Potential for mine water reuse in an abandonedcoal mine in northern Spain

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Abstract The search for alternative water resources has been promoted and the use of mine water in it has become especially relevant in areas with abandoned mining operations; moreover, the new technological developments in the field of mine water treatment have opened new horizons for a potential mine water reuse. In the municipality of Gijón, in north-western Spain, underground coal mining operations accomplished in a small carboniferous basin are in an abandonment phase, and the mine works are in a flooding process as a consequence of the pumping cessation of water drained from the mine works. This mine water rebound through the mine voids involves the creation of a new pseudo-karstic type of aquifer, which can be considered like an underground dam; with the advantage in front of the surface dams is the absence of evaporation losses and the availability for use during drought periods as a complement to the conventional water resources. Depending of their physico-chemical characteristics, these new water bodies can be considered as unconventional resources that can be applied for use in the industrial and environmental fields. This alternative will lead to a substantial decrease on the use of conventional resources promoting a sustainable management of the available water resources, by complementing the primary water resources with unconventional resources.

Key Words Mine Closure, Mine Water, Reuse, Spain

Introduction

An object of study in this paper is the potential reutilization of mine waters for industrial and environmental uses in municipalities with big industrial activities; for these purposes several campaigns of mine water characterization in La Camocha Mine (Figure 1) have been accomplished to evaluate the mine waters as a new resource in the hydrologic balance of the supply to populations with industrial and environmental objectives. In this context, the potential of mine waters from La Camocha Mine, located in Asturias (Northwestern Spain) and abandoned in 2008, are being studied as part of potential water supply for industrial areas or recreational facilities of the municipality of Gijón.

The city of Gijón is located in the Cantabrian coast and its economy is currently based on the intense industrial activity located in the periphery and in the seasonal tourism. The mining activity in the Camocha throughout the twentieth century has been very important, as it was the only coal mine located into the municipality of Gijón. The activity in the mine began in 1901 with the first research drills to evaluate the coal potential of the area, but it is not until 1932 when the exploitation of the coal began. The mine reached the maximum production in 1960 with 400.000 Tm followed by declining production until its closure in 2008.

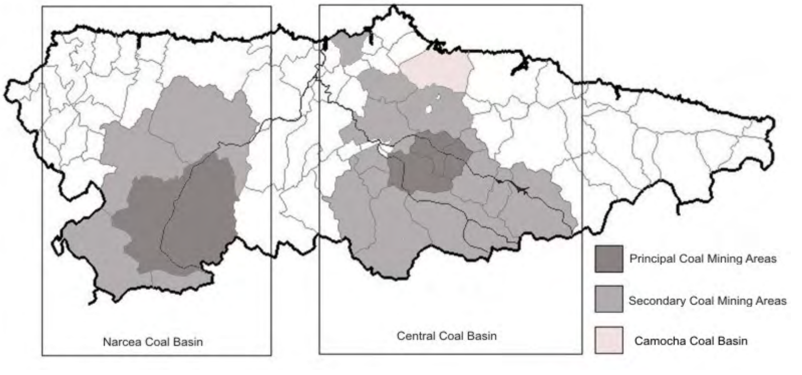

Figure 1 *La Camocha Coal Basin situation*

The search for the use of the lands began after the closure of the mine, which had more than seventy years of mining activity. In this search for new alternatives for the mine site, an important aspect to consider is the mine water. During the life cycle of the mine, water has been one of the most important problems; at the beginning of the exploitation, during the construction of the shaft in 1902, an aquifer has been intercepted at 16 m. depth, with a flow of 16 litres per minute; at 38 m it was necessary to pump a flow in the order of 500 litres per minute (Pendás et al., 1995). This shaft was abandoned in 1904 because it was not possible to accede to more than 62 meters with the techniques of this time, due to the problem of water that access to the mine works. It was in 1930 when the advance in the dumping techniques and the election of another place for the shaft allowed putting the mine in production.

Along the life cycle of the mine, there was a constant problem with water, with more than 1,900 m^3/day pumped on the last years. The mine has dumping in second, fifth, seventh and eighth levels. For years the pumping prevented the flooding of the mine works, but when pumping stopped the effects of water rebound in surface water will be unpredictable by its interrelation with drained groundwater. In this sense, some studies have alerted the risks caused by water rebound in the subsoil. The flooding by overflowing of the fluvial courses and landslide of hillsides can be considered among these risks (Ider 2008; Sadim 2008). La Camocha coal basin is associated with a horst delimited by two faults the La Granda fault and the Llantones faul. There is evidence by hydrogeological studies (Pendas et al 1995) that in the area of La Granda fault the Permian stratigraphic series of the Horst enters in contact with clays. This area is close to the Piles River and it is the main discharge of the hydrogeological system with a flow predominantly ascendant along the fault.

The hydraulic behaviour of the groundwater of the Permian aquifer is given by the recharge produced by the infiltration of rain water whereas the lateral contributions are from the Jurassic carbonate rocks. On the other hand, the discharge is made by surface run-off, evapotranspiration, discharges to springs and drainage to the Piles River.

Analysis of potential of mine water reuse

Neither of the existent studies contemplates the possibility of maintaining the pumping in the mine, but there is no water control during the mine flooding so the economic costs could be higher (Ider 2008; Sadim 2008). A possibility could be the consideration of the mine water not as a waste but as a new potential resource, and this is especially important in times of climatic change and the search for a sustainable management of the available water resources (Loredo et al 2008).

Based on the mine work plans and according to a preliminary valuation of the secondary porosity in the post exploitation works the volume of the underground dam can be estimated in 2.8 to 3.5 Hm^3, using as the calculus base a section of gallery of 10 m^2 and a correction factor caused by subsidence and a filling of 45 to 55 %. The mine water drainage together with other options of supplementary water supply could suppose for the municipality the maintenance of a good environmental quality in a river of the area and the water supply to industrial areas in the periphery of the city. The town currently consumes more than 70,000 m^3 of water per day in low touristic seasons, whereas the water consumption in summer season is in the order of 101,000 m^3 by day, shared unequally between the different uses (Loredo et al 2008).

The water supply to Gijón (Figure 2) comes from an area distant from the municipality and the nearby aquifers. The city receives water from the springs of Llantones, Arrudos and Perancho, also from the wells in the limestones and dolomites of the liasic of Villaviciosa system. These contributions comprise 50% of the supply, which is complemented with water resources from Tanes and Rioseco dams, managed by CADASA (Consorcio de Aguas de Principado de Asturias).

In years where the drought affects the dams of the north Basin, the water supply to Gijón does not have problems due to the coordinated management of surface and groundwater, but the flow level of some rivers in the area has decreased; for example, the Peñafrancia River has been dry for a month in 2009, due to the pumping in the aquifers to supply water to the city, with the environmental cost that this incurs. At this moment, the potential use of mine water with environmental aims is possible, allowing maintaining in drought periods the flow level of the small rivers which fed the aquifers used for the water supply to the city (Pendas 2005).

The mine water quality is good for its use in different purposes. According to hydrochemical data, it is bicarbonated water with low content of sulphates and iron (0.1mg/L; Figure 3). All water

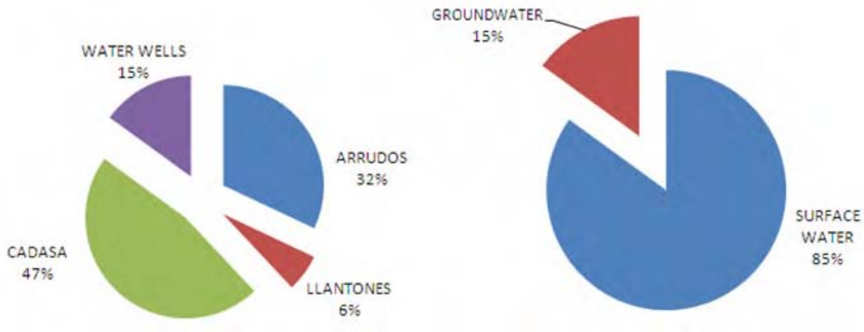

Figure 2 *Gijon water supply*

samples have neutral pH. There is no type of treatment for environmental uses or irrigation, because concentration of trace metal is below water legislation for human consumption. Furthermore, the analysis of other mine waters in the central coal basin indicate that there are waters included in the category of A1 treatment according to the 75/440/CEE Directive, allowing even its use for human consumption (García-Carro et al 2008). Table 1 shows mine water quality for potential irrigation use.

Furthermore the quantity of water can also be shown from the theoretical volume stored in the underground mine works, which are estimated between 3,8 and 2,3 Hm^3, using as a calculation base a gallery section of $10m^2$, and a checker coefficient of the exploitation by filling and collapse of 45—55% for maximum and minimum estimations.

The use of the resource does not present big costs, as the transport distances of water from the mine are small (4 km maximum). A supply by gravity from the mine, located at 101 meters above sea level, to the areas of interest. Two golf fields located in the proximities of the mine, which have a daily consumption of 6 L/m^2 (Loredo et al 2008) could be included among the potential areas to supply. Furthermore the mine water could be used for irrigation of a Botanical Garden located in the area of the mine. The supply to the industrial area located near the mine and a sportive centre with eight football fields are other potential users of the mine water.

Conclusions

The use of mine water from La Camocha for supply to industrial areas and irrigation will allow maintaining the ecological flows in Rivers flowing through the area of the mine, and minimizing the potential impacts of the process of water pumping cessation in the mine. It will be necessary to accomplish a hydrogeological study, a technical and economical viability for the different option of use of mine water and especially to accept a new approach in the role of mine waters once the cessation of activity of mine operations occurs. This approach allows considering the mine water not only as a waste but as a potential water resource in the system.

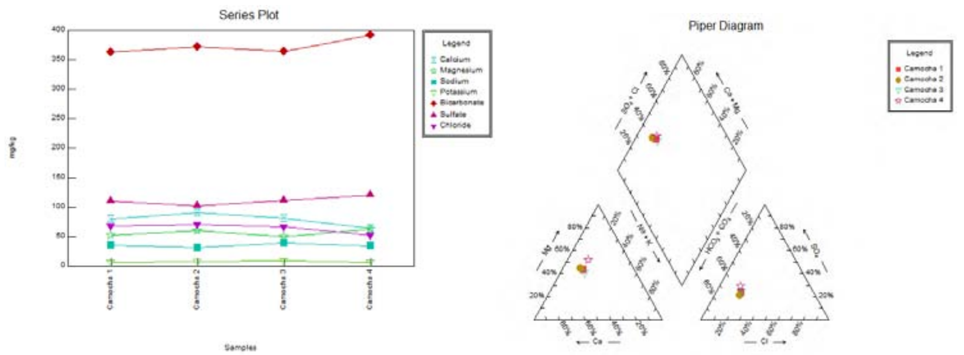

Figure 3 *Series and Piper diagrams for Camocha´s mine water*

***Table 1** Mine water characteristics*

WATER SAMPLES					
CAMOCHA 1			CAMOCHA 2		
Fluid Properties			Fluid Properties		
Water Type	Mg-HCO_3		**Water Type**	Mg-HCO_3	
Dissolved Solids	717 mg/kg	715.26 mg/L	**Dissolved Solids**	735 mg/kg	733.23 mg/L
Density	0.99757 g/cm^3		**Density**	0.99759 g/cm^3	
Conductivity	880 µmho/cm		**Conductivity**	924.71 µmho/cm	
Hardness (as $CaCO_3$)			**Hardness** (as $CaCO_3$)		
Total	422.05 mg/kg	421.02 mg/L	Total	432.08 mg/kg	431.04 mg/L
Carbonate	422.05	421.02	Carbonate	432.08	431.04
Non-Carbonate	0.0	0.0	Non-Carbonate	0.0	0.0
Irrigation Waters			Irrigation Waters		
Salinity Hazard		High	**Salinity Hazard**		High
Sodium Adsorption Ratio		765×10^{-3}	**Sodium Adsorption Ratio**		619×10^{-3}
Exchangeable Sodium Ratio		0.187	**Exchangeable Sodium Ratio**		0.142
Magnesium Hazard		52.2	**Magnesium Hazard**		52.1
CAMOCHA 3			CAMOCHA 4		
Fluid Properties			Fluid Properties		
Water Type	Mg-HCO_3		**Water Type**	Mg-HCO_3	
Dissolved Solids	723 mg/kg	721.25 mg/L	**Dissolved Solids**	732 mg/kg	730.23 mg/L
Density	0.99758 g/cm^3		**Density**	0.99758 g/cm^3	
Conductivity	880.12 µmho/cm		**Conductivity**	842.17 µmho/cm	
Hardness (as $CaCO_3$)			**Hardness** (as $CaCO_3$)		
Total	413 mg/kg	412 mg/L	Total	472.28 mg/kg	471.14 mg/L
Carbonate	413	412	Carbonate	472.28	471.14
Non-Carbonate	0.0	0.0	Non-Carbonate	0.0	0.0
Irrigation Waters			Irrigation Waters		
Salinity Hazard		High	**Salinity Hazard**		High
Sodium Adsorption Ratio		858×10^{-3}	**Sodium Adsorption Ratio**		722×10^{-3}
Exchangeable Sodium Ratio		0.212	**Exchangeable Sodium Ratio**		0.177
Magnesium Hazard		50.1	**Magnesium Hazard**		61.9

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