3

Ground Water Design Parameters for Mining and Milling

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INTRODUCTION

The history of mining has been shaped to a large degree through engineering innovation and a variety of economic incentives. Involved in both engineering and economics of mining are a large spectrum of parameters. The evaluation and control of ground water through engineering is one such parameter.

GENERAL

The purpose of this paper is to present alternative mathematical methods that enable prediction of mine dewatering pumpage rates. Those predictions may serve as a basis for both environmental impact assessments and the development of mine design plans and cost estimates.

In development of a mining prospect, ground water is frequently encountered in a variety of geologic conditions, and may be in either a confined or unconfined state. The state of ground water is directly proportional to water level change per unit volume of water introduced or removed from the ground water system of interest.

The spatial change of water level associated with the introduction or removal of water is proportional to the geometry of the system of interest and the hydrologic conductivity and thus is subject to mathematical analysis.

The physical geometry of the mineral of interest relative to the water bearing section or sections is important in the design and operation of ground water control systems.

Ground water level change associated with the locations and timing of pumpage is controlled by the aquifer characteristics. These include hydraulic conductivity, thickness and areal extent of the aquifer, and the storage coefficient. Hydraulic conductivity is defined as the flow of water per unit time per unit area under a gradient of 1-foot per foot. Thickness refers to the vertical dimension of the system or systems of interest. The storage coefficient is defined as the volume of water that a vertical column of aquifer of unit cross-sectional area releases from storage as an average head within the column declines a unit distance.

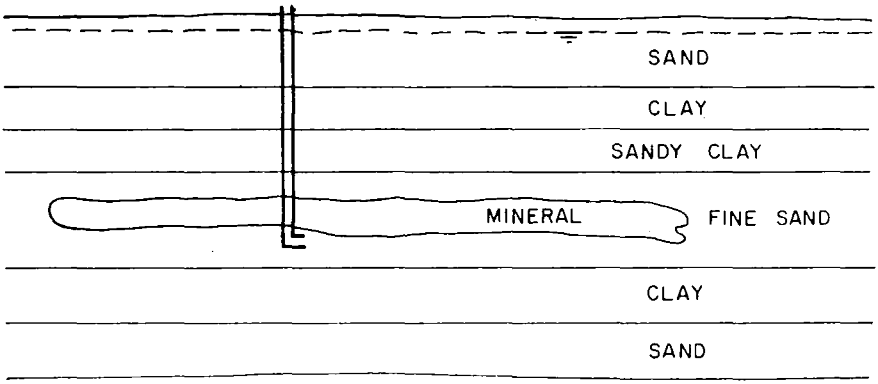
Therefore, the process is one of determining the aquifer coefficients, development of conceptual mine design, and engineering the associated ground water control systems. The location relative to the mineral interval of interest is important to design of a mine. In order to illustrate some of the above concepts, examples will be used.

EXAMPLES

Example 1 shown on Figure 1 is a typical uranium deposit surrounded by aquifers both above and below. The mineral interval also can be an aquifer of some importance. Typically, deposits of this kind may be mined in three ways: in-situ leaching; open pit mining or underground mining. In order for the engineer to select an approach to development of a mine, he must understand the aquifer system in the vicinity of the mineralized interval. However, independent of how the system is to be developed, explicit information concerning the hydrology is still needed.

Analysis

Initially geologic research and mapping, followed by a drilling and testing program would be needed to develop information on the ground water system. This program



Typical Mineral Deposit.
Figure 1

would result in geologic information as shown on Figure 1, along with the associated aquifer characteristics of each part of the system. Pumping tests require withdrawal of water from intervals of interest with concurrent measurement of the change in water level in the aquifers of interest. These data are then utilized to compute pertinent aquifer properties and coefficients. One of a variety of published techniques (1, 2) are used, but the most common method is by C.V. Theis and can be stated as follows:

Equation 1

$$s = \frac{Q}{4\pi T} W(u)$$

where

s - drawdown
Q = pumping rate per unit time
$W(u)$ - Exponential integral
$u = \frac{r^2 S}{4Tt}$
r = distance from pumping well to the point of observation
s = storage coefficient
t = time

After the aquifer coefficients from the testing and analysis program are computed, two important types of conditions should be considered: first, a constant pumping condition, which creates a continuously varying drawdown; and second, a constant drawdown condition, which creates a continuously varied rate of pumpage. These two conditions and their method of analysis are well known. The first condition is implicit in Equation 1 above. The second condition is illustrated in a paper written by C.E. Jacob and L.S. Lohman (3). Jacob and Lohman's solution can be stated as follows:

Equation 2

$$Q = 2\pi T S_w G(a)$$

where

Q = discharge as a function of time

T = transmissivity

S_w = drawdown at the well

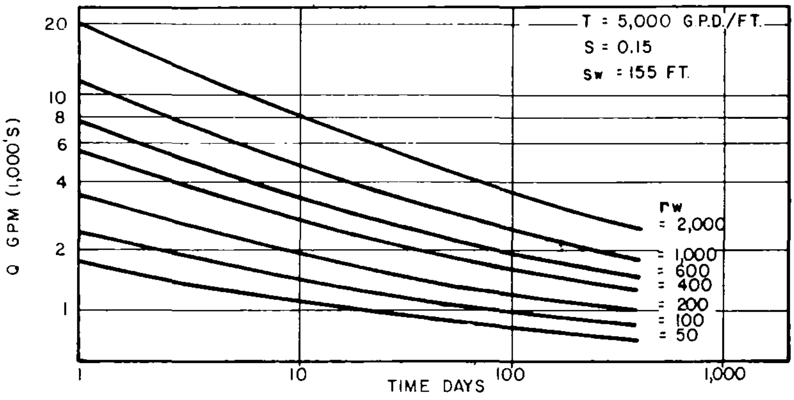
$$G(a) = \frac{4a}{\pi} \int_0^{\infty} B e^{-ab^2} \{(r/w) + \tan^{-1}[Y_o(x)/J_o(x)]\}$$

$$a = Tt/sr^2_w$$

The use of the above equations can be illustrated by referring to Figure 1. The coefficients of the aquifers shown would be developed through pumping tests and analysis of data using Equation 1. The second equation shown above, would be used to determine the time dependent pumpage rate to maintain the dewatered state.

Even if the horizontal extent of the mineral interval is unknown, the total pumpage required to allow open pit mining per unit pit bottom radius still may be estimated. For example, if pumping tests have yielded a transmissivity of 5000 GPD per foot and a specific yield of .15, the results shown on Figure 2 for various effective radii would be applicable. Constant drawdown for this example problem is 155 feet. Calculation of rates for other constant heads with the same aquifer coefficients can be calculated directly from the figure, as rate is directly proportional to the constant head condition.

Example 2, for underground mining is also shown on Figure 1; however, the vertical scale has been increased by a factor of 10 and clearly there is an immediate need to understand the ground water system for proper dewatering design.



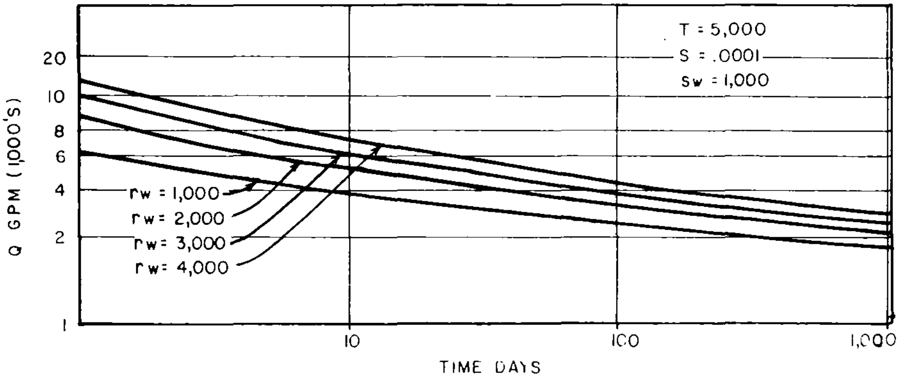
Open Pit Groundwater Flow Rates Based On Pit Bottom Radius.
Figure 2

In deep underground mining, ground water data needs are essentially the same as those required in Example 1. A major problem from the analysis standpoint is a reduction of the mine plan geometry to effective radius. A variety of methods can be used, a few of which are discussed below.

Method 1 entails approximation of the mine plan as a well and using the constant head Jacob-Lowman equation to calculate flow rates. This method generally yields a pumpage rate that is too high.

For Method 2, the technique of interfering wells is utilized, wherein each drift face of the proposed mine plan is considered to be a well. The cumulative production of the drift "wells", which typically are mutually interfering, is an approximation of the expected production from the mine.

For Method 3, the technique of confined-unconfined theory and the Jacob-Lowman theory are combined to calculate the required pumpage. The effective radius in this method is chosen as the radius at which the aquifer of interest goes from the confined to the unconfined state. Therefore, the concept focuses on fluid entering the unconfined state from elastic yield of the confined state.



Groundwater Flow Rates Based On Radius To Transition Confined-Unconfined Flow.
Figure 3

A discussion of the confined-unconfined problem can be found in Ehlig and Halepaska (4).

Method 3 has been used for analyzing Example 2 where aquifer transmissivity was 5000 GPD per foot, the storage coefficient was .0001 and the head change was 1000 feet. The results, shown on Figure 3, are for four different effective radii.

CONCLUSIONS

Development of an underground mineral generally requires design of ground water control systems. This process entails development of ground water characteristics, development of a conceptual mining plan and prudent application of the theory. Generally, many different mining plans will be developed over the design period and each will have its own dewatering design parameters.

REFERENCES

1. Theis, C.V., The relation between the lowering of the piezometric surface and the rate and discharge of a well using ground water storage, Tans. Amer. Geophys. Union, V.16, pp519-524, 1935.

2. Jacob, C.E., Flow of ground water, In Proceedings of the Fourth Hydraulics Conference, Edited by Hunter Rouse, 1950, John Wiley.

3. Jacob, C.E., and S.W. Lohman, Nonsteady flow to a well of constant drawdown in an extensive aquifer, Tans, AGU Vol.33, No. 4, Aug. 1952.

4. C. Ehlig and Halepaska, J.C., A numerical study of confined-unconfined aquifers including delayed yield and leakage, Water Resources Research, Vol.12, No. 6, December 1976.