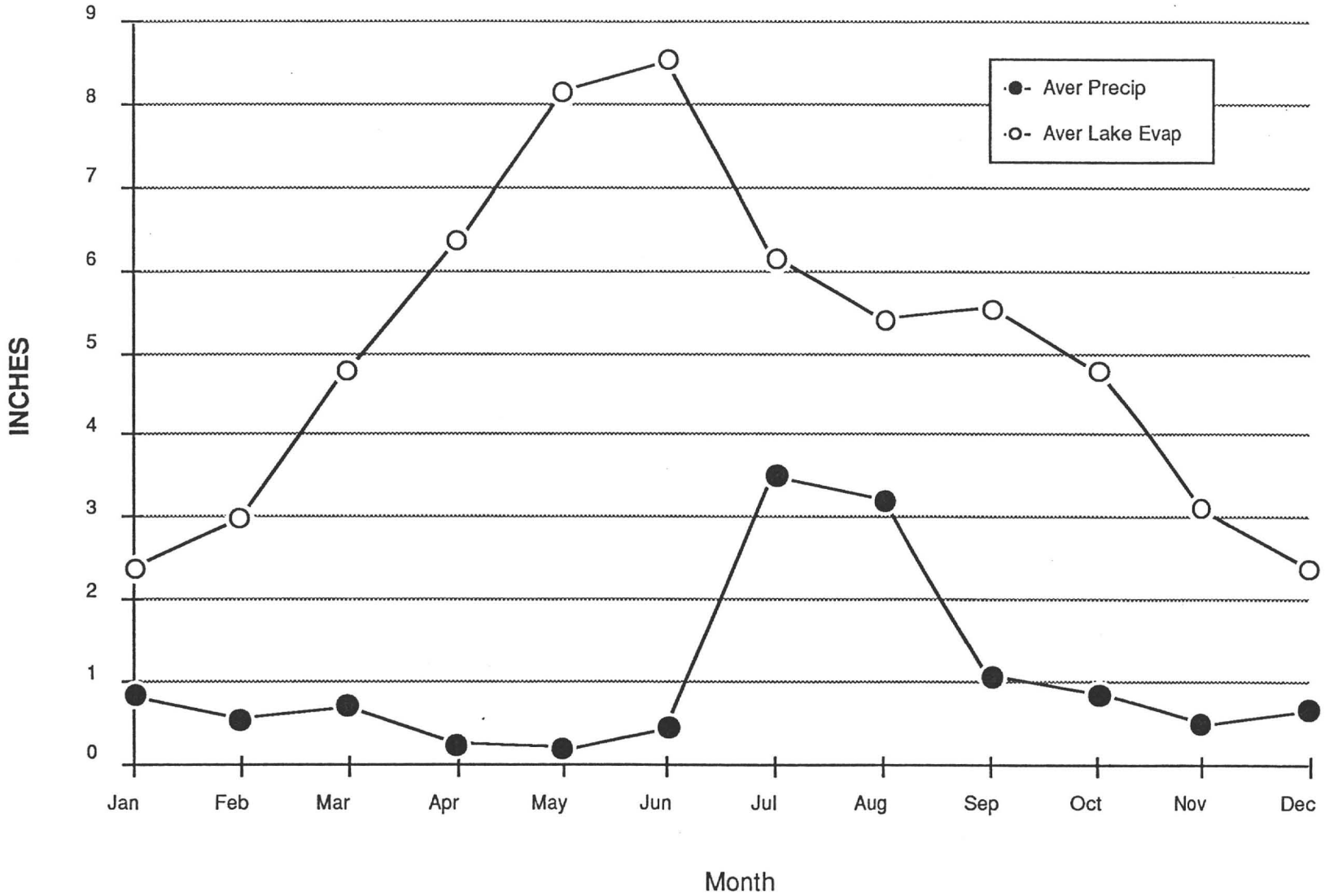


Figure 4-1 Tombstone, Arizona - Average Monthly Precipitation and Evaporation

SECTION 5

5.0 SITE HYDROLOGY

The site hydrology in the PBR Minerals area has been well described by Hollyday (1963). The following description is adapted from this source, together with modifications resulting from more recent drilling activities and excavations conducted by PBR Minerals and its predecessors.

5.1 Geology

The geology of the Tombstone Mining District has been examined in detail with respect to both general and economic geology. One of the first studies of the general geology and ore occurrence was prepared by W. P. Blake (1882) in response to mine litigation. Blake subsequently published additional general reviews of geology and mining development in 1902 and 1904. J. A. Church (1903) published a report on the regional occurrence of ore deposits and the general geology, which incorporated local stratigraphic names.

Dr. F. L. Ransome (1920) published a comprehensive study of the geology of the surface and subsurface of the Tombstone Mining District, and introduced the type stratigraphic names as utilized in the Bisbee District. This work was continued and carried to completion by B. S. Butler, E. D. Wilson and C. A. Rasor (1938) in a description of the geology and the occurrence of ore in the central portion of the Tombstone Mining District.

James Gilluly, J. R. Cooper and J. S. Williams (1954) conducted a detailed study of the Pennsylvanian-Permian stratigraphy in the adjacent Tombstone Hills, and upgraded Ransome's Naco Formation into a Group, which they subdivided into four formations. Gilluly subsequently conducted a regional study of the stratigraphy and structure in the Tombstone Hills, Dragoon Mountains and the northern half of the Mule Mountains (1956).

5.1.1 Surficial Geology

Soils within the PBR Minerals area are generally thin and discontinuous, and are formed by the in-place weathering of bedrock which occurs at or very near the land surface. Soils tend to be rather coarse-grained in nature, reflecting such mechanical weathering, and are generally of low plant productivity.

Alluvium occurs in the northeastern corner of the Tombstone Mining District, and is largely composed of coarse sand and gravel, which in many locations is cemented with caliche deposits to depths as great as 90 feet (Hollyday, 1963). The alluvium thickens to the northeast and east of the town. Here, the upper 30 to 90 feet of alluvium is predominately composed of limestone pebbles and cobbles derived from Palezoic carbonates and cemented with caliche. Below this layer, the alluvium is unconsolidated to moderately well-indurated gravel composed of fragments derived from shales and sandstones of the Bisbee Formation. This gravel has a maximum thickness of between 45 and 120 feet. The lowest portion of the alluvium consists of a gravel layer

which is unconsolidated to weakly cemented, with a maximum known thickness of 300 feet. This lower-most layer is primarily composed of a mixture of gravel and sand derived from the Bisbee Formation and from quartz latite volcanics. A well, drilled approximately one mile east of Tombstone, encountered the water table in the alluvium at a depth of approximately 455 feet, but caved before it could be pumped to determine the water-bearing properties of the alluvium. Hollyday (1963) presents information that indicates the water table in the alluvium is interconnected with the water table in consolidated bedrock, where the alluvium receives sufficient recharge to be saturated. Alluvium is absent or only rarely present in the PBR Minerals site.

5.1.2 Subsurface Geology

The Tombstone Mining District is underlain by a thick sequence of intrusive rocks and Precambrian metamorphics, Paleozoic clastics, Paleozoic carbonates, the Bisbee formation and volcanic rocks.

Intrusive and Metamorphic Rocks: As noted by Hollyday (1963) "the intrusive rocks and Precambrian metamorphic rocks consist of three generalized geologic formations: Precambrian intrusive and metamorphic rocks, Triassic-Jurasic intrusive rocks, and Tertiary intrusive rocks." The Precambrian intrusives consist of albite granite, quartz diorite, gneissic granite, and saussuritic quartz diorite. In general, these rocks are highly fractured, altered and weathered, with the fractures sealed with clay-sized weathering products. As a result, they yield small quantities of water only within the first few tens of feet below the water table (Hollyday, 1963).

The Triassic and Jurasic intrusive rocks occur in the western portions of the Mule Mountains and along the core and southern portion of the Dragoon Mountains. These are predominately quartz monzonite and granite which have been intensely altered and sheared. As in the case of the Precambrian rocks, they are generally quite impermeable below the first few tens of feet.

The Tertiary intrusive rocks outcrop in the northern and western portions of the Tombstone Hills and in the northern portion of the Dragoon Mountains. These intrusives are intermediate in composition, similar to quartz monzonite. The Schieffelin Granodiorite found in the western portion of the Tombstone Mining District is characterized by an irregularly-spaced, three-directional fracture system which stores small quantities of water. Shallow dug wells along Tombstone Gulch furnished water for the town of Tombstone during the first two years of its existence, and derived such water from fractures within the Schieffelin Granodiorite. Dewatering activities in the rocks east of the Schieffelin Granodiorite did not result in change in water level within the granodiorite, thereby documenting that the Schieffelin Granodiorite is not hydrologically connected with consolidated rocks to the east.

Dikes of granodiorite to diorite composition, similar to the Schieffelin Granodiorite in origin, cross the Tombstone Mining District along a trend of North 12 degrees East and dip steeply to the west.

Paleozoic Clastic Rocks: The Bolsa Quartzite of middle Cambrian age is predominately composed of well indurated quartzite derived from quartzitic pebble grit and coarse sand, with a thin basal conglomerate. It crops out in the Tombstone Mining District, along the western edge of the Mule Mountains, and in the core of the Dragoon Mountains. Hollyday (1963) reported a 440 foot thick homogeneous aquifer in the Bolsa Quartzite as a result of numerous joints and fractures. The Bolsa Quartzite is one of the best crystaline-rock aquifers within the Tombstone Mining District.

Paleozoic Carbonates: The various Paleozoic carbonate formations in the area are generally undifferentiated in the following discussion. These Paleozoic carbonates include the Abrigo Limestone, the Martin Limestone, the Escabrosa Limestone and the four local formations in the Naco Group; the Horquilla Limestone, the Earp Formation, the Colina Limestone and the Epitaph Dolomite. The composite thickness of these Paleozoic carbonates is approximately 5,200 feet, of which approximately 13% or 660 feet consist of partly siliceous material metamorphosed to hornfels near younger intrusive rocks. Such hornfelsic material yields moderately large quantities of water. The remaining 4,540 feet of non-siliceous material in the Paleozoic carbonate sequence is composed of predominately limestone with subordinate amounts of nodular chert, dolomite and calcarious shale. Fractures in the carbonate material have generally been enlarged by solution cavity development above and to a depth of 200 to 300 feet below the water table.

Bisbee Formation: The Bisbee Formation of Cretaceous age outcrops in the central portion of the Tombstone Mining District and the Tombstone Hills. It also underlies most of the northern half of the Mule Mountains and the eastern portion of the Dragoon Mountains. The Bisbee Formation, within the Tombstone Mining District, is subdivided into three generalized geologic units: Bisbee Formation clastics, Blue Limestone and Joe Limestone. The Bisbee Formation has a composite thickness of approximately 3,000 feet, of which approximately 160 feet is limestone. The lowermost clastic rocks at the base of the Bisbee Formation are locally known as "novaculite", and unconformably overlie the Epitaph Dolomite, ranging in thickness between 55 and 125 feet. The "novaculite" is an interbedded sequence of limestone fragments in a quartzitic sand matrix, sandy limestone, calcarious shale and chert. The "novaculite" has been altered to extremely hard and brittle hornfels.

The "novaculite" is conformably overlain by the Blue Limestone. It is a medium to thin-bedded silty limestone ranging in thickness between 20 and 40 feet. The Blue Limestone has generally been subjected to

extreme solutioning above the present water table prior to deposition of silver ores.

The Joe Limestone is a cherty limestone of approximately 20 feet thickness. Numerous fissures and faults within the Bisbee Formation have been accompanied by strong zones of shattering. These zones give the Bisbee Formation clastics relatively high porosity and permeablity, as compared with the Paleozoic carbonates.

Volcanic Rocks: Two ages of volcanics occur within the Tombstone District. The Cretaceous-Tertiary volcanics outcrop along the San Pedro River, southwest of the Tombstone Hills. These are composed of andesite and quartz latite, and have been intruded and broken by younger rocks. The upper quartz latite member contains water-deposited tuff beds, with a total thickness of Cretaceous-Tertiary volcanics of approximately 6,000 feet.

Tertiary-Quarternary volcanics outcrop in the area of Stockton Hill, between the Tombstone Hills and the southern part of the Dragoon Mountains. These volcanics are predominately latite tuff and rhyolite tuff, together with flows of hornblend andesite. A small plug-shaped mass of olivine basalt occurs within valley alluvium approximately three-quarters of a mile northeast of Tombstone. These volcanics supplied much of the detrital material forming the alluvium in the valley northeast of Tombstone.

5.1.3 Structure

Geologic structure within the Tombstone Mining District has an appreciable impact on the hydrologic conditions within the area. Four major structural elements have been identified, and are designated the Tombstone Syncline, the Schieffelin Dome, the Ajax Hill Horst and the Tombstone Alluvial Basin.

Tombstone Syncline: The central portion of the Tombstone Mining District lies in a broad, asymetrical synclinal basin which plunges to the southeast. Three minor folds bring Paleozoic carbonate rocks to the surface. The syncline has resulted in the presence of a thick section of clastic rocks, thereby producing a potential storage reservoir for ground water. Clastic rocks thicken to the east southeast, as a result of the synclinal plunge.

The synclinal basin is traversed by at least eight major fissures, trending approximately North 45 degrees East and dipping steeply to the southeast. The fissures have been widened by solution activity above the water table and for a distance below the water table, and thus may impart a strong preferential orientation to the permeability of rocks within mine workings.

The synclinal basin is also traversed by a set of normal faults trending North 10 to 15 degrees East, and by a minor set of normal

faults at approximately right angles to these faults. The faults apparently are relatively open channelways for water circulation at depths greater than 400 feet below the water table (Hollyday, 1963).

The Tombstone Syncline is bounded on the west by the Schieffelin Dome, a granodiorite intrusive which plunges below the Tombstone Syncline at an angle of approximately 60 degrees (Hollyday, 1963). As noted earlier, the Schieffelin Dome acts as a barrier to ground-water circulation west of the Tombstone Syncline.

Ajax Hill Horst: The Tombstone Syncline is bounded on the south by the Ajax Hill Horst. These two features were formed by reverse movement on the Prompter Fault, with a maximum stratigraphic displacement of approximately 4,000 feet. Paleozoic carbonate rocks in the vicinity of the Emerald Mine dip 50 to 60 degrees east. The Prompter Fault and its associated branches uplift relatively impermeable Precambrian albite granite which continue the impermeable hydrologic boundary formed by the Schieffelin Granodiorite.

Tombstone Alluvial Basin: The Tombstone Syncline is bounded on the north and northeast by the Tombstone Alluvial Basin. Water in the alluvial deposits occur at a distance of approximately 1,500 feet east of the northeast corner of the Tombstone Mining District. Such alluvial water forms an important source of recharge to mine rocks during heavy pumping operations.

5.2 Hydrology

Hydrology of the Tombstone Mining District has been extensively studied and reported by Hollyday (1963). The following discussion is largely taken from that source.

5.2.1 Surface Water

Surface water does not exist in the Tombstone Mining District except during and immediately after periods of intense precipitation. The closest perennial stream to the Tombstone Mining District is the San Pedro River, a northerly-flowing stream located approximately six miles to the west of Tombstone.

5.2.2 Ground-Water Occurrence and Movement

Interest has long centered on ground-water conditions in the Tombstone area as a result of the problems presented to mining operations by the presence of large quantities of ground water. W. F. Staunton first reviewed the dewatering records of previous mining companies in order to estimate the requisite capacity of a new pumping plant. Staunton explained the reasoning behind his estimate in a 1908 paper and reviewed the accidental flooding of the mines, the then-existing pumping plant and problems associated with regaining the 1,000-foot level in an article published in 1910. E. W. Walker (1908) also described the Tombstone Pumping Plant and some of the dewatering problems. J. A. Church (1905) investigated the water problems in the

district and published hypotheses as to the source and movement of water and its potential for control. Charles LeGrand (1914) reviewed existing pumping and provided an estimate of contemporary cost of dewatering. R. B. Brinsmade (1906, 1907) reported on the method used for sinking wet shafts and proposed suggestions with respect to the source of the water. He also reported on progress in handling water problems at the Tombstone Mining District. By far the most complete description of hydrologic conditions in the area has been provided by Hollyday (1963).

Ground water occurs under both fissure occurrence in fractured consolidated rocks and as interstitial water in alluvium. The alluvial reservoir is located north of the Tombstone Mining District. Minor perched water occurs in local deposits of alluvium along desert washes immediately following precipitation events.

The consolidated-rock aquifer consists of water-filled minute fractures, larger fissures and major solution openings, where metamorphism and structural deformation have developed large secondary permeability within the rocks. In the Tombstone Mining District this consolidated rock reservoir is encountered in all but the extreme western part of the district. Static water levels are found at depths ranging from 400 to 600 feet below land surface. The bulk of this ground-water reservoir is contained within the upper 300 feet of saturated rock (Hollyday, 1963). Below this depth, fissures and fractures decrease in open space, and solution cavities become almost non-existent. Recharge to the consolidated rock ground-water mass occurs by infiltration of precipitation through highly-fractured zones in the bedrock of the mountains and through alluvial recharge along washes in the valley areas. Water in the ground-water reservoir moves slowly down gradient, away from the mountain front, toward the San Pedro River and Whitewater Draw. The direction of ground-water flow within the Tombstone District is generally to the north in areas south of the city and to the west in areas north and east of the city. Discharge is as seepage outflow to the San Pedro River and as transpiration by phrentophytes in the river valley and along Whitewater Draw.

Hollyday (1963) has divided the Tombstone Mining District into four generalized hydrogeologic regions. The region of greatest yield and least drawdown is located to the northeast of Tombstone, in the area of valley alluvium which is, in turn, underlain by the Bisbee Formation. Region 2, including the PBR Minerals site, is the area of next highest yield, but is characterized by a greater specific drawdown. This region contains the thicker portions of the Bisbee Formation clastic rocks. Region 3 is the area of lowest yield and greatest drawdown within the mining district, and is underlain by predominately carbonate rocks adjacent to the impermeable Schieffelin Dome and Ajax Hill Horst. Region 4 is characterized by the Schieffelin Dome west of the Tombstone Syncline and the impermeable albite granites in the western part of the Ajax Hill Horst.

Ground-water development in the Tombstone Mining District has dealt primarily with efforts at dewatering, to allow deep mining. These efforts included empirical testing to estimate dewatering capability, along with the provision of water for milling operations. Only minor water development has occurred for municipal use.

The first known discovery of water was made in the Sulphuret Shaft in March, 1881 at an elevation of approximately 4,110 feet. The Sulphuret Shaft is immediately adjacent to the present open cut which was operated by the PBR Minerals predecessors. In April, 1882, the Grand Central Shaft encountered water at approximately the same elevation as that in the Sulphuret Shaft. Water was encountered at an elevation approximately the same in the Contention Shaft and the Head Center Shaft in the winter of 1882. The Emerald Shaft, located south of the main mining district, encountered water in 1988 at an elevation of approximately 4,090 feet, after the first efforts at pumping and dewatering had been in place. All these shafts are now within or immediately adjacent to the large open pit on the PBR Minerals site.

The first major efforts at dewatering were installed by the Grand Central Company during 1883, with a capacity of approximately 0.5 million gallons per day combined capacity. These pumps proved inadequate to lower the water to a significant depth, so an additional capacity of 1.5 million gallons per day was installed. At approximately the same time, the Contention Company installed an additional capacity of 1 million gallons per day. The two main companies were thus able to lower the water table approximately 100 to 130 feet during 20 months of pumping between May, 1884 and May, 1886 (Hollyday, 1963). By April, 1886, water had been encountered in the West Side workings in the northern part of the district, at an elevation of approximately 4,116 feet, and an average withdrawal of 153 gallons per minute resulted in an 11-foot drawdown. Water from the West Side workings were used for supply in the Girard Mill. During 1890 water was encountered in a winz at the bottom of the Lucky Cuss workings at an elevation of 4,110 feet. Dewatering at this site by means of pneumatic pumps and iron bailers succeeded in lowering the water table approximately 100 feet. This variety of experience demonstrated that successful dewatering would require the construction of a modern (for that time) pump plant of large capacity under centralized management.

Pumping and shaft sinking for a new Pump Shaft was begun in December, 1902. Apparently the plans were to reach the 1,000-foot level in less than two years; however, a four-year time period was required before the 1,000-foot level was actually reached. Interruptions to the steam power supply caused the ultimate submergence of the pumping equipment in June, 1909. Records indicate that the Pump Shaft produced 36,900 acre feet of ground water over the 8-year period, or an average of 2,830 gallons per minute, with a maximum pumpage of 5,280 gallons per minute for a 24-hour period. The pumpage resulted in a 440 drawdown during cross cutting operations on the 1,000-foot level. Efforts to regain the 1,000-foot level led to the ultimate termination of pumping

in January, 1911 and the resultant bankruptcy of the Tombstone Consolidated Mines Company.

Problems encountered during these dewatering operations were primarily related to the insufficient pumping capacity and problems associated with submergence of equipment during brief periods of power supply failure. Finally, the companies failed to take into account the vast quantity of water which would have to be pumped from storage during dewatering operations. Such dewatering operations were, of course, conducted before geohydrology theories were developed.

During 1954 and early 1955, Newmont Mining Corporation conducted an extensive dewatering operation, utilizing the West Side shaft to dewater the 600-foot level, provide water for diamond drilling, and test aquifer response. The dewatering operations were carefully monitored, utilizing the modern techniques of geohydrology. The West Side shaft produced an average of 505 gallons per minute for the first six months, and 41 gallons per minute for the remaining nine months. The water level was lowered approximately 35 feet in the West Side shaft, with a concomitant lowering of approximately 13 feet at an observation well one-third of a mile away. The main problem during this time was the clogging of pump intake screens with wood pulp and debris from the flooded workings.

The first recorded use of the ground water for municipal supply was in May, 1948, at which time Tombstone completed its 700-foot-deep Well #1 on the south side of town, to augment the municipal water supply derived from springs, located in Miller Canyon, during periods of low flow. Intermittent pumping of approximately 260 gallons per minute occurs during daylight hours on peak demand.

The various efforts at dewatering have been utilized to determine aquifer characteristics such as the coefficient of transmissibility (T) and the coefficient of storage (S). Assumptions implicit in hydrologic theory require that:

- The aquifer is homogeneous and isotropic;
- The well being tested completely penetrates the aquifer and is of infinitesimal diameter,
- The coefficient of transmissibility is constant in all places and at all times,
- The aquifer is bounded by impermeable strata both above and below,
- The coefficient of storage is constant and water is released instantaneously from storage with a decline in head,

- The flow to the well is laminar and radial or unidimensional in sectional view, and

- The aquifer is of infinite areal extent.

Geologic evidence indicates that none of these assumptions is actually valid in the Tombstone Mining District. In spite of the significant departures, the assumptions may be approximately fulfilled by taking into account the macro-scale fissure patterns and the interconnections formed by the extensive mine workings in the Tombstone Mining District. Hollyday (1963) concluded that the Tombstone aquifer complex may, indeed, be treated by hydrologic theory if observation well data is taken from tests of long duration. Hollyday utilized the existing pumping data to calculate transmissivities and storage coefficients. Table 5-1, adapted from Hollyday, provides information calculated on the various pumping efforts during the period from 1903 to 1955. Coefficient of transmissibility values range over a rather narrow range from 10,000 to 15,000 gallons per day per foot. The coefficient of storage ranges from a low of 0.003 to a high value of 0.2. Hollyday explained this rather wide range as a change in storage coefficient as the cone of depression spreads. In essence, the pumping efforts are significantly different depending on whether or not the interconnected workings are dewatered.

5.2.3 Ground-Water Utilization

Ground water is not generally used widely in the PBR Minerals area, as a result of the great depth to water, and the ready availability of an imported source of potable water from springs in Miller Canyon, supplied by the Town of Tombstone. Nearby ranches utilize windmills drawing from perched water masses in alluvium along various dry washes. Table 5-2 provides information on wells registered with the State of Arizona within at least a 3-mile radius of the proposed PBR site. These wells are located on Plate II-1

PBR Minerals currently maintains 3 wells in the vicinity of their existing wash facility. One of these (well #2, D-22-20-12ccd) is pumped continuously and used for makeup water at the facility. While no completion data are available on this well, it is located in the vicinity of numerous old mine workings, and probably draws water from old mine openings. The other two PBR Minerals wells (wells #1, D-22-20-12ccd, and #3, D-22-20-11ddb) are also in the general vicinity of mine workings; however, they are not pumped except on an intermittent basis, for water-quality sampling. As will be discussed in the following section, the water quality of wells #1 and #3 indicate they are not completed in as highly mineralized a rock mass as is well #2.

Ground water from the competent rock formations is withdrawn for supplemental municipal use by means of Tombstone Well #1 (D-22-11adb). As reported by Hollyday (1963), this 700-ft deep well was completed in May, 1948 and is pumped at a rate of 260 gpm during daylight hours during periods of peak demand. The Tombstone Well is located

approximately 1 mile north of and downgradient from the proposed PBR Minerals leach facility.

It is proposed that PBR Minerals construct a fourth well (D-22-20-13aad) in the area immediately north (downgradient) from the proposed leach facility. This well will be pumped continuously, thereby forming a cone of depression which will assure capture and detection of any ground-water degradation which might result from the proposed leach facility. Pumped water will be discharged into the barren pond, where it will serve as make up water for the leach facility.

5.2.4 Ground-Water Quality

Prior, published studies of the geohydrology of the Tombstone area have not addressed water quality to any significant detail. Hollyday (1963) makes no mention of water quality. Fortunately, PBR Minerals and its predecessors have collected water quality data, for selected parameters, over a long period of record. Occasionally samples have been collected and assayed for a more complete suite of parameters, by both PBR Minerals and the Arizona Department of Health Services.

Table 5-3 presents data on the concentration of mercury, nitrate, and total and free cyanide for the three PBR wells and Tombstone Well #1 during the period June 16, 1987 through May 5, 1988. These samples were collected by the PBR chemist or by personnel from Smith and Smith Laboratories, and analyzed by Smith and Smith Laboratories. The data are also plotted on Figure 5-1, with concentration shown as a function of time.

The data show that Wells #1 and 3 are generally of high quality. Well #2 is generally more mineralized, as a result of its location within the area of old mine workings. This is reflected by the relatively elevated values of mercury, with a mean concentration of 0.026 mg/l and a standard deviation of 0.006 mg/l for the period June, 1987 through April, 1988. This is 13 times the US EPA Primary Drinking Water standard of 0.002 mg/l, and doubtless reflects a long-term contamination associated with natural mineralization, perhaps exacerbated by historial use of mercury for precious-metals recovery. Mercury is not generally detected in PBR Wells #1 or #3, with only one detection value (caused by a contaminated sample container) in Well #3, and no detectable values in Well #1. The Tombstone well has only one, barely-detectable mercury value.

During prior Well #2 monitoring by the previous operator (T.E.I.), it was found that the well contained detectable free and total cyanide. There is no Federal drinking water standard for cyanide; however, Arizona uses a value of 0.20 mg/l total cyanide. It was believed that this contamination likely had resulted from prior use of cyanide for precious-metals leaching by prior tenants of the site. Elevated values of nitrate, in excess of the EPA Primary Drinking Water Standard, were also considered to be from the prior use of cyanide, as

cyanide can be oxidized to form nitrate. Nitric acid had also reportedly been used by a prior tenant.

On February 23, 1987, representatives of the Arizona Department of Health Services (ADHS) collected samples of water from Well #2, and from Tombstone Well #1, and analyzed these samples for major ions, nutrients, and trace metals. The sample from Well #2 (Table 5-4) was found to contain 0.200 mg/l total cyanide, but no detectable free cyanide. The "total" cyanide was probably present in the form of a stable metallic complex such as copper, iron, or nickel cyanide. Mercury was present at elevated levels of 0.0235 mg/l, which is consistent with PBR monitoring results, and nitrate was present at 27.3 mg/l, again generally consistent with the levels established by PBR monitoring. Best (July 9, 1987) indicates earlier sampling had detected up to 74.8 mg/l nitrate on May 8, 1986; thus the levels have declined somewhat.

The ADHS sample from Tombstone #1 did not detect mercury or cyanide. Nitrate was present at 10.32 mg/l, slightly in excess of the EPA Primary Drinking Water Standard.

Major-ion data from the two ADHS samples, collected February 23, 1987, were entered into a computer data base and used to generate trilinear plots (Piper diagrams) and Stiff plots (Figure 5-2 and 5-3). As shown by the diagrams, both waters are calcium bicarbonate types, with Well #2 showing somewhat greater concentrations of magnesium sulfate. This is consistent with the known mineralization in the area of the well. The reported potassium value of 410 mg/l apparently is a typographical error and should have been 4.10 mg/l. The reported value cannot be correct, and a value of 4.10 is consistent with the ion balance. Using 4.10 mg/l yields an ion balance of 1.3, whereas use of 410 mg/l yields an unacceptance ion balance of 3.98.

On May 5, 1988, samples of water were collected from PBR Wells #1 and #2 and from Tombstone Well #1 by personnel of Geochemical Engineering, Inc. and PBR Minerals, Inc. Prior to sampling, the wells were pumped to purge standing water in the well bore. Samples were collected directly from the wellhead into appropriately pre-preserved, clean sample containers and delivered to the analytical laboratories within 24 hours of sample collection.

In addition to the normal sample parameters, sample analysis was requested for all metals covered by Primary and Secondary Drinking Water Standards, and for major-ion concentrations. To provide quality control information on the existing data base from Smith and Smith labs, a blind duplicate sample was collected from PBR Well #2, intentionally misidentified as "PBR Well #6", and sent to Smith and Smith labs. An interlaboratory quality control sample was collected from Well #2 and submitted to Western Technologies, Inc. lab. For PBR Well #1 and Tombstone Well #1, interlaboratory duplicate samples were also collected for the two laboratories. Results of the May 5, 1988 sampling are provided on Table 5-5.

The interlaboratory and intralaboratory quality control duplicates indicate that Smith and Smith Labs (the prime lab that has been used in the development of the existing data base) are capable of producing data that agrees within the lab and between labs, and hence produce a credible data base.

The results from both labs confirm that the various wells comply with Drinking Water Standards, with the exception of mercury, nitrate and total dissolved solids in Well #2. The mercury and TDS are probably a result of natural mineralization in the rock around Well #2, while the nitrate is from both natural sources and prior waste-disposal practices in the vicinity.

Major-ion data from Western Technologies' results was used to plot trilinear and Stiff diagrams (Figures 5-4 and 5-5) for the 3 wells. As with the earlier ADHS results (Figures 5-2 and 5-3), the waters are calcium bicarbonate types, with Well #2 being a calcium (magnesium) sulfate bicarbonate type, reflecting the presence of mineralization in and adjacent to the old underground workings in the vicinity of the well. PBR Well #1 shows the least effect of mineralization; this despite the proximity of this well to a number of shafts. Tombstone Well #1 is an intermediate quality between the two PBR wells.

The data indicate that "background" values of nitrate are very close to the EPA Drinking Water Standard. Such a finding is not at all uncommon, especially in semiarid regions. Nitrate is "fixed" from atmospheric sources and flushed to the water table. Numerous investigations have documented the presence of nitrate salts and minerals in soils and rock material above the water table in arid regions. These investigations have also shown that nitrate salts can be leached by increasing infiltration of meteoric water or by elevation changes in the water table. In the case of the Tombstone Well, this may have been exacerbated by the prior disposal of sewage into old mine workings in the vicinity of the town well.

The data strongly indicated a relationship between prior use of cyanide at the site and observed elevated values of cyanide and nitrate in Well #2; however, this was not consistent with geochemical experience. While it is known that nitrate commonly is conservative (e.g., it moves at the same rate as ground water), the geochemical literature has documented that cyanide tends to form metallic complexes and not be mobile in the ground-water environment. It was thus difficult to explain how cyanide from the old processing facility could have migrated 500 feet to the water table, followed by a lateral migration of several hundred feet to report to Well #2.

This question was answered in a rather direct manner during April, 1988. During the process of removing contaminated clay from a prior liquid holding pond, an earth scraper broke through into a vertical shaft leading to abandoned mine workings connected to mine workings in the vicinity of Well #2. It is apparent that cyanide-bearing wastes had percolated through the clay covering the vertical shaft, moved

down the shaft, and reported to Well #2. Continued pumping of this well has returned the free cyanide to generally non-detectable levels. There have been annual peaks of free cyanide, probably associated with rainfall and resultant migration of recharge down the shaft. This should not be a future factor, now that the contaminated clay has been removed from around the shaft collar.

Table 5-1 Calculated Values of Transmissivity (T) and Storage Coefficient by Pumping Event Corrected for Schieffelin Grandodiorite Boundary (From Hollyday, 1963)

Date	Pumped Well	Observation Well	T, (gpd/ft)	S	Notes
1903-11	Pump Shaft	Emerald Shaft	12,000	0.0035	Drawdown
1903-11	Pump Shaft	Silver Thread Shaft	14,000	0.003	Drawdown
1903-11	Pump Shaft	West Side Shaft	12,000	0.003	Drawdown
1903-11	Pump Shaft	Pump Shaft	12,000	0.003	Drawdown (1)
1911-18	Pump Shaft	Pump Shaft	15,000	0.01	Recovery
1953-54	West Side Shaft	West Side Shaft	15,000	0.1 to 0.01	Drawdown (2)
1953-54	West Side Shaft	West Side Shafft	10,000	0.2	Recovery (3)

Notes: (1) Points selected for near steady-flow conditions
(2) Apparent change in S as cone expands
(3) Minor pumping during recovery period

6/27/88

Table 5-2

ARIZONA DEPARTMENT OF WATER RESOURCES WELL REGISTRATION REPORT
OPERATIONS DIVISION

Plate II-1 Key	QUAD	TOWN	RANGE	SECT	Q1	T2	R3	REG NO	NAME	WELL DEPTH	DEPTH CASED	COASEM	WATER LEVEL	YIELD (GPM)	WELL DRILL DATE
1	D	19.0	22.0	33	D	A	C	55-616263	AZ STATE LAND DEPT	0140	0140	06	0070	00013	0/00/1879
2	D	19.0	22.0	33	D	A	C	55-646126	PIONEER NAT TRUSTCO	0140	0140	06	0070	00015	0/00/1879
3	D	19.0	22.0	35	C	C	C	55-616264	AZ STATE LAND DEPT	0150	0150	06	0070	00013	0/00/1952
4	D	19.0	22.0	35	C	C	C	55-646121	PIONEER NAT TRUST CO	0150	0150	06	0070	00015	0/00/1879
5	D	19.0	22.0	35	D	D	C	55-632637	US DEPT OF AGRICULT	0314	0314	06	0233	00000	12/00/1966
6	D	19.0	23.0	31	C	C		55-603454	HOLIDAY ENT INC	0505	0505	08	0394	00100	3/00/1963
7	D	19.0	23.0	31	D	D	D	55-602550	HULL	0485	0485	06	0400	00010	0/00/1963
8	D	19.0	23.0	32	A	B	B	55-519329	BALL, STEPHAN	0650	0650	08	0595	00000	10/23/1987
9	D	19.0	23.0	32	B	A	C	55-520988	TAYLOR, JOHN	0590	0590	08	0470	00000	6/02/1988
10	D	19.0	23.0	35	A	C	C	55-616269	AZ STATE LAND DEPT	0600	0300	06	0250	00002	12/31/1925
11	D	19.0	23.0	35	A	C	D	55-616270	AZ STATE LAND DEPT	0300	0250	06	0250	00002	0/00/1920
12	D	19.0	23.0	35	A	C	D	55-646073	KENDALL	0300	0250	06	0250	00000	6/00/1920
X	D	20.0	22.0	01				55-650661	HANSEN	0376		08	0315	00000	
X	D	20.0	22.0	01				55-650365	MONESMITH	0080	0025	02	0020	00000	10/00/1952
13	D	20.0	22.0	01	C	A	A	55-616499	TOMBSTONE, CITY OF	0600	0465	06	0278	00300	11/04/1967
14	D	20.0	22.0	01	D	D	C	55-616500	TOMBSTONE, CITY OF	0890	0600	16	0333	00300	0/00/1976
15	D	20.0	22.0	03	A	A	A	55-609574	BARKLEY	0232	0232	08	0000	00008	0/00/1950
16	D	20.0	22.0	04	A	A	A	55-642799	ESCAPULE	0085	0085	08	0022	00020	8/00/1967
16	D	20.0	22.0	04	A	A	A	55-642798	ESCAPULE	0040			0022	00006	0/00/1890
17	D	20.0	22.0	08	D	D	B	55-642800	ESCAPULE	0212	0080	06	0160	00000	8/03/1935
18	D	20.0	22.0	09				55-507064	SANTA FE MINING INC					00000	
19	D	20.0	22.0	10	A	D	B	55-646123	PIONEER NAT TRUST CO	0150	0150	06	0070	00015	0/00/1879
20	D	20.0	22.0	10	D	C	B	55-644489	LEE	0060	0010	06		00000	0/00/1976
20	D	20.0	22.0	10	D	C	B	55-644490	LEE	0140	0010	06	0040	00060	10/29/1976
20	D	20.0	22.0	10	D	C	B	55-644491	LEE	0040		05	0035	00000	
20	D	20.0	22.0	10	D	C	B	55-644492	LEE	0270	0010	06	0035	00005	10/29/1976
21	D	20.0	22.0	11	A	D	B	55-616498	TOMBSTONE, CITY OF	0612	0511	04	0490	00225	0/00/1941
22	D	20.0	22.0	11	D	D	B	55-086448	TOMBSTONE DEVELOPMEN	0715	0715	06	0510	00100	1/10/1981
23	D	20.0	22.0	12	C	C	A	55-516482	TOMBSTONE DEVELOPT.	0800	0800	08	0440	00170	1/17/1987
24	D	20.0	22.0	12	C	C	D	55-505610	T I E INC	0620	0580	06		00000	6/30/1983
25	D	20.0	22.0	13	C	B	C	55-622882	CRIST	1000	1000	04	0550	00035	0/00/1945
26	D	20.0	22.0	15	A			55-642575	WINTERS					00000	
27	D	20.0	22.0	15	A	C		55-650957	CAN AMERICAN MINING					00000	
27	D	20.0	22.0	15	B	D		55-650956	CAN AMERICAN MINING					00000	
27	D	20.0	22.0	15	B	D	A	55-647089	ESCAPULE			06		00000	
28	D	20.0	22.0	16	A	A	C	55-647090	ESCAPULE			06		00005	
28	D	20.0	22.0	16	A	A	C	55-645012	CHARLOU CORP	0250			0200	00000	0/00/1967
29	D	20.0	22.0	16	A	C		55-601135	TOMBSTONE SILVER	0500	0000	05	0200	00020	7/00/1968
30	D	20.0	22.0	16	B	A	C	55-645011	CHARLOU CORP	0600	0500	05	0225	00020	0/00/1974
31	D	20.0	22.0	16	D	B	B	55-086097	ESCUPULE	0310	0289	06	0194	00040	0/00/1980
32	D	20.0	22.0	16	D	D	C	55-645015	ESCAPULE	0262	0250	04	0195	00005	0/00/1963
33	D	20.0	22.0	17	A	A	A	55-647092	ESCAPULE					00000	
34	D	20.0	22.0	18	D	A	A	55-646124	PIONEER NAT TRUST CO	0150	0150	06	0070	00015	0/00/1879
35	D	20.0	22.0	18	D	A	A	55-616334	AZ STATE LAND DEPT	0150	0150	06	0070	00013	0/00/1879
36	D	20.0	22.0	20	B	C	D	55-804769	ALANCO LTD				0100	00000	0/00/1969
37	D	20.0	22.0	23	A	B		55-649056	IRVINE					00000	
38	D	20.0	22.0	23	B			55-642573	WINTERS					00000	
39	D	20.0	22.0	23	B			55-642574	WINTERS					00000	
40	D	20.0	22.0	23	B	B		55-649054	SILVER RIDGE MINING	1000	1000	04	0425	00035	0/00/1980
40	D	20.0	22.0	23	B	B		55-649055	SILVER RIDGE MINING					00000	
40	D	20.0	22.0	23	B	B	B	55-085566	SILVER RIDGE MINING	1000	1000	04	0420	00000	9/02/1980
41	D	20.0	22.0	29	A	B	D	55-616335	AZ STATE LAND DEPT	0140	0140	06	0070	00013	0/00/1879
42	D	20.0	22.0	29	A	B	D	55-646125	PIONEER NAT TRUST CO	0140	0140	06	0070	00015	0/00/1879
43	D	20.0	22.0	30	C	A	A	55-616336	AZ STATE LAND DEPT	0035	0035	06	0010	00013	0/00/1879
43	D	20.0	22.0	30	C	A	A	55-646122	PIONEER NAT TRUST CO	0035	0035	06	0010	00015	0/00/1879
44	D	20.0	23.0	08	B	A	A	55-619135	COWON	0427	0436	06	0362	00015	5/30/1934
45	D	20.0	23.0	29	D	C	C	55-511150	WHITE	0350	0350	08	0175	00015	11/01/1985

Table 5.3

PBR MINERALS TOMBSTONE, ARIZONA

WATER QUALITY DATA
Smith & Smith Lab

		Well #1				Well # 2				Well #3				Tombstone #1			
				Cyanide				Cyanide				Cyanide				Cyanide	
Day of Sample	Date Sampled	Mercury mg/l	Nitrate mg/l	Total mg/l	Free mg/l	Mercury mg/l	Nitrate mg/l	Total mg/l	Free mg/l	Mercury mg/l	Nitrate mg/l	Total mg/l	Free mg/l	Mercury mg/l	Nitrate mg/l	Total mg/l	Free mg/l
1	6/16/87	0.001	2.6	<.01	<.01	0.026	8.9	0.05	<.01					0.0011	5.8	<.01	<.01
38	7/24/87	<0.001	1.5	<.01	<.01	0.026	7.0	0.13	0.02					<.001	8.6	<.01	<.01
51	8/6/87	<0.001	2.0	<.01	<.01	0.024	6.7	0.13	0.03	<0.001	2.5	<0.01	<0.01	<.001	7.5	<.01	<.01
64	8/19/87					0.024	10.9	0.07	NS								
85	9/9/87	<0.001	2.3	<.01	<.01	0.026	9.0	0.08	0.01	<0.001	6.2	<0.01	<0.01	<.001	6.0	<.01	<.01
100	9/24/87					0.0264	12.4	0.13	<0.01								
113	10/7/87	<0.001	3.0	<.01	<.01	0.020	22.3	0.12	0.01					<.001	2.5	<.01	<.01
119	10/13/87									<0.001	8.7	<0.01	<0.01				
127	10/21/87					0.0235	22.3	0.08	0.01								
141	11/4/87	<0.001	2.6	<.01	<.01	0.028	24.9	0.13	0.02	<0.001	10.1	<0.01	<0.01	<.001	9.4	<.01	<.01
155	11/18/87					0.0297	16.3	0.09	0.02								
170	12/3/87	<0.001	3.3	<.01	<.01	0.026	28.8	0.04	0.01	0.0166*	17.4*	0.02*	<0.01	<.001	8.6	<.01	<.01
180	12/21/87					0.034	24.2	0.13	0.01								
204	1/6/88	<0.001	4.0	<.01	<.01	0.0386	23.5	0.14	<.01					<.001	9.1	<.01	<.01
216	1/18/88					0.029	22.6	0.09	0.01	<0.001	10.2	<0.01	<0.01				
232	2/3/88	<0.001	2.2	<.01	<.01	0.020	23.4	0.14	0.01					<.001	8.6	<.01	<.01
247	2/18/88					0.020	31.5	0.12	<.01								
261	3/3/88	<0.001	3.9	<.01	<.01	0.020	18.5	0.11	<.01					<.001	7.1	<.01	<.01
289	3/31/88					0.024	23.4	0.20	0.03								
295	4/6/88	<0.001	2.8	<.01	<.01	0.027	23.0	0.18	0.02					<.001	8.2	<.01	<.01
309	4/20/88					0.030	22.9	0.08	<.01								
323	5/4/88					0.034	17.8	0.18	0.02					<0.001	8.1	<0.01	<0.01
324	5/5/88	<0.001	2.4	<.01	<.01	0.025	-	0.15	0.01					<0.001		<0.01	<0.01
						0.028**		0.16**	0.01**								
338	5/18/88					0.034	21.2	0.12	<0.01								
	Mean:		2.717			0.027	19.159	0.117	0.015		9.18				7.46		
	Std. Dev.:		0.741			0.005	7.101	0.041	0.008		4.96				1.93		

* Contaminated Sample Container, data invalid ** Duplicate Sample

Table 5-4

Results of Chemical Analysis

(in mg/l unless noted)

Arizona Department of Health Services

February 23, 1987 Sampling

PBR Minerals, Tombstone, Arizona

Parameter	Tombstone Well #1	PBR Minerals
Major Ions & General		
pH (units)	7.4	7.0
Conductivity (u mhos)	611	733
Calcium	72.7	91.7
Magnesium	20.3	26.9
Sodium	32.6	24.7
Potassium	3.67	410 (?)
Carbonate	<2	<2
Biocarbonate	235	183
Sulfate	50.4	81.4
Chloride	36.6	50.1
TDS	410	481
Alkalinity, Total	193	150
Alkalinity, Phenophthalien	<2	<2
Fluoride	2.08	2.17
Nitrate and Nitrite	10.35	27.3
TKN	<0.05	0.96
Metals and Trace Elements		
Arsenic	<0.020	<0.020
Barium	<0.10	<0.10
Beryllium	<0.0005	<0.0005
Boron	0.10	<0.10
Cadmium	<0.0010	0.0012
Chromium	<0.01	<0.01
Copper	<0.01	<0.01
Iron	<0.01	0.13
Lead	<0.02	<0.02
Manganese	<0.05	0.05
Mercury	<0.0005	0.0235
Selenium	<0.005	0.0052
Silver	<0.005	<0.005
Zinc	<0.05	0.255
Cyanide		
Total	<0.016	0.200
Free	<0.016	<0.016

Table 5-5
Interlaboratory Comparison
May 5, 1988 Sampling of PBR Minerals Wells
Tombstone, Arizona
(Western Technologies, Inc. and Smith & Smith)

Well Identity	Well #1		Well #2			Town of Tombstone Well #1		
Laboratory:	W.T.	Smith	W.T.	Smith	Smith Dup	W.T.	Smith	Drink Wtr Standards
Time Sampled:	- 09:25 -		- 09:09 -			- 10:00 -		
Laboratory Results (mg/l unless noted)								
Arsenic, Total	<0.02		<0.02	<0.01	<0.01	<0.02	<0.01	0.05
Barium, Total	<0.1		<0.1	<0.5	<0.5	<0.1	<0.5	1.0
Cadmium, Total	<0.005		<0.005	<0.01	<0.01	<0.005	<0.01	0.01
Calcium, Total	54		130	141.1	146.4	72	92.3	-
Chromium, Total	<0.02		<0.02	<0.05	<0.05	<0.02	<0.05	0.05
Copper, Total	<0.05		<0.05	<0.05	<0.05	<0.05	<0.05	1.0(2)
Iron, Total	<0.01		<0.01	<0.1	<0.1	<0.01	<0.1	0.3(2)
Lead, Total	<0.02		<0.02	<0.05	<0.05	<0.02	<0.5	0.05
Magnesium, Total	15.0		36.0	25.0	26.3	20.0	16.2	-
Manganese, Total	0.05		<0.05	<0.05	<0.05	<0.05	<0.05	0.05(2)
Mercury	<0.001		0.027	0.029	0.028	<0.001	<0.001	0.002
Potassium, Total	4		6	8.1	8.2	5	3.9	-
Selenium, Total	<0.01		<0.01	-	-	<0.01	-	0.01
Silver, Total	<0.02		<0.02	<0.025	<0.025	<0.02	<0.025	0.05
Sodium, Total	17		2.6	32.0	32.0	29	39.0	-
Zinc, Total	<0.05		0.08	0.04	0.05	<0.05	0.02	5.0(2)
Alkalinity,Ttl.	163		157	-	-	180	-	-
Bicarbonate	199		192	-	-	220	-	-
Carbonate	<2		<2	-	-	<2	-	-
Chloride	12		44	107	108	33	98	250.0(2)
Cyanide, Total	<0.01	<0.01	0.18	0.15	0.16	<0.01	<0.01	-
Cyanide, Free	<0.01	<0.01	<0.04	<0.01	<0.01	<0.01	<0.01	-
Fluoride	2.0		1.2	-	-	1.7	-	1.4-2.4(2)
Nitrate Nitrogen	1.9	2.4	23	-	-	8.2	-	10
Sulfate	26		160	173	174	47	39	250.0(2)
Total Dissolved Solids	282		666	-	-	414	-	500.0(2)

(1) Standard is Temperature Dependent
(2) Secondary Standard Only

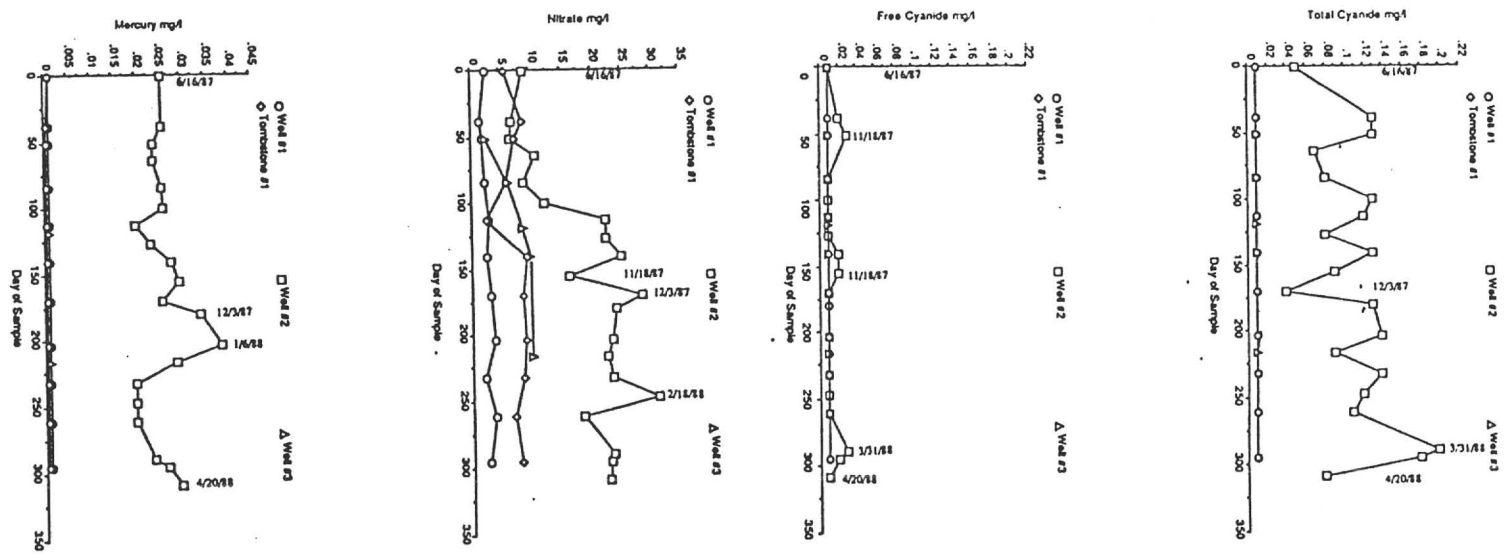


Fig. 5-1 Water-Quality Variation with Time,
PBR Minerals, Inc. Monitoring Data

No.	TDS	Well Name
1	452	Tombstone Well #1
2	463	Well #2

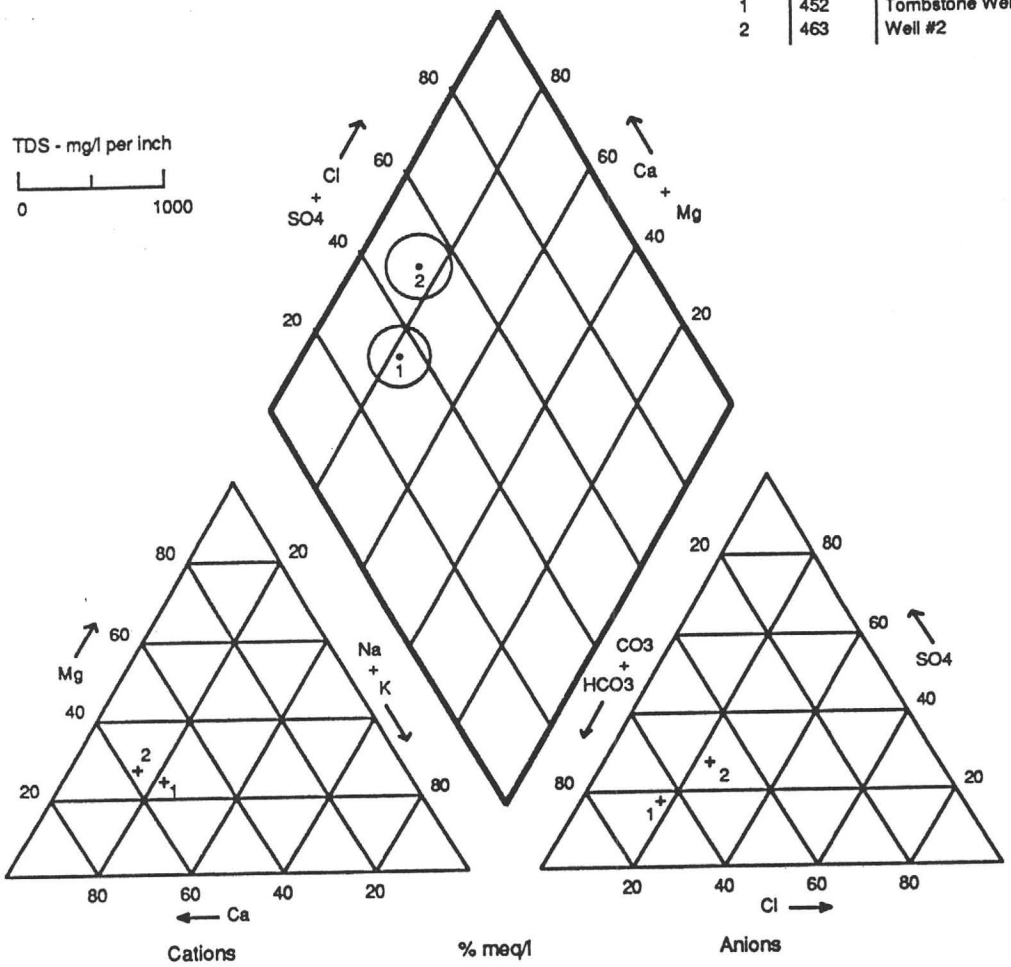


Fig. 5-2
ADHS DATA

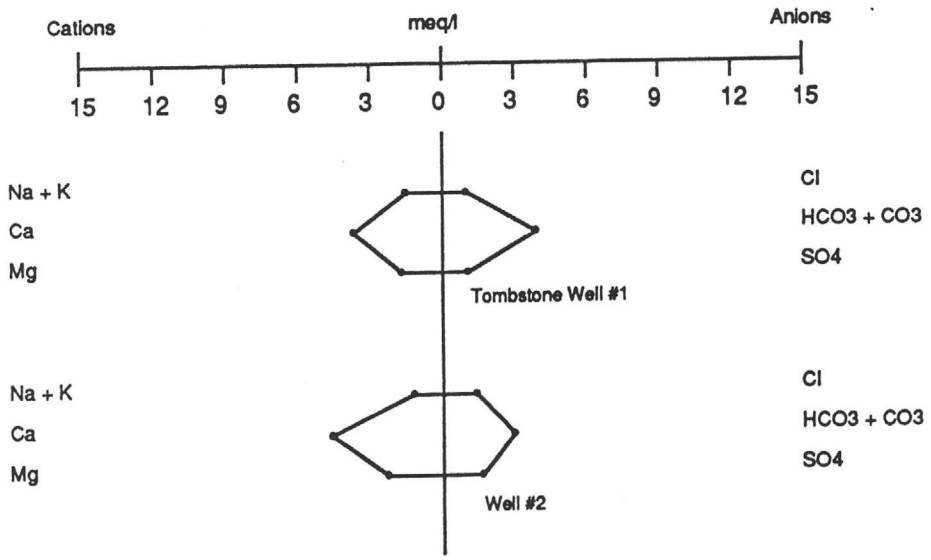


Fig. 5-3
PBR Minerals - Major Ions

PBR Minerals Tombstone, Arizona

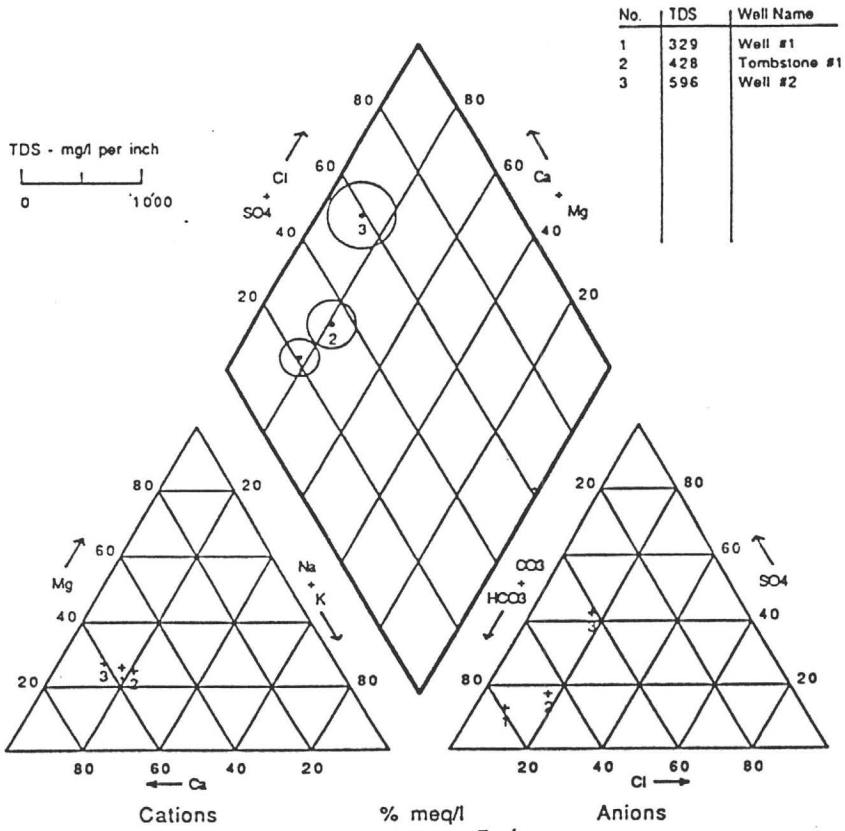


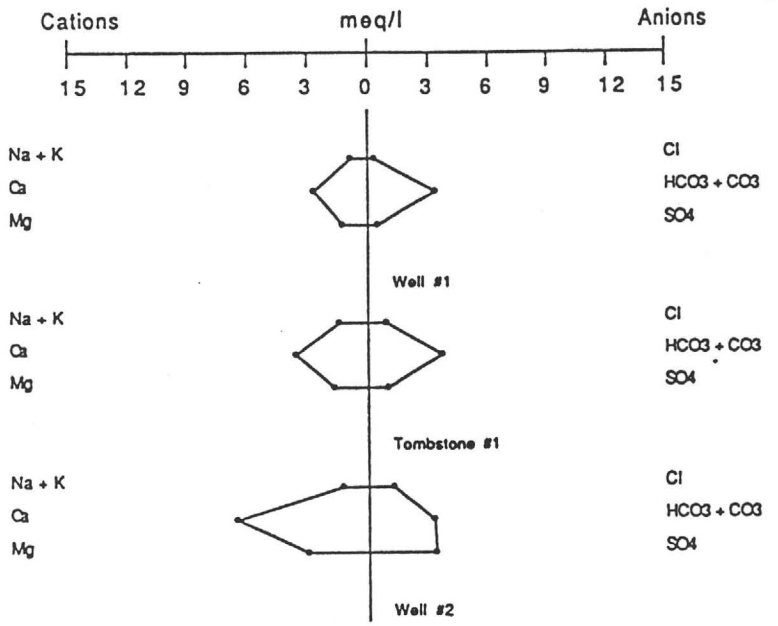
Fig. 5-4

May 5, 1988

Western Technologies Data

Fig. 5-5

PBR Minerals Tombstone, Arizona



SECTION 6

6.0 DISCHARGE IMPACT ASSESSMENT

The proposed PBR Minerals heap-leaching facility will not have an impact on the ground-water resource of the area, under any reasonably-foreseeable scenarios. This is because of the multiple, redundant protection offered by the multiple liners, the heap leach leak-detection facility, the geochemical attenuation capacity of the clay liner and the thick, unsaturated zone which occurs between the proposed facility and the water table. While an impact is not reasonably foreseeable for the above-stated reasons, should an unforeseen event occur and result in ground-water contamination, the potential impact will be further restricted by the proposed utilization of a pumped-monitoring well located immediately down gradient of the facility, as described in the following Section 7. Should such an impact occur, it would extend no further than the location of the proposed pumped monitor well, since such a well will form a cone of depression assuring capture of any potential contamination from the facility.

SECTION 7

7.0 MONITORING PLAN

As is noted earlier, at present there is no monitoring conducted in the immediate vicinity of the proposed heap leach operation. PBR Minerals currently maintains a monitoring program on the three existing PBR wells, together with the Town of Tombstone Well #1.

Because of problems associated with siting a single passive monitor well or series of wells to intercept potential flow paths in the fractured rock typical of the PBR facility, it is proposed that pumped monitor well technology be utilized. In the pumped monitor well approach, a single well is located in the area down gradient of the proposed facility, and pumped on a continuous basis to form a cone of depression in the water table. Such a cone of depression will assure that any contamination which escapes from the facility will report to the well and be detected.

The pumped monitor well approach is well suited for use of a phased monitoring technique, which draws upon the use of conservative major ions for indicator detection. Thus, it is proposed that the pumped monitor well will be monitored on a continuous basis by means of a recording conductivity meter. In addition, water-quality samples will be collected from the well discharge on a monthly basis, or in the event that the conductivity values indicates a major change. These samples will be analyzed for major ions (calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, nitrate and total dissolved solids). Samples will be collected on a quarterly basis for the geochemically-retarded contaminants of concern (total and free cyanide, arsenic and mercury). Samples will also be analyzed for cyanide, arsenic and mercury in the event that the conservative parameters record a change in water type.

Samples will be collected directly from the pumped monitor well discharge, placed in appropriately pre-preserved, clean sample containers and dispatched to certified water-quality laboratories for analysis in accordance with EPA-approved analytical methods. Results will be submitted to the State of Arizona within two weeks of their receipt by PBR Minerals. Quarterly samples will be sent to two separate labs, for quality-control purposes for the first two quarters of sampling, and once per year thereafter during the life of the mine operation. Monitoring shall continue as above for two years following closure of the mining and leaching operations.

SECTION 8

8.0 CONTINGENCY PLAN

As noted earlier, there is no reasonably-foreseeable geohydrological scenario associated with the PBR Minerals heap-leach facility which would result in the violation of ground-water standards or the exceedance of ambient water-quality conditions, whichever is greater. While a violation of these standards or ambient conditions is not anticipated, the proposed pumped monitor well approach is well-suited for contingency actions should monitoring detect that ground-water contamination has occurred. In such a case, the pumped monitor well would continue to be pumped, with water placed in the barren storage pond or, in the event of an indication of a leak, such water would be spray-irrigated onto the surrounding desert. The cone of depression would be maintained and the contaminants drawn into the well for removal to the surface. Spray irrigation onto the desert would result in degradation of cyanide should it be present, and would also result in immobilization of toxic metals by means of geochemical attenuation reactions with the surface material.

SECTION 9

9.0 CLOSURE AND POST-CLOSURE

9.1 Closure

Upon cessation of mining and leaching activities, water from the barren pond will continue to be pumped onto the last heap, without the addition of cyanide, and the resultant pregnant solution processed through the metals recovery plant so long as the precious metals values justify plant operation.

After values in the leachate drop below recoverable values, the contents of the barren pond will be treated with alkaline chlorination to degrade free cyanide. The neutralized solution will be sprayed onto the heap, to reduce cyanide levels in the barren heap. Alternatively, the barren solution may be treated with nutrients to promote biodegradation of residual cyanide. The final process selection will be dependent on the outcome of pilot testwork on biological degradation of cyanide.

Water from the barren pond will continue to be sprayed onto the heap, thereby facilitating cyanide degradation and evaporation, until pond contents are exhausted. The barren pond liner will then be removed and buried in the spent ore on the heap. The pregnant pond liner will be left in place, to serve as an evaporation pond for leachate from the pads.

9.2 Post-Closure

Upon the completion of closure activities, the monitoring program will be continued two years. Pumped water will be used for dust control and reclamation efforts, with sampling on a quarterly basis for the major ions. At the end of the two years (assuming no significant ground-water quality change) the pumps will be removed from the wells and a locking security cover installed. This would thus allow for additional future monitoring, by the re-installation of pumping equipment.

SECTION 10

10.0 REFERENCES CITED

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APPENDIX 1

GEOCHEMICAL EVALUATION

OF CLAY-SUBLINER MATERIAL

PBR MINERALS, INC.

AUGUST 3, 1988

GEOCHEMICAL ENGINEERING
INCORPORATED

1.0 PURPOSE AND SCOPE

This Geochemical Report was prepared in support of PBR Minerals' "Application for a Ground-Water Quality Protection Permit" for a gold mining and heap-leaching facility to be located south of the town of Tombstone, Cochise County, Arizona. The report summarizes the results and conclusions from laboratory testwork conducted to evaluate the geochemical attenuation ability of locally available clay-bearing material which is to be used in the construction of clay-subliners for process water impoundments and leach pads.

The principal objectives of the laboratory program were twofold:

(1) determine the mineralogical and geochemical properties of the clay-subliner material; and

(2) confirm through laboratory testwork whether the clay-subliner material can retard or attenuate the movement of chemical constituents that may be present in seepage.

2.0 INTRODUCTION

PBR Minerals, Inc. is submitting a permit application of operate a gold mining and heap-leaching facility in Cochise County, Arizona. The facility will include a conventional heap-leaching circuit, where crushed ore will be loaded on a low-permeability pad and leached with a dilute solution of sodium cyanide. Gold-bearing solutions collected from the heap leach will be treated to recover precious metals and then recycled. Spent ore will be neutralized and moved to a spent ore disposal area.

The leach pad and process water ponds will be lined with synthetic membranes which will be placed over compacted clay subliners. The clay subliners can serve two purposes. In addition to acting as a geotechnical barrier to seepage movement, the clay subliners can function as a geochemical barrier to contaminant migration. If the clay-subliner material has the right geochemical properties, the clay can interact with chemical constituents which may be present in seepage. Under the right conditions such interactions can lead to geochemical reactions that fix and immobilize constituents and remove them from solution. Examples of such geochemical mechanisms include cation- and anion-exchange, sorption, precipitation and coprecipitation. Performing in this way, a clay subliner can introduce one additional safeguard against contaminant migration. The spent ore disposal area will be lined with a similar clay, to protect against contamination from spent ore leachate.

3.0 GEOCHEMICAL PROGRAM

The geochemical program that was implemented for PBR Minerals was designed to complement geotechnical and geohydrological investigations at the site. The program consisted of laboratory analyses and testwork on clay-bearing material that was targeted for use in the construction of impoundment and leach pad subliners, as well as spent ore disposal area liners.

Specific objectives of the laboratory program included the following:

(1) prepare a synthetic heap-leach solution that resembled possible seepage solutions;

(2) determine the mineralogical and geochemical properties of the clay-subliner material; and

(3) evaluate in sequential batch tests the ability of the clay-subliner material to act as a geotechnical trap and retard the migration of chemical constituents present in seepage.

3.1 Preparation of Heap-Leach Solution

The synthetic cyanide solution which was utilized in the clay subliner evaluation studies was prepared at Core Laboratories, Aurora, Colorado, from samples of ore and well water provided by Mr. Gary Lindroos, Technical Superintendent, PBR Minerals, Inc. Care was taken to assure that the heap-leach solution would be representative of the heap-leaching practices anticipated at PBR Minerals. The solution was synthesized from actual ore that will be processed in the PBR Minerals heap-leach circuit and by using water from the No. 2 well at the site. Cyanide and lime were added in proportions that would duplicate leaching conditions in the heap. The matrix that PBR Minerals anticipates using is 1 pound NaCN and 4 pounds lime per ton of ore.

Duplicating this matrix, the heap-leach solution was prepared by agitating a mixture of 10 pounds of ore composite, 9 grams of lime, 2.5 grams of NaCN in 10

liters of water, for about 24 hours. The procedure is described in more detail in the testwork protocols included with the analytical report from Core Laboratories that is appended to this report. At the conclusion of the procedure, the mixture was settled and the cyanide solution was decanted. Chemical analysis of this synthetic heap-leach solution is presented in Table 3-1.

The solution that is profiled in Table 3-1 resembles the heap-leach fluids that would come into contact with clay-subliner material in the unlikely event of liner leakage. The solution is alkaline (pH 11.6), enriched in cyanide concentrations, and contains traces of arsenic, cadmium, and mercury. The synthetic cyanide solution contains silver at a concentration of 2.03 mg/l. This concentration of silver reflects the fact that no attempt was made to recover the precious metal from solution. Silver and gold will be recovered during commercial plant operations.

3.2 Geochemical Characterizations of Clay-Subliner Materials

A sample of the clay-subliner material was analyzed for mineralogical and geochemical properties at Core Laboratories, Aurora, Colorado. Mineralogical identification consisted of quantitative x-ray diffraction analysis to determine bulk mineralogy and relative clay abundances. Geochemical evaluation involved laboratory analyses of the sample for geochemical properties to include the following:

- cation-exchange capacity and exchangeable cations
- acid-soluble iron and manganese
- organic carbon content
- soil pH
- base neutralizing potential

3.2.1 Mineralogical Properties

The x-ray diffraction analyses completed on the bulk sample and on the clay-size fraction are summarized in Table 3-2. The analysis indicates that the subliner material is calcareous and contains various clay minerals. The mineral calcite ($CaCO_3$) constitutes the major percentage (46% by weight) of the bulk material. Clay minerals constitute a smaller but significant fraction

(24% by weight). The principal clay-forming minerals in this fraction are the mixed-layer smectite or montmorillonite type of clay minerals. Kaolinite and illite make up a minor percentage of the total clay-mineral phase.

3.2.2 Geochemical Properties

The results of geochemical analyses completed on the clay-subliner sample are presented in Table 3-3. The size of the clay-size fraction was determined by qualitative clay separation techniques. Cation-exchange capacity was measured by using the sodium acetate extraction procedure; exchangeable bases were determined by using a soluble cation extraction procedure in combination with an ammonium acetate extraction procedure. Organic carbon was analyzed using a modified Walkley-Black acid-digestion method, and the amount of iron and manganese hydrous oxides present was estimated by soaking the sample in dilute hydrochloric acid and measuring the iron and manganese that were solublized in the process.

The clay-subliner sample contains about 35 percent clay-size material and shows a moderate cation-exchange capacity (14.7 meq/100 g). Calcium is the predominant exchangeable cation, suggesting that any smectite or montomorillonite clay is calcium saturated. The discrepancy between the reported exchangeable calcium and the total cation-exchange capacity of the sample is related to the presence of $CaCO_3$ in the material. Calcium-bearing minerals such as calcite are slightly soluble in the ammonium acetate solution that is used in the exchangeable cation procedure. Dissolution of the calcite interferes in the exchangeable calcium analyses.

As expected, the clay-subliner sample is low in organic carbon content (0.11% by weight). The results of iron analyses suggest that traces of iron hydrous oxides may be present in the material. The soil pH of the clay-subliner sample is near-neutral. However, the sample shows an ability to neutralize the pH of alkaline solutions.

3.2.3 Geochemical Evaluation

Overall, the clay-subliner sample shows very favorable mineralogical and geochemical properties. The properties suggest that the clay-subliner material can geochemically interact with seepage solutions and immobilize potential ground-water contaminants.

The material is enriched in clay minerals, especially in mixed-layer type clays such as montmorillonite. Montmorillonite-type clays are well known for their

ability to undergo cation- and anion-exchange reactions with chemical constituents and to immobilize potential ground-water contaminants. Likewise, the material contains traces of organic carbon and iron hydrous-oxide impurities which can be beneficial. Organic carbon can act as a chemical reducing agent and the iron hydrous oxides can scavange and sorb chemical constituents from ground water.

Although the soil pH of the clay-subliner sample is slightly alkaline, the material has the ability and capacity to neutralize the alkaline pH of potential cyanide seepage solutions. By neutralizing the alkaline pH, conditions are established that promote degradation or attenuation of cyanide. Cyanide volatilization becomes significant when the pH of seepage solution is reduced below approximately 9.4; sorption of cyanide by natural clay-bearing materials is more efficient at less alkaline pH.

3.3 Sequential Batch Testwork

Sequential batch testwork is a laboratory procedure that is commonly used to evaluate the attenuation ability of clay-liner materials. Sequential batch testwork is described in more detail by Houle and Long (1980). The procedures simulate continuously leached columns wherein successive seepage solution comes in contact with fresh clay-subliner material that can effect attenuation of potential contaminants. The procedure can simulate years of potential field seepage through a clay subliner in a few days of laboratory testwork.

3.3.1 Testwork Procedures

A schematic of the sequential batch test that was designed for the PBR Mineral's geochemical program is illustrated in Figure 3-1. The procedures consisted of mixing measured portions of clay-subliner material and the synthetic heap-leach solution discussed in section 3.1 and gently agitating the slurry in rolling bottles for a period of 24 hours. At the conclusion of each test in the series, the solution was sampled for chemical analysis and, after filtering, the liquid and solid portions were advanced in sequence according to the matrix illustrated in Figure 3-1.

3.3.2 Discussion of Results

Table 3-4 summarizes the results of chemical analyses completed on leachate samples from each batch test. The results are reported on a dissolved basis since leachate samples were filtered through 0.45 um prior to analysis. For comparison purposes, the chemical profile of the synthetic heap-leach solution used in the testwork is included in Table 3-4.

The pH measurements presented in Table 3-4 clearly show the pH buffering capacity of the clay-subliner material. Contact of the heap-leach solution with the clay material in each test neutralized the alkalinity of the solution from pH 11.6 to pH of about 8-9. As expected, the greatest amount of neutralization was observed in batch tests A1, A2, and A3, where the solution to solids ratio was 1:1. However, the alkalinity (pH 11.6) of the heap-leach solution was reduced significantly even in batch test C1 (pH 9.31), where the solution to solids ratio was 3:1. By neutralizing the alkalinity of the heap-leach solution, pH conditions are established that promote the functioning of geochemical mechanisms which remove potential ground-water contaminants from solution.

The arsenic, cadmium, and mercury analyses summarized in Table 3-4 confirm that the clay-liner material is capable of scavenging heavy metals and removing chemical constituents from solution. Arsenic, for example, which was present in the heap-leach solution at a concentration of 0.07 mg/l was not detected in most of the samples from the batch tests. The solutions from batch test A1 and B2 did report 0.01 mg/l arsenic. Arsenic will be immobilized from solution by any number of geochemical mechanisms. Under neutral to slightly acid pH conditions, arsenic in the form of the monovalent arsenate ($H_2AsO_4^{-1}$) anion will undergo exchange with montmorillonite-type clays. In addition to anion exchange with clay minerals, arsenic is likely to undergo adsorption and precipitation reactions with common clay impurities. For example, arsenic may be adsorbed on hydrous oxides of iron or may be precipitated as an insoluble arsenate by metals such as iron, copper, or zinc. Similar geochemical mechanisms (cation-exchange, adsorption, and precipitation) were probably responsible for removing cadmium and mercury from the heap-leach solution during the batch testwork. The effectiveness of these reactions are illustrated by the chemical analyses of leachate samples A1, A2, and A3.

The capacity of the clay-subliner material to attenuate the movement of arsenic, cadmium, and mercury is indicated by the calculations summarized in Table 3-5. The table lists the amounts of arsenic, cadmium, and mercury that were removed from the heap-leach solution by 500 g of the clay-subliner material during batch tests A1, B1, and C1. The calculations indicate that the clay-subliner material is capable of sorbing at least 0.41 mg/kg arsenic, 0.21 mg/kg cadmium, and 0.27 mg/kg mercury. The capacity estimate is conservative since the attenuation properties of the clay-subliner sample were not exhausted during the course of the testwork. Even after two prior contacts with heap-leach solution, the sample in batch test C1 continued to remove arsenic, cadmium, and mercury from solution. These results suggest that the ultimate capacity of the clay-subliner material for immobilizing arsenic, cadmium, and mercury is even greater.

Neutralizing the alkaline pH of the heap-leach solution had a pronounced effect on the cyanide concentrations reported in the batch test solutions. Prior to contact with clay-subliner material, the synthetic heap-leach solution used in the sequential batch testwork contained over 100 mg/l cyanide. With each contact, the concentrations of cyanide were reduced. The solution sample from batch test A3 reported about 16 mg/l total cyanide and about 4 mg/l WAD cyanide. These concentrations represent a decrease of 86 and 97 percent in the total and WAD cyanide levels, respectively, from the start of the batch tests.

Volatilization is a major physiochemical mechanism that will degrade and retard the movement of cyanide through the clay subliner. Neutralizing the alkaline pH of the heap-leach solution reduces the pH into a range where significant cyanide volatilization can occur. Cyanide volatilization becomes significant when the pH is reduced below 9.4.

TABLE 3-1
CHEMICAL ANALYSIS OF SYNTHETIC HEAP-LEACH SOLUTION

PARAMETER	CONCENTRATION, in mg/l
pH (units)	11.6
Arsenic	0.07
Barium	0.06
Cadmium	0.09
Chromium	<0.01
Lead	<0.01
Mercury	0.0474
Selenium	0.04
Silver	2.03
Total Cyanide	115.
Free Cyanide	120.
Weak-Acid-Dissociable Cyanide	138.

TABLE 3-2
MINERALOGICAL PROPERTIES OF CLAY-SUBLINER SAMPLE

CONSTITUENT	BULK MINERALOGY (wt %)	
Quartz	24	
Feldspar	06	
Plagioclase		02
K-Feldspar		04
Calcite	46	
Clay Minerals	24	
	100%	

CONSTITUENT	RELATIVE CLAY ABUNDANCES (wt %)
Kaolinite	09
Chlorite	---
Illite	16
Mixed-layer, Illite/Smectite	75
	100%

TABLE 3-3
GEOCHEMICAL PROPERTIES OF CLAY-SUBLINER SAMPLE

PARAMETER	UNITS	VALUE
Moisture (Air-Dry)	%	4.13
Clay Content	%	35.0
Cation-Exchange Capacity	meq/100g	14.7
Exchangeable Cations:		
Calcium	meq/100g	39.3
Magnesium	meq/100g	3.64
Sodium	meq/100g	1.07
Potassium	meq/100g	0.23
Acid-Soluble Iron	%	0.61
Acid-Soluble Manganese	%	0.02
Total Organic Carbon	%	0.11
Soil pH	pH units	7.58
Base Neutralizing Potential		

TABLE 3-4

CHEMICAL ANALYSES OF SOLUTIONS FROM SEQUENTIAL BATCH TESTS

PARAMETER	SYNTHETIC HEAP-LEACH SOLUTION	CONCENTRATION, in mg/l					
		A1	A2	A3	B1	B2	C1
pH (pH units)	11.6	7.90	7.31	7.51	9.03	8.28	9.31
Arsenic	0.07	0.01	<0.05	<0.05	<0.01	0.01	<0.01
Cadmium	0.09	0.02	0.01	<0.01	0.05	0.03	0.07
Mercury	0.0474	0.001	<0.0025	0.0005	0.0008	0.0006	0.0042
Total Cyanide	115.	72.8	41.6	15.8	98.8	55.2	87.6
Free Cyanide	120.	92.4	37.2	16.6	95.6	62.8	100.
Weak-Acid Dissociable Cyanide	138.	83.6	33.2	4.2	81.6	50.0	83.6

TABLE 3-5
CAPACITY OF CLAY-SUBLINER MATERIAL TO ATTENUATE
ARSENIC, CADMIUM AND MERCURY

BATCH TEST	LIQUID TO SOLIDS RATION	AMOUNT ATTENUATED, IN MG ARSENIC	CADMIUM	MERCURY
A1	0.5	0.030	0.035	0.0233
B1	1.0	0.070	0.040	0.0466
C1	1.5	0.105	0.030	0.0648
	TOTAL:	0.205	0.105	0.1347
	ATTENUATION CAPACITY:	0.41 mg/kg	0.21 mg/kg	0.27 mg/kg

SEQUENTIAL BATCH TESTWORK - PBR MINERALS, INC.

CLAY - SUBLINER SAMPLE

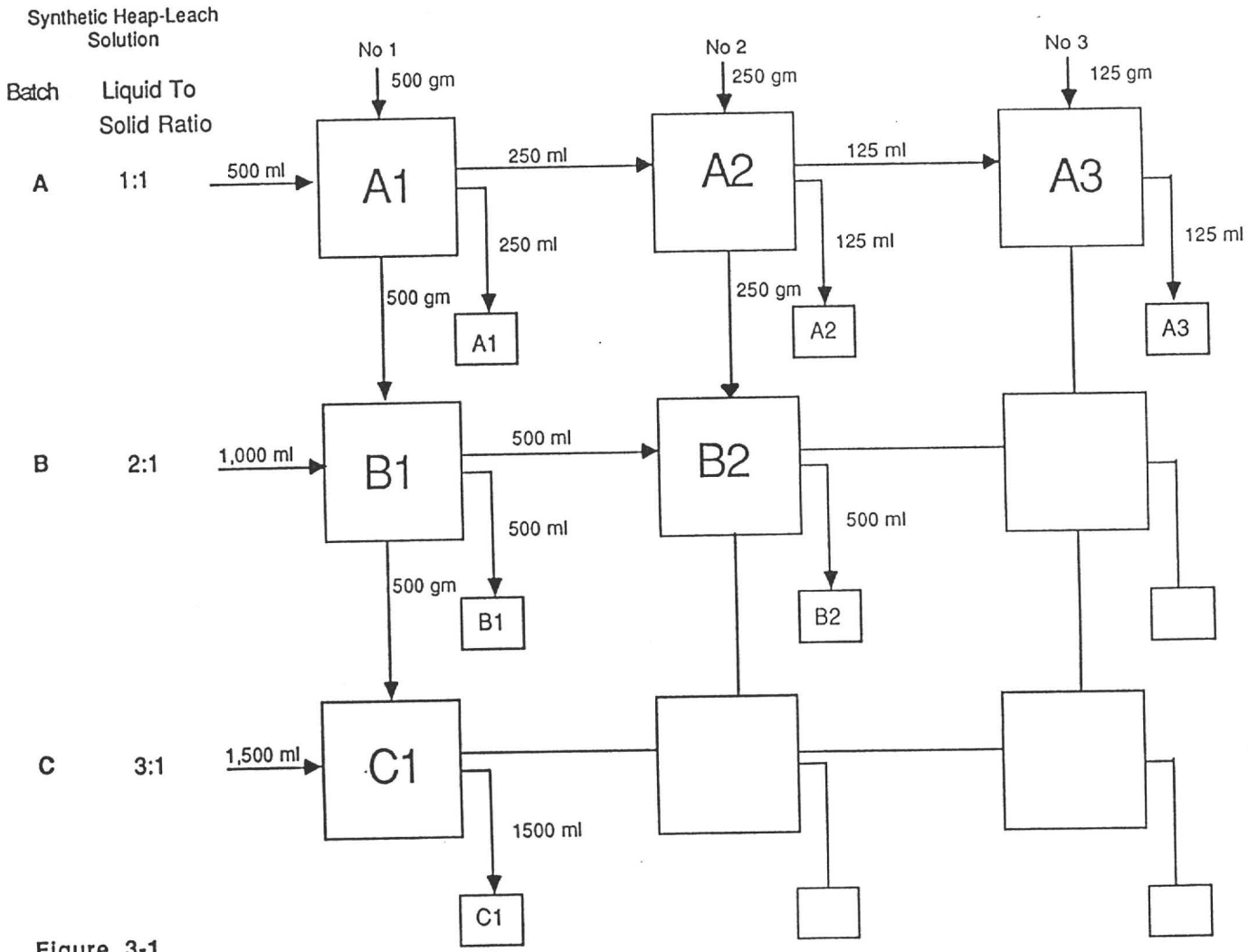

Figure 3-1

GEOCHEMICAL ENGINEERING INCORPORATED

4.0 CONCLUSIONS

The results of the geochemical analyses and the sequential batch testwork lead to the following conclusions:

1. The mineralogical and geochemical properties of the clay-subliner sample are typical of natural materials which retard or attenuate the movement of chemical constituents.

2. The principal clay-forming minerals in the clay-subliner sample are smectite or montmorillonite-type clays. Trace amounts of organic carbon and iron hydrous-oxides are present in the material. Most importantly, the clay-subliner material is capable of neutralizing the alkaline pH of heap-leach solutions.

3. By neutralizing alkalinity, favorable pH conditions are established which promote the functioning of geochemical mechanisms which immobilize heavy metals such as arsenic, cadmium, and mercury, and degrade or volatilize cyanide.

4. Sequential batch testwork confirms that the clay-subliner material will interact with any unlikely seepage and is able to attenuate potential ground-water contaminants such as arsenic, cadmium, mercury, and cyanide.

TESTWORK PROTOCOLS

PBR MINERALS

A. LABORATORY PREPARATION OF HEAP-LEACH SOLUTION

PROCEDURE:

1. Air-dry, mix and composite ore sample;
2. Weigh 10 pounds of ore composite and transfer to leach vessel;
3. Introduce 10 liters of water from No 2 well, and agitate mixture (0.31% solids);
4. Measure pH of mixture after about 15 minutes of agitation;
5. Add 9 grams of lime ($Ca(OH)_2$) to mixture amd agitate;
6. Measure pH of mixture after about 15 minutes of agitation;
7. If pH is alkaline (>9.0), add 2.5 grams of NaCN and agitate;
8. Measure pH of mixture after first 15 minutes and each 2 hours thereafter (during first 8 hours of mixing);
9. Agitate for 24 hours;
10. Let stand , measure pH and decant clear solution for use in sequential batch-contact tests.

B. GEOCHEMICAL CHARACTERIZATION OF CLAY-LINER MATERIAL

PROCEDURE:

1. Air-dry, mix and composite clay-liner sample;
2. Analyze composite sample for the following:
   a. Cation-exchange capacity and exchangeable cations;
   b. soil pH and base-neutralizing potential;
   c. organic carbon content;
   d. acid-soluble iron and manganese content
   e. clay-sized material
   f. bulk-mineral analysis and clay-mineral analysis

C. SEQUENTIAL BATCH-CONTACT TESTS

PROCEDURE:

1. As of Figure 1

SEQUENTIAL BATCH TESTWORK - PBR MINERALS, INC.

CLAY - SUBLINER SAMPLE

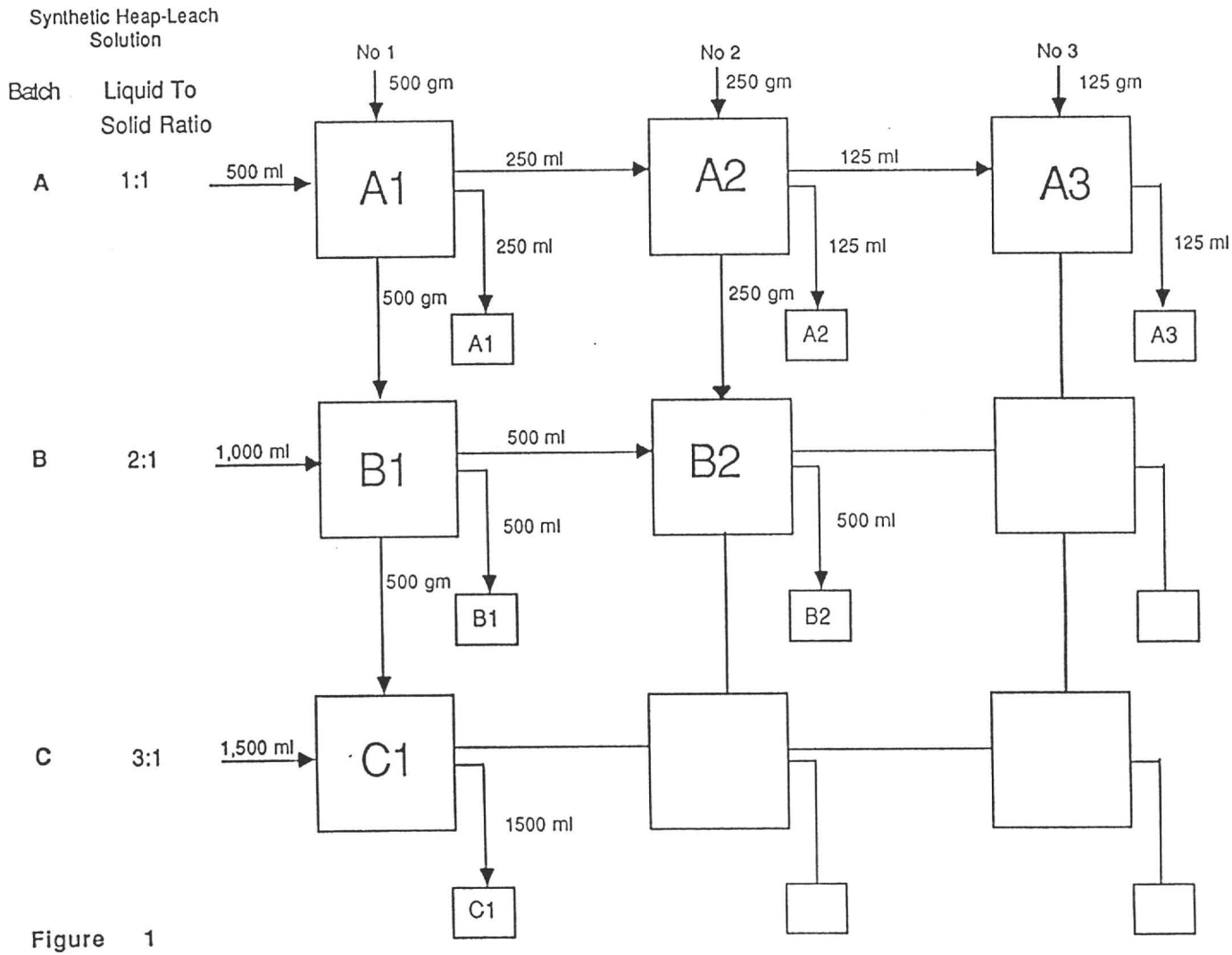

Figure 1

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Western Atlas International
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CORE LABORATORIES

Analytical Report

880487

GEOCHEMICAL ENGINEERING INCORPORATED

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CORE LABORATORIES

ANALYTICAL REPORT

July 14, 1988

Client Sample I.D.		KBR Minerals Ore Sample	KBR Minerals Clay Liner
Lab Sample I.D. (880487)		#1	#2
PARAMETER	UNITS		
% Moisture-Air Dry	%	3.21	4.13
* Soil pH (1:1 paste)	pH Units	----	7.58
Cation Exchange Cap.	meq/100gm	----	14.7
Exchangeable Cations			
Calcium	meq/100gm	----	39.3
Magnesium	meq/100gm	----	3.64
Sodium	meq/100gm	----	1.07
Potassium	meq/100gm	----	0.23
Acid Soluble Fe	%	----	0.61
Acid Soluble Mn	%	----	0.02
Organic Carbon (W.B.)	%	----	0.11
Clay Content	%	----	35.0
Base Neutralizing Cap.	meq/gm	----	6.4

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CORE LABORATORIES

ANALYTICAL REPORT

July 14, 1988

The following are results on extracts from bottle roll tests performed as illustrated in Figure 1 (Copy attached). The solution used for each test (Heap Leach Solution - 880487-3) was prepared following the directions provided (A - attached). The solids used in each test was the PBR Minerals Clay Liner Material - 880487-2.

Client Sample I.D. (KBR Minerals)		Heap Leach Solution	2A1	2A2
Lab Sample I.D. (880487)		#3	#4	#5
PARAMETER	UNITS			
pH	pH Units	11.6	7.90	7.31
Total Cyanide	mg/l	115	72.8	41.6
Free Cyanide	mg/l	120	92.4	37.2
W.A.D. Cyanide	mg/l	138	83.6	33.2
Arsenic	mg/l	0.07	0.01	<0.05
Barium	mg/l	0.06	----	----
Cadmium	mg/l	0.09	0.02	0.01
Chromium	mg/l	<0.01	----	----
Lead	mg/l	<0.01	----	----
Mercury	ug/l	47.4		
Selenium	mg/l	0.04	----	----
Silver	mg/l	2.03	----	----

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ANALYTICAL REPORT

July 14, 1988

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Client Sample I.D. (KBR Minerals)		2B1	2A3	2B2
Lab Sample I.D. (880487)		#6	#7	#8
PARAMETER	UNITS			
pH	pH Units	9.03	7.51	8.28
Total Cyanide	mg/l	98.8	15.8	55.2
Free Cyanide	mg/l	95.6	16.6	62.8
W.A.D. Cyanide	mg/l	81.6	4.20	50.0
Arsenic	mg/l	<0.01	<0.05	0.01
Cadmium	mg/l	0.05	<0.01	0.03
Mercury	mg/l			

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ANALYTICAL REPORT

July 14, 1988

The following are results on extracts from bottle roll tests performed as illustrated in Figure 1 (Copy attached). The solution used for each test (Heap Leach Solution - 880487-3) was prepared following the directions provided (A - attached). The solids used in each test was the PBR Minerals Clay Liner Material - 880487-2.

Client Sample I.D. (KBR Minerals) 2C1

Lab Sample I.D. (880487) #9

PARAMETER	UNITS	
pH	pH Units	9.31
Total Cyanide	mg/l	87.6
Free Cyanide	mg/l	100
W.A.D. Cyanide	mg/l	83.6
Arsenic	mg/l	<0.01
Cadmium	mg/l	0.07
Mercury	mg/l	

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X-RAY DIFFRACTION ANALYSES

FOR

CORE LABORATORIES - AURORA

Western Atlas International
A Litton/Dresser Company

CORE LABORATORIES

5295 Hollister Road
Houston, Texas
77040-6295
(713) 460-9600

June 6, 1988

Core Laboratories - Aurora
1300 South Potomac Suite 130
Aurora, CO 80012

ATTN: Mr. Doug Lempke

Subject: X-Ray Diffraction Analyses
Sample No.: 880487-2
File No.: 288283

Dear Mr. Lempke:

This report presents the results of an X-ray diffraction analysis performed on one (1) submitted sample (your sample number 880487-2). The sample was received by the Reservoir Geology/Petrographic Services Group of Core Laboratories on June 1, 1988. This report provides the analytical procedures as well as the results (see Table 1). Note that, due to sample heterogeneity, the entire sample was ground in a mortar and pestle and passed through a 40 mesh sieve. This was done in order that a representative sample could be obtained. Please advise us if you would like the sample returned to you.

It has been a pleasure performing this study for Core Laboratories - Aurora. Should any questions arise, or if we can be of further assistance, please feel free to contact us.

Sincerely,

CORE LABORATORIES, INC.

William L. Reese
XRD Analyst

Michael L. Dixon
Manager, Houston
Reservoir Geology/
Petrographic Services

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ANALYTICAL PROCEDURES

X-Ray Diffraction Analysis

The samples selected for quantitative X-ray Diffraction Analysis are disaggregated with a mortar and pestle, weighed and transferred to deionized water, where further disaggregation is performed with a sonic probe. The samples are then centrifugally size-fractionated into sand/silt (>4 microns) and clay-size (<4 microns) fractions. The suspended clay-size fractions are decanted and vacuum-deposited on silver metal membrane filters to produce oriented mounts. Each clay mount is analyzed dry (relative humidity = 50%) and after treatment with ethylene glycol. If necessary, samples are analyzed a third time following heat treatment (375°C for one hour).

The sand/silt fractions of each sample are dried and weighed to determine weight loss due to the removal of clay-size material. The dried sand/silt fractions are then mixed with alumina (Al_2O_3) as an internal standard and ground in water to a fine powder using a micronizing mill. The resultant slurries are dried, disaggregated and packed into aluminum powder holders using a modified pellet press.

Quantitative XRD analyses are performed using an automated Philips 3620 powder diffractometer. The weight percentages of minerals present in the sand/silt fractions are determined using internal standard ratio techniques. The weight percentages of the various clay minerals (and other clay-size rock forming minerals) in the clay-size fractions are determined by Lorentzian profile fitting/empirical peak-area-ratio methods. The whole-rock compositions are then calculated by mathematically combining the XRD data from both size fractions.

Compositions and species of clay minerals detected in the clay-size fractions are determined according to procedures outlined by Weaver (1956), Jonas and Brown (1959), Carroll (1970), Reynolds (1980), and Srodon (1980). The detectability limit is 0.5% - 1.0% for crystalline phases present in the size fractions analyzed.

Western Atlas International
A Litton/Dresser Company

CORE LABORATORIES

5295 Hollister Road
Houston, Texas
77040-6295
(713) 460-9600

Core Laboratories - Aurora
Sample No. 880487-2

File: 288283

TABLE 1

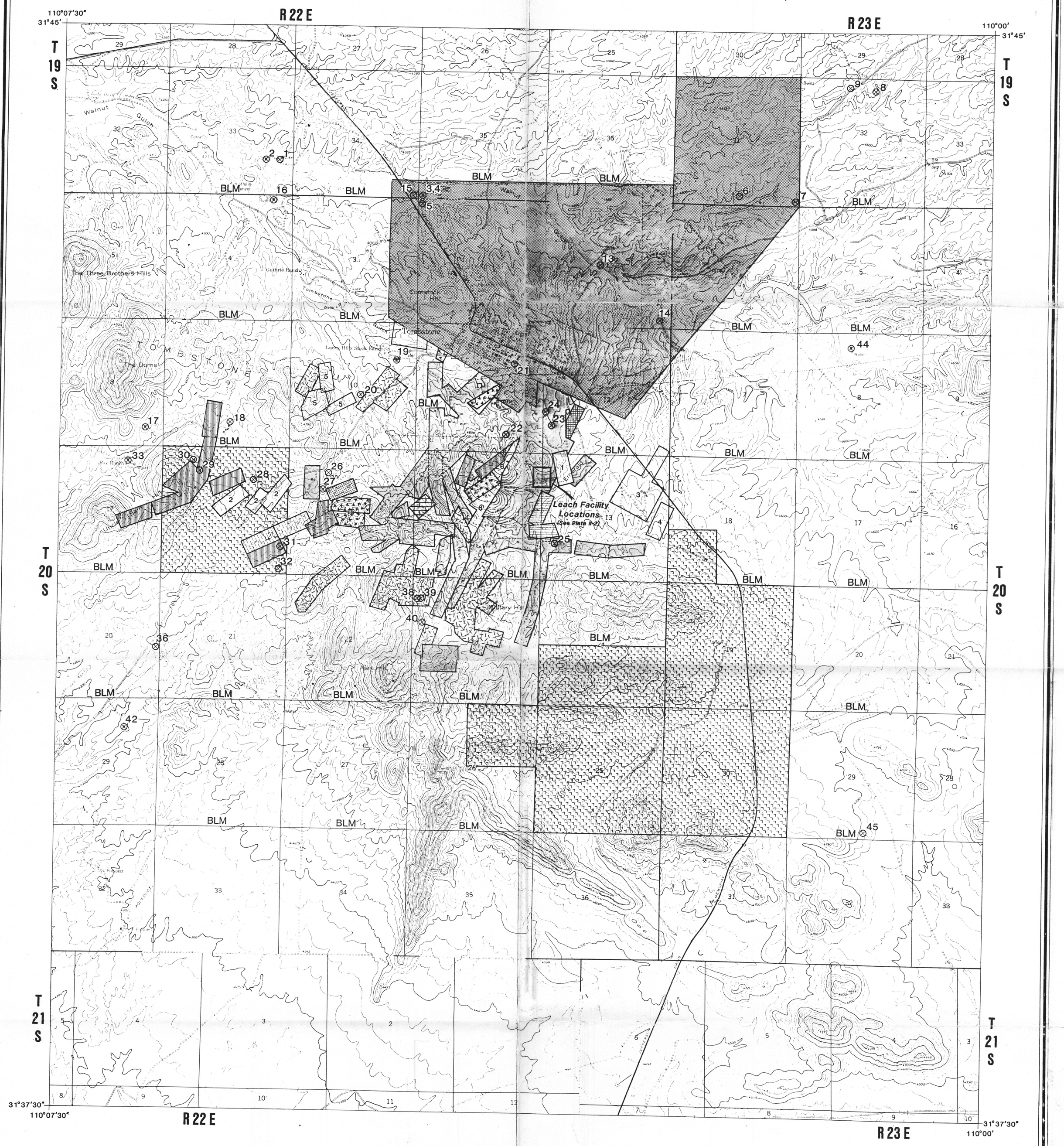
X-RAY DIFFRACTION (XRD) DATA
(Weight Percent)

Sample:	1
Bulk Mineralogy (Calculated)*	
Quartz	24
Feldspar	06
Plagioclase	02
K-Feldspar	04
Calcite	46
Clay Minerals	24
	100%
Relative Clay Abundances (Normalized to 100%)	
Kaolinite	09
Chlorite	--
Illite	16
Mixed-layer** Illite/Smectite	75(80)
	100%

* Bulk mineralogy is calculated from sand/silt-size and clay-size XRD data.

** Numbers in ( ) are percent expandable smectite interlayers in mixed-layer clays.

This report is based upon information and materials supplied by the client and is prepared for the exclusive confidential use of the client. The analyses or interpretations contained herein represent the opinion of Core Laboratories and its employees assume no responsibility and specifically disclaim any expressed or implied warranties or representations as to the utility of this report to the client or as to the productivity, proper operation, or profitableness of any oil, gas or other mineral activity or well in connection with which such report may be used or relied upon.



Legend:

Land Ownership

- Bureau of Land Management
- Tombstone Development Corp. / PBR Minerals, Inc.
- Urban Area
- State of Arizona
- Haber Corp. *Tombstone, Arizona*
- Escapule *Tombstone, Arizona*
- Bill Hart
- Bill Smith *Tombstone, Arizona*
- Bob Crist *Tucson, Arizona*
- Mrs. Betty Austring *Tombstone, Arizona*
- Lewis *Tucson, Arizona*
- University of Arizona *Tucson, Arizona*

⊗ Registered Water Well

1. Tracy Thomas *Tombstone, Arizona*
2. Tombstone Silver Mines *Tombstone, Arizona*
3. 3-Star Oil Company *Houston, Texas*
4. Harry Hughs *Tombstone, Arizona*
5. Tima and Assoc. *Tucson, Arizona*
6. City of Tombstone

North

SCALE: 1: 24000

0 2,000 4000'

FEET

GEOCHEMICAL ENGINEERING, INC.

Denver, Colorado

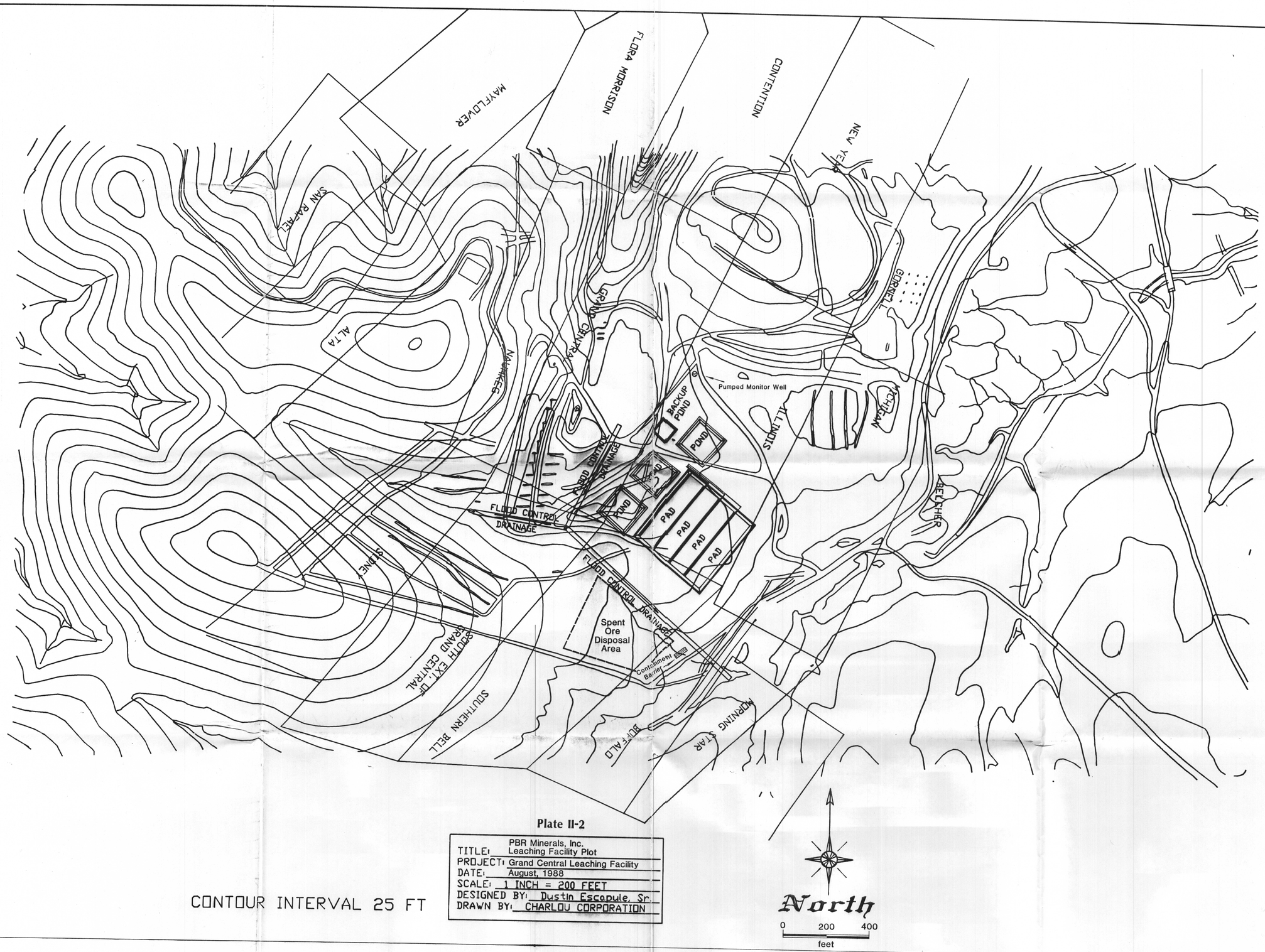
PBR MINERALS, INCORPORATED

Grand Central Leaching Facility

Tombstone, Arizona

Plate II-1

Facility Location Map, Land Ownership, and Registered Water Wells



CONTOUR INTERVAL 25 FT

Plate II-2

TITLE:	PBR Minerals, Inc. Leaching Facility Plot
PROJECT:	Grand Central Leaching Facility
DATE:	August, 1988
SCALE:	1 INCH = 200 FEET
DESIGNED BY:	Dustin Escopule, Sr.
DRAWN BY:	CHARLOU CORPORATION