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Depressurization Systems: Design, Construction, and Cost Considerations to Prevent Floor Heave

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ABSTRACT

Depressurization of underburden water-bearing zones to prevent floor heave is an integral part of many mining operations. A successful depressurization program is based on an understanding of the geohydrology of underburden materials. However as a practical matter, determination of depressurization amounts and design of depressurization systems starts not with geohydrologic considerations but with an evaluation of power reliability and mine operational goals. Only after these two factors have been thoroughly evaluated are depressurization amounts and detailed system design including well sizing and layout, technical and cost factors associated with electrical and discharge considerations, regulatory and mitigation issues, and pumping costs versus safety-factor evaluated.

Key Words: Depressurization, floor heave, lignite, pumpage, artesian pressure

PURPOSE OF DEPRESSURIZATION

Depressurization is the lowering of artesian pressure in important water-bearing strata beneath maximum mining depths. The purpose of depressurization is to prevent heaving of the mine pit floor and attendant upward ground-water flow. Such flows can be large and can contaminate mine product, affect mine floor trafficability, decrease highwall and spoil stability, and be unsafe.

In Texas there are about 15 operating surface lignite mines. Many of these mines produce lignite from the Wilcox Group. The Wilcox is composed of sands and clays deposited by ancient river systems in East and Northeast Texas, and in ancient barrier-bar and lagoon-bar systems in Central and South Texas. Historically, only the shallowest lignite seams were mined. However, over the years deeper lignite seams were mined. With the advent of deeper mining, depressurization activities were needed where lignite seams overlaid significant water-bearing sands. In Northeast Texas, depressurization activities are generally minor due to the lack of sands beneath and in close proximity to targeted lignite seams. However, in Central Texas, between the Colorado and Trinity Rivers, the Wilcox contains a significant water-bearing unit. The Wilcox has been subdivided into three formations: the Hooper Formation, composed of clay and minor amounts of sand; the

Simsboro Aquifer, composed predominantly of sand which forms a major water-bearing unit in Texas; and the Calvert Bluff Formation, composed predominantly of clay with some sand. The Calvert Bluff Formation is the principal lignite-bearing formation and much of the mining in Central Texas is conducted in the lower Calvert Bluff Formation, which directly overlies the Simsboro. Figure 1 presents a generalized cross section of the Wilcox Group.

The Simsboro is a major aquifer in Texas with sands commonly more than 200 feet in thickness, and well yields up to 3,000 gallons per minute (gpm). Transmissivities range from 20,000 to over 100,000 gallons per day per foot (gpd/ft). In areas where the Simsboro directly underlies targeted lignite seams, depressurization activities become a major operational activity for the mine. Without depressurization activities, floor heave would occur, and water inflows of over 4,000 gallons per minute to the pit could occur with associated stability, operational, and trafficability concerns. Current systems in individual mines are pumping up to about 30 million gallons of ground water per day to obtain artesian pressure declines of up to about 160 feet. Much larger depressurization pumpage amounts creating over 250 feet of artesian pressure decline are projected as mines recover even deeper lignite seams, in the future.

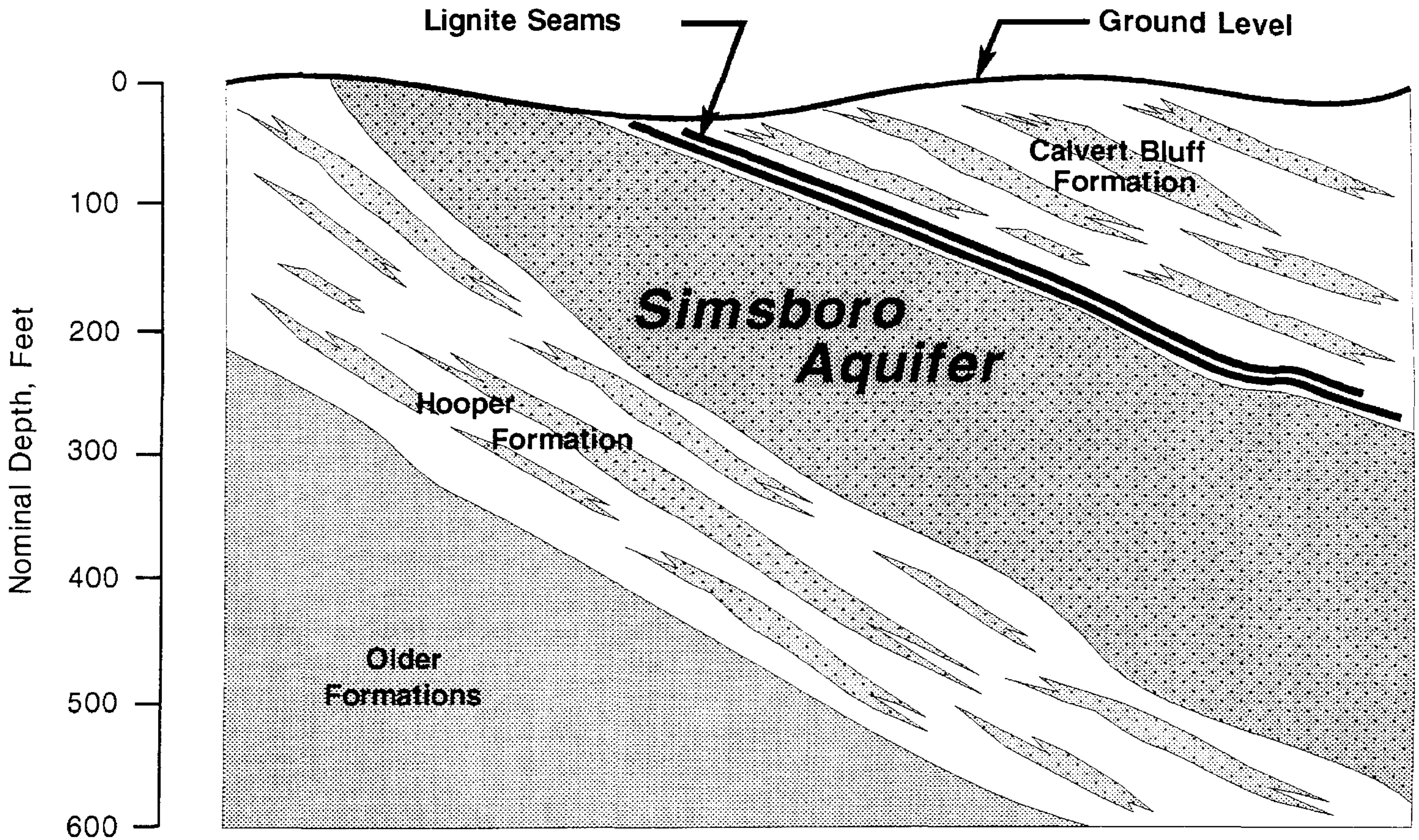
To prohibit floor heave, depressurization systems must be pumped 24 hours a day, 365 days per year, without interruption. Because of the possible severe impacts of floor heave, there is redundancy in system design including standby wells and pumping equipment, spare pumps, generators, alarms, contractors on-call for immediate repairs, and emergency action plans if well field failure occurs. Such activities are required due to the significant operational, safety, and cost issues associated with floor heave.

DEPRESSURIZATION AMOUNT

The most important, and sometimes difficult, decision when evaluating depressurization is determining the amount of depressurization (pressure relief) required to safely and cost-effectively conduct mining operations. At a minimum to prevent floor heave, the upward artesian pressure force of the underlying water-bearing zone(s) must not exceed the downward force exerted by the weight of materials between (separating) the pit floor and the top of the water-bearing zone (referred to herein as the separation), plus the strength of the separation materials. The minimum artesian pressure reduction required to prevent floor heave is site-specific and depends on the separation thickness, the amount of artesian pressure, details of the mine plan including pit width and length, the shear and tensile strength of separation materials, and the restraining effects of the spoil and highwall slopes. If the artesian pressure exerted at the top of the underlying water-bearing zone exceeds the weight and strength of separation materials and the restraining effects of the spoil and highwall, the mine pit floor will heave. For convenience and planning purposes, three depressurization levels are commonly used. Figure 2 schematically shows important depressurization terms and demonstrates the three depressurization levels.

1. Minimum Depressurization - The amount of artesian pressure reduction which results in the upward artesian pressure force at the top of the underlying water-bearing zone(s) being equal to the weight and shear and tensile strength of separation materials and the restraining effects of the spoil and highwall slopes.

FIGURE 1. Generalized cross section showing geologic units



2. Safe depressurization - The amount of artesian pressure reduction which results in the upward artesian pressure force at the top of the underlying water-bearing zone(s) being equal to the weight of separation materials. Shear and tensile strength of separation materials, and the restraining effects of the spoil and highwall slopes are not considered.
3. Dry Depressurization - The artesian pressure reduction required to lower the artesian pressure in the underlying water-bearing zone(s) to just below the mine pit floor (deepest lignite to be mined).

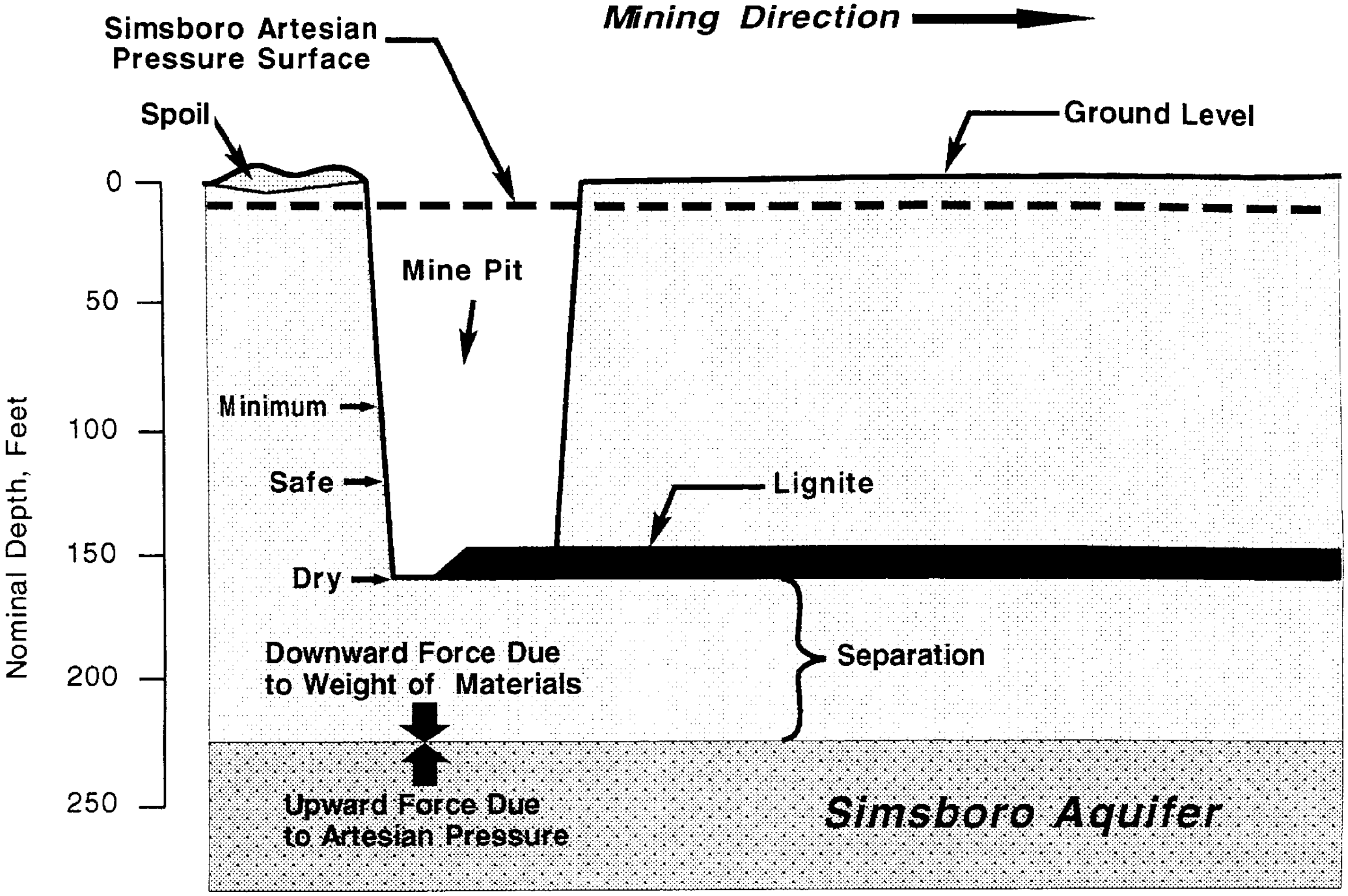
The selection of the appropriate depressurization amount for a mine or part thereof should be based on numerous factors. The following provides some guidance which should be used when evaluating the amount of depressurization (pressure relief) required:

- Application of Minimum Depressurization Requirement
  - When separation thickness is uniform.
  - When the materials composing the separation are homogenous.
  - When artesian pressures are consistent and predictable.
  - When cost and/or pumpage minimization is critical.
  - When sufficient standby equipment is available and power reliability is good.
  - When data concentration and reliability are high.
  - When floor heave would not result in significant operational problems or concerns.
  - When the material strength of separation materials is well understood and quantifiable.
  - When pit dimensions are reasonably constant.

- Application of Safe Depressurization Requirement
  - When separation thickness is variable.
  - When lithology of the separation thickness is variable.
  - When standby equipment is somewhat limited.
  - When significant operational concerns are associated with floor heave.
  - When equipment on the pit floor will require time to evacuate.
  - When power reliability is poor.
  - When spoil side mining is taking place.

- Application of Dry Depressurization Requirement
  - When floor heave has occurred in previous adjoining pit(s).
  - When unplugged bore holes and/or wells into the underburden sands exist.
  - When there is minimal standby equipment.
  - When power reliability is poor and power outages are common and reasonably lengthy.
  - When the separation is thin.

FIGURE 2. Schematic diagram showing depressurization terms



Most depressurization operations in Central Texas are generally depressurizing to between the safe and dry conditions. This is primarily due to the operational concerns if heave were to occur, power reliability, the variability in thickness and lithology of the separation zone and the cost-benefit of increased safety factor. At present, no large-scale depressurization activities in Texas are occurring with the minimum depressurization amount as the goal. This is primarily due to the difficulty, likely variability and confidence level of trying to determine tensile and shear strength of underburden materials, the varying effects of the spoil and highwall slopes in each pit and the costs associated with required increased standby equipment and power. The closer depressurization goals are set to the minimum depressurization amount the quicker floor heave will occur upon well or well field failure and therefore the more standby equipment required.

Generally, with a separation thickness of about 60 feet, average pit dimensions and typical Calvert Bluff separation lithology, depressurization from minimum to safe amounts results in about 20 to 25 per-cent more pressure reduction. However, the amount of this additional pressure reduction declines as the separation thickness thins, pit dimensions expand and underburden materials weaken. As the separation thickness becomes thinner the minimum and safe depressurization requirements approach dry depressurization requirements. When the separation thickness is zero, the minimum, safe and dry depressurization requirements are the same.

In practice, selection of a depressurization amount is not specific to one of these three depressurization goals and usually varies per mine and even per areas within a mine. In addition, in any given mine area depressurization goals change as mining progresses due to 1) depressurization requirements increasing in the downdip direction, and 2) the fact that most depressurization systems by necessity are located on the downdip edges of mine blocks and most pits are oriented along strike. Therefore as pits move downdip, depressurization requirements increase, pumpage requirements increase, and the time between well field failure and floor heave decreases as the mine pits are moving closer to the depressurization wells. These factors result in the necessity to periodically re-evaluate the system and adjust pumpage and equipment needs to meet operational and safety goals.

The starting point for the design of a depressurization systems is an evaluation of how much time after total well field failure and/or single well failure is required to get a well or entire well field system back on line and at what level of confidence or reliability should the depressurization system be designed. With that critical information the actual depressurization amount(s) can be determined, based on geologic, hydrologic, mechanical, and cost considerations involved in the design of such systems. In such evaluations statistics can be an important tool in assessing power reliability, data requirements, safety and operational considerations. With sufficient data, systems can be designed to target specific levels of confidence. Graphs of cost versus degree of confidence of preventing floor heave can be developed and used as an evaluation tool for planning a depressurization system.

COST CONSIDERATIONS

Once the depressurization amount has been determined, the next consideration is how to cost-effectively meet this depressurization amount. This is a reasonably simple but sometimes time-consuming task. For purposes of this cost consideration discussion, it is assumed that the basic geohydrology of the system has been thoroughly defined including:

1. Local and regional transmissivity.
2. Boundary conditions affecting drawdown including leakage, faults and outcrop areas.
3. Available drawdown.
4. Artesian storage coefficients and specific yields.
5. Variability of transmissivity at well sites.
6. Likely efficiency of production wells constructed.

Two cost considerations come into play in design of a depressurization system, (1) how most cost-effectively to remove the required rate of water, and (2) how most cost-effectively to meet the mine operators required recovery time prior to potential heave upon well or well field failure. To address the first issue, evaluations need to be conducted on probable well yields based on transmissivity, available drawdown, interference drawdown and likely well efficiencies. This evaluation is usually conducted for the maximum depressurization pumpage amount in a given mine area as interference drawdown is maximized. Based on this evaluation, these pumpage amounts are then used to determine the appropriate size for well casing(s) in accordance with applicable pump diameters and total head considerations. Additionally, a larger number of smaller-capacity wells versus fewer larger-capacity wells, based on contractor costs for constructing different sized wells should be evaluated. In the end, the most cost-efficient well needs to be based on the cost of the well and pumping equipment along with costs for electrical and discharge infrastructure. Generally, depressurization of the Simsboro is most cost-effective with 10-inch diameter wells, capable of pumping up to 1,200 gpm, when data indicate individual well yields likely will equal or exceed 700 to 800 gpm. In areas where the transmissivity, available drawdown, boundary conditions and other factors indicate well yields of less than about 700 gpm, a larger number of 8-inch wells are more cost-effective. Cost evaluations indicate the breakover point between 8- and 10-inch wells is at about 700 gpm.

A more difficult evaluation is how to most cost-effectively meet the mine operators recovery times prior to floor heave occurring. Considerations such as overpumping to increase the time to potential floor heave, if a well or well field fails, versus having more standby wells and generators needs to be evaluated. With the targeted amounts of pumpage and the cost for wells, power and electrical calculated, a graph can be made of the capital costs and operation and maintenance costs to overpump versus the capital and maintenance costs for standby generators and wells. The results of these evaluations often change from mine area to mine area, even within the same mine. Generally to cost-effectively design the final system requires properly and accurately scheduling out costs by mine year for depressurization of an entire mine area. The costs should include wells, pumps, generators, electrical, discharge, standby wells and all equipment for the various scenarios.

The detailed analysis to conduct such cost comparisons are too extensive to be included in this paper. However, various spreadsheets can be developed which can assist in conducting the calculations and result in the preferable, most cost-effective system. However, for many mines the system selected in the end must meet one additional critical factor. The system must have the flexibility to meet likely changes in the mine plan without significantly affecting the correctness of the decision on number, size and placement of wells, power and discharge.

INTEGRATED APPROACH

Successful and cost-effective depressurization generally requires a detailed plan to address the items discussed. This often means detailed interaction and planning between the geologist, ground-water hydrologist, mine engineer, civil engineer and electrical engineer. Figure 3 shows a general approach/flowchart for the design of such a system. As discussed, it begins with quantification/identification of power and depressurization system reliability and safety factors, evaluates the various considerations with respect to depressurization design, costs out in detail the actual depressurization system and then, re-evaluates the depressurization amount and design ensuring that all safety and operational considerations are addressed cost-effectively. Oftentimes, the iteration may involve several different scenarios. On occasion, the planning is even integrated and incorporated into the mine plan and methods. Interestingly, in the end the selection of the appropriate depressurization amount is based primarily on operational considerations (power and system reliability), rather than geohydrologic or geotechnical considerations.

Such an approach has resulted in successful large-scale depressurization activities in several surface lignite mines in Texas and more are planned. Some of the current larger systems have been in operation since 1988, and cost-effectively pump up to 30 million gallons per day. Floor heave has not occurred since inception of depressurization activities in these mines, thus demonstrating the success of such an approach to conducting depressurization operations.

FIGURE 3. General approach to depressurization system design