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Dewatering Techniques for Rheinbraun's Open Pit Lignite Mines

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1. INTRODUCTION

1.1 Geology and Hydrology of the Rhenish Lignite Mining District - an Overview

During the Oligocene and Miocene epochs of the Tertiary period, enormous quantities of organic matter accumulated in the southern part of the Lower Rhine Graben, a major tectonical element to the northwest of the Rhenish Mass. Over an area of 2 500 square kilometers ($\sim$965 square miles) between the cities of Aachen, Cologne, and Moenchengladbach, this matter developed into a huge lignite deposit containing some 55×10^9 (metric) tons of lignite (fig. 1). With the present technical means - bucket wheel excavator, conveyor belt, stacker working in a continuous open pit operation - 35 x 10^9 tons out of this total are technically and economically recoverable from pits that may eventually be as deep as 600 meters ($\sim$ 1 950 feet). In recent years, 110 to 120 x 10^6 tons of lignite have been mined annually by Rheinische Braunkohlenwerke AG (abbr. Rheinbraun). The deepest open pit mine is now worked at a depth of 300 meters.

The lignite occurs in three seam formations, two of which are mined by five open pit mines. The nature of the strata top and bottom of the seams reflect the paralic environment between the rising mainland in the south and the then North Sea, where they were deposited. They are made up of very thick sequences of sands which are separated from each other by silt and clay deposits. This kind of stratification fostered the development of three major aquifer units above the seam formations, one within the seams, and two below them. Locally, there may occur even more aquifers (see fig. 2).

To enable a safe mining operation, the topwall aquifers in the pit areas must completely be dewatered, and the footwall aquifers sufficiently depressurized (1).

Some major and numerous minor normal faults with NW-SE strike dissect the mining district and form the characteristic horst and graben structures which are featured in figures 1 and 2. The major faults usually act as barriers to ground water flow.

Sedimentary and tectonical processes thus have created a geologically and hydrologically very complicated deposit which requires intelligent solutions for mining planning and techniques, including dewatering. The aim of this paper is to give a glimpse into the planning and the execution of the dewatering measures.

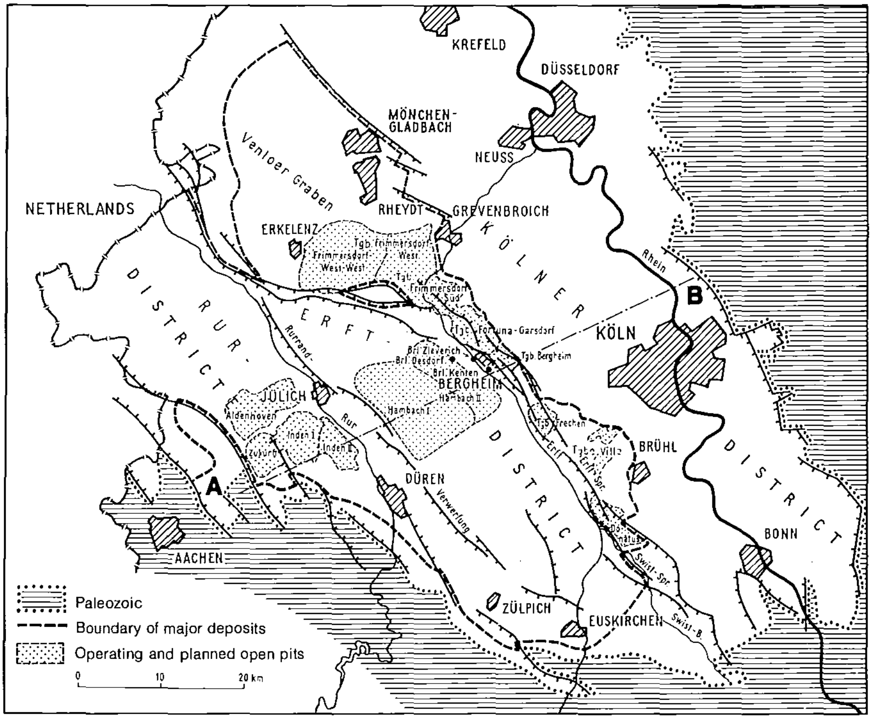

Figure No. 1, Operating and planned open pit mines in the Rhenish Lignite Mining District

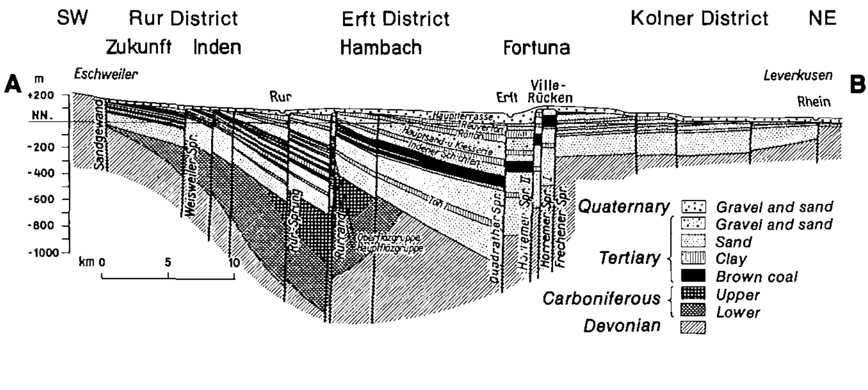

Figure No. 2, Geological section across the mining district

1.2 Hydrological Investigations

The prerequisite for planning the adequate dewatering measures for an open pit lignite mine which may reach a depth of a few hundred meters, is information as complete as possible of the hydrologic parameters of the aquifers involved and of their boundary conditions. The latter may substantially vary in time in the course of maximum drawdown or even full depletion of an aquifer. Any investigation of a lignite deposit must be accompanied therefore by an investigation of the respective hydrologic properties and boundary conditions (1). The methods to compile and evaluate such data are standard practice and need not be mentioned. Special attention is given to maintaining a dense network of observation wells which are screened in the pumped aquifers. Many investigative bore holes are turned into such observation wells or piezometers. Rheinbraun drills approximately 25 000 meters ($\sim$ 82 000 feet) per year for investigative or piezometer bore holes. Across the area which is affected by the withdrawal of ground water, approximately 3 100 piezometers are monitored permanently. Up to six of them, sealed against each other, are arranged in a single bore hole (fig. 3). State agencies and private users of ground water observe additional 1 600 piezometers.

2. PLANNING OF DEWATERING MEASURES

2.1 Introductory Remarks

The hydrological planning department of Rheinbraun sees its responsibilities as follows:

- within the longterm planning process, the dewatering schemes for open pit mines are to be designed, the cross rates of discharge to be calculated and the effects of ground water withdrawal to be determined

- within the shortterm planning process, the individual wells, galleries of wells and other dewatering means are to be designed, their operation monitored and their effects continuously checked against the theoretical calculations.

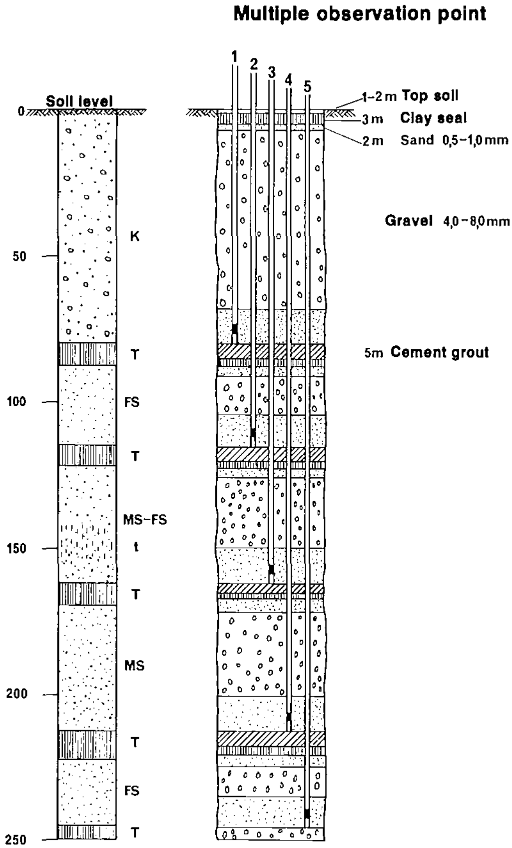

Figure No. 3, Piezometer group in a single bore hole

In doing so, several approaches to solve the interesting problems are chosen. Based on the classical well formulas of Dupuit-Thiem and the semi-empiric investigations of Sichardt (2), diagrams were developed which permit a prompt design of gravel packed dewatering wells. These take into account the maximum or Sichardt's capacities at different phases of drawdown.

Versatile tools are ground water budgets that quite often enable the hydrologists to assess hydraulic parameters, especially the specific yield, and certain boundary conditions.

The major tools, however, are methods to model the dewatering processes by simulation. Traditionally, Rheinbraun's hydrological department has employed one-dimensional approximate methods, originally developed by Siemon (3). For the past years, however, numerical two-dimensional aquifer models have come in use (4).

2.2 One-dimensional Approximation of Dewatering Process

Siemon (3), observing the development of the cones of depression in result of large-scale dewatering for lignite mines, noted typical patterns during the growth of the cones. He termed them phases of drawdown.
During the first phase, a gallery of dewatering wells discharges at maximum capacity. Most of the withdrawn ground water is taken from storage. The cone develops as schematically shown in fig. 4-1.

The second phase of drawdown is characterized by a decrease of the rate of discharge due to decreasing capacities of the wells. A higher percentage of discharged water is now from recharge, the cone of depression flattens, and withdrawal of water in storage occurs more or less evenly across the cone (fig. 4-2).

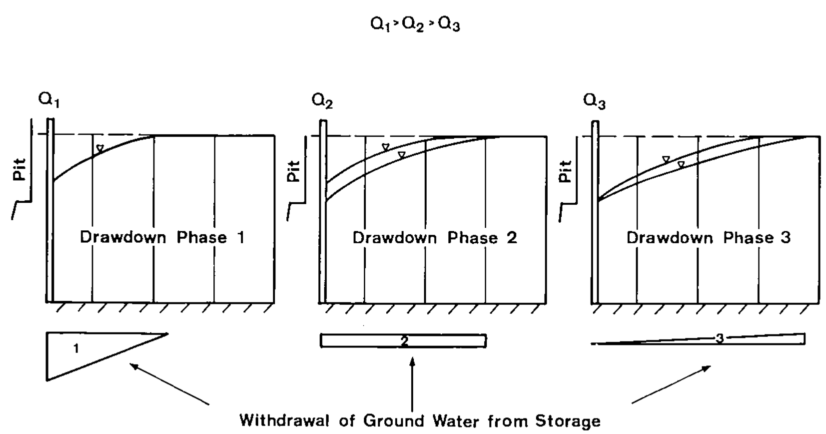

Figure No. 4, Consecutive phases of drawdown in an aquifer due to mine dewatering, after (3)

To the end of the third phase, the drawdown along the perimeter of the mine has arrived at the required level, and the cone, no more deepening any more, tends to stabilize by adjusting to the rate of recharge (fig. 4-3).

The second phase exists over a long period of the dewatering process. On assuming the even withdrawal of water in storage to be effective and taking account of the boundary conditions the calculation of heads in sections for parallel flow and radial flow becomes possible. This enables the hydrologist to determine for given drawdowns and rates of discharge in the center of the dewatering gallery successive phases of drawdown. Despite inherent errors this method has proven very suitable to model the dewatering process for a mine in more or less good approximation.

2.3 Two-dimensional Numerical Modelling

2.3.1 Mathematical Ground Water Model

The present numerical program GW1 (Ground Water One) was developed for the hydrogeologic conditions of the Rhenish Lignite District. It is based on a mathematical model which utilizes a finite difference method to compute the distribution of head in an aquifer under steady-state or unsteady-state conditions (4, 5).

The continuous aquifer is replaced by a non-uniformly spaced grid of acute triangles, a system which permits a rather accurate image of irregularly shaped aquifer boundaries (6). Thus, Darcy's law is applied to calculate the partial flow rates along the sides of the triangles. The continuity equation becomes an equation that describes for any nodal point the node-to-node water transfer rates, the rate of water released from, or taken into storage, the withdrawal rate and the rates of recharge and/or discharge (e. g. leakage to or from the aquifer). Any nodal point of such a grid is surrounded by o neighbouring nodal points. The mid-verticals of the sides of the triangles form a polygon, the area of which, A_B, is represented by nodal point B (see fig. 5). The area A_B is the surface area of a vertical aquifer prism whose properties are characterized by the assigned parameters.

The interval r_{Bj} describes the width of the cross-sectional area between nodal point B and its j^{th} neighbouring nodal point (fig. 5).

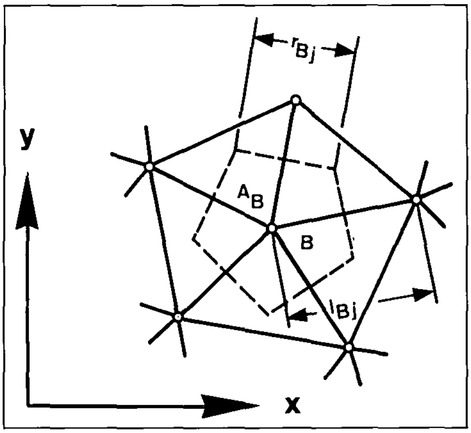

Figure No. 5, Basic element of triangle grid

In analogy to the spatial discretion of the aquifer, the continuous process of unsteady-state flow is replaced in the mathematical model by a discrete series of quasi-steady state flow states.

The continuity equation in nodal point B requires the sum of all node-to-node B water transfer rates plus the sum of all water rates leaving or entering the system in B to be equal to the change of storage in the aquifer prism per time increment.

$$\sum_{j=1}^{o} Y_{Bj} \times (h_{j,u+1} - h_{B,u+1}) + Q_{sonst,u+1}$$

$$= \frac{A_B \times S_B}{\Delta t} (h_{B,u+1} - h_{B,u}) \qquad (1)$$

where

$$Y_{Bj} = \frac{r_{Bj}}{l_{Bj}} \times m_{Bj} \times K_{Bj} \tag{2}$$

$$Q_{sonst} = q_B \times A_B + Q_B \tag{3}$$

and

o = number of neighbouring nodal points
n = index of time increment
m_{Bj} = saturated thickness
A_B = surface area represented by nodal point B
K = hydraulic conductivity

Under steady state conditions, the right hand side of equation (1) becomes zero.

Calculation is based on the method of successive overrelaxation. By correction of the head calculated for the preceding iteration step, by the change of head, as deduced from the balance quantity Q (bracketed in equation (4)), a new value of head is calculated for a new time increment.

$$\begin{aligned} h^{w+1}_{B,u+1} = h^{w}_{B,u+1} + \lambda \times \Bigg[& \sum_{j<B} Y_{Bj} \times h^{w+1}_{j,u+1} + \\ & + \sum_{j>B} Y_{Bj} \times h^{w}_{j,u+1} - \Big(\sum_{j=1}^{o} Y_{Bj} + \frac{A_B \times S_B}{\Delta t}\Big) h^{w}_{B,u+1} \\ & + \frac{A_B \times S_B}{\Delta t} h_{B,u} + Q_{sonst,u+1} \Bigg] \end{aligned} \tag{4}$$

with $\lambda = \varphi \times \Omega$ (5)

$$\Omega = \frac{1}{\sum_{j=1}^{o} Y_{Bj} + \frac{A_B \times S_B}{\Delta t}} \tag{6}$$

where

Ω = factor to convert Q to h
φ = relaxation coefficient
w = iteration index

By utilizing equation (4), all nodal points will successively be calculated again and again until the balance quantity is less than a given value.

The water table of an unconfined aquifer is taken account of by setting the saturated thickness equal to the head that was calculated for the preceding iteration step.

2.3.2 Modelling the Dewatering Process for an Open Pit Mine

Ground water flow problems that must be solved by numerical modelling of a dewatering process for a mine differ somewhat from those usually encountered by hydrologists. Any mine dewatering aims at completely depleting the aquifer portion top of the lowermost working level within the mine. In general, during ground water withdrawal, an initially confined aquifer will successively become unconfined and finally, in the working area, be fully depleted. Withdrawal is usually accomplished by gravel packed tube wells. Here, the special need arises to simulate discharging wells and to compute their maximum capacity as function of the head just outside of the well.

The hydraulically possible rate of discharge per well and time increment must be computable by the program to allow for proper selection of the appropriate pump.

In any nodal point, where the initially confined aquifer becomes unconfined, the storage coefficient S changes to the specific yield Sy. Due to the fact, that S and Sy usually differ by several powers of ten, equation (4) may easily become unstable. Busch & Luckner (7) recommend a numerical procedure to compensate for the jump of S. In GW1, this is done by setting the head h in any nodal point equal to z_o, the top of the aquifer, as soon h becomes less than z_o. From the next iterative step on, storativity in this nodal point is represented by Sy.
Depletion of the aquifer is solved for in a similar way. As soon as the head h falls short of the base, z_u, of the aquifer, the respective nodal point is taken out of computation. The total flux to this nodal point thus is set to zero. Flow then occurs

around the depleted part of the aquifer.

Single dewatering wells and galleries of wells are simulated by summing up the rates of discharge of all wells that fall into the surface area A_B of the aquifer prism and assigning the sum Q_{sonst} to the respective nodal point B. The head h_B computed this way represents the average head of the prism. As a rule, it will be substantially higher than the water table in a well. To design the dewatering wells and to calculate their maximum capacities, the heads at the effective radii of the wells must be known, however. Since the linearity of Darcy's law does not hold any more in the vicinity of a discharging well in an unconfined aquifer, another approach, that is based on Sichardt's concept, had to be made (2).

The water table for a well under quasi steady-state conditions, that is located in a nodal point, is calculated by utilizing Thiem's formula

$$h_{well} = \bar{h} - \frac{Q}{2\pi K\bar{m}} \ln \frac{\bar{r}}{r_{well}}$$

where

h_{well}	=	head at effective radius of well
$\bar{h}$	=	arithmetical mean of heads of neighboring nodal points
$\bar{m}$	=	arithmetical mean of saturated thicknesses between nodal point and neighboring nodal points
$\bar{r}$	=	arithmetical mean of horizontal distances to neighboring nodal points
r_{well}	=	effective radius of well, identical with drill hole radius

For a node representing more than one well, the drawdown must be reduced. Due to the principle of superposition, the resulting cone of depression will be considerably deeper than the individual cones around the wells. To enable determination of the head at each well, a reduction factor, fi, was devised.

From

$$h_{well} = \bar{h} - s_{well} \quad (7)$$

follows

$$h_{well} = \bar{h} - f_i \times s_{well} \quad (8)$$

where

f_i = reduction factor.

Its numerical value varies between 1.0 for one well and 0.3 for seven and more wells per nodal point.

The yield of a well discharging from an unconfined aquifer is limited by the so-called Sichardt's maximum capacity (2).

This maximum capacity is the product of wetted area of the well (assumption: wetted area is fully screened) and specific discharge v at the effective radius of the well.

$$Q_{max} = 2\pi \times r_{well} \times \bar{h}_{well} \times K \times I_{max} \quad (9)$$

and

$$I_{max} = \frac{1}{15\sqrt{K}} \quad \text{(dimensionally incorrect!)} \quad (10)$$

where

Q_{max} = Sichardt's maximum capacity

I_{max} = maximum hydraulic gradient

K = hydraulic conductivity

Inserting equation (10) in equation (9) yields

$$Q_{max} = 2\pi \times r_{well} \times h_{well} \times \frac{\sqrt{K}}{15} \quad (11)$$

After each time increment, the program compares the discharge Q with the maximum capacity Q_{max}. In addition, it controls Reynolds' number if it exceeds the numerical value of 2 (assumed to be the upper limit of laminar flow). As soon as one of both conditions no longer holds, the time increment must be recalculated with a reduced rate of discharge.

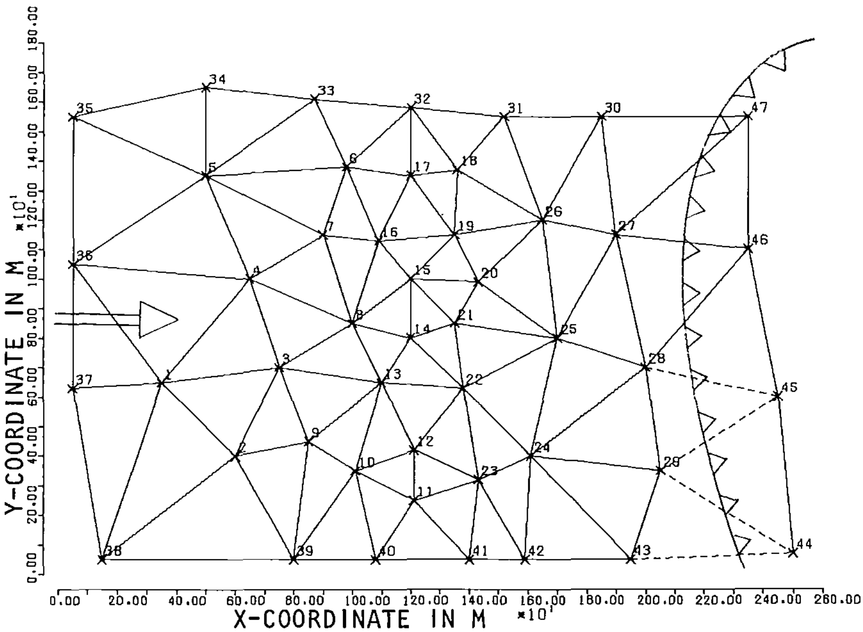

Figure No. 6, Example of plotted model grid.The flow is directed from West to East. The toothed line represents the perimeter of the mine.

A few examples of plots of a run of this model serve to illustrate the results. A cutout of a plotted model grid is shown in fig. no. 6. The ground water flow is directed from west to east towards the open pit. Nodal points 44 through 47 represent the aquifer portion within the boundaries of this pit. Nodal points 11, 12, 14, 16, 17 simulate sites of dewatering wells. In fig. no. 7 a, top and bottom of the aquifer are indicated by full lines (on the original plots, upper and lower aquifer boundaries are marked in a different color). Differently dotted lines represent successive stages of drawdown after 3 months and 20 days, 6 months and so on.

Fig. 7 a and 7 b show drawdown vs distance graphs for different time steps and drawdown vs time graphs for nodal point 28 just in front of the perimeter of the mine.

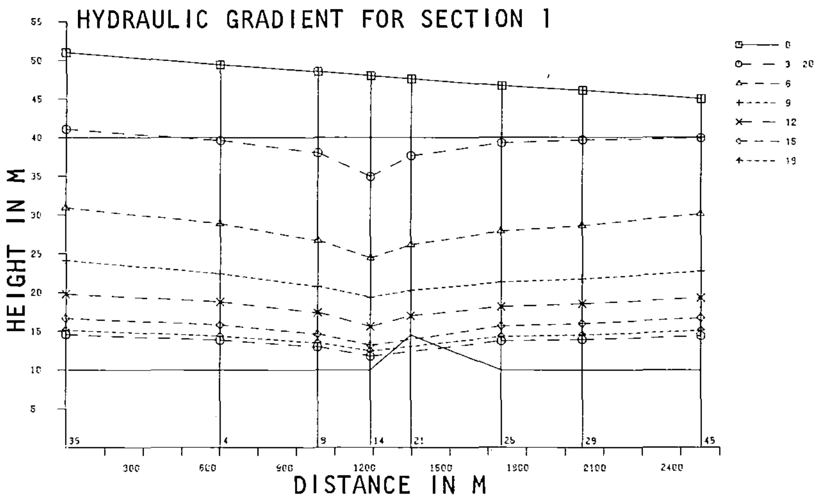

Figure No. 7 a, Drawdown vs. distance plot of successive stages of drawdown.

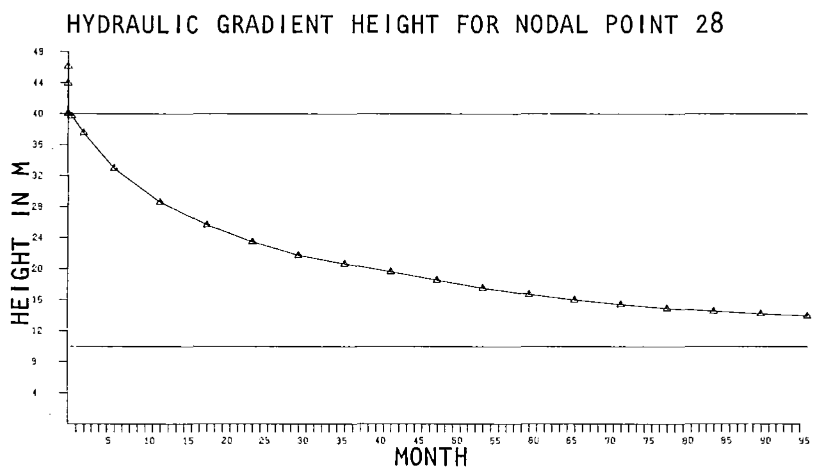

Figure No. 7 b, Drawdown vs. time plot for nodal point 28.

3. EXECUTION OF DEWATERING MEASURES

3.1 Introductory Remarks

The transmissivities of the water-bearing strata top and bottom of the coal reach values as high as $T = 5 \times 10^{-2}\ m^2s^{-1}$ ($\sim 3.5 \times 10^5$ US gallons/day - foot). Such high transmissivities and the large areal extent of these strata render gravity discharge by vertical tube wells the only economical solution to withdraw the large rates of water as necessary.

To lift the water from great depths to the ground surface, high-capacity submersible motor pumps are required which, in turn, demand large drilling diameters and likewise large widths of screens and casings. Today, company-operated drilling rigs regularly sink wells down to depths of more than 500 meters ($\sim$ 1 650 feet). Standard drilling diameters range between 1 200 and 1 800 mm (about 48 inches and 71 inches) and nominal widths of well screens and inner casings between 300 mm and 800 mm (about 12 inches and 32 inches). All wells are drilled by means of a reverse circulation drilling method (8).

3.2 Reverse Circulation Air Injection Drilling Method

Reverse circulation methods are characterized by the drilling fluid descending within the annulus between drill rods and bore hole wall and ascending loaded with cuttings. Upon discharge into the settling pond, the cuttings settle out and the sediment-free fluid begins its cycle again. The air injection method as applied by Rheinbraun maintains this cycle by injecting pressured air into the drill rods via inlet nozzles above the drill bit or the drill collars. As drilling fluid, untreated water is usually employed.

Fig. 8 shows schematically the operation of such a rig. Generally the bore hole remains stable during drilling only because of the difference in heads of the drill water column and the aquifer. This minimum must not fall short of 3 meters ($\sim$ 10 feet), i. e., in case of an artesian aquifer special procedures will become necessary.

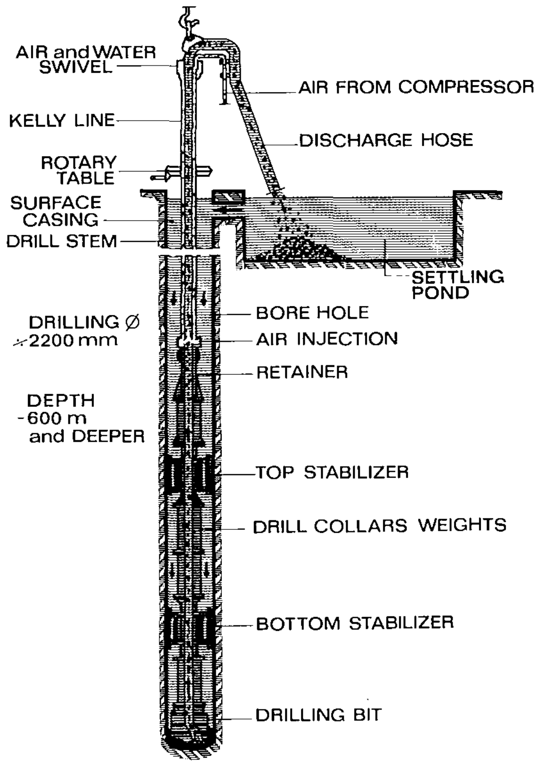

Figure No. 8, Working scheme of a reverse circulation air injection drilling rig (9).

The diagram of figure 9 shows the sequence of operations for an average 500 m - well (8). Considering preparatory and finishing work, the average rate of progress of a L 15-rig is 12 meters (~ 40 feet) per 8 hour-shift. This figure increases to 50 meters (~ 165 feet) per shift if only the drilling job is considered.

Rheinbraun employs exclusively trailer-mounted Wirth drilling rigs. Their derricks, draw and feed works are designed to also handle the strings of casings and screens during installation. The table below gives some technical data of Wirth rigs operated by Rheinbraun.

Type	L 4	L 10	L 15
Drive	230 HP diesel engine	200 HP diesel engine	250 HP diesel engine
Hook load			
a. regular	36 metric tons	100 metric tons	160 metric tons
b. maximum	72 metric tons	120 metric tons	195 metric tons
Compressor	5.7 cubic meters per minute (∼1 500 US gallons per minute)	20 cubic meters per minute (∼5 280 US gallons per minute) (2 units)	20 cubic meters per minute (∼ 5 280 US gallons per minute) (2 units)
Regular duties with Rheinbraun			
a. drilling diameters	1 200 - 1 700 millimeters (∼ 48 inches - 67 inches)	1 200 - 1 700 millimeters (∼ 48 inches - 67 inches)	1 200 - 1 700 millimeters (∼ 48 inches - 67 inches)
b. drilling depths	400 meters	600 meters	600 meters

Theoretical investigations and field tests revealed that the rate of fluid (water) circulation in 300 mm (12 inches) drill-rods amounts to approximately 12 to 18 cubic meters per minute (∼ 3 170 through 4 755 US gallons per minute). Depending on the depth of injection, between 15 and 30 cubic meters per minute in compressed air at pressures up to 20 bars (∼ 290 pounds per square inch) has to be blown into the drill stem. The total discharge is then 12 cubic meters per minute at a content of solids of approximately 8 per cent. This figure is equivalent to a discharge of 130 through 140 (metric) tons of drill cuttings per hour (9).

The only drill bits still in use are roller bits, i. e. flat head roller bits and multiple-stage bits. To guarantee plumbness, up to eight drill collars, each having a weight of 6 (metric) tons and two stabilizers, are added to the bits. Rheinbraun no longer uses excentric (Züblin) bits. Experience showed that the drilling progress in dewatered, i. e. compacted sediments was unsatisfactory when these bits were employed.

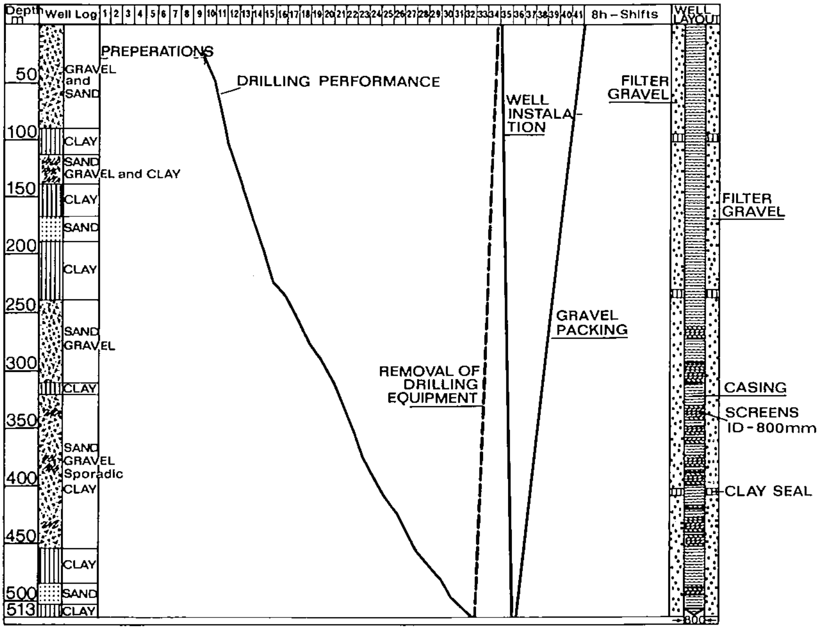

Figure No. 9, Work vs. time diagram for an average 500 meters - dewatering well.

As already mentioned, untreated water serves usually as drilling fluid. Difficulties arise, however, when drilling certain clay formations, because the clays tend to swell by water absorption and to cave in. To overcome these difficulties, natural or synthetic polymeric additives, such as carboxylmethylcellulose (CMC) and Stokopol (a polyacrylamide) are put into the water to increase its viscosity and to hinder the water molecules from entering the crystal lattice of the clay (10).

3.3 Well Design

All dewatering wells are equipped with asbestos-cement inner casings and screens (fig. 10). Special couplings allow for a suspended installation.

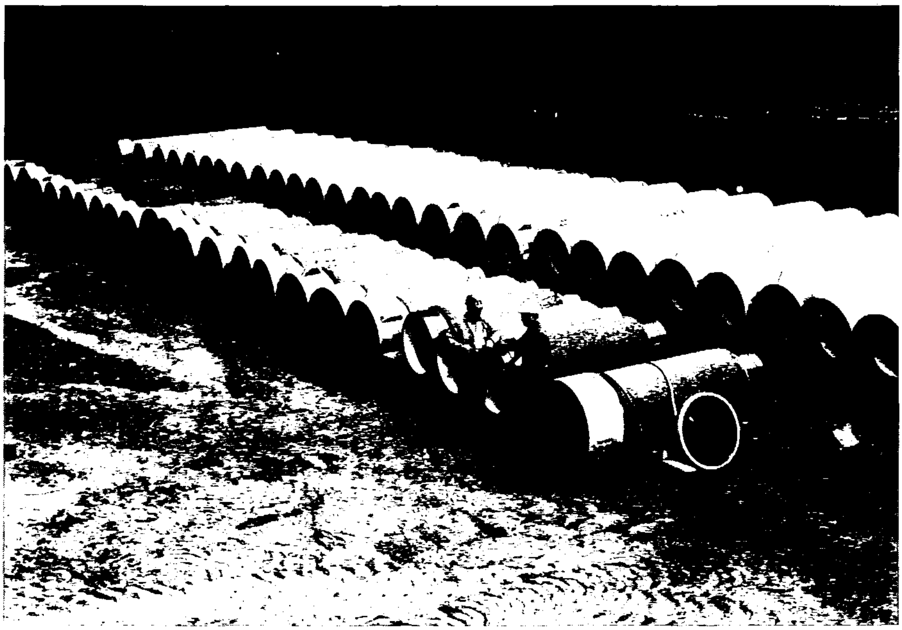

Figure No. 10, Asbestos-cement inner casings and gravel wall screens ready for assembly. Some of the couplings are equipped with spacers.

Both casings and screens are distinguished by high tensile strength and sufficient crushing strength. They are corrosion-resistant, i. e. they are hardly affected by aging processes. Below depths of 350 m ($\sim$ 1 150 feet) the casings are wrapped with styrofoam bodies to increase their buoyancy, i. e. to make up for higher tensile stresses. Wells equipped with asbestos-cement tubes can be easily cut portion by portion by the excavators. Even their angular fragments can be transported via the conveyor belts without damaging the rubber. This property renders them very advantageous for continuous open pit mining where the dewatering wells are successively operated on any working level. Screens consist of pierced asbestos-cement pipes of the same widths that are coated with a 30 or 35 mm thick resin-glued gravel walls. The gradations of the gravel used for these walls are 2 - 3 mm, 3 - 5 mm, 4 - 7 mm.

Upon installing the string of casings and screens and supporting them above ground surface, the annular space is carefully gravel packed (fig. 9). The method applied to ensure proper gradation of filter gravel uses a characteristic grain size of the water-bearing formation. Originally developed in Germany (11), it is also described by (12). It employs the standard relation

Gravel pack standard grain size = Aquifer standard grain size x screening factor

Aquifer standard grain sizes for any aquifer are taken from charts (11). The screening factor is defined as the increase in grain size necessary to prevent passing of aquifer material through the gravel pack. Usually, its numerical value ranges between 4 and 5.

3.4 Submersible Motor Pumps

Because of their well-known superiority to other pumps, Rheinbraun uses only submersible motor pumps for regular service. Right now, there are around 1 800 pumps in stock, about half of them are in service, the other in reserve or in repair. Two types may suffice to indicate the lower and upper capacity limits:

Q: 0.035 cubic meters per minute at H: 35 meters
(∿ 925 US gallons per minute) (∿ 115 feet)

Q: 32.60 cubic meters per minute at H: 215 meters
(∿ 8 600 US gallons per minute) (∿ 705 feet)

There are numerous other in between types such as pumps with higher delivery heads but lower rates of discharge. All larger pumps are of the double-suction type. To extend their service time, which today may be as high as 32 000 hours, the larger pumps are exclusively powered by slow-moving motors.
Depending on the rate of discharge, standard riser pipes between DN 100 and 400 (corresponding to 4 inches and 16 inches) are used.

Rheinbraun uses submersible motor pumps manufactured only by two German manufacturers, KSB and Ritz. Both pump producers have developed several series of pumps, the performance curves of which link up with each other. Since at least two, often even six pump changes are necessary during the lifetime of a single well, selection of the suitable sequence of pumps is facilitated (fig. 11).

To power the pumps there are company-owned 110 kV-overhead line systems around the different mines. Close to the centers of well batteries, the high voltage is transformed down to local 25 kV-systems which serve transformers that in turn feed individually 6.3 kV-transformers and switches in the vicinity of individual wells and well groups.

3.5 Mine Dewatering - the last Percent

Despite the fact that dewatering procedures as described above account for perhaps 99 per cent of Rheinbraun's total discharge of ground water, there is always the threat of saturated strata just ahead of the bucket wheel. Typical cases are undetected, narrow strips of sediments between faults which act as barriers, or strata with low hydraulic conductivities. In both cases, the transmissivities are too low to allow normal gravity flow dewatering wells to sufficiently operate.

In dealing with such problems two ways to solve them are possible. The first one is to leave it the ingenuity of the mining engineers to handle the semi-liquid flow of material that will occur when the wheel cuts into the saturated strata. The other one is to devise emergency-dewatering schemes that yield satisfactory results in a very short time.

One of these emergency measure which has proven very effective is to sink large-diameter bore holes into the low-transmissivity strata, to design them with small diameter screens and pack them with very coarse gravel. Because the latter allows both the water and the sand of the associated formation to pass, it will gradually be destroyed by such kind of discharge. The well will last, however, just for the few weeks, the time required to remove the small volumes of ground water by intermittent pumping.

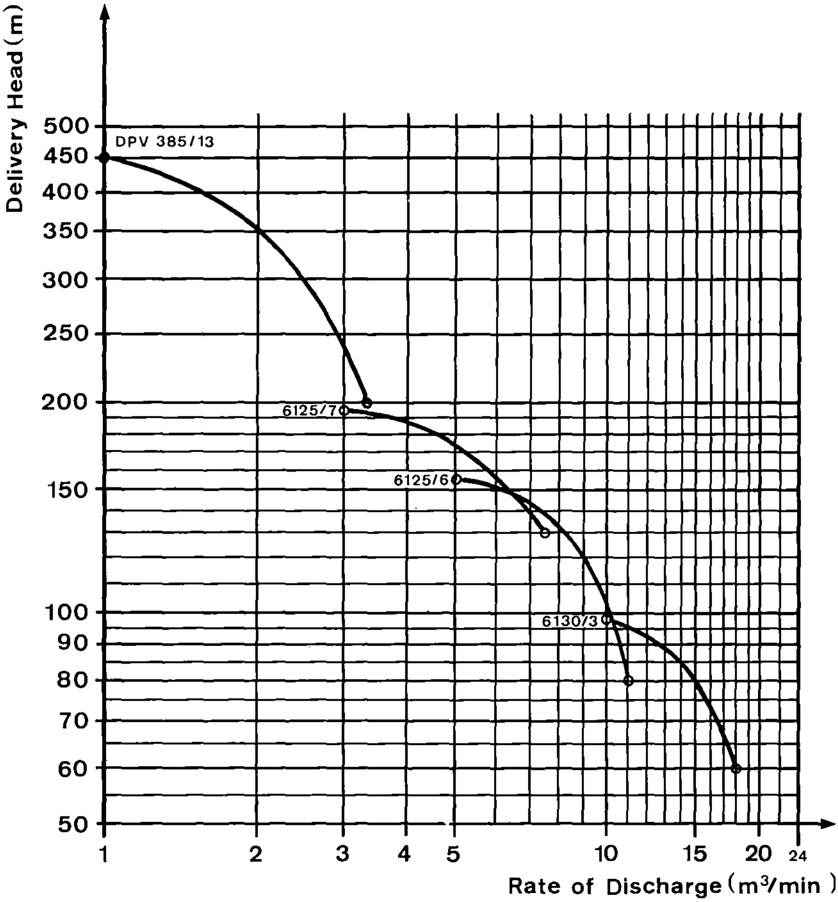

Figure No. 11, Possible sequence of submersible motor pumps in a dewatering well.

Ritz-6130/ 3 stages (865 Volts, 280 kilo Watts, diameter: 600 millimeters ~ 24 inches, overall length: 4 260 millimeters ~ 168 inches)

Ritz-6125/ 6 stages (865 Volts, 280 kilo Watts, diameter: 500 millimeters ~ 20 inches, overall length: 4 615 millimeters ~ 182 inches)

A method to enable the excavators to cut slopes in strata with hydraulic conductivities as low as 10^{-6} through 10^{-7} meters per second (~ 2 through 0.2 US gallons/day - square foot) is to stabilize the latter by vacuum dewatering (13). Figure 12 shows schematically how this method works.

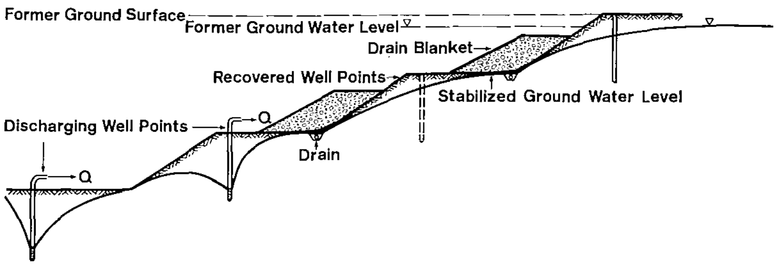

Figure No. 12, Stabilization of ground water level by vacuum dewatering measures.

Two-inch well points, consisting of a slotted screen of one meter length and six meters casing are flush-drilled into the beds at horizontal intervals between one and two meters (~ 3.3 and 6.5 feet). Upon sealing the annular spaces with clay, all well points are connected to a vacuum pump via a hose pipe. The dump reduces the system pressure to around 0.3 through 0.4 atmosphere, i. e., a vacuum which is equivalent to depths

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Ritz-6125/ 7 stages	(865 Volts, 280 kilo Watts, diameter: 500 millimeters ~ 20 inches, overall length: 4 871 millimeters ~ 192 inches)
KSB-DPV 385/13 stages	(865 Volts, 185 kilo Watts, diameter: 315 millimeters ~ 12.4 inches, overall length: 4 875 millimeters ~ 192 inches)

between 7 and 6 meters (~ 22 feet to 19 feet). Maintaining such a vacuum results in the withdrawal of ground water that otherwise would not have flowed to wells in a reasonable time. After two through four weeks, steady state conditions prevail.

Under protection of a line of well points, a 6 meters high slope can be cut by a bucket wheel or a dragline. Along its foot, a drain is designed to discharge into a pump sump. As an additional measure of safety, a drain blanket is added as shown in fig. 12. Eventually, a highwall, consisting of a series of many small slopes, has been featured. Ground water is still flowing towards the open hole of the mine but it is intercepted by the small drains.

4. SUMMARY

In the Tertiary lignite deposits between the cities of Cologne, Aachen, and Moenchengladbach, W. Germany, Rheinbraun runs five open pit mines at depths of today about 300 meters (~ 990 feet). The sequence of water bearing and confining strata above and below the seam formations as well as numerous faults form a complicated system of aquifers which, in the pit areas, must be completely or partially depleted.

Specially modelling techniques to simulate the ground water flow towards dewatering wells have been applied, both one-dimensionally and two-dimensionally. The latter model is based on a finite difference method. In addition to "standard" ground water modelling, it handles specific problems such as full depletion of parts of the aquifer or simulation of the decreasing capacities of dewatering wells.

More than 100 dewatering wells are drilled annually by Rheinbraun, with maximum depths now around 500 meters (~ 1 650 feet). To sink these wells, the reverse circulation air injection method is employed. The well design is based on the use of asbestos-cement casings and gravel wall screens with nominal diameters between 300 and 800 millimeters (12 and 32 inches). The wells are equipped with submersible motor pumps which discharge between 0.035 and 32.6 cubic meters per minute (∿925 and 8 600 gallons per minute).

Despite all efforts, it is not always possible to remove the water completely from the mines. In such cases, small scale dewatering measures are put into operation that are adapted to the local hydrogeologic conditions.

5. REFERENCES

1. Voigt, R. (1976) "Evaluation of Geologic, Hydrologic, and Geomechanic Properties Controlling Future Lignite Open Pit Mining" - Proc. first Int. Coal Explor. Symp. London, pp. 296 - 323.

2. Sichardt, W. (1928) "Das Fassungsvermögen von Rohrbrunnen und seine Bedeutung für die Grundwasserabsenkung, insbesondere für größere Absenkungstiefen" - Julius Springer Verlag Berlin

3. Siemon, H. (1958) "Berechnung von Grundwasserabsenkungen unter Berücksichtigung des Grundwasserhaushaltes" - Ministerium f. Ernährung, Landwirtschaft und Forsten d. Landes Nordrhein-Westfalen, Düsseldorf, 72 p.

4. Boehm, B. (1975) "Beitrag zur indirekten Ermittlung von Parametern für Grundwasserströmungsmodelle" - Mitt. Institut f. Wasserwirtschaft, Hydrologie u. landwirtschaftl. Wasserbau d. Techn. Univ. Hannover, vol. 32, pp. 3 - 130.

5. Tyson, N. H. & Weber, E. M. (1964) "Groundwater Management for the Nation's Future - Computer Simulation of Groundwater Basins" - J. Hyd. Div. ASCE, No. HY 4, pp. 59 - 77.

6. McNeal, R. H. (1953) "An Asymmetrical Finite Difference Network" - Quarterly of Appl. Mathem., vol. 11 (3), pp. 295 - 310.

7. Busch, K.-F. & Luckner, L. (1973) "Geohydraulik" - VEB Verl. f. Grundstoffindustrie, Leipzig.

8. Blank, R. (1976) "Tagebauentwässerung im Rheinischen Braunkohlenrevier mit großkalibrigen Tiefbrunnenbohrungen und entsprechenden Tauchmotorpumpen" - bbr vol. 27 (3), pp. 87 - 92.

9. Emrich, D. (1979) "Entwässerung der Tagebaue im Rheinischen Braunkohlenrevier" - Bergbau, vol. 30 (3), pp. 126 - 132.

10. Häge, K. (1977) "Die Verwendung künstlicher Polymere als Schutzkolloid in Bohrspülungen" - Braunkohle, vol. 29 (5), pp. 197 - 202.

11. Bieske, E. (1961) "Zur Schüttkornbestimmung bei Kiesschüttungsbrunnen" - bbr, vol. 12 (9), pp. 407 - 411.

12. Blair, A. H. (1970) "Well Screens and Gravel Packs" - Ground Water, vol. 8 (1), pp. 10 - 21.

13. Proff, H.-J. (1975) "Erfahrungen bei der Böschungsherstellung in Altkippen, dargestellt am Beispiel des Tagebaues Alversdorf" - Braunkohle, vol. 27 (6), pp. 168 - 175.