

Well-Field Mechanics for In-Situ Mining

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Over the last several decades in-situ leach mining has become increasingly popular. Conventional mining produces tailings, runoff, and considerable land disturbance—all requiring significant rehabilitation. With in-situ leach mining methods (see diagram below), disturbance is reduced because only multiple boreholes are drilled for recovery. Rehabilitation is much simpler, consequently, the number of in-situ mining operations is steadily increasing. In-situ leach mining can be done to extract a variety of different products including potash, uranium, copper, gold and silver.

Extraction can be accomplished using one of two methods; the well-to-well recovery method discussed here, or stope leaching, a process where broken, low-grade ore is leached from caved areas within former underground mine workings. The first large-scale implementation of the well-to-well recovery method for copper was completed in 1994 at the San Manuel mine in Arizona. Most in-situ mining projects are operated at sites with small ore deposits, lower-grade ore deposits, or where ore bodies are deep.

Distance from drinking water supplies or environmentally sensitive ecosystems is also considered. Sites with large deposits can be divided into several smaller sections that are mined one at a time, allowing the operator to optimize the process.

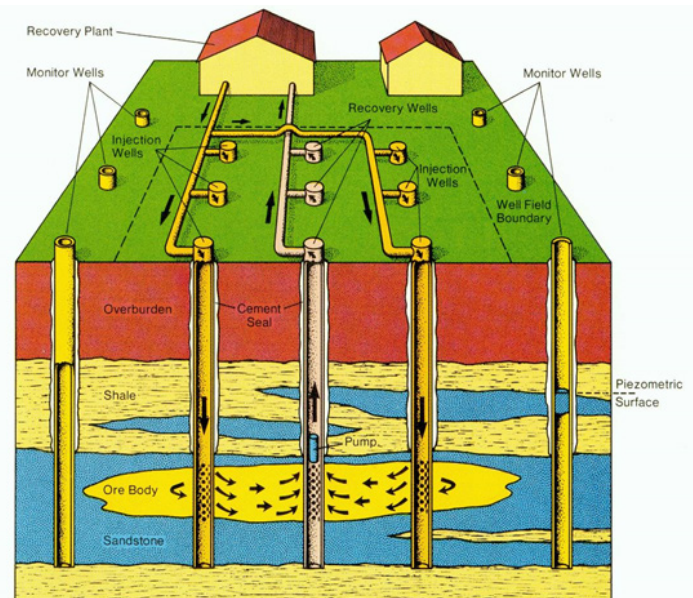
Hydrogeologic Analysis

Basic to an in-situ mining operation is a thorough understanding of the site's hydrogeology, particularly the degree to which fluid movement can be predicted and controlled. The hydrogeology of each site is specific; in-situ mining may not be practical for every ore deposit. In determining feasibility, important questions to be answered include: Is the ore body deposited in the saturated zone with sufficient available drawdown? Do the upper and lower confining units of the aquifer provide enough vertical confinement for the lixiviant (leaching solution)? Is the formation's hydraulic conductivity high enough for wells to achieve reasonable well productivity and injectivity?

Well productivity and injectivity are directly proportional to the values of formation transmissivity. Hydraulic conductivity, defined as transmissivity divided by aquifer thickness, is generally used as the measure for well productivity and injectivity. In a typical well-field setting, in order to maintain a minimum well flow of 10 to 25 gallons per minute, a hydraulic conductivity of one foot per day would be considered the minimum value suitable for in-situ mining.

The storage coefficient, a ratio of the water pumped to the volume of cone of depression, is important when estimating the radius of influence of pumping and injection. Typically, unconfined and confined aquifers have storage coefficients ranging from 10 to 25 percent and from 0.001 to 0.1 percent, respectively.

Once hydrogeologic feasibility of ISR has been determined, engineers can increase the economic feasibility of the operation and minimize the associated environmental effects by addressing three major aspects. Recovery process design influences how efficiently the target ore mineral is removed; well-field design optimizes resource recovery and containment; and monitoring programs provide baseline data and detect potential leakage from the site.



Schematic of the In-Situ mining process

Well-Field Design

Areal sweep efficiency is defined as the percentage of an area covered by injected

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solution at the time of breakthrough. Several standard well-field patterns are commonly used (see diagram below). Sweep efficiency varies with well configuration. For example, staggered line drive, with sweep efficiency of 74 to 78 percent, is a much better well-field pattern than direct line drive, with sweep efficiency of 55 to 60 percent, although these two patterns have the same number of wells.

Controlling the flow pattern in such a way that the breakthrough times for all streamlines will be similar ensures that the peak mineral concentration will be high and the mineral recovery time short. Ideally, all streamlines would break through at the same time, meaning 100 percent areal sweep efficiency, but that is not possible.

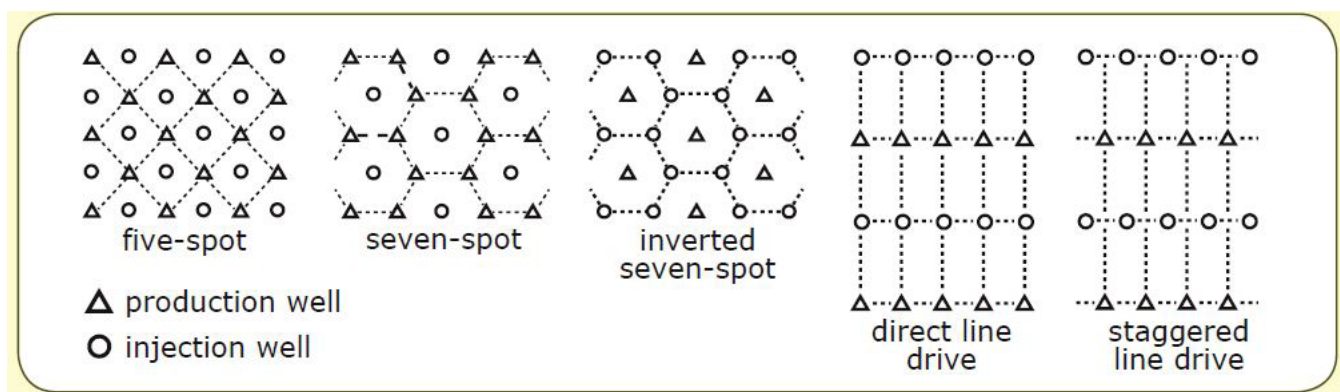
In order to ensure containment, the total pumping rate is generally 1 to 3 percent higher than the total injection rate.

The idea is to create an inward flow gradient and to control lixiviant flow. The effect of regional groundwater flow on well flow rates and in-situ mining operations is usually negligible since regional groundwater flow is very slow, generally less than 50 feet per year. A groundwater model is usually developed and its streamlines are examined as part of the well-field design process.

Well productivity and injectivity provide a good indication of the type of basic well-field pattern to be considered. Productivity is limited by the available drawdown, and injectivity is limited by the fracture pressure. If well-injection pressure exceeds the pressure at which hydraulic fractures would begin to develop, short circuits could form between injection and production wells.

In estimating well productivity and injectivity, well efficiency should be considered. In the case of uranium ore extraction, the typical well operates with a 60 to 80 percent efficiency. One hundred percent efficiency is usually not possible because of well-bore damage during drilling and well-screen plugging due to chemical deposits during operation.

Flow reversal: Inevitably, after a period of production, the mineral recovery rate shows a marked decline. This is because it is difficult to recover the areas between two production wells and between two injection wells. When decline occurs, switching some wells from production to injection, or otherwise altering the flow pattern, can boost recovery.



Common well-field design patterns

Groundwater Monitoring Program

A groundwater monitoring program is essential for protecting areas surrounding the mining operation. This consists of a ring of production-zone monitor wells located 400 to 500 feet (depending on regulatory requirements) outside the production zone, with spacing between wells less than 500 feet. Additional monitor wells overlaying and underlying the aquifer are needed to monitor vertical leakage. An inner ring of warning monitor wells is recommended (though not required by law) as an early warning system for potential leakage (see diagram below).

In-situ mining uses groundwater from the ore body fortified with a complexing agent and an oxidant. Because the leaching process alters the pH of the formation water, pH is the best parameter to monitor for potential leakage. Conductivity and groundwater level are also monitored as indicators of potential leakage. Often these three parameters are measured hourly and are used as a field screening tool for detecting the presence of contamination. The analyses of uranium and other appropriate parameters are included in the weekly and monthly water sampling programs. If abrupt changes in the water quality indicators are observed, additional water samples are collected immediately and analyzed.

References

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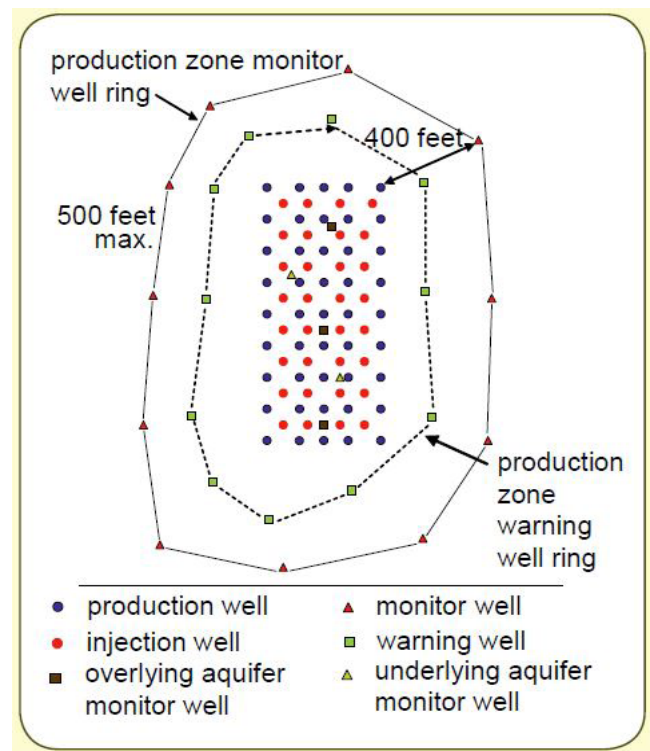
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Bottom Line: Parameters Are Key

Other than a site's ore reserves (the amount of recoverable ore mineral), hydrologic characterization of the formation is the most important consideration in determining the economic feasibility of an in-situ mining operation. Constant-rate pumping tests, sometimes combined with slug tests, are used to define average hydrologic conditions.

A proper well field pattern with the optimum areal sweep efficiency reduces the duration of the operation, lowers costs, provides better control of lixiviant flow, and minimizes the area of potential leakage. A combination of real-time monitoring of key water-quality indicators (pH, conductivity, and water level) and scheduled groundwater sampling is essential to a successful groundwater monitoring program.



Typical well placement for an ISR operation