COAL MINE DEWATERING AS A KEY ASPECT IN PRE-MINE FEASIBILITY PLANNING IN THE SEMI-ARID WESTERN UNITED STATES

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ABSTRACT

In the semi-arid western United States, one does not think that groundwater inflow into a coal mine pit poses a significant problem in the economics of coal mining. Groundwater discharge into most pits is usually less than a few cubic meters per second and pumps can easily dewater most pits. However, there are cases in the states of Wyoming, Montana, Colorado, and New Mexico where the interception of an alluvial aquifer or a clinker zone (burned coal seam) by a pit has caused severe problems due to the cascading of water into the mining area and the subsequent failure of the pit wall. The following paper presents a case history where groundwater and geotechnical studies were used to predict pit inflow and the stability of the mine wall. These studies have played a key role in the feasibility planning of a coal mine.

Initial reserve studies at the Salt River Project's (SRP) Fence Lake Property in Catron County, New Mexico indicated that a significant portion (5%) of a proposed mining area may be restricted from mining due to potential groundwater problems. To determine the extent of these problems, a groundwater and geotechnical investigation took place, and a model was developed for the mining scenario. The results of the study indicate that the slope stability of the alluvium and the potential for pit floor heaving due to a confined aquifer below the coal may inhibit mining of the area. However, with the proper placement of dewatering and depressurization wells, these problems could be solved economically.

Whether or not this area will be mined is still under debate. The mining engineers on the project are still concerned with the angle of repose and other aspects of high wall stability. Additional geotechnical studies are now taking place to determine the final outcome.

INTRODUCTION

The Salt River Project (SRP), a utility, is investigating a dragline mining operation in a remote part of Catron County, New Mexico (Figure 1). Groundwater inflow into the pit and slope stability are the primary concerns of the mining operation in the alluvial area.

This paper presents the results of this dewatering study which was made to determine the feasibility, both economic and engineering, of mining in this area. During this study, conceptual as well as analytical models were developed for the site. This paper presents a general site overview as well as the results of these models. Finally, conclusions are drawn concerning the feasibility of the operation.

SITE OVERVIEW

The site known as the Fence Lake Property lies within the Little Colorado River Drainage Basin. The major drainages within the area include Tejana Draw, Frenches Arroyo and Nations Draw. Each of these drainages flow to the southwest toward Largo Creek and are considered to be ephemeral. The mining area has a moderate topographic relief with elevations ranging from 2,005 to 2,103 meters. Drainage divides consist of sandstone-topped ridges with steep side slopes.

The sedimentary and igneous strata exposed at the surface and near surface on the Fence Lake property constitute six separate and distinct formations ranging in age from Late Cretaceous to Quaternary. Of particular concern to this study are the coal bearing, Cretaceous Moreno Hill formation and the Quaternary alluvium. The Moreno Hill formation consists of continental deposits of sandstone, silty sandstone, siltstone, mudstone, shale, carbonaceous shale and coal.

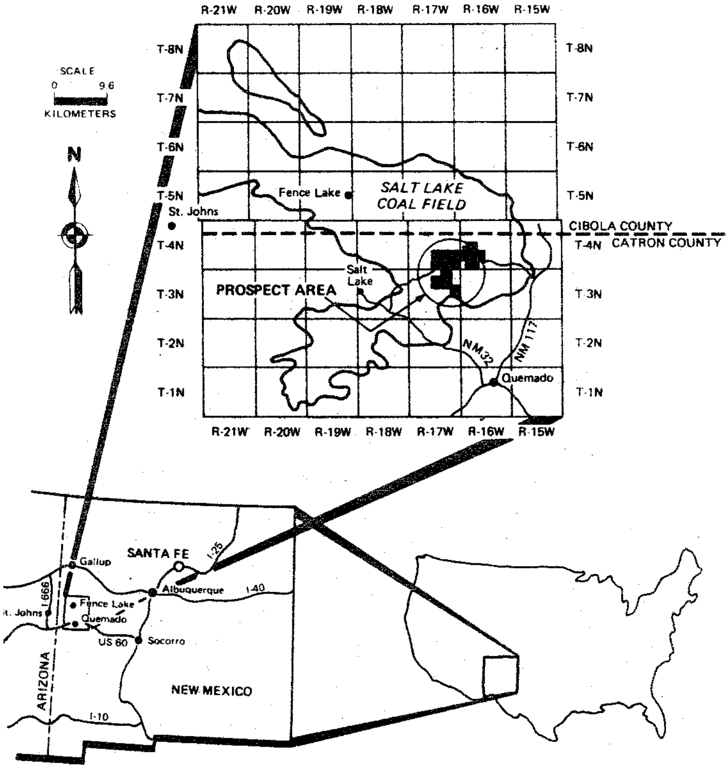
Unconsolidated alluvial deposits of sand, silt, clay, and gravel fill the valley bottoms of Nations, Frenches and Tejana Draws. The thickness of this alluvial material ranges from a thin veneer on the slope of the hills to greater than 50 meters in the valley center.

The structure of the bedrock is relatively flat. The prominent features are a small anticline (with dips less than 2 degrees) in the north central portion of the property trending northeast-southwest and a small shallow syncline in the northwest portion of the property.

SITE HYDROGEOLOGY

Data acquisition

During the summer of 1984, over 50 groundwater observation wells and piezometers were installed by Salt River Project on its Fence Lake property. The purpose of these wells was for collecting groundwater quality and hydrogeologic information. A production well was completed to a depth of 60 meters. This



LOCATION MAP

FIGURE 1

well had an inside diameter of 25 cm and was completed using galvanized steel.

The most detailed work was done on the production well.

Observation wells were placed 72 and 184 meters northeast of the production well for distance and drawdown relationships. The production well was pump tested for 24 hours at a rate of 80 cubic meters per second for the first four hours and 57 cubic meters per second for the remainder of the test. Drawdowns were recorded for each of the observation wells.

Two other wells are also completed in the alluvium. Single well pump tests as well as slug tests were used to determine the hydraulic nature of the alluvium. Additional information on the alluvium was obtained from three geotechnical bore holes. Grain size distribution and compaction characteristics gave insight into the nature of the alluvium.

Additional piezometers were placed to study the coal and associated bedrock and the sandstone underlying the coal. Hydraulic heads were observed, and slug tests were performed on these.

Hydrogeologic characteristics

There are three hydrogeologic units of particular importance to mine planning. These are the Quaternary alluvium; the coal with the associated siltstones, claystones, shales and sandstone; and the underlying sandstone. Hydrogeologic data are lacking for each of these units due to this preliminary stage of hydrogeologic evaluation. Basic descriptions of these units are as follows:

Alluvium

Consisting of unconsolidated deposits of sand, silt, clay and gravel, the alluvium averages approximately 30 meters in thickness in the Frenches Draw area. The thickest deposits of alluvial material correspond with middle of Frenches and Lee Draws with thinning occurring towards the sides of the valleys. Bedrock outcrops bound the alluvium on the valley edges. The upper portion of the alluvium consists of fine grain sediments. Grain size analyses show that the percentages of silts and clays range from 16 to 98 percent on the twelve samples analyzed with most samples tested having a silt and clay content over 50%. These analyses indicate that the upper alluvium has a relatively low permeability. A slug test which was completed in the fine grain zone yielded a hydraulic conductivity of 1.7E-6 cm/sec. Consequently, this portion of the alluvium where saturated would be difficult to drain.

Consistently underlying the fine grained sediment is a sand and gravel deposit. This deposit ranges in thickness from over

30.5 meters in the center of the valleys to less than 1.5 meters on the valley edges. The pump test on the production well yielded a transmissivity of 1.22E-3 meters squared/second and a confined storage coefficient of 0.00075. Due to the nature of this deposit, the specific yield was estimated to be 0.2.

Figure 2, potentiometric surface map of the alluvium, indicates that the alluvium is more permeable in the middle of the valleys where the groundwater surface is flatter and the hydraulic gradient is on the order of 0.0006 m/m. The steeper portions of the potentiometric surface correspond with sides of the valleys and have an hydraulic gradient on the order of 0.002 m/m. The potentiometric surface is for the most part controlled by the topography. When the potentiometric map is combined with the alluvium thickness map, an average saturated thickness of 11 meters is obtained.

Coal and associated bedrock

The coal and associated siltstones, claystones and shales are expected to yield very little water into the pit. Having hydraulic conductivities which range from 9.2E-7 to 2.9E-5 m/s, this unit is considered relatively impermeable when compared to the sand and gravel of the alluvium.

Sandstone below the coal

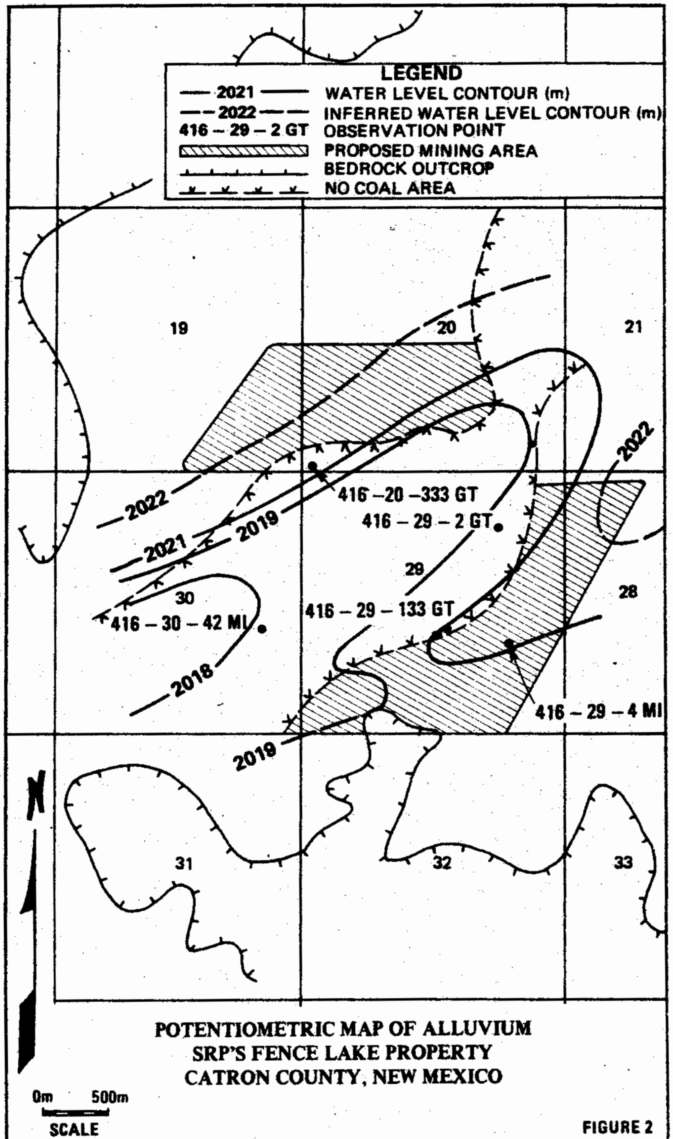
Averaging 4.6 meters in thickness, this unit is very consistent throughout the Fence Lake Project. This unit often lies directly under the coal and is some times separated from the coal by shale. It varies in transmissivity from between 6.7E-6 to 9.6E-4 meters squared/second. The average transmissivity is estimated to be 5.4E-4 meters squared/sec. Wells in the area show artesian heads on this aquifer and depressurization wells may be required.

PIT INFLOW PREDICTIONS

Because of the preliminary nature of the study, analytical models of groundwater flow were used to simulate inflows to the proposed Fence Lake coal mine in the vicinity of Frenches Draw. The relatively small amount of hydrogeologic data did not justify a more sophisticated modeling effort. The analytical model used was developed by Koch and Associates (1982) specifically for simulating the hydrogeologic impacts of mines. The model provides a preliminary two dimensional simulation of groundwater flow toward a mine pit.

Model description

The analytical model is based on the steady state solution of the problem of a discharging finite length sink in a homogeneous aquifer of infinite extent (Muskat, 1937). The



POTENTIOMETRIC MAP OF ALLUVIUM
SRP'S FENCE LAKE PROPERTY
CATRON COUNTY, NEW MEXICO

FIGURE 2

program extends the algorithm to transient problems using the method of successive steady states. The method of successive steady states assumes the potentiometric surface has a steady state curvature at all points in time. The radius of influence is estimated using a semi-empirical equation. The successive steady state algorithm is an excellent approximation at all but the shortest times.

Mine pits are simulated by assuming the pit may be represented by finite length, constant head line sinks. The inflow to these sinks may be calculated at any point in time. Drawdowns away from the pit may also be calculated. The movement of the mine pit may be simulated by using a series of finite length, constant head line sinks. The backfilled mine pit is simulated by the superposition of the finite length line sinks that inject water into the aquifer thus causing the potentiometric surface to recover. The new position of the mine pit is represented by a new finite length, constant head line sink. By repeating the process of creating new line sinks, the progress of the mine pit may be simulated.

The analytical model assumes a uniform, homogeneous aquifer of infinite areal extent (the assumptions of the Theis equation for nonsteady well discharge). In order to simulate an aquifer with boundaries, either constant head or impermeable, the theory of superposition may be used. Superposition may be used because drawdown is directly proportional to discharge, as it is with the Theis equation. Boundaries for finite length line sinks may be simulated using the same methods that are used with well simulation models. An impermeable boundary is simulated by placing an image line sink on the other side of the assumed boundary and equidistant from it. A constant head boundary is simulated by placing an image line source (injection or buildup as opposed to discharge or drawdown) on the other side of the assumed boundary and equidistant from it. Multiple boundaries are simulated using a series of image sinks or sources.

Modeling approach

Many simplifying assumptions are necessary to apply the analytical model. The model assumes a single, homogeneous aquifer, either confined or unconfined. The hydrogeology of the alluvium at the Fence Lake site is complex: The aquifer is both heterogeneous and finite in extent. The analytical model was applied to two different cases with each case representing a different conceptual model of the aquifer. These two cases are believed to be limiting cases for the actual alluvial aquifer.

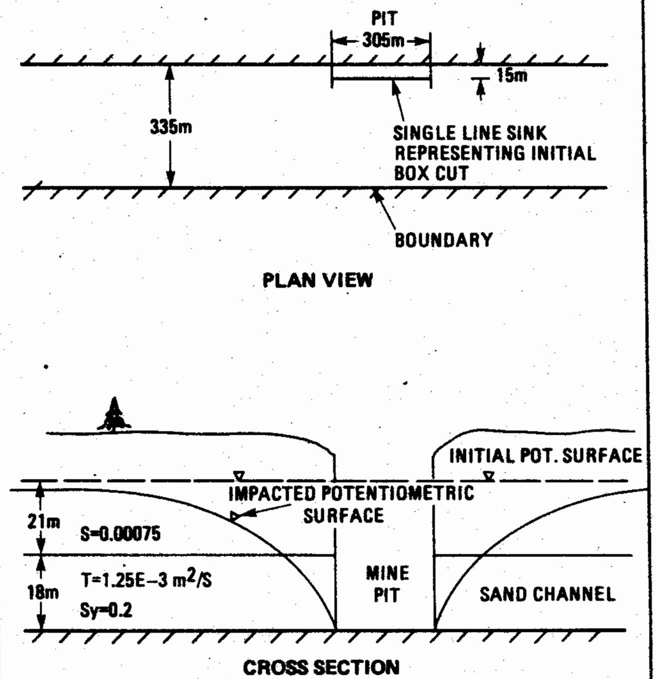
The largest source of groundwater to the mine pit is likely to be the channel of sand and gravel that meanders through the alluvium. Pump testing of this channel sand indicates that it is confined by the overlying alluvial silts and clays. The mine will only intersect this sand channel at its edges since the thickest part of the sand channel corresponds to areas where the coal is not present. The preliminary mine plan indicates that the initial box cuts will be made at the edge of the sand channel. Large groundwater inflows to the mine pit would be expected when the pit is close to the sand channel and much smaller when the pit moves away from the channel towards the sides of the valley. The first simplifying assumption is that all groundwater inflow to the mine pit will result from the drainage of the sand channel aquifer and the rest of the alluvium is impermeable.

The pit inflow from this sand channel to the mine pit was simulated by assuming the initial box cuts penetrate the edge of this sand channel. The channel was assumed to have uniform permeability, thickness and width. The initial box cut was assumed to penetrate 15 meters into the channel and through the entire thickness of the channel. For the simulation of the mine pit inflow, the channel aquifer was assumed to be unconfined with the initial water level at the top of the aquifer. The artesian storage of the sand channel aquifer was ignored since the amount of water released from storage is several orders of magnitude less than the amount of groundwater that will be drained from the sand channel. For the simulation of drawdowns within the sand channel, the channel aquifer was assumed to be confined, and drainage of the aquifer in the immediate vicinity of the mine pit ignored. Drawdowns due to drainage of the sand are small compared to drawdowns affecting artesian storage.

While the primary source of groundwater to the mine pit is expected to be the sand channel, some groundwater will also drain from the silt, clay and sand which overlie the sand channel. The second conceptual representation is that the alluvium is homogeneous and contains a uniform water table aquifer bounded on the northwest and south by impermeable outcrops of bedrock. The aquifer was assumed to have a constant saturated thickness, constant hydraulic conductivity and constant specific yield.

The single sand channel model simulates the pit inflow and drawdowns caused by the mine pit assuming that the alluvium is impermeable except for a single channel. The channel was assumed to be 335 meters wide and 18 meters thick. The hydraulic conductivity was assumed to be 1E-7 m/s and the storage coefficient was 0.00075 with a specific yield of 0.2. The mine pit was represented by a single constant head line sink that was 305 meters long and 15 meters from the edge of the sand channel. Three hundred meters is considered a typical intersection length.

Figure 3 shows the conceptual setup of the model. To simulate mine pit inflows, the sand channel was assumed to be unconfined with the potentiometric surface at the top of the aquifer and



SINGLE SAND CHANNEL CONCEPTUAL MODEL
SRP'S FENCE LAKE PROPERTY
CATRON COUNTY, NEW MEXICO

FIGURE 3

the mine pit penetrating to the bottom of the aquifer. The impermeable boundaries of the sand channel are simulated using the theory of superposition. Image line sinks are placed on the other side of the boundary at the same distance as the real line sink. The initial box cuts of the mine should be opened for two to four months. Inflow to these initial cuts is predicted by the model to be between 1.9E-2 and 3.8E-2 m/s.

The second conceptual representation of the alluvial aquifer assumed a single, homogeneous water table aquifer bounded on the south and northwest by outcrops of bedrock. This aquifer was estimated to have an average saturated thickness of 11 meters, a hydraulic conductivity of 4.5E-5 cubic meters per sec. and a specific yield of 0.15. The hydraulic conductivity was based on and was estimated as a composite of the sand and gravel zone and the overlying silts and clays.

Based on the preliminary mining plan, mining was assumed to occur to the northwest and southeast of the no coal area. The mine pit was assumed to be 1609 km long and 41 meters wide. Mining northwest of the sand channel was assumed to take six to seven years. Mining to the southeast of the no coal area was assumed to take 4.5 to 5.5 years.

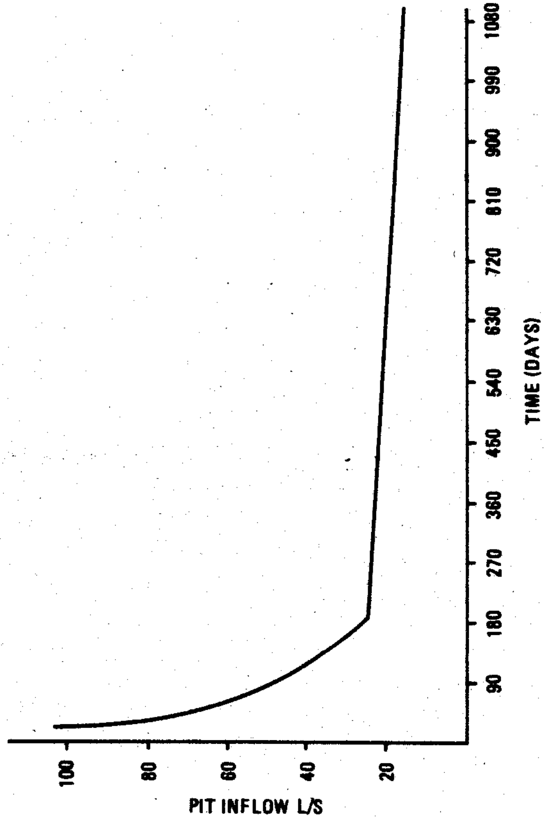
Inflows to the pit were calculated at 20, 30, 60 and 180 days and for one, two, and three years. The predicted inflow is between 16 and 100 l/sec (Figure 4). The peak inflow of 100 l/sec is an arbitarily high number. The model assumes a mile long pit is created instantaneously. In reality, the pit advances continuously; thus, early instantaneous inflows predicted by the model are high estimates. The predicted inflow at the end of three years is arbitarily low. The model assumes a stationary pit. The advance of the pit will cause inflow from the alluvium to be relatively constant with time after the initial cuts are completed.

Finally, there is a sandstone unit which underlies the coal and is under artesian pressure. When the bottom of the mine pit is below the potentiometric surface of this aquifer, inflow from this aquifer to the mine pit may be anticipated. In many places, there is a confining layer of shale between the sandstone and the bottom coal seam that will restrict inflow to the pit, but pit floor heave due to artesian pressure may be a problem. The maximum inflow to the mine pit from the aquifer assuming no confining layer of shale exists was estimated using the analytical equation for a flowing well (Jacob and Lohman, 1952) which may be stated as follows:

$$Q = 2(pi)T(sw)G(x)$$

where:

Q = discharge (m^3pd)
T = transmissivity (m^2ps)



COMPOSITE AQUIFER PIT INFLOW
SRP'S FENCE LAKE PROPERTY
CATRON COUNTY, NEW MEXICO

FIGURE 4

sw= drawdown (m)
G(x) = flowing well function
t = time (days)
S = storage coefficient
rw = radius of well (m)
pi = 3.1416

Based on the data given in the section, Site Hydrology, an artesian storage coefficient was assumed to be 0.0001; on the observed water level with the pit floor will be 20 meters below the sandstone aquifer potentiometric surface; and an average area of 18,580 square meters, pit inflow calculated at 20 days is 1.5E-2 l/s. The average pit inflow between 20 and 90 days is 1.4 l/s. These estimates of pit inflow are very conservative because it was assumed that there was no shale between the pit floor and the sandstone aquifer; where a shale layer is present, inflows would be an order of magnitude lower.

The pressure exerted by the groundwater is a problem; heaving of the pit floor may occur. A common rule of thumb (Terzaghi and Peck, 1967) assumes that the saturated soil and rock is twice the weight of water, thus the head in the sandstone aquifer needs to be less than two times the distance from the top of the sandstone to the bottom of the pit. From drill logs, it is calculated that the head in the sandstone needs to be reduced to less than 3.6 meters in order to avoid heaving of the pit floor. The sandstone will have to be depressurized where excessive artesian pressures exist.

DEWATERING APPROACH

Dewatering may be necessary for this mining operation. Based on the limited amount of hydrogeologic data available, a dewatering plan has been developed. This plan encompasses the use of wells to dewater the saturated alluvium; the installation of depressurization wells for the underlying sandstone; and the use of a pit sump to discharge excess water (i.e., precipitation and groundwater from the coal and associated bedrock) from the pit.

In developing a dewatering plan several factors were taken into account:

* the dewatering of the sand and gravel
* the depressurization of the underlying sandstone
* the use of pit sumps to handle excess water

Sand channel dewatering

Earlier, two different assumptions were made in predicting the pit inflow from the alluvium. The first case was that the groundwater in the alluvium was confined to a single channel deposit that was 18 meters thick and 335 meters wide. The mine pit would only intersect this channel on the initial box cuts.

The second case was that the alluvium was a single homogenous aquifer bounded by impermeable bedrock. In the design of the dewatering plan, the first case was used because it appears to be more realistic with the hydrogeologic and geologic data available.

The sand and gravel channel may be dewatered with wells. Complete dewatering of the alluvium is not possible without wells that are extremely closely spaced. However, wells may be used to lower the water table to decrease pore pressure and the volume of flow into the pit. This groundwater will be under a reduced pressure and will seep out along the pit wall.

The well spacing and pumping times presented are somewhat arbitrary. Other combinations of well spacings and pumping times can achieve the same results. Closer well spacings and/or longer pumping times could be used to achieve larger reductions in pit inflow.

The same analytical model to predict pit inflow to the initial box cuts along the sand channel was used to design dewatering wells. The drainage time of the silts and clays overlying the sand channel was computed using Terzaghi's (Terzaghi and Peck, 1967) one-dimensional consolidation theory. This theory assumes consolidation is due to vertical drainage of groundwater out of void spaces in the silts and clays.

Two preliminary dewatering schemes were devised. The first consisted of series of wells 15 meters from the box cuts in the sand and gravel channel. A second method in conjunction was developed with wells in the proposed pit which would be mined through.

Alternative 1

With the first preliminary dewatering scheme for the initial box cuts that intersect the sand and gravel channel, there will be five wells. Three wells spaced 76 meters apart will be 30 meters behind the pit. The remaining wells will be 15 meters from either side of the pit. Each well would have to be pumped at a rate of 5.4 l/s for 180 days before the opening of the pit and during mining. Of the 5.4 l/s, 2.8 l/s would be required to dewater the sand channel as determined by the model and 1.6 l/s for dewatering the underlying sandstone and overlying silts and clays respectively. The latter values were determined using Hantush (1964). The results of the modeling show that pit inflow will be reduced 17 percent with dewatering. More important, the potentiometric surface would be lowered.

Alternative 2

The first alternative dewatering plan may interfere with mine operation. An alternative sand channel dewatering plan would be to place dewatering wells along the sand channel and mine through them as the mine pit progressed. The proposed alternative plan would have 12 wells along the edge of the sand channel at a spacing of 76 meters. As the wells were destroyed by the mining operation, new wells would be drilled and pumping started further along the sand channel.

The same analytical model and assumptions were used for analyzing this alternative dewatering plan. Each of the 12 dewatering wells will need to be designed to pump 4.5 l/s (2.8 l/s from the sand channel + 0.4 l/s from artesian storage + 1.3 l/s from leakage from the silts and clays). The total discharge from the 12 wells will be about 55 l/s.

Depressurization of sandstone underlying the coal

Based on the available data, including water level data, depressurization of the sandstone will be necessary in the southeast pit area and due to the dip of the coal of the Fence Lake property to prevent pit floor heaving. The section, Pit Inflow Predictions, showed that 18 meters of drawdown is necessary. There are two basic methods of depressurizing this sandstone aquifer. First, dewatering wells may be placed ahead of the pit and pumped to dewater the sandstone thus depressurizing an extensive area. Trial and error with a well simulation program indicates that these sandstone depressurizing wells will need to be placed at a spacing of 152 meters and pumped at a rate of 6.3 l/s for approximately six months. Second, pressure relief wells may be placed in the bottom of the mine pit. These would flow by gravity and reduce the pressure in the sandstone aquifer to that at the bottom of the pit. The pressure relief wells would have to be drilled at an angle into the sandstone aquifer ahead of the mine pit and closely spaced to achieve the necessary reduction in pressure. A spacing of 30 meters was found to be adequate. At this spacing each bleeder well would flow 0.5 l/s assuming a grid of bleeder wells based on a finite element model of the system.

Dewatering excess pit water

The dewatering wells will only fractionally reduce groundwater inflow into the pit. Groundwater will continue to seep from the pit walls on both the highwall and cut walls. Precipitation has the potential to add significant water to the pit. Water will continue to flow from the angle depressurization holes if they are used. The pumps in the pit sump should be able to handle at least 125 l/s. Additional pumps may be required to prevent shut down due to pump malfunction or a large rainfall event.

CONCLUSIONS

The following are conclusions based on the results of this study:

* Significant alluvial aquifer exists at the proposed Salt River Project Fence Lake mine site. The alluvium consists of a sand and gravel channel overlain by silts and clays.

* An analytical model was used to predict the inflow to the proposed mine pit. Using assumptions based on the available data, inflow to the initial box cuts from the sand and gravel channel will be between 16 and 100 l/s.

* The alluvial aquifer may require dewatering to maintain slope stability. The preferred alternative (Alternative 2) is to place dewatering wells along the edge of the sand channel aquifer at a spacing of 76 meters. Twelve wells will be pumping at any one time. This will reduce pit inflow by about 11 percent and significantly reduce pore water pressures. The remaining groundwater and surface water inflow from precipitation will be removed from the pit by routing the flow to a pit sump and using a sled or float mounted pump.

* Depressurization of the sandstone aquifer below the coal may be necessary using depressurization wells. These should be placed in a grid pattern over the area requiring depressurization at a pacing of 152 meters. These wells should be pumped at a rate of 0.4 l/s for six months prior to mining.

* Based on preliminary cost estimates not presented in this text, it is feasible to mine coal in this area.

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