Artificial recharge of groundwater in mining

Rafael Fernández Rubio[1], David Lorca Fernández[2]

[1]FRASA Consulting Engineers, Dr Mining Engineer, Luna 45, 28120 Ciudad Santo Domingo (Madrid), Spain, rfrubio@gmail.com
[2] FRASA Consulting Engineers, Head of Projects, Luna 45, 28120 Ciudad Santo Domingo (Madrid), Spain, proyectos@frasaingenieros.com

Abstract Artificial recharge is becoming increasingly necessary in some mining operations. Driving factors for this are firstly, the required protection of aquifers from contamination and depletion; secondly, the convenience of water storage to meet the demands for different uses; and finally, the increasingly stringent regulations on water resources for sustainable development. Some examples of water re-injection in mine aquifers are described in this paper, with the objective to review the experience gained worldwide in mines operating artificial groundwater recharge.

Key Words Artificial recharge, environmental behaviour, mine water management, wetlands, water supply

Mining: a water-producing industry

The mining industry requires water for many of its activities. However, it is the only industry that produces water as a real by-product. Indeed, the need to excavate in the ground hundreds or even thousands of meters deep, extending the excavations under the ground for kilometres, or the need to excavate an open pit of many thousands of square meters, and hundreds of meters depth, generally entails finding groundwater. This is what happens in mining.

Mining operations are usually conducted in "dry" conditions or at least with a minimum amount of water in the working areas. Therefore, incoming water must be abstracted through drainage wells, pumping stations and galleries. Part of this water can meet the supply requirements of mining and related activities, while the rest can be used to meet other demands. In order to adequately meet these requirements, and many others, it is necessary that the pumped water attains the best possible quality.

Objectives of artificial recharge

While it is necessary to depress the water level in the mine, this often results in lowering of the groundwater levels in the vicinity. Consequently, it may affect users of those aquifers, who would be entitled to compensation. An ideal way to avoid this problem may be the artificial recharge of the aquifer concerned with the water abstraction. Another specific reason for artificial recharge with water from mine drainage may be to store the water in aquifers, to meet a demand that does not have the same rhythm as the drainage of the mine.

In other cases the goal may be to avoid the environmental effects caused by drawndown water levels in wetlands. When wetlands are fed with the same water drained by mining, serious impact on the flora and fauna can occur. Also here it is possible to avoid these undesirable effects by artificial recharge. In addition, another target for groundwater recharge can be avoiding or diminishing the risk of spontaneous coal combustion. This risk can be particularly significant in shallow sub-horizontal coal layers as a result of lowering water tables. The wetting of the coal can be achieved by recharging the aquifer with drainage water, although some of the injected water can flow into the mine drainage system in a closed circuit.

Mine water artificial recharge examples

We will briefly describe some examples of artificial recharge from which we have direct experience or from which we have received information through colleagues who have worked in them.

Mt Whaleback Iron Mine (Pilbara, Western Australia)

In arid and semiarid climates, where there is a high evaporation rate and a noticeable irregularity in the availability of water throughout the year and between wet and dry years, a possible means of increasing the available water resources is the use of artificial recharge to aquifers in times of surplus, for abstraction in times of low water availability. This is what is undertaken at the iron ore mine at Mt Whaleback, operated by Mt Newman Mining Company (MNMC), one of the largest known iron ore deposits in the world.

The MNMC must meet the water needs of a community of about 6,000 people, provide water for dust suppression, particularly in the mining area, and supply water for the ore processing plant. This means a requirement of 10 Mm^3/year. In 1979, investigations on pumped water from the aquifer concluded that about 3 Mm^3/year corresponded to safe yield (average renewable resources) and about 7 Mm^3/year corresponded to overexploitation since 1975. This happened despite the heavy summer rains causing flooding and large volumes of surface water recharging the shallow aquifers.

To compensate for this large annual deficit, the Ophthalmia dam was constructed. The dam has a storage capacity of 30.6 Mm^3 and is located in the Fortescue River. It stores water from the river which is subsequently injected into the shallow alluvial aquifer system. Thus, the water supply availability to the mine and township of Mount Newman is increased. The average flow in the Fortescue River (1907—1989) is 29.9 Mm^3/year, with variations between 0 and 150 Mm^3/year. The dam consists of a series of retaining walls, which intercept runoff from the River and some tributaries.

Recharging is undertaken through four excavated ponds and two river basins. Dam and recharge facilities were completed in 1981. The reservoir water flows by gravity to the recharge facilities. The first part consists of two interconnected basins capable of holding 1169 megalitres. There are four additional artificial recharge ponds, covering nearly 11 hectares, which can store 204 megalitres. In 1981—1982 about 7.9 million cubic meters of surface water (equivalent to about 280 L/s) were recharged to compensate for the over-exploitation of the first season of operation. Recharge was carried out as one continuous event over some 190 days, with overall infiltration rates of 20cm/day for the concrete ponds and 4cm/day for the river basins being obtained (Clark & Kneeshaw 1983).

The water needed to meet the requirements of the mine and township of Newman is extracted from 34 production pumping wells tapping the unconfined alluvial aquifers. In a more recent development, water obtained from dewatering two satelite orebodies (Orebody 23 and Orebody 25) is supplied to Mt Whaleback as process water and surplus is diverted to the aquifer recharge scheme at Ophthalmia Dam (Australian Govt. D.R.E.T. 2008).

Alquife Iron Mine (Granada, Spain)

When the mine drainage water has an appropriate quality, it can be used to meet various demands. A significant case in the final period of the mining operation was the Alquife iron mine. Its drainage water was used without further treatment not only to satisfy the requirements of the mine and the population of the mine town, but also to assist in the artificial recharge of a detrital aquifer downstream. This aquifer was later exploited for irrigation.

The Alquife iron deposits are hosted in marble of the Nevado-Filabride Complex, covered by detrital sediments partially consolidated. The marbles and the detrital sediments aquifers are partially connected due to the presence of interbedded clay layers. The open pit mine (started in 1963) extends for 2 km in length and sinks more than 200 meters, penetrating below the regional groundwater level. Therefore, the mine must maintain a continuous drainage facility to allow dry mining operations. The drainage was performed from wells drilled in and out of the open pit, which pumped water from the karst and detrital aquifers, with a third system consisting of small-diameter wells to interconnect both aquifers.

This mine drainage, of approximately 400 L/s, resulted in a significant cone of depression in the extensive alluvial aquifer, reducing downstream flows from springs and qanats (collection galleries), with serious impacts for the environment and irrigation in the area. Thus, in 1984, artificial detrital aquifer recharge was carried out with drainage water from the mine. The intention was to re-establish the flow in springs and qanats in the Verde River floodplain.

For this artificial recharge, conducted by the Spanish Geological Survey, infiltration ponds with water diverted from the drainage channel of the mine were used. All ponds were controlled with nine piezometers. Artificial recharge was reserved only for the winter months, since during spring and summer farmers diverted all the mine drainage water evacuated through the channel for irrigation. The operation, conducted with satisfactory results, ceased at the closure of the mine (1996).

Las Cruces Copper Mine (Sevilla, Spain)

This mine exploits a secondary copper zone (chalcosine) which lies close to the top of a volcanogenic massive sulphide deposit. The mineralization is overlain by an average of 135—140 m of Tertiary sediments which include the basal detrital sediments which form the Niebla-Posadas confined aquifer (normally between 0—15 m detrital sediments). The fractured mineralized Palaeozoic rocks, together with the alteration zone and the associated gossan are highly permeable and constitute an essential part of the aquifer (Doyle et al. 2002).

In order to reduce the amount of groundwater coming into contact with the mine workings, a dewatering system has been implemented to intercept as much of the aquifer water as possible, using mainly a ring of drainage wells around the perimeter of the open pit. A total of 36 wells have been drilled. To mitigate any adverse effect on the water levels affecting the users of wells in the surrounding areas, a ring of reinjection wells around the mine site, at approximately 0.9–3.2 km distance, are continuously operating, and thus preserving the aquifer water quality and quantity. A total of 28 wells have been drilled.

Previously, numerous long-term pumping and reinjection tests were carried out in conjunction with mathematical modelling to provide prognosis of the aquifer system evolution. The model has been used to predict the effects of this extraction-injection system and the testwork carried out in the field has been designed to give suitable information to allow accurate calibration of the model under conditions as close as can be reasonably achieved to the designed system.

The combined extraction-injection cycle operates as a closed circuit to prevent ingress of oxygen to the system and subsequent changes in the chemistry and biological activity of the aquifer water. In April 2010, the pumping rate was 202,519 m^3/month and the reinjection rate 185,234 m^3/month (71 L/s); the difference corresponds mainly to the rejection of the reverse osmosis treatment plant, used to purify some water to be reinjected to standard norms quality.

Betze-Post Gold Mine (Carlin Trend, Nevada, USA) (Zhan 2010)

This mine exploit an important strata-bound gold deposit located on the most prolific gold mining district in the Western Hemisphere. The epithermal-dispersed deposit is localized in Devonian metamorphic carbonates and in intrusive rocks that contributed the gold. Its hydrogeological conditions are special, due to the presence of one important water-bearing zone, with high water temperature.

The Barrick Goldstrike Mines Inc. (BGMI) operations include the Betze-Post open pit and the Meikle and Rodeo underground mines. The majority of this ore body is located below the water table. Accordingly, pumping of groundwater as part of gold mining operations along the Carlin Trend has occurred for about four decades. The mine's drainage is accomplished by means of pumping wells located in the surroundings and inside the open pit. Groundwater pumping for dewatering at BGMI increased from less than 190 L/s in 1989 to a peak of more than 4,400 L/s in 1993—1994 and has resulted in a drawdown of 518 m around the mine site. The required pumping rate to maintain present water level has been continuously declining since the target water level was reached in 2000. The present dewatering rate (2010) is approximately 950 L/s.

Of this water, approximately 5 % is consumed by the mine itself (dust control, processing and exploration drilling); 10 % is used for irrigation; the 85 % remaining is infiltrated/re-injected in the same water-bearing zone (volcanic aquifer) as that from which it was extracted, at a great distance from the mine, by means of surface reservoirs and deep wells. Infiltration has occurred primarily through a large natural fissure beneath the TS Ranch Reservoir, supplemented by five injection wells and two infiltration ponds. Infiltration/injection has resulted in the volcanic aquifer water level rising to above the level of volcanic outcrops, creating three springs, which water is collected, then either pumped to irrigation pivots (in irrigation season), or infiltration ponds (in non-irrigation season) through two pumping stations. BGMI has an extensive hydrologic monitoring network which covers approximately 600 square miles with a total of 112 monitoring wells. Among those, 35 wells are equipped with telemetry units. In addition, there are a total of 20 surface water monitoring stations along the major creeks.

Garzweiler Lignite Mines (Rhineland, Germany; Forkel et al. 2002, RWE Power 2007)

Wetlands near mines can be affected by the water table drawdown caused by mine drainage. Through artificial recharge of the aquifer concerned with water drainage, it is possible to correct this situation recovering the presence of water in the subsoil. This is carried out, for example, in the opencast lignite mining area at the north of the Rhineland (Germany), where RWE annually removes about 100 million tons of lignite, pumping about 600 million m^3 of water.

The exploitation of these mines requires a previous lowering of the groundwater level of the aquifers located above and below the coal seams to maintain the water level below the bottom of the mine. Dewatering is achieved by mine drainage through swap drainage and hundreds of dewatering wells. In particular, in 2001, Garzweiler open pit mine counted approximately 650 drainage wells pumping about 110 million m^3 of water. The decline in water level extended to a wide area to the north of the mine, affecting sensitive wetlands, – such as the Natural Park of Schwalm-Nette –, in river valley bottoms, where plant growth is conditioned to the presence of groundwater and surface water. Therefore, the operating plan Garzweiler I / II was raised with the premise of no harm to the wetlands.

In this scenario, water is first filtered through gravel, followed by addition of oxygen to precipitate and remove iron and manganese ions present in the drainage water. The treated water is transported and distributed through a pipe network, with a total distance of about 125 kilometers. Pipes are 300—1000 mm in diameter, usually fabricated in steel, welded and coated with cement mortar, and placed under the ground along roads and highways, not to affect land use. Aquifer recharge is accomplished through both surface and underground systems. The surface system consists of 40 meters long, 1 meter wide and 6 meter deep ditches; underground systems allow injection into deeper aquifers through wells of 1 meter diameter and 10—120 meters depth, though special wells can sink up to 150 m depth. Wells usually have a pre-well of 2 m of diameter, which is pre-filled with gravel, while the slots area is filled with a sand filter.

The rehabilitation of wetlands has been implemented in areas that were affected by lower mine drainage, to restore the presence of water. The measures taken are succeeding in restoring the water levels in key areas and ensuring that the wetland vegetation is on track to regenerate in the medium term. It is worth noting that a monitoring system has been installed in cooperation with the authorities. The system includes controls in the opencast, and infiltration facilities in wetlands, with stochastic and deterministic prediction tools for planning.

Acknowledgements

Thank those who have provided useful information included in this paper: Don Armstrong (Australia); Thomas Rüde (Germany); Juan Carlos Baquero (Spain); Johnny Zhan, Kirk Nordstrom and Robert Kleinmann (USA).

References

Australian Government. Department of Resources, Energy and Tourism (2008) Leading practice sustainable development program for the Mining Industry. 102 pp.

Clark GB, Kneeshaw M (1983) Artificial Recharge in the Pilbara, Western Australia. In: Hydrology and Water Resources Symposium. Hobart. Institution of Engineers. 08: 92—102.

Doyle MG, Fernandez Rubio R, Baquero Úbeda JC (2002) Las Cruces Mining Project (Sevilla, Spain). Hydrogeology and Groundwater Management System. XI Congreso Internacional de Industria, Minería y Metalurgia, Zaragoza (Spain). 16 pp.

Forkel C, Trumpff H, Boehm B (2002) Grundwasseranreicherung und Monitoring zur Sicherung von Feuchtgebieten im Norden des Rheinischen Braunkohlenreviers. Vortrag auf der Mining. Clausthal-Zellerfeld. 16 pp.

RWE Power (2007) Ökologie im Nordrevier. Waer für die Feuchtgebiete. Essen – Koln. 10 pp.

Zhan J. (2010) Water Management at Barrick's Goldstrike Mine, Carlin Trend, Nevada. Unpublished paper, Environmental Department, Barrick Gold Corporation. 9 pp.