# Sustainable mining. Environmental assets

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## Abstract

Mining is considered by many as an activity that produces great negative environmental impacts, suffering strong opposition from many environmentalist groups. Nevertheless, much effort is being made lately to not only minimize the impacts, but also to provide environmental assets whenever is possible. In this framework, this paper describes several mining examples that should serve as a reference for the possibilities offered by environmental engineering technologies in the rehabilitation of mining areas.

## Introduction

Traditionally, mining is censured as a depredatory activity that provokes very important environmental impacts, and thus, although it is essential for development and for our day-to-day routine, almost all environmentalist groups have attacked it. This environmental liability exists and, because until recent times ecological aspects were not objects of concern in industrial processes and in mining, the effects remain in the long term.

Confronting this fact, and especially during recent years, a good mining operation accomplishes an important roll not only to cause the minimum environmental impact, but also to provide environmental assets, as much as possible.

In this context I will try to emphasize some experiences within mining that reflect such good practices. In many of those examples I have taken part in a larger or smaller degree, or I have known them directly.

## Las Medulas Gold Mines (Leon, Spain): Heritage of Humanity

The Roman gold mines of Las Medulas merit, more than enough, the UNESCO declaration as Humanity's Heritage (1997), and its nomination as Cultural Landscape to the archaeological mining zone (1931) (Fig. 1).

**Fig1.** Roman gold mining in Las Medulas (Leon, Spain) declared Cultural Landscape and Heritage of Humanity (UNESCO).

In few places has mining intervention (in this case Roman, during two and half centuries), left such an impression. Mining has joined with nature to complement a landscape of spectacular beauty, mixing the Miocene red alluvium, in peaks and vertical cuts, with the green of chestnuts and oak trees and the blue and white of sky and clouds.

This intensive mining, probably the biggest of the Roman Empire, started in the latter third part of the first Century after Christ, when the Roman *Legio VII*, installed in Leon lands, was no longer an occupation army, but a standing army that played an important role in mining activity. Its role included managing the relationships between the indigenous population, slaves and free men; contributing engineers and being responsible for mineral prospecting; constructing canals to carry water and dams in which to accumulate it (*piscinae* or *stagna*), etc. The peak of this activity corresponds to Emperor Trajano's epoch (end of 1$^{st}$ Century AC and beginning of 2$^{nd}$ Century). The activity was extinguished at the beginning of the 3$^{rd}$ Century.

Plinio the Old (23 - 79 B.C.), in his *Naturalis Historia*, described the exploitation method, known as "*ruina montium*" (Fig.2). It was based on the excavation of long galleries, with successive enlargements and narrowings, in the Miocene alluvium (of which very good examples remain), perforating the rock with wedges of iron and mallets, and lighting up with oil lamps. After that water was spread through these galleries with great hydraulic load, and pressure, provoking erosion and roof collapse.

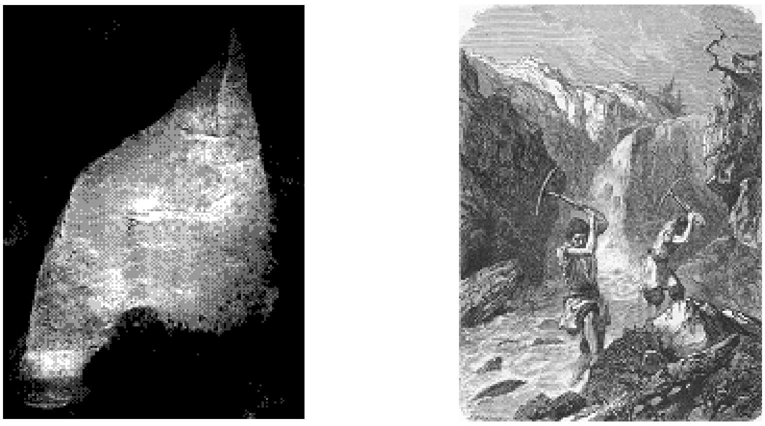

**Fig 2.** Exploitation by the "*ruina montium*" method in Las Medulas and works for disintegration of auriferous alluvium.

After separating the thick fraction (*murias*), the segregated alluvium was transported and processed in washing canals (*agogae*), covered by branches of gorse that retained the native gold. The gorse was later burned and the ashes washed, in order to separate the gold mineral.

Today we can take delight in reviewing the story of those miners, going over their very itineraries and observing the geology of these extensive strengthened alluviums (Fig. 3), the hydraulic infrastructure, the hollows and the work fronts, the devices used to obtain the gold and the deposits of waste, all of it in a state of incredible conservation.

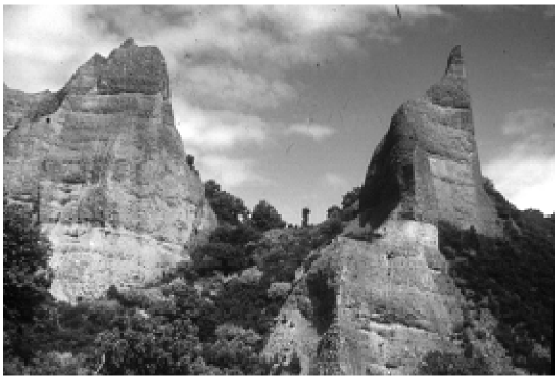

**Fig 3.** Residual landscape of Roman gold exploitations in Las Medulas among chestnut forests that supplied the miner's food.

These miners (estimated from 10,000 to 60,000) attained great technological development, and a model organizational system which allowed them to move over 100 million cubic meters of alluvium, extracting around 500,000 kg of gold.

## Rodalquilar Gold Mines (Almeria, Spain): Flora Endemics Nursery

Rodalquilar's gold mines were worked in Roman times. More recently, a British company exploited them until 1923 when it abandoned them due to lack of profitability. In 1933 exploitation was restarted and Rodalquilar knew better times. After the Spanish civil war they became practically abandoned. Activity recommenced in 1956 and, due to its lack of profitability, was closed out six years later.

Rodalquilar's volcanic crater, the one that locates the ore body, corresponds to an oval structure of collapse, some 8 km in length and 4 km in width, developed 11 million years ago.

Rodalquilar's mining complex is an example of industrial archaeology (Fig. 4), which should have merited a better conservation. In any case, it is impressive to contemplate the ruins of those facilities surrounded by the ochre, brown and reddish colours of the surrounding volcanic rocks.

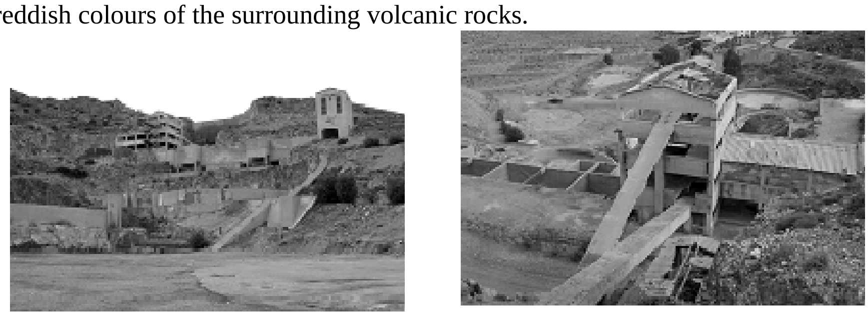

**Fig 4.** Abandoned treatment plant for auriferous mineral in Rodalquilar (Almeria, Spain).

In this isolated, lost and virgin place, in the surroundings of the Natural Park of the Gata Cape - Nijar, under the shelter of the mountains that surround it, and next to the antique mining town and to his church, among petrology and mineralogy, the Government of Andalusia has located a nursery of autochthonous plants: The Albardinal, which merits a visit, in order to take pleasure in the contemplation of plant species endemic in the Iberian Peninsula's flora.

A perfect flora adapted to drought, some of it exclusive to this part of the world (endemism) and some that shows the common past of the European and African continents. The Albardinal shows to the visitor a great part of this territory's rare flora that is threatened with extinction; plants than would be very difficult to see in Nature or that would be in places difficult to access (Fig. 5 & Fig. 6).

At this nursery we can see how man has been able to survive and prosper utilizing the plants offered to him by the environment, adapting to agricultural use plants that have resistance to demanding environmental conditions.

**Fig 5.** The flora of the semiarid zones of East Andalusia can be observed in this nursery.


**Fig 6.** East Andalusian flora, showing the common past of Europe and the African continent, in the Rodalquilar Mine’s nursery.

The esparto (native grasses) and the thickets of native shrubs on the volcanic and calcareous soils can be observed during the visit; the fields of thyme; the short-lived and prickly pastureland; the Aleppo pine; the zone vegetated with Andalusian brambles, halophytes, and plants typical of coastal dunes and gypsum soils; the traditional arboreal, herbaceous and horticultural cultivations; the endemism; the useful plants and the palms and succulents. All of it with very useful information to help visitors enjoy their visit. In short, an example to apply in another mining areas.

## Mangabeiras Iron Mine (Minas Gerais, Brazil): Public Park Symbol of Belo Horizonte's City

The Mangabeiras Park (Fig. 7), designed by Roberto Burle Marx, and inaugurated in 1982, is located at the foot of the Serra do Curral where a mine exploited an iron deposit. It is the property of the Town Council of Belo Horizonte (Minas Gerais, Brazil), and is integrated completely into the urban area.

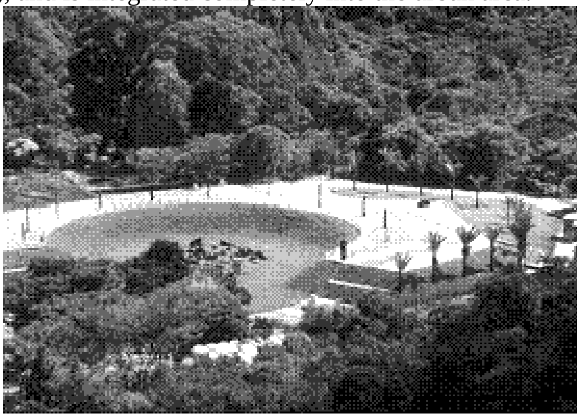

**Fig 7.** The natural surroundings of the Mangabeiras Park and details of its facilities (Belo Horizonte, Brazil).

This public park, with an area of 337 hectares, the biggest green area of the city dedicated to environmental conservation (Fig. 8), has been chosen by the population as Belo Horizonte's symbol, and it can be visited following the Water's Route, the Forest's Route and the Sun's Route (Fig. 9).

**Fig 8.** The city of Belo Horizonte and, in the foreground, the Mangabeiras Park.

**Fig 9.** Different environments in the old Mangabeiras Iron Mine.

Today this antique mine is not only the habitat of many plant and animal species, but also a meeting place of thousands of people and a centre of innumerable cultural activities.

## Cabarceno Iron Mines (Cantabria, Spain): Nature's Park

The Peña Cabarga iron mines in Cantabria, Spain, were active for more than 2,000 years (the Roman writer Plinio wrote about these mining works). The final operator, Agruminsa, to which I gave geological advice, closed the activity in 1989.

This deposit in housed in carbonate rocks of the Upper Aptien. Limestone and dolomite karstification processes were very important in its genesis (Fig. 10). As a consequence of their dissolution, the ore body was formed from the insoluble residue of iron oxides and hydroxides.

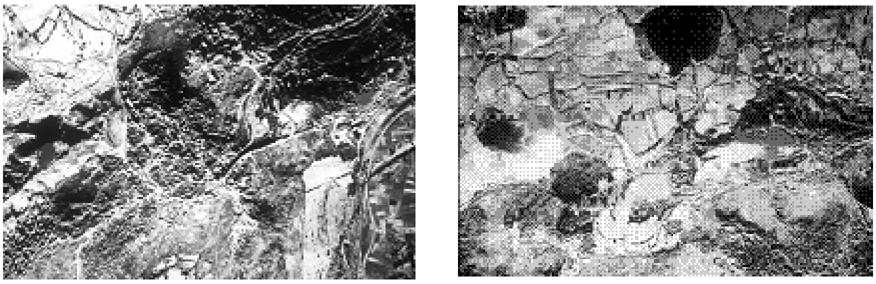

**Fig 10.** Infrared aerial photos of the closed Cabarceno Iron Mines (Cantabria, Spain).

For many years, and especially from the Middle Ages to the first half of the 20th Century, mining exploitation was carried out using craft methods, employing thousands of miners who excavated with pick and shovel. They revealed a magnificent tropical karst, developed many millions of years ago (Fig. 11). The miners, by their hard work, opened corridors and labyrinthine runners, with heights of several tens of meters, creating a jungle of rocks that human imagination would not be capable of visualising.

**Fig 11.** Landscape of tropical karst exhumed by the ancient mining works in Cabarceno (Cantabria, Spain).

When the exploitation ceased, and due to an agreement between the government of Cantabria and the mining company, a Nature Park (Fig. 12) was developed over 750 hectares (inaugurated in 1990), where, today, spectacular karstification landforms can be observed. It is also a place for leisure and in touch with nature, with a varied fauna from all five continents (over 50 species in danger of extinction).

**Fig 12.** In the Cabarceno Nature Park the fauna is distributed in ample space on the site of a closed down iron mine, with a very well developed road network.

Here the animals live and reproduce in freedom surrounded by a variety of vegetation that gives life and colour to an incredible nature (Fig. 13).

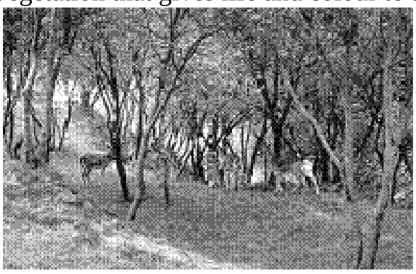

**Fig 13.** The fauna of the five continents with over 50 species in danger of extinction find the best habitat here.

Here it is possible to enjoy the spectacle of nature from magnificent lookouts. A network of roads, very well laid out and tens of kilometres in length, make it possible to contemplate a variety of fauna that finds protection, refuge and food in the park.

The visitor can observe at close distance, in 21 ample areas, hundreds of all the zoological community’s animals, among them many steinboks, jaguars, giraffes, lions, Siberian and Bengal tigers, leopards, hyenas, bisons, elephants, hippopotamuses, rhinoceroses, dromedaries, camels, llamas, zebras, ostriches, etc. as well as Cantabria's fauna including wolves, deer, roe deer, chamoises, wild boars and the most important Hispanic reserve of brown bears. All of it safely, with barriers perfectly integrated into the landscape.

Several lakes that were open pit exploitations complement this exceptional space. A variety of waterfowl lives on the lakes and fishing is allowed in them.

There is also a complex of restaurants and coffee shops, parking lots, gift stores and a reptilarium with a specialized collection of snakes.

Thus this rehabilitated mining space has become a cultural and scientific attraction to Cantabria. It has to date welcomed over ten million visitors.

## Betze-Post Gold Mine (Carlin Trend, Nevada, USA): Water for Irrigation and Aquifer Artificial Recharge

This mine exploits an important strata-bound gold deposit that we have had the opportunity to study. The epithermal-dispersed deposit (oxides at the top and sulphides below) is localized in Devonian metamorphic carbonates and in intrusive rocks that contributed the gold. Its hydrogeological conditions are a little bit special, due to the presence of one important water-bearing zone, with high water temperature (Fernandez Rubio, 2002).

This mine, operated by Barrick, is one of several open pit exploitations located in northeastern Nevada (Fig. 14). Some exploitations have continuity in subterranean works.

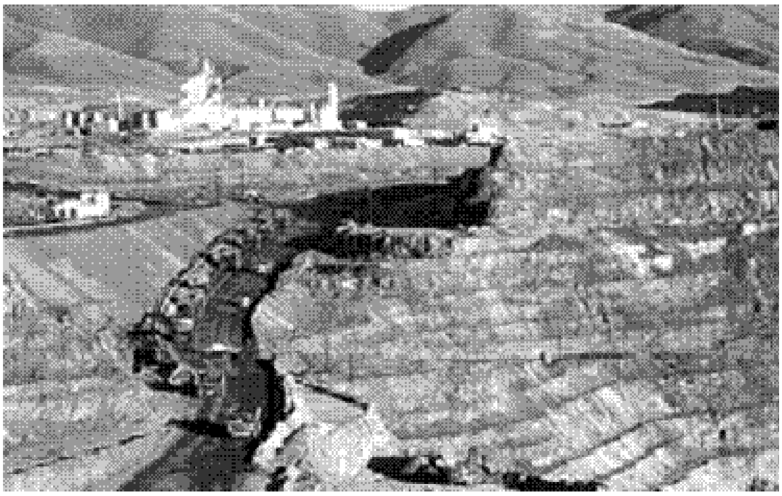

**Fig 14.** Betze-Post gold mine (Nevada, USA) (P. Bourton courtesy).

This mining Goldstrike's district, considered the biggest area of gold exploitation in North America, and one of the most important in the world, has the biggest net of subterranean refrigeration in the world.

The mine's drainage is accomplished by means of pumping wells located in the surroundings and inside the open pit (Fig. 15). The pumping rate is 3,670 litres per second. Special care is taken to avoid water contamination with the result that a perfect water quality is achieved.

**Fig 15.** Wells for drainage from within and at Betze-Post mine's periphery.

Of this water, approximately 5 % goes is consumed by the mine itself; 10 % is used to irrigate around 2,000 hectares; the 85 % remaining is re-injected in the same water-bearing zone as that from which it was extracted, at a great distance from the mine, by means of deep wells and surface reservoirs (Fig. 16 & Fig. 17) (Fernandez Rubio, 2002).

**Fig 16.** Re-injection well and conoids of the water table due to mine drainage and recharge.

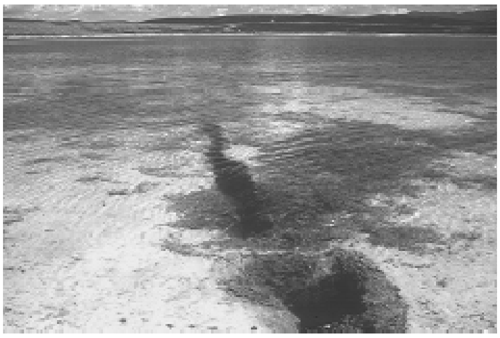

**Fig 17.** Reservoir for aquifer water recharge.

## Cottbus Nord and Jänschwalde Lignite Mine (Germany): Hydrological and Environmental Rehabilitation

Many thermal power plants of Central Europe are supplied with lignite obtained from large open cast mines. Special effort is made to care for environmental aspects, among which we can emphasize the ones related to water protection and to land rehabilitation. A good example is offered by the Cottbus-Nord and Jänschwalde mines exploited by the Laubag Company in the eastern sector of Germany, close to the border with Poland (Fig. 18).

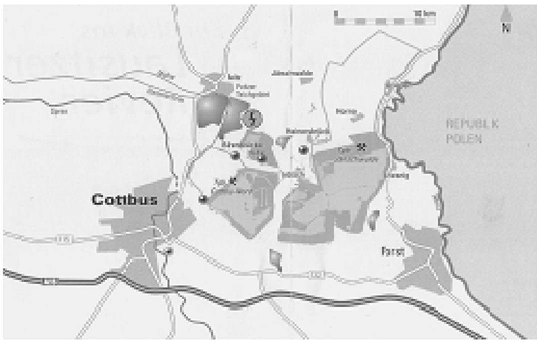


**Fig 18.** Exploitations of lignite in Germany near the Polish border.

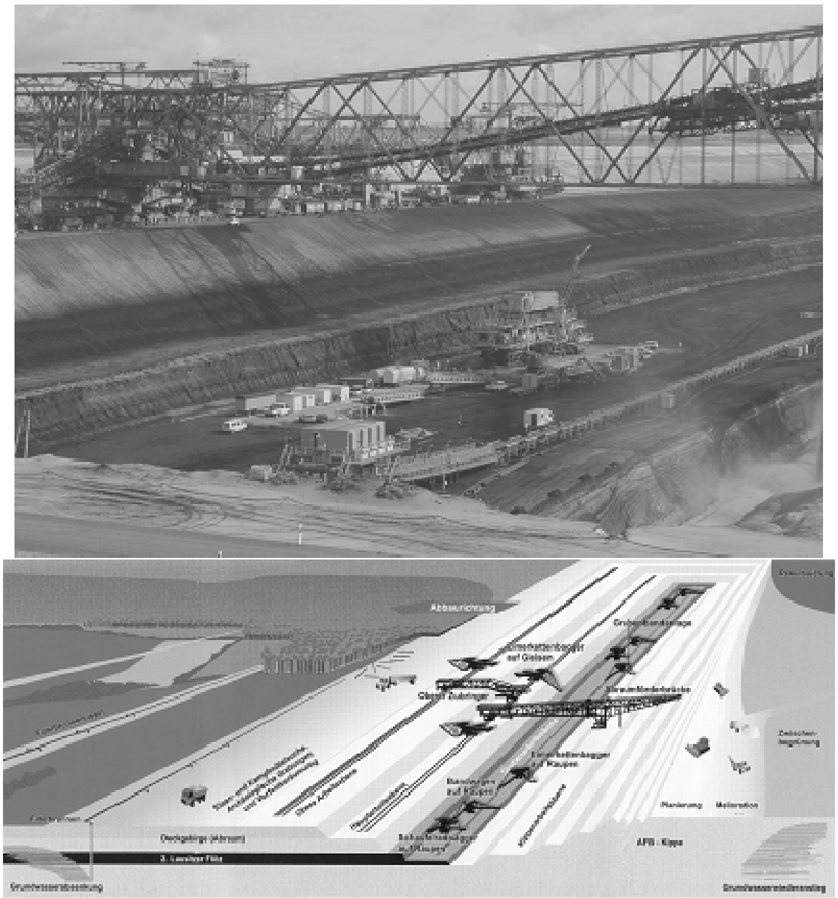


**Fig 19.** Cottbus-Nord lignite mine (Germany).

The cases selected concern mines where it is necessary to excavate a relatively large thickness of unconsolidated sediments before extracting selectively the sub-horizontal lignite layers (Fig. 19). The waste materials are piled systematically, in a transference mining operation, and the lignite is transported by railroad to the thermal power plant.

The water drained by means of peripheral deep wells, and the water picked up in the bottom of the excavation is subjected to a very efficient process of treatment and elimination of suspended solids. After treatment, half of the water is used for steam production and cooling in power stations (Fig. 20) while the other half is discharged into the rivers Spree and Schwarze Elster.

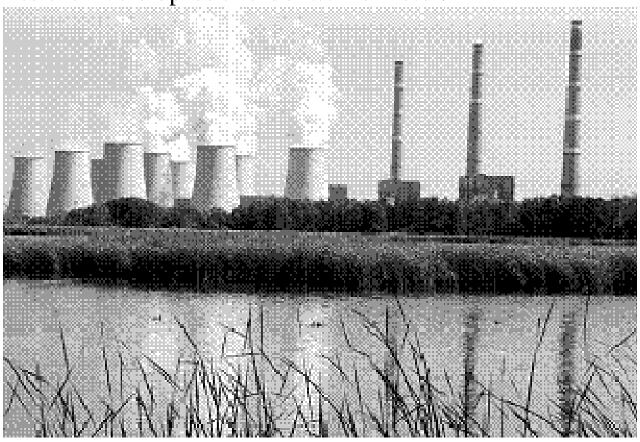

**Fig 20.** Thermal Power Plant of Jänschwalde (Germany).

The quality of this water is such that it is employed for fish production at fish hatcheries. It also feeds lakes, giving ideal conditions for large numbers of waterfowl such as herons, seagulls, swans and storks (Fig. 21).

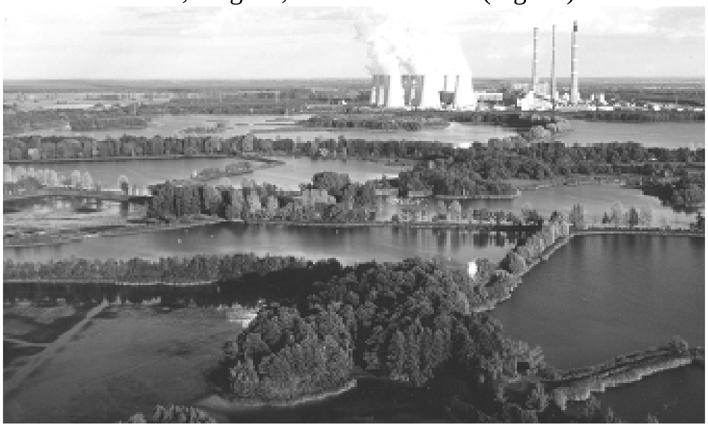

**Fig 21.** Environmental, hydrological and mining restoration surrounding the Thermal Power Plant of Jänschwalde (Laubag Company courtesy).

## Emma Coal Mine (Ciudad Real, Spain): Environmental Restoration Example

Since 1976, Encasur has operated a strip mine to exploit two coal seams (soft sub-bituminous coal), metres thick, in bituminous shale, deposited in a lake connected with the sea during the Carboniferous (Fig. 22). A recent sediment cover overlies the sequence.

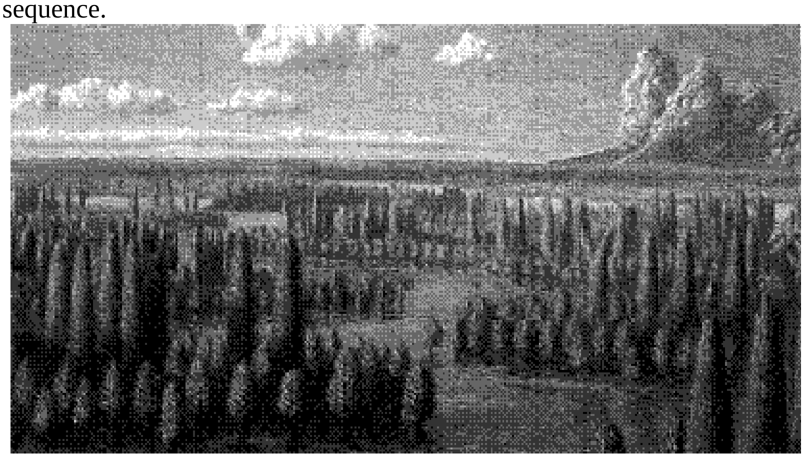

**Fig 22.** Reconstruction of the palaeogeological environment where Puertollano's coalfield (Ciudad Real, Spain) was developed.

The installed production capacity of the mine is in excess of a million tons per year, generating 400 direct jobs. The operating system utilized is "transference mining". Once the initial hole is opened, and after removal and storage of the organic-rich topsoil, the overburden that covers the coal is transferred to the area just mined. The mine is, thus, a void that advances, leaving at its rear a shaped and reconditioned land from which the coal was extracted.

Rehabilitation of the land which the overburden has been transferred is one of the most important achievements of this exploitation. The rehabilitated surface is dedicated mainly to pasture or cereal with oaks. Where, as a consequence of the increased slope, it is not possible to accomplish cultivation, a cover of herbaceous autochthonous vegetation is developed to avoid erosion and to improve the landscape. In such conditions in the medium and short term, the environmental restoration appears in magnificent condition.

During the exploitation of this mine there are discovered quite frequently numerous fossil remains of sharks (skulls and jaws, teeth, bones, scales), acanthodians and amphibious creatures (skeletons, skulls and bones) along with osseous fishes. These discoveries are given protection under a conservation programme, in association with the Madrid Complutense University.

## Rother Valley Country Park Coal Mine (England): Multipurpose Rehabilitation

A rehabilitation case that merits special attention is that related to the coal pit of Rother Valley, exploited by the National Coal Board (1976 - 1981), over 300 hectares of land surface. The pit, from which 1.7 million tons of high quality coal was extracted, is located in England in the areas of Rotterdam, Sheffield and North East Derbyshire.

During the exploitation, a public all-round consultation was carried out, in order to define the final destiny of the mining area. The final destiny decided on was a park meeting three principal objectives:

- To create four lakes and a surrounding landscape, where a wide range of recreational activities based on the use of the water and the land could be pursued;
- To develop different habitats to accept the numerous animal species that inhabit or migrate to the zone;
- To implement an efficient system for the control of excess flows, to protect the urban and industrial surroundings downstream.

With these objectives in mind, when the coal extraction was completed, a compacted clay layer, a meter thick, was placed as a waterproof membrane and the mining void was filled with clean water (Fig. 23) pumped from the Moss Brook, situated at a distance of 2.5 km.

**Fig 23.** General appearance of the old coal mine in Rother Valley after rehabilitation.

In the area surrounding the pit, 480,000 trees and shrub were planted. The old Bedgreave Mill and the buildings close to it were restored in order to maintain the installations of the park. In May 1983, almost two years after completion of the mining operation, the park was inaugurated. Since that time it has received a growing number of visitors that now surpasses 750,000 people each year (Fig. 24).

**Fig 24.** The old coal mine in Rother Valley, a venue for aquatic sports.

The total cost of the rehabilitation project amounted to four million pounds. The Countryside Commission contributed one million in the form of a subvention, the Sports Council contributed 50,000 pounds, and the rest was a contribution from local Councils.

As the vegetation grows, the park becomes more valuable for animal life, and new recreational activities are added. On the other hand, surrounding the Bedgreave Mill complex new buildings have been added. A Nautical Centre, perfectly environmentally integrated, has been built with the same materials and appearance as the buildings over 100 years of age.

In 1990 an Aquatics Sport Centre was built in the Rother Valley Lake's southern part (Fig. 25). In the same year a system of water ski by fixed cable was established for people who like more active sports. The velocity can be changed from 27 to 58 km/hour and eight skiers can use the facility simultaneously, allowing this sport to be practised at a low cost and with minimum environmental impact.

**Fig 25.** Aquatic recreational activities in the old coal mine in Rother Valley (Rother Valley Country Park Courtesy).

At the main lake, many local clubs develop their activities. These include diving, exhibitions of scale models of ships, fishing competitions, etc. There is also a privately financed golf course of 18 holes that was inaugurated in 1996 (Fig. 26).

**Fig 26.** Practice of golf on the old coal mining operation ground (Rother Valley Golf Centre courtesy).

Many other activities are carried out in this park. There are: playgrounds for children; four football fields; a volleyball field; orientation courses, with a wide range of circuits, from 2.6 to 5 km in length; ski on grass on an old mine waste disposal dump's slope, where a National on Grass Ski Championship has been celebrated; three circuits for bicycles, free of cars. Two of these are over flat ground and on compacted roads, ideal for children, while the third has hills up to 60 metres high and zones that are flooded in rainy times and is specially suited for motor cross; pedestrian circuits; areas for picnics and barbecues; coffee shop; information centre, handicraft stores; etc.

Since in a mining rehabilitation the vegetative cover cannot generally be achieved in a short period of time, planting was commenced during the life of the mine to secure the establishment of vegetation as soon as possible. A lot of little groves, preferred by many species and giving easy access to open areas food were planted. Hedges have been given the roles of fauna refuges and fauna corridors, allowing wildlife to move from one area to another.

In the wetlands, special emphasis has been placed on offering an ideal habitat for many types of waterfowl. One of the lakes is specially preserved for native fauna, with its banks planted with adapted vegetation and marshlands where the fish spawn, the birds install their nests and the frogs complete an ideal biotope; the vegetation protects against erosion and favours sedimentation of the suspended solids. This lake includes an island, ideal to protect the birds again any predator. Careful control of the lake level improves its conditions; for example, during the autumnal bird migration, the water level is drawn down in order to expose banks of mud, rich in little invertebrates, where the birds find food; in spring the water level is raised slightly, in order to create numerous small islands where the birds nest and get shelter from the foxes that inhabit the reserve.

The rehabilitation of this mining area has made room for a varied mosaic of landscapes and different habitats: wetlands, lakes, grasslands and groves.

Before the mining operation flooding in the lowlands was a recurrent problem. Now the system of lakes plays a very important role in the control of the excessive flow. A series of well-placed canals diverts water toward the lakes with the simple raising of floodgates. This system permits the control even of floods with a probability of occurrence of once in a hundred years (one million cubic metres). The system has already been used successfully, in emergency situations, evacuating in two days the stored floodwater and returning the water levels in the lakes to their normal positions.

## Tara Lead and Zinc Mine (County Meath, Ireland): Green Mine in an Emerald Island

In 1969 a lead and zinc deposit was discovered in County Meath, Ireland, in limestone and dolomite of the Lower Carboniferous. The Tara mine was developed to exploit this deposit (Fig.27).

**Fig 27.** General overview of Tara Mine surroundings. Main surface facilities and general overview of Tara Mine surroundings.

The mining operation that began in 1977 has exposed the possibility of environmental coexistence of a great mining operation (the principal lead-zinc mine in Europe) in a rural scenario famous for its bovine cattle and its high agricultural productivity, all of it in a residential area densely populated and only 40 km from Dublin (Fernandez Rubio, 1992). The sense of environmental responsibility embraced from the beginning of the mining operation is based on the strict application of techniques of environmental engineering in long-term planning.

The deposit is located only 1,500 meters from the centre of Nava, a city of 16,000 inhabitants, and adjacent to a rural residential area. It is also located at the confluence of the rivers Boyne and Blackwater, the former being one of the more important salmon rivers in a country that gives the highest priority to its fluvial fishing. Under these conditions the success of planning and operation was dependent on the support of the community and municipal authorities.

The local population's suspicion was justifiable due to the scarce mining tradition of Ireland compared with its extensive agricultural inheritance. A starting objective was to plan a mining operation in these surroundings in such a way that it would not only respect national legislation, but would also comply with future regulations, especially those of the European Union (Ireland joined the EU in 1973, just before Tara mine operations started).

In 1971, six years before the commencement of production from the mine, a very detailed environmental baseline study was conducted, controlling all the relevant environmental reference parameters for water, air, soil, noise and vibration. Since then, monitoring of these parameters has been carried out on a routine basis, in the field and laboratory. The company submits monthly an environmental report to the Municipality. It is necessary to mention that Tara maintains an open-door policy with townspeople (some of them live over the deposit) and encourages them to express any complaints they might have.

The controls and analyses are conducted at the mine's laboratories; however, specimens are sent regularly to independent laboratories to be tested. Environmental control equipment is renewed every time there is an advance in technology. This is done to ensure credibility and reduce the townspeople's scepticism. It is also necessary to emphasize that Tara requires frequently the services of consulting environmental specialists.

Internally, a program of continuous education is being carried out, so that each employee has the opportunity to appreciate the work accomplished in each section of the mine. This process, combined with an increase in environmental awareness, has resulted in a pragmatic valuable orientation of the workpeople towards the environmental achievements. At the same time, the mine accomplishes educational campaigns with the local inhabitants, especially in schools.

Although a mine is normally a great producer of water, in the case of Tara an additional source is required (Boyne River) for treating the mineral. The mill's effluent (waste, water and metal traces) is deposited into a great tailings dam, in whose bottom the sediment accumulates. The water rests in the lagoon at least 30 days in summer and 50 in winter, and is then reused in the process.

A reduced amount of the clarified water goes back to the Boyne River, fulfilling the specifications of the licence for the effluent and the receiving water. The controls include the quality of both and the ratio of dilution, as well as requisites relative to the piscicultural fauna and to toxicity (Fig. 28).

**Fig 28.** Electric fishing in the Boyne River for control of piscicultural quality downstream of the residual waste water disposal point at Tara Mine.

The tailings dam (Fig. 29), the biggest water body in County Meath, attracts migratory birds coming from Iceland that arrive to spend the winter in a warmer place. In this water the traces of metallic elements have been measured for several years now, as well as the contents in the muscular tissue, liver and kidney of the birds. No group has shown evidence of noticeable changes in the levels of metals in muscles, and only a slight increment in levels in organs has been detected. The studies are still in progress and will be continued before a decision about the final destiny of the dam is decided.

**Fig 29.** Tara Mine tailings dam resting place for an abundant bird population.

The exploitation of the deposit, which is located in calcareous rocks, produces a great volume of alkaline waste, which is used to refill the hollow voids (stopped-and-pillar). The waste, which is not returned to the mine, constituted mainly of crushed limestone, is deposited in a dam located 5 km from the mine.

As the company will have to deliver its properties to the community at the end of the exploitation, it has made a big effort to accomplish a conscientious fact-finding program, accompanied by ample rehabilitation studies, including consideration of the construction of wetlands and swamplands, with plantations of native species.

Since the waste from the concentrator does not contain nutrients or bacteria, fertilizers are added to get self-fertilization of the ground started and to establish a natural ecosystem with gradation from the dry to the wet areas. Dry areas are vegetated with pasture grasses, shrubbery and trees while wet areas are planted with species of the swamplands. The metal contents of pastures are measured.

Taking into account the proximity of the population, all reasonable efforts have been made to reduce the level of noise around the mine site: earth embankments to attenuate noise, and maintenance and repair of the vehicles. One of the principal systems of ventilation has two centrifugal fans, each 2.94 m in diameter at the surface. They provide 118 $m^3/s$ of ventilation. The two 500 kW motors have an attenuation of the noise level such that it is not noticeable at a distance of 120 m where the nearest housing is located (the level of noise is less than 29 dB (A)).

Additionally, all surface buildings, including the mill and the compressors' installation, are soundproofed to reduce the level of noise.

The quantities of explosive used are controlled with the help of measurements from acoustic stations and vibration records, to ensure that environmental requirements are fulfilled. The explosions are designed so that at any house the maximum vibration produced will not exceed half the authorized limit. All instruments for noise and vibration recording are calibrated daily, to guaranty that international and national regulations are obeyed, and the Municipal Council's engineer visits the data centre monthly to inspect records.

## Dalhalla Stone Quarry (Sweden): Turned into Amphitheatre

Draggängarna (Sweden) was an old quarry of Ordovician limestone. Its exploitation was initiated in the decade of 1940 and it continued until 1991. Today it is a fantastic open amphitheatre, with 4,000 seats and spectacular acoustics (Lovgren, 2003) (Fig. 30).

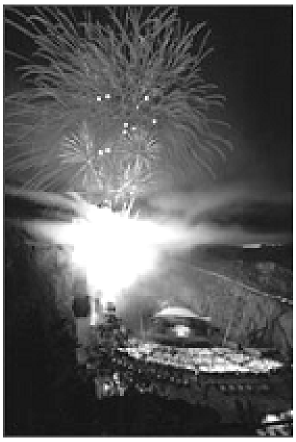 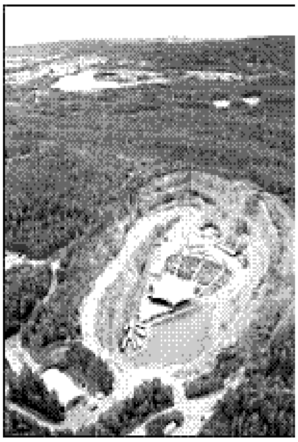

**Fig 30.** The first view of Dalhalla is impressive.

Just after the cessation of mining, Margarita Dellefords, renowned opera singer, was travelling through Sweden looking for a location suitable for presenting opera spectacles in summer. A friend suggested she should visit a limestone quarry located in the Rättvik forest in the central Swedish region (the Dalarna). The moment she stood in front of the stone pit she realised that it was what she was looking for: the excavation was 400 m in length, 175 m in width and a natural amphitheatre with a height of 60 m. She went down to the bottom of the quarry and could not resist the temptation to begin singing the opera Tosca. Soon adaptation was initiated at a relatively modest cost (one million dollars), and in 1994 the first concert was offered in Dalhalla.

The creators of this rehabilitation project saw in this site the perfect place for the opera. Being located in the Dalarna region, and being Valhalla, the Heaven of the Heroes in Nordic mythology, they gave it the name of Dalhalla.

The visitors arrive through a road crossing the forest and unexpectedly the majestic stone pit opens in front of them. The inside of the excavation has a stage that is framed among rocks, in front of a quiet green water lake.

The acoustics are so fantastic that many operas come true without microphones. The public must stay quiet since their sounds would be amplified and they would interfere with the spectacle. It is what they have named “green acoustics”.

Dalhalla has vitalized Dalarna's tourist industry, and it has become famous rapidly for its concertos and presentations in summer. It now attracts over 100,000 visitors a year, and it has been estimated that it provides annually an additional income from tourism of thirteen million dollars.

## Braga Stone Quarry (Portugal): Football Stadium

In the Portuguese city of Braga, a municipal stadium was built for the recently held 2004 European Football Championship. The stadium is an example of an environmental asset related to mining.

The Souto Moura architectural project is, without doubt, an original and magnificent wok that has permitted the environmental rehabilitation of a granite quarry located at Monte Castro hill. This stadium has only lateral steps, running along the major axis of the football field, leaving open the goals (Fig. 31). Because of this, the spectators can observe on one side the spectacle of the excavated fractured rock, in its varied tonalities, of the old quarry, while on the other side the view extends to the green landscape of the immense Minho River plain, sprinkled with dwellings.

**Fig 31.** Braga's Municipal Stadium (Portugal) constructed in a closed stone quarry (www.worldstadiums.com).

The architect has made good use of the difference in heights to allow access to seating from the top of the stadium level with the rock excavated, and from the bottom at the level of the playing field. As well as doing this, the architect has played with concrete, in order to create forms that are in harmony with the rocky context.

Under the field he has constructed an enormous room in which to hold expositions or to offer various spectacles.

## Capao Xavier Iron Mine (Minas Gerais, Brazil): Compatibility of Mining Drainage and Urban Water Supply

In this project (Fig. 32) we have had a very active participation, by request not only from the mining company (Mineracoes Brasileiras Reunidas), but also from the company responsible for the water supplies in Minas Gerais State (Copasa). We have accomplished the Mining-Environmental Hydrological Impact Study, and we have directed all the hydrogeological investigations, to a level of very precise detail, as well as the planning of drainage, including the design of all the hydrological control structures, the hydrogeological model, and all the follow-up annual reports (from 1995) and the director plans (Fernandez Rubio *et al*., 1997, 1998; Quadros Amorim *et al*., 1999).

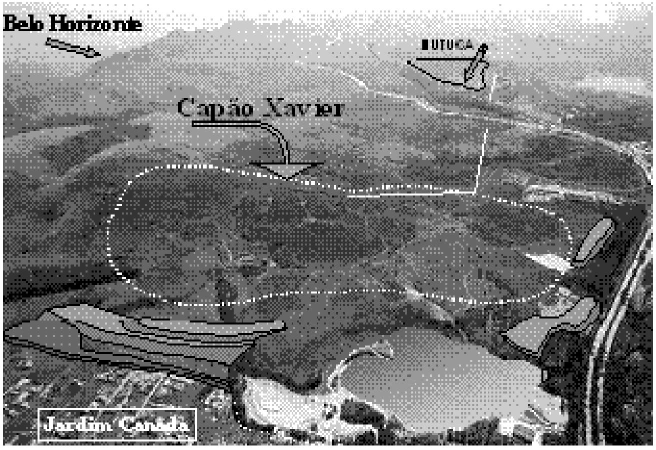


**Fig 32.** Capao Xavier Mine location (Minas Gerais, Brazil), and environmentally planned surroundings.

This deposit, with exploitable stock of 140 million of tons of iron ore of high quality, is located only 15 km south of the city of Belo Horizonte (three million inhabitants). It is in an area named the Iron Quadrangle, a metallogenic province that is one of the world’s richest in iron ore. It is also located next to a protected forest, and close to springs that supply water for Belo Horizonte.

The location of the deposit has necessitated very careful environmental mining planning, for the preservation of hydrological and environmental resources, in a sustainable project, whose principal objective was not only to minimize the impact of drainage, but also to improve the management of the water resource. This has been attained by means of a very deep analysis of all the basic data, with its computerization, and a field works geological investigation, with participation of both the company’s technicians, and professors of the Geological Department of the Federal University of Ouro Preto.

We have accomplished this work in close and fruitful contact with the technical staff, planning and designing the required meteorological infrastructure, gauging stations, piezometers, and systematic analysis of the surface waters and ground waters. All these works have provided the basis for establishing hydrological protective criteria, a programme starting with a preventive drainage system (with pumping wells and monitoring piezometers), and continuing with detailed monitoring in order to make the mining operation compatible with the city water supply.

The designed drainage system allows the quality of the water used to supplement the supply to be guaranteed and allows an optimised hydrological management. This is especially important in an area with very irregular rainfall, which varies between less than 500 mm and over 2,800 mm per year.

The hydro-environmental component of this project is very important, optimising the mine drainage, and making it compatible with the water supply, but also planning a lake at the end of the mine life (60 million cubic metres capacity) (Fig. 33). The lake will contribute to the biodiversity of this area, and will provide a scenic attraction and water of quality, placed at the infiltration water-bearing zone (Fernandez Rubio, 2002).

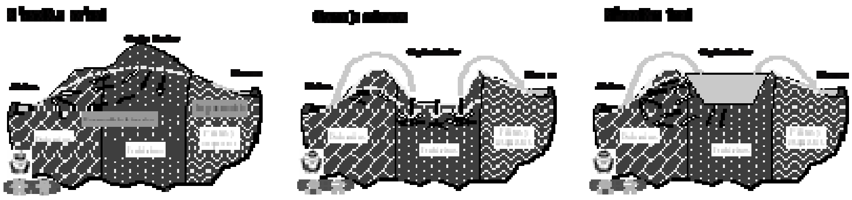

**Fig 33.** Schedule of hydrogeological operations performed during the pre-mining, exploitation and after-closure phases of Capao Xavier mine project.

In this regard, detailed studies have investigated the possibilities of water eutrophication and salinization during establishment of the hydrological balance (rainfall, evaporation and subterranean flow). In any case we have designed an Environmental Management System to guarantee the fulfilment of established ground rules, and the attainment of the defined objectives, and especially a positive effect of the mining project on the hydrological resources.

Special attention has been given to reducing to a minimum the effect of the mining operation on Jardim Canada's urban population itself, and to the integration of the final lake into the environment (Fig. 34).

As an added benefit, the waste produced in this mining operation will allow (by transference mining) the filling of a nearby mine that has recently been closed down (Mutuca Mine).

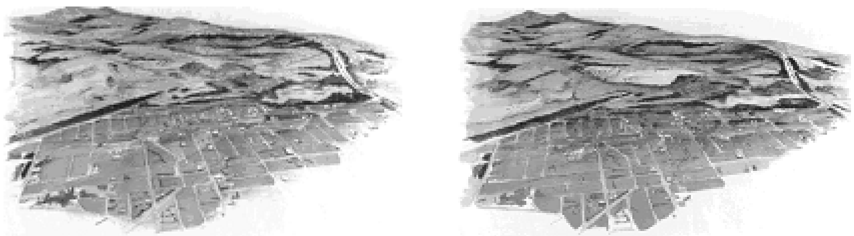

**Fig 34.** Environmental integration of mining excavation and of the final lake of Capao Xavier mine project.

## Las Cruces Copper Mine (Seville, Spain): Environmental Mining Project

### Project Location

The mineral deposit of Las Cruces is located very near to Seville city, in the Iberian Pyrite Belt (which extends through the Hispanic Southwest and the Portuguese South), with mining activity as old as five thousand years, and with well known exploitations such as: Rio Tinto, Tharsis, Neves Corvo, Sotiel, Almagrera, S. Domingos and many others mines, both active and abandoned.

### General Description of the Project

In this project (property of MK Gold, based on Salt Lake City, Utah, USA ) we had the duty to deliver the Environmental Baseline Study (EBS) and the Environmental Impact Study (EIS), as well as other environmental and hydrological studies with a team of over thirty specialists (Fernandez Rubio, 2001). It is important to emphasize that the Engineering Project has developed simultaneously with the EIS, incorporating from the beginning all the protective criteria and environmental corrections in all the design elements.

In this EIS we have carried out physical and mathematical modelling of the more significant aspects of the Project: visual impact, atmospheric emission, noise, vibration, surface water hydrology and groundwater.

Prior to the extraction of the mineral it is necessary to excavate a 140 m thickness of marl. The marl will go to the waste dumps, the mineral to the treatment plant, and the Palaeozoic rocks to a special repository of mine waste. A total of 190 Mt of materials will be excavated producing an open pit of surface dimensions 1500 m x 900 m and 245 m depth. The Project, when full-fledged, will occupy some 1,100 hectares (presently depopulated agricultural land), and the pyritic waste coming from the treatment plant will be progressively encapsulated in a dry state below the extracted overburden marls.

A confined aquifer is located over the ore body. It will be necessary to drain this aquifer all around the excavation and even under the bottom of the pit. In order to accomplish this objective, while preserving the quality and quantity of water in the surrounding aquifer and not affecting the users, a system of drainage-injection peripheral wells has been designed (Fig. 35).

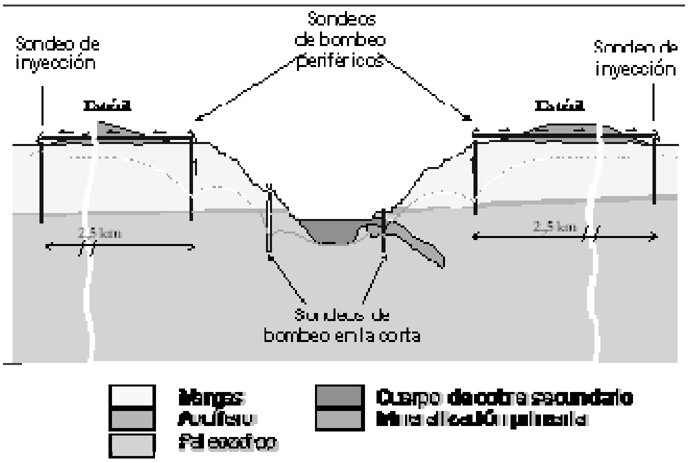


**Fig 35.** Scheme of drainage-reinjection for aquifer protection.

To avoid lowering the piezometric level, away from the immediate surroundings of the mining operation, the pumped water will be carried in pipes, and will be re-injected into the aquifer through wells situated 2-3 km away from the open pit (Fig. 36).

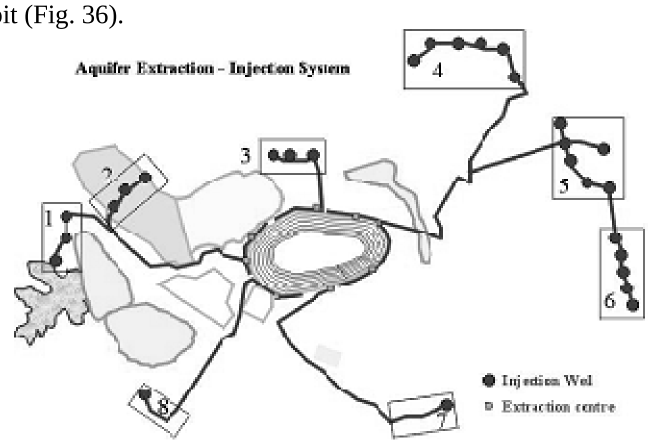


**Fig 36.** Drainage and injection wells for aquifer protection in the Las Cruces Project.

The total amount of water (estimated to be 200-250 l/s), will circulate in a closed and continuous circuit, during all the mining operation, in such a way that the water extracted by the pumping wells will return to the aquifer, to avoid any significant effect on users outside the ring of injection wells. This installation has been tested by means of mathematical models, and a long-term pumping-reinjection experience.

As a complementary protective measure, starting at a certain point in the operation, some of the marl will be used to partially fill the mine void (transference mining), to isolate and to protect the aquifer, an action that will be completed in the closure phase, reducing the surface area occupied by the marl dumps.

## Stream Re-location

The opening of the mine requires the diversion of 3.2 km of one stream and modification of 800 m of another stream. The relocation of these streams will be used as an opportunity to create a naturalized stream that allows presently degraded ecosystems to recover. To do that, the new stream will maintain its hydraulic conditions, with a naturalized morphology and an improved habitat.

## Rehabilitation Plan

The rehabilitation plan covering all the areas affected by the mining operations follows a naturalistic development, with autochthonous vegetation, and the possibility of improvement for other uses. All of this will be included in a rehabilitation process that will improve the ecological biodiversity of this zone.

This plan, based on a progressive non-stop treatment process, starting at the beginning of the construction and continuing through all the exploitation, will allow the waste rock dumps to acquire a morphology of natural appearance, integrated with the landscape, with limited heights (maximum 50 m above the original surface) and soft slopes (maximum 14º). The relief created will make possible diversified future uses of the ground, once the mining operation is concluded; reconstructed areas have been designed allowing for the maximum possibilities for future alternative uses, and recovering and improving the biodiversity (introduction of autochthonous flora, river vegetation, etc.).

The rehabilitative strategy will be progressive and non-stop, in such a manner than only a small part of the waste from treatment and from the mine will be uncovered at any time, and at the end of the mine operation only a small area will be left to rehabilitate. This performance will minimize visual impact and will also minimize the disturbed surface, facilitating the environmental integration after the closure of the mine, optimising future uses of the soil and improving the ecological habitat and the hydraulic resources.

The rehabilitation plan designed considers, once the mining operation is finished, the possibility of employing the mine void for storage of inert waste, or the creation of a 60 $Hm^3$ lake with quality water. Prior to this, part of the extracted marl will be returned to the mine to cover the Palaeozoic rock and the overlying aquifer.

The priority of the rehabilitation plan is optimisation of use of the ground after the cessation of mining (Fig. 37). The plan begins with the start of the Project in the year -2, and continues during all the life of the mining operation, and has the following key elements:

- Over 25 % of the permanent restoration accomplished before the beginning of production
- Almost 40 % of the permanent restoration ends up during the first year of production, and the visual North and East barrier will be finished and re-vegetated during the year -2.
- 22 % of the material extracted is extracted for environmental ends, including the final covering of waste from treatment and the mine as well as the partial filling of mine.

**Fig 37.** Assigned models of restoration.

Evaluations of the following factors have been taken into account in appraising the positive and negative impacts of the project: climate; emission of particles; emission of gases; noise; relief; geotechnical stability; vibrations; soils; surface waters; ground waters; ground ecosystems; aquatic ecosystems; protected species; landscape; land uses; archaeology; infrastructures; population and public services; economy and social environment. All of it under the pre-mine and after-mine conditions, evaluating the ecological profits and losses produced by the project (Fig. 38).

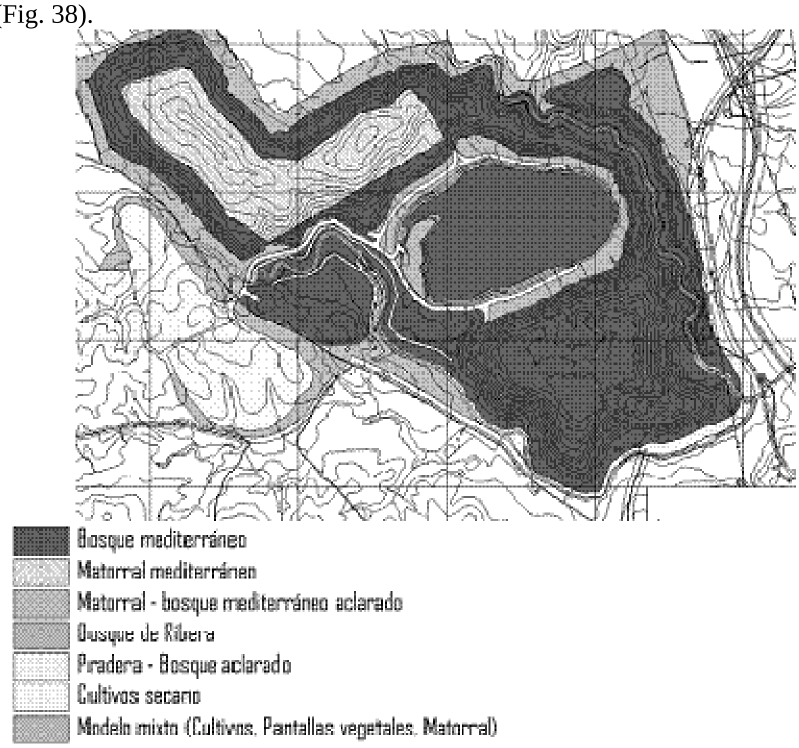

**Fig 38.** Ecological values before and after the Las Cruces project (more dark more ecological value).

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