State of the Art of mine restoration techniques

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Cristina Beseler Soto, VAERSA, cristina.beseler@vaersa.org

Maria Dolores Bofías Aledo, dbofias@vaersa.org

Cristina Gil Monteso, VAERSA, cristina.gil@vaersa.org

Ibán Hurtado Picó, VAERSA, ihurtado@vaersa.org

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CONTENT

ABSTRACT

Mining is a strategic sector for Europe and Spain. The Opinion of the European Economic and Social Council on non-energy mining in Europe (2009/C 27/19) indicates that 70% of European industry is dependent on mineral substances. Therefore, the development of an industrial policy that guarantees the supply of these substances is essential.

The strategic mining of the 21st century will be possible if it is technically, economically, socially and environmentally viable. During the last 30 years, environmental policies and mining regulations have been developed at EU and national level. These regulations offer administrations additional instruments for the application of principles - precautionary, prevention, correction and compensation - that have helped the development of sustainable mining operations.

The EU also ensures that mining, mining waste and human rights are managed properly by a combination of environmental, health and safety and human rights law.

Surface mining operations often take place in forest areas of high landscape and ecological value, severely modifying them. The environmental effects of mining are drastic: the result is a deep alteration of the landscape and almost the total destruction of the affected ecosystems.

The restoration of these areas is regulated by national and regional legislations. However, the technical and environmental requirements are poorly defined. Too often, the pressure from local authorities to obtain short-term visible results leads to the application of fast revegetation treatments to reduce visual impact. However, these measures may condition the future evolution of the restoration, directing it towards to ecosystems other than those desired. (Chambers et al. 1994; Holl 2002; Jorba et al. 2002).

The International Ecological Restoration Association defines ecological restoration as the process of assuring the restoration of an ecosystem that has been degraded, damaged or destroyed. In the case of quarries, ecosystems need to be completely recreated and reintegrated into the landscape.

Restoration failures are very common, despite the development of mining restoration techniques and material and cost-effective efforts of the companies

This document approaches renaturation and landscape reintegration techniques from three points of view: hydro-geomorphology, vegetation restoration and soil quality.

A summary of existing guidelines on mine restoration is presented. They can be a referent in the design of future extractive activities.

Mining activities leave considerable sign of its activity in the territory. However, its restoration and enhancement may contribute to local economic development through construction of museums or parks. Several examples are shown.

New technologies and knowledge are available and may contribute to ensure the return of long-term environmental resources disrupted by mining operations.

INTRODUCTION

Mining is well known by its economically profitable industrial activity. It is the selective extraction of rocks and minerals from the earth's crust. This activity entails surface or underground operations that require the application of mining techniques or the use of explosives as well as other needed actions for treatment of the extracted substances such as crushing, sizing, washing, concentration, etc.

The strategic role of this activity lies in the fact that supplies the rest of the industry with basic raw materials necessary for modern life. Consequently, the rate of consumption of mineral resources increases as science, technology, economic development, industrial expansion, civil and building works and population growth. Henceforth, possible difficulties in the supply of these mineral raw materials may affect the functioning of the rest of the industrial activity.

In today's mining industry, several mineral substances are obtained from one exploitation, all of which are of interest and of considerable economic value. Even raw material that was usually stored in the dumps is now used for other industries.

Recently, mining has been undergoing drastic changes because of several reasons, these are:

- Mining products are traded in global markets and search into new mineral deposits and opening of a mine is highly dependent on global world prices.
- The involvement of many different professionals.
- New regulations related to environmental impact, waste disposal, increased pollution, potential geological soil risk or changes in local water quality.

The global extractive industry sector is characterized by a relatively small number of groups of international companies operating across continents. Many of the products are traded globally and prices are set in global financial markets. A group of small companies usually controls the extraction of building materials in local markets with low benefit.

Since 2008, the European Union has developed the Raw Materials Initiative with the main objectives of guarantee access to raw materials, promote their extraction from European sources and promote recycling. This could increase efficiency in the use of resources and reduce dependence on third countries. It has defined a policy to ensure that mineral resources are exploited in an economically viable way by reducing dependence on supply and establishing mining plans.

The European Union is largely self-sufficient in the extraction of building materials. However, it has to import a large number of other minerals that are essential for manufacturing activities. As a result, metallic minerals, mainly the so-called strategic minerals (CMR), led the European Commission, in 2011, to adopt new strategies to address the supply of raw materials in European markets.

Mining is a strategic sector for Europe and Spain. The Opinion of the European Economic and Social Council on non-energy mining in Europe (2009/C 27/19) indicates that 70% of European industry is dependent on mineral substances. Therefore, the development of an industrial policy that guarantees the supply of these substances is essential.

This strategic mining is the sustainable mining of the 21st century, which will be possible if it is technically, economically, socially and environmentally viable. During the last 30 years, environmental policies and mining regulations have been developed, both, at EU, and national level. These regulations have offered administrations additional instruments for the application of principles - precautionary, prevention, correction and compensation - that have helped the development of sustainable mining operations.

However, there is strong social pressure against new mining projects and pressure is exerted on the administrations involved and mainly on the local administrations.

It is worth to highlight the study carried out by the World Bank on the growing role of minerals and metals in the future with carbon reduction (The Growing Role of Minerals and Metals for a Low Carbon Future). This study indicates that the demand for minerals such as lithium, cobalt, copper, rare earths, molybdenum or manganese could increase by up to 1000%.

The sustainable development of our society will continue to depend on the production of mineral substances and mining. Mining must be sustainable and must be developed wherever the minerals are located and, preferably, wherever there are environmental standards such as those joined by EU states.

In Spain, due to its varied geology, there are deposits of very different rocks and minerals, which gives rise to a diverse and important mining production. National mining production reached 2,965 million euros in 2015, 1.7% less than in 2014. Despite the overall decline, with the exception of energy mining, the rest of mining production has improved, maintaining the slight upward trend of recent years.

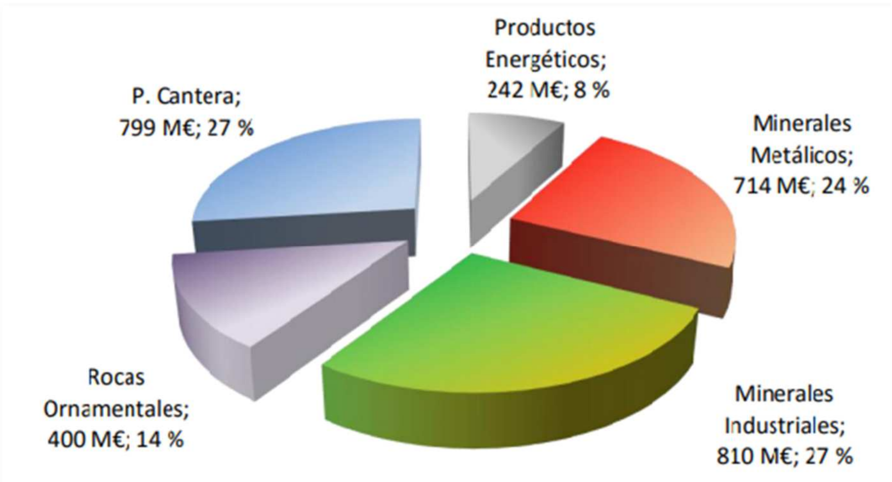

Figure (1): Production in million € and % of total production, year 2015
Source: Ministry of Energy, Tourism and Digital Agenda

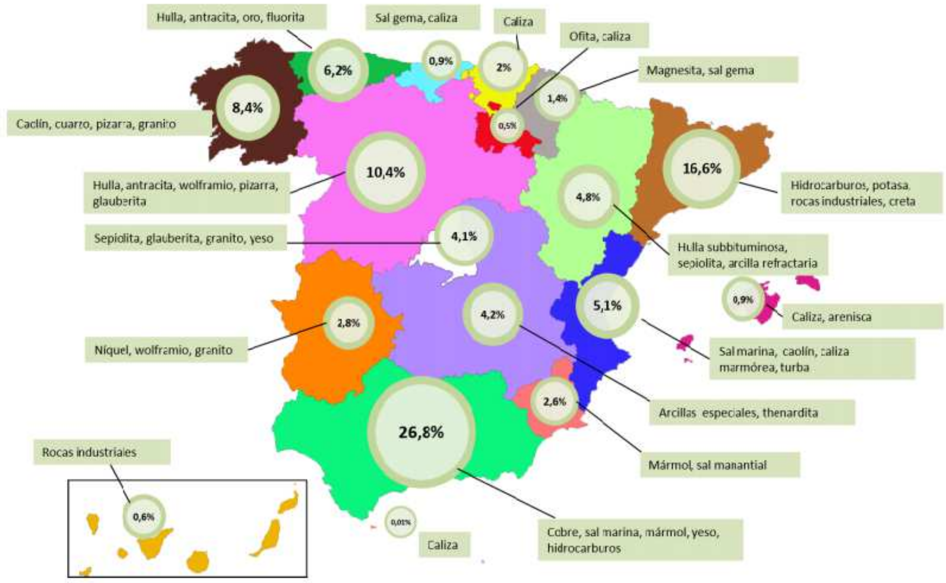

Figure (2): Value of mining production (%) by Region. Year 2015.
Source: Ministry of Energy, Tourism and Digital Agenda

The following figure shows the Regions with highest production value in 2015

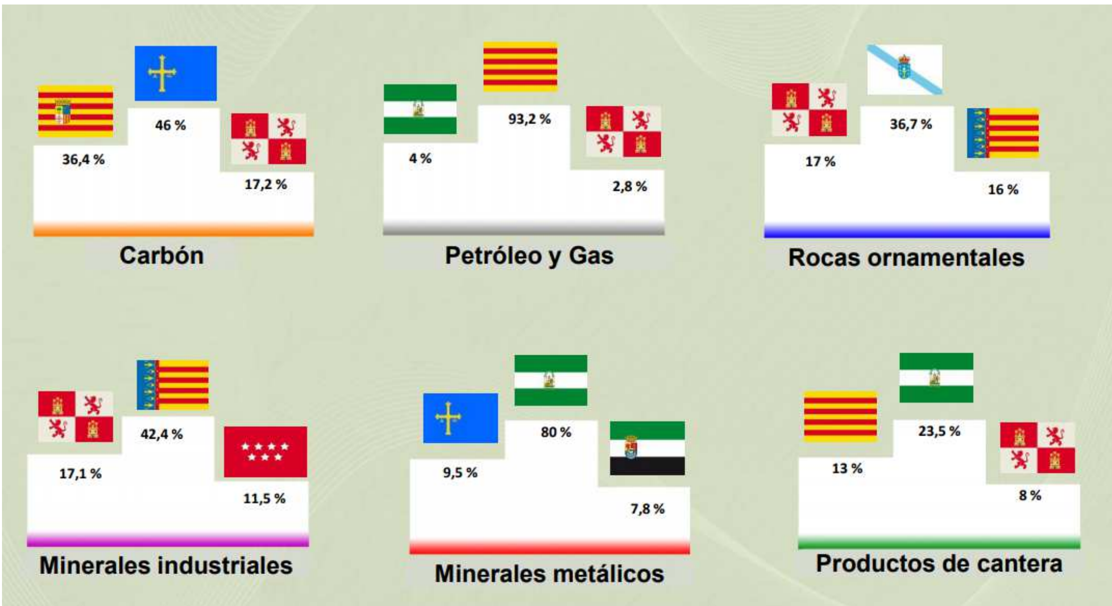

Figure (3): Regions with the highest production value. Year 2015.
Source: Ministry of Energy, Tourism and Digital Agenda

LEGAL FRAMEWORK

The EU ensures that mining, mining waste and human rights are managed properly by a combination of environmental, health and safety and human rights law. The European Convention of Human Rights, the Charter of Fundamental Rights of the European Union and the European Social Charter, all of which bind EU Member States and the institutions of the EU, guarantee certain human rights- concerning health, safety and environment from serious actual or threatened environmental harm- that can be impaired by mining activities.

The EU has also enacted a number of Directives that operate to ensure that mining and mining wastes do not imply a risk to the environment or human health or safety.

The **Directive 2004/35/EC** on environmental liability with regard to the prevention and remedying of environmental damage (the ELD) was enacted to deal with "pure ecological damage". The objective is to ensure that operators pay for ecological damage caused by their activities either by remedying it themselves or by paying a public authority for doing so.

It was extended to cover extractive waste from mines and quarries by **Directive 2006/21/EC** on the management of waste from extractive industries (the MWD) resulting from "prospecting, extraction treatment and storage of mineral resources and the working of quarries". Certain wastes are excluded from the application of the MWD altogether. Wastes not covered by article 2 of the MWD may be regulated pursuant to different EU legislation, including the Waste Framework Directive 2008/98/EC, Directive 99/31/EC on the landfill of waste, Directive 200/60/EC on Community action in the field of water policy and the IPPC Directive. However, the provisions in the Waste Framework Directive on waste do not apply to mining waste covered by MWD.

The ELD is connected with **Directive 2008/1/EC** concerning integrated pollution, prevention and control, since a holder of an IPPC or waste licence for mining and related waste activities in the EU is subject to the ELD because activities listed in Annex III to the ELD include any installation subject to a permit in pursuance of IPPC Directive. Although the list of Annex I activities does not cover all or even most mines, many mines become subject to IPPC because of their associated activities

Water catchment and impoundment subject to prior authorization under **Directive 2000/60/EC** of the European Parliament and of the Council of 23 October 2000, establishing a framework for Community action in the field of water policy (the WFD), also falls within the activities listed in Annex III, often associated with almost all mining. Furthermore, activities dealing with mining waste were added to Annex III by article 15 of the MWD.

Mining and mining activities must also ensure compliance with the obligations in the Directive 98/83/EC on the quality of water intended for human consumption.

Meanwhile, **Directive 92/43/EEC** on the conservation of natural habitats and of wild fauna and flora, establishes obligations related to protected habitats and Council **Directive 79/409/ECC-** amended by Directive 2009/147/EC may require a State itself to take proactive measures, including remediation of a protected habitat damaged by mining.

At a strategic level, **Directive 2001/42/EC** on Strategic Environmental Assessment (SEA) encourages a more integrated approach to territorial planning where environmental considerations are taken into account at an early stage in planning process. SEA may result in the identification of locations or development constrains where operators of proposed mining projects may, or will, encounter difficulties in obtaining the required environmental authorizations.

Three amendments of the Environmental Impact Assessment **Directive (85/337/EEC)** have been set by Directive 2011/92/EC, also amended in 2014 by Directive 2014/52/EU. Most substantial mining projects fall within its scope. Older mining projects subject to an environmental re-authorization must also be subject to an environmental impact assessment.

Mining activities must also obey the limit values prescribed by under **Directive 2008/50/EC** on ambient air quality and cleaner air for Europe.

A number of Directives deal with risk of mining accidents. The most important is **Directive 96/82/EC** on the control of major-accident hazards involving dangerous substances (the SEVESO II Directive). **Directive 2003/105/EC** amended SEVESO II to cover the processing and storage of mineral containing dangerous substances extracted in mining, quarrying and tailings disposal and other mining waste facilities. Some mines are subject to this Directive, but accidents from Category A mining waste facilities are specifically regulated under the MWD and not under Directive 96/82/EC.

At a non-strategic level, the Habitat Directive imposes substantive requirement on operators seeking permits for mining and waste projects likely to have significant effects on protected habitats flora and fauna. The Directive mandates “appropriate assessment” of any mining or waste mining plan or project. This assessment for projects is usually managed in the context of a permit system and /or under the legislation implementing **Directive 2001/41/EC** on the assessment of the effects of certain plans and programmes on the environment.

SURFACE MINE RESTORATION

Surface mining operations often take place in forest areas of high landscape and ecological value, severely modifying them. The environmental effects of mining are drastic: the result is a deep alteration of the landscape and almost the total destruction of the affected ecosystems. Therefore, the purpose of restoration is always to rebuild natural ecosystems. (Jorba et al. 2008).

The restoration of these areas is regulated by national and regional legislations. However, the technical and environmental requirements are poorly defined. Within this legislative framework, the restoration is evaluated according to the criteria of each competent agent involved in the process. Too often, the pressure from local authorities to obtain short-term visible results leads to the application of fast revegetation treatments to reduce visual impact. However, these measures may condition the future evolution of the restoration, directing it towards to ecosystems other than those desired. (Chambers et al. 1994; Holl 2002; Jorba et al. 2002).

The International Ecological Restoration Association defines ecological restoration as the process of assuring the restoration of an ecosystem that has been degraded, damaged or destroyed. In the case of quarries, ecosystems need to be completely recreated and reintegrated into the landscape.

The restoration process in the mining sector should make compatible the fast stabilization of substrates under extreme conditions of stability, short-term naturalization and increasing the richness of species from the earliest stages of revegetation.

The term ecological restoration is strongly anchored in the extractive sector and encompasses all recovery interventions over the years. Thus, the restoration of the mining areas will be approached from three points of view: hidro-geomorphology, vegetation and soil.

Following, there is a review of what has been researched so far, the degree of development achieved to date as well as the present situation.

HYDRO-GEOMORPHOLOGICAL RESTORATION

Mining activity nourishes society with raw materials, which are essential elements for our life style in today's modern society. Surfing the web is enough to find clear references concerning this issue, like CATERPILLAR machinery Company showed us in a video (https://www.youtube.com/watch?v=60B7iCEN2xY).

We must be aware that almost everything we use is linked to mining in some way, from food processing, electronic compounds, construction elements, plastics, recreational activities, roads and railroads to energy transportation. Almost everything we use is extracted from mines all over the world, and, in addition, has to be transported to processing and manufacturing centres.

Both, at European and national level, we know mining activity has a high economic importance. At a regional level, mining activity in Valencian Community provides raw materials to strategic sectors in economic development, like construction, infrastructures and ceramic and tile industry. Mines in Valencian Community are located in a densely populated territory with great tourist potential, with many inland districts with a large number of surface mines.

Figure (4): A world without mines? Road CV-35. Valencia-Ademuz.

Back in 1996, J. Cairns conveyed us the triangular image that connects nature with technology and human welfare. The environmental impact occurs between the connection of nature and technology, with technology increases leading to loss of ecological services.

Mining activity has a high impact on nature, particularly on certain elements of physical environment such as soil, biodiversity, water resources and even landscape: Forest areas and other high ecological value zones are being fragmented.

Figure (5). Aerial image of a mine in a public forest. Municipal District of Higueruelas. Valencia.

Nowadays, the demand for minerals in the most industrialized countries, likes USA, Japan or Germany, exceeds 18 tons per inhabitant per year, regardless of petroleum products. This decade, consumption is expected to reach 22 tons per inhabitant per year. At a national level, these rates of demand are not reached yet, but the trend is also increasing, especially in the construction and civil engineering sectors, followed by coals, irons and cements. (**El recorrido de los minerales en la Comunidad de Madrid–Dr. Carlos López Jimeno et al**.)

Human beings are affecting nature to an unprecedented extent in history. Hooke quoted, that in 1994 it was estimated in the USA a circulation of 3 giga-tons of materials for road construction, 3.8 giga-tons generated in surface mining and 1 giga-tons used in housing development. That is to say, the sum of the three equalled what was produced by natural geological agents like rivers, glaciers, wind, etc.

In Spain, the Ministry of Civil Works estimated 10 m^3 per linear meter built, with an apparent density of 2t/m^3, resulting 300 million tons in earth works between 2005 and 2020.

Human activities have become the main geomorphological agent that nowadays modifies the Earth's surface. Accordingly, it is necessary a careful review of geological, hydrological and geomorphological elements to grant the dynamic equilibrium of the earth. (**Restauración ecológica de áreas afectadas por infraestructuras de transporte. Capítulo 2 – Consideraciones geomorfológicas e hidrológicas – Dr. José F. Martín Duque et al).**

In this context, mining should be approached in terms of sustainable development and governments must guarantee economic development while returning environmental resources that have been disrupted.

In this line of thought, a specific legal framework was set in place in our region by approving the Decreto 82/2005 of 22nd April, of the Consell, on Environmental Management of Mining Exploitations in Forestry Areas of the Valencian Community.

Later on, it was approved the Real Decreto 975/2009, of 12 June on the management of waste from extractive industries and protection and rehabilitation of areas affected by mining activities. The objective of the Real Decreto is to establish measures, procedures and guidelines to prevent or reduce, as far as possible, adverse effects on the environment, particularly on water, air, soil, fauna, flora and landscape, and risks to human health, as well as assure proper management of mining waste. Currently, a sustainable mining law is being drafted in the Valencian Community.

The desirable scenario is to achieve sustainable development, in order to maintain and conserve environmental services that are essential for our well-being, and that unfortunately are decreasing.

A series of policies have been proposed, such as: the reuse of minerals (aluminium and copper), to carry out studies on existing resources and extractions in order to avoid extracting resources that are not necessary, to approve mineral and environmental management plans and, above all, that subsequent restoration has to be performed using the best available techniques.

Criteria for surface mining operation are defined by geological data that will allow us to define the mineral inventory and the economic model. This will influence the design of the operation based on geotechnical, operational and environmental criteria to assess the exploitable reserves. Nor should we forget that, the mining legislation through the Complementary Technical Instructions, which develop the General Regulation on Basic Standards for Mining Safety (RGNBSM) – Act 863/1985, of 2 April, establishes geotechnical stability and safety as priorities.

Therefore, we find that, still having mineral deposits available, the operation criteria must meet four fundamental parameters or criteria:

a) Geometric criteria: Structure and morphology of the deposit

b) Geotechnical criteria: Search for maximum stable slope angles

c) Operational Criteria: Dimensions suitable for the machinery to be used

d) Environmental Criteria: Hide openings or dumps, reduce impacts and allow restoration of affected areas.

For practical purposes, in all mining operation, in our country, we find a geomorphology of exploitation and its future restoration based on a batter/berm profile. The schema used is shown below:

Figure (6). Standard profile of surface mining operation. (**Manual de Evaluación y Diseño de explotaciones mineras. Bustillo Revuelta & López Jimeno**)

Most of the mines in the Valencia Region (plaster, clays, silica sands, marble, limestone and aggregates) have this shape.

Figure (7). Operation of red clay and kaolin mine. Municipal District of Alpuente. Valencia.

Figure (8). Operation of red clay and kaolin mine. Municipal District of Higueruelas. Valencia.

Figure (9). Marble mine. Municipal District of Pinoso. Alicante.

Figure (10). Limestone mine. Municipal District of Enguera. Valencia.

Figure (11). Limestone mine. Municipal District of Tous. Valencia.

Another important point to consider are the road and ramps to access the benches, which involve topographical changes in the sites shape. Other impacts to take into consideration are heavy traffic and the suspended dust that exists in the areas close to the stockpiles of organic, mineral and sterile soil in nearby dumps.

Figure (12). Accesses in coal extraction area. Municipal District of Andorra. Teruel.

Figure (13). Tracks, stockpiles, sterile and dust in suspension. Municipal District of Higueruelas. Valencia.

Moreover, safety and geotechnical stability in mines are a priority, so we will have to design the restoration with difficult starting conditions.

The main problems encountered in actual mine restorations may be grouped into the following points:

a) Severe erosion
b) Hydrological impacts (sedimentation of ravines, ditches, and suspension in river waters)
c) Rectilinear topographic designs
d) Concealment of visual impacts through dumps
e) Use of artificial elements (concrete, gunite, bolts, meshes, etc.)
f) Unstable areas and geomorphological movements
g) Design of haul roads that favour erosive processes
h) Failure or ditches plugging
i) Problems in the substrates that do not allow stabilization of vegetation
j) Landscape affection

This indicates that a search for long-term ecological stability is not pursued and restauration works usually have the problems described above.

The following images show the difficulties found throughout the mines of the Valencian territory.

a) Severe erosion

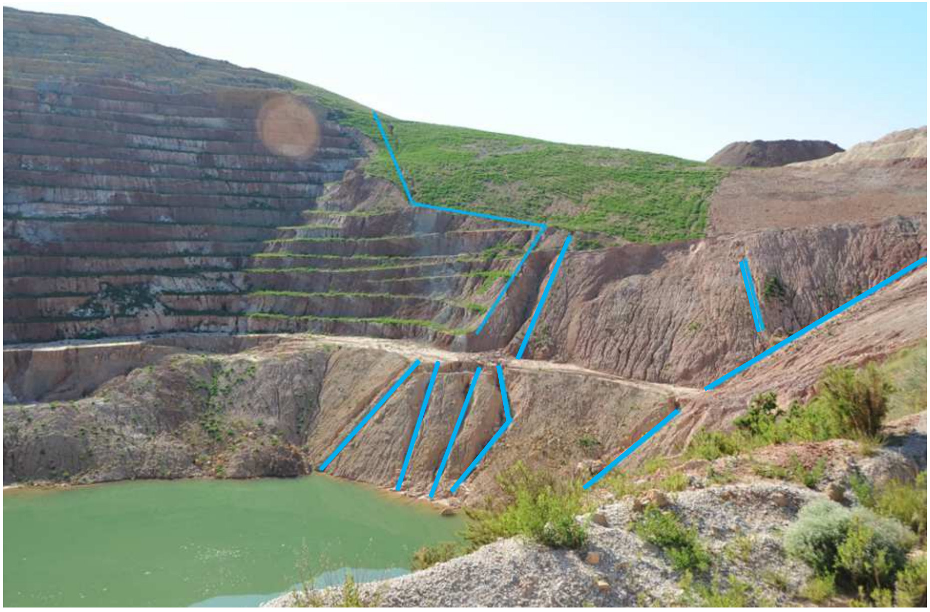

Figure (14). Active erosive processes after restoration. Municipal District of Higueruelas, Valencia.

Figure (15). Active erosion on slopes before restoration. Municipal District of Higueruelas, Valencia.

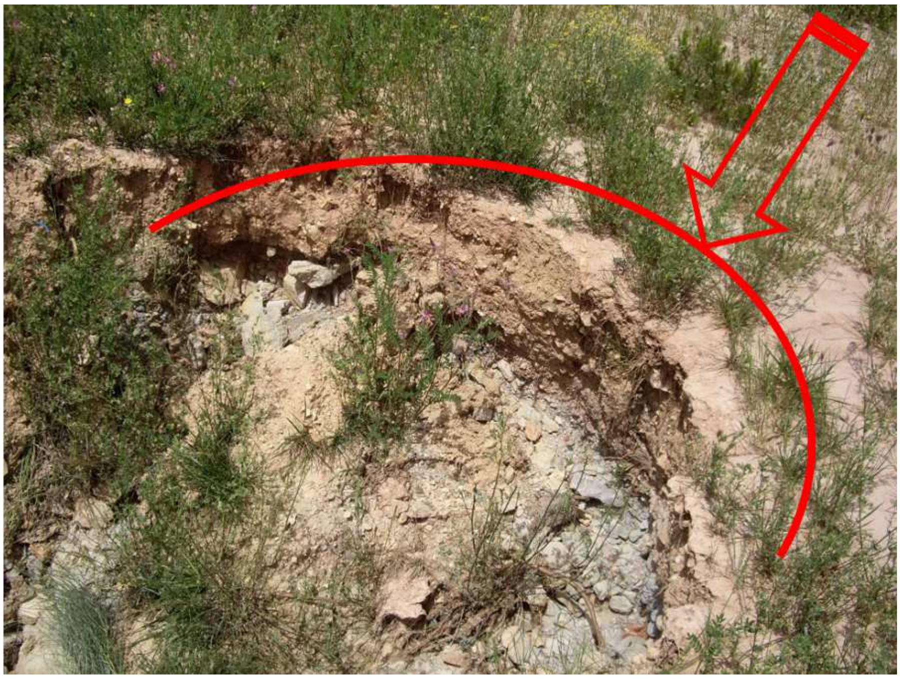

Figure (16). Piping in restored benches. Municipal District of Andilla, Valencia.

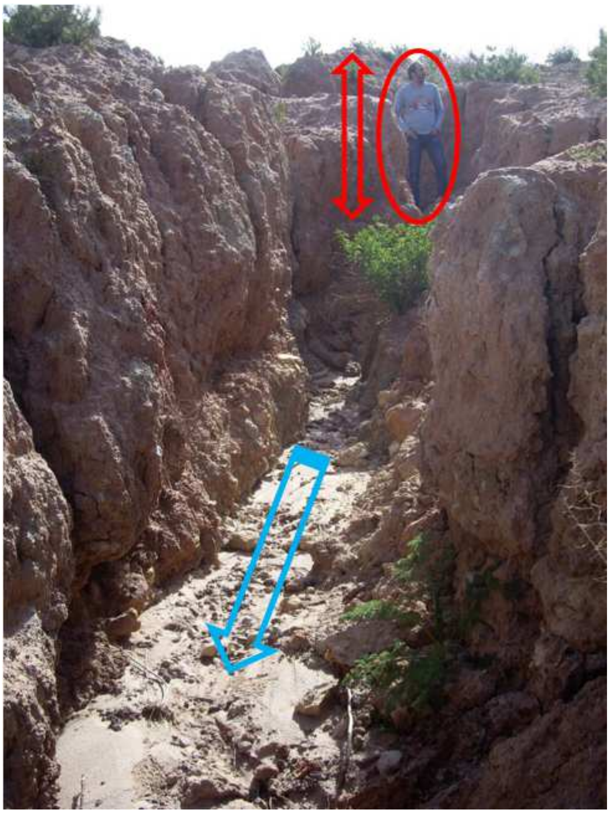

Figure (17). Two (2) meters head cut in restored areas. Municipal District of Higueruelas, Valencia.

Figure (18). Slope breakage due to erosion and sedimentation of material. Municipal District of Andilla, Valencia.

Figure (19). Erosion in low slope areas, roads and accesses. Municipal District of Higueruelas, Valencia.

Figure (20). Head ward erosion in low-grade areas. Municipal District of Andilla, Valencia.

Figure (21). Head ward erosion in benches after 10 years of restoration. Municipal District Andilla, Valencia.

The images show that there are active processes (head ward erosion, pipping, destruction of benches, etc.) after more than a decade of the restoration works. The processes take place not only on slopes, but also in flat areas, benches and the stockpiles of barren and organic soils.

b) Hydrological impacts (ravine sedimentation, ditches, and suspension in river waters)

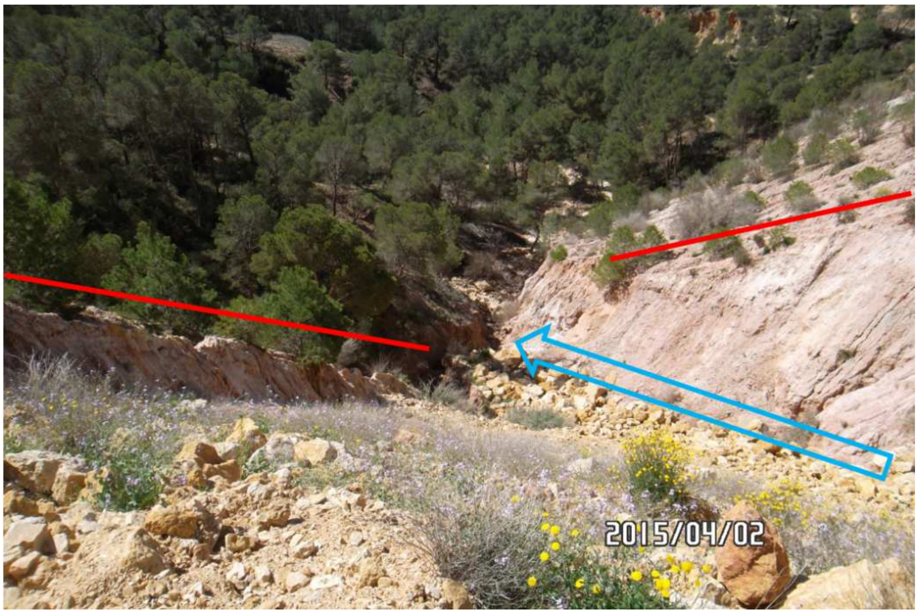

Figure (22). Slopes destruction by heavy rains. Limestone and sandy deposits in "El Madroño" ravine. Municipal District of Higueruelas, Valencia.

Figure (23). Dragging of sandy and limestone material on local roads. Municipal District Andilla, Valencia.

Figure (24). Failure of local road that connects forest public areas, due to the hydrological impact on the clayey material. Municipal District of Higueruelas, Valencia.

Figure (25). Stone banks and ditch sedimentation and after restoration. Municipal District of Higueruelas, Valencia.

The above images show that hydrological impacts take place after mine restoration. In some spots, water concentration starts erosive processes, which causes sedimentation and gullies in local roads.

c) Rectilinear topographic designs

Figure (26). Restoration of terraces on a Public Forest. Municipal District of Alpuente, Valencia.

Figure (27). Restoration in terraces on highly sloped small surfaces, by filling with mine's own sterile material, to reduce visual impact on the A23 Highway. Municipal District of Jérica, Castellón.

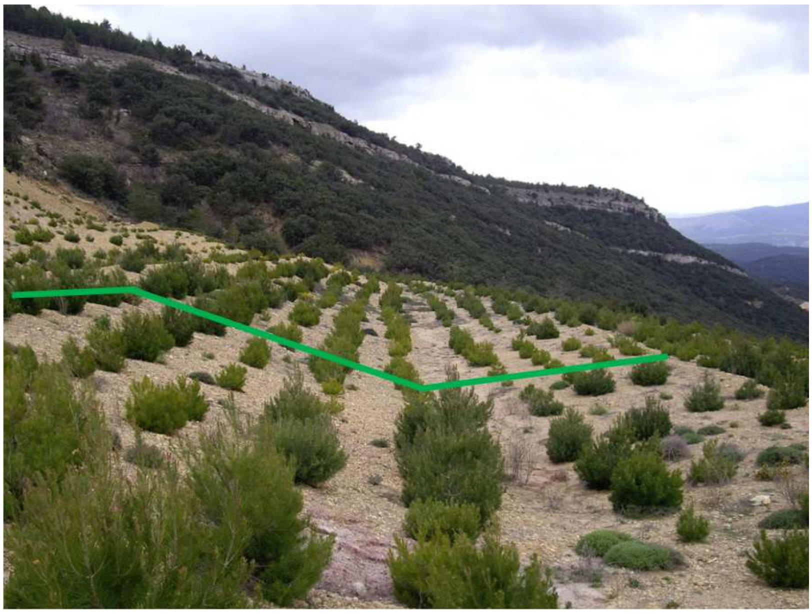

Figure (28) Counter slope benches with gravel mulch restoration. Municipal District of Alpuente, Valencia.

Figure (29). Restoration of slope-berm profile after operation of the mine with same configuration. Municipal District of Sagunto, Valencia.

Images show that most of the restorations meet the criteria of stability and mining safety.

Earth works reshape the original topography by diminishing the height and slopes of benches and creating new ones, filling them with sterile from the operation itself and create new geometric and rectilinear designs.

Slopes are re-shaped according to the following scheme, very common in restoration projects, where the final restoration line is represented in green as opposed to the red line of operation

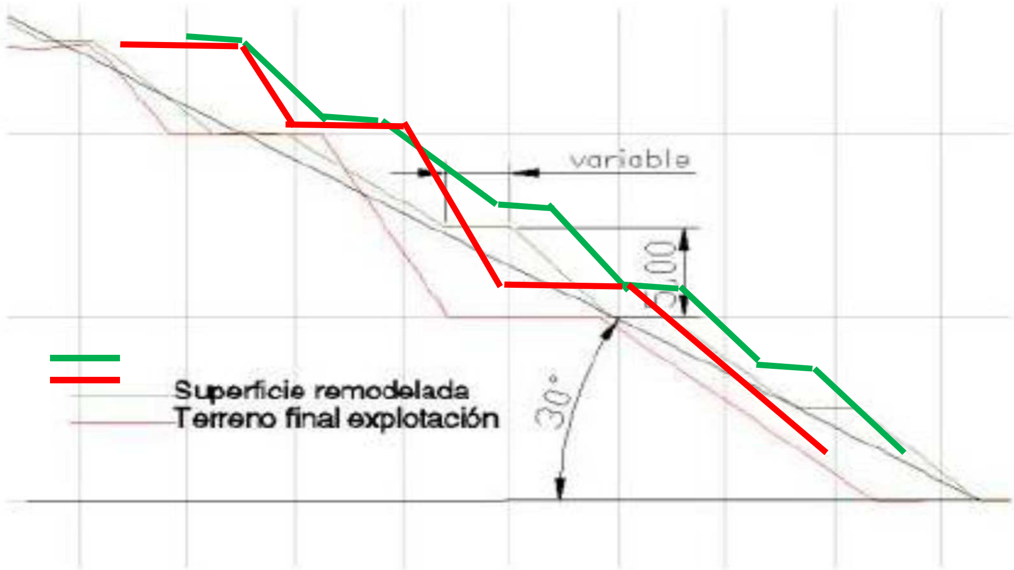

Figure (30). Slope-berm profile type in operation and restoration. Extracted from a Mining Restoration Plan.

d) **On Concealment of visual impacts**

Figure (31). Concealment of the marble deposit with waste dumps on existing accesses roads. Municipal District of Pinoso, Alicante.

In some cases, the height of the slopes may exceed 40 meters with a pyramid-like configuration that has its own erosive processes.

e) On the use of artificial elements (concrete, gunite, bolts, mesh, etc.)

Figure (32). Retaining net in limestone ridge. Municipal District of Alicante, Alicante.

Figure (33). Concrete and limestone channels in clay mine. Municipal District of Higueruelas, Valencia.

Figure (34). Rip-rap for retention of eroded limestone. Municipal District of Alpuente-Aras, Valencia.

Figure (35). Rip-rap terraces to retain sand. Municipal District Alpuente, Valencia.

Figure (36). Concrete ditches through the entire restoration. Municipal District of Andilla, Valencia.

Figure (37). Concrete sedimentation basin. Municipal District of Jérica, Castellón.

Figure (38). Trench with vegetable net placed as soon as the restoration is completed. Municipal District Higueruelas, Valencia.

Mining companies construct artificial works (trenches, sediment ponds, concrete structures, culverts) that involve a high cost and that hardly obtain the desired results of erosion control.

f) On unstable areas with geomorphological movements

Figure (39). Slope instability in clay mine. Municipal District of Higueruelas, Valencia.

Figure (40). Instability of limestone in clay mine. Municipal District of Alpuente-Aras, Valencia.

Figure (41). Limestone instability in clay mine. Municipal District of Alpuente. Valencia.

Figure (42). Instability and landslide in red clay mines. Municipal District of Andilla, Valencia.

Movements and instabilities in many rocky areas must be taken into account, especially on sandy and clayey materials, which are generated after visible cracks in the ground.

g) On the design of haul roads that favour erosive processes

Figure (43). Erosion on slopes and restoration accesses. Municipal District of Higueruelas, Valencia.

Road construction may boost erosion on the slopes. That is why the design of these accesses must be reviewed.

h) Failure or ditches plugging

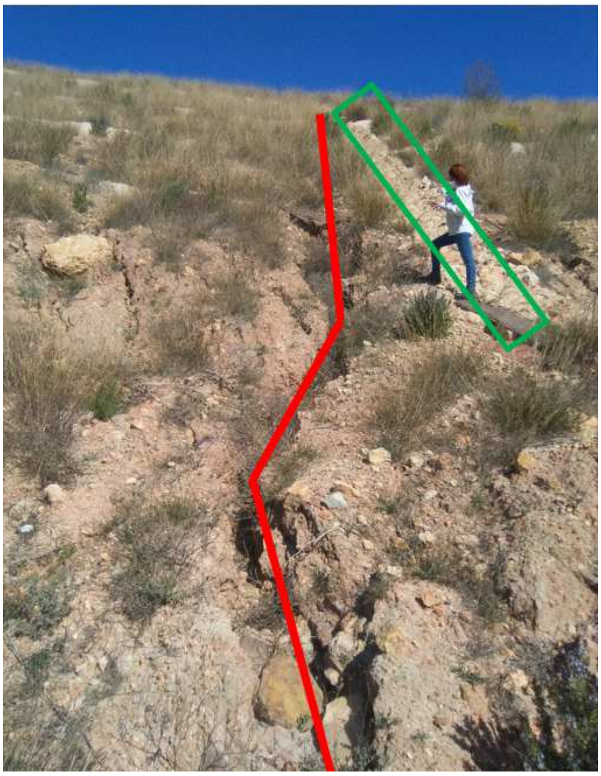

Figure (44). Projected ditches are shown in green colour. Actual line of water flow is showed in red colour. They usually do no match. Municipal District of Andilla, Valencia.

Figure (45). Erosion in areas different from those projected. Municipal District of Andilla, Valencia.

Figure (46). Concrete pipes on a local road. Scouring at the toe of the structure. Municipal District of Alpuente, Valencia.

Companies make designs with computer software that involve the execution of ditches and water outlets. Usually, after the restoration water follow other paths. This is because final topography is different from the projected topography. This causes unexpected sedimentation or toe erosion processes that may induce failures of slopes or structures.

Mining companies use many material and economic resources. However, they do not achieve the expected results in their final objectives neither they accomplish requirements proposed in projects presented to the public administration.

i) On problems in the substrates, which do not allow stabilization of vegetation

Figure (47).Fifteen (15) years after restoration works, slopes have not been revegetated. Municipal District of Andilla, Valencia.

Figure (48). Slopes and water impoundment. Seven (7) years after restoration works there is no vegetation. Municipal District of Losa del Obispo, Valencia.

Figure (49). Slopes in operation and slopes in restoration. Municipal District of Salem, Valencia.

Even after several years of restoration works slopes are not re-vegetated due to the height and angle of slopes, near 60º Vegetation stablishes only in flat terraces.

j) On landscape impacts

Figure (50). Landscape impact. Los Serranos County, Municipal District of Alpuente, Valencia.

Figure (51). Landscape impacts. Los Serranos County, Municipal District of Andilla-Higueruelas, Valencia.

Figure (52). Landscape impacts. Los Serranos County, Municipal District of Domeño, Valencia.

The above-mentioned problems are not unique in the Mediterranean region. It has a climate with heavy rains concentrated at certain times of the year. There are different zones and climates in Central or South America that have the same processes. **(J.F. Martín Duque and J.M. Nicolau, Valencia 2016 Jornada de restauración minera).**

Therefore, the concern for these processes led to a review in agencies and competent authorities at national and international levels.

An important milestone in mining restorations worldwide was the approval of the 1972 "Clean Water Act" in the USA, which prioritizes protecting water bodies by reducing offsite effects. This law reoriented the focus of the restorations, incorporating new topographic remodelling while minimizing sediment exports from mining areas to natural streams.

Based on the above, as J. Pedraza pointed out in 1996, it becomes essential to analyse and understand geomorphological dynamics based on the analysis of the terrain forms and the processes that originate them.

Substrate instability due to surface gravitational movements and water erosion, dramatically limits the possibilities for ecological restoration. There are currently examples of failures in restorations and linear infrastructures caused by geomorphological instability. **(Ecological restoration of areas affected by transport infrastructure. Chapter 2 - Geomorphological and Hydrological Considerations - Dr. José F. Martín Duque et al).**

Another important consideration is the effect of erosion that takes place in surface mines. Based on the International Erosion Control Association's approach (www. ieca.org) different authors (Fifield in 1996 and 2004, Evans 2000, Hancock et al 2000), have identified as key elements the following actions: calculate the volume of sediments that can reach the basin, calculate actual sediments and design actions for erosion control and sediment retention.

Works have been conducted to stop erosion on slopes with external elements, i.e. fascines to slow down the speed of the water. Experience shows that erosion has continued, causing sedimentation or failure of concrete structures.

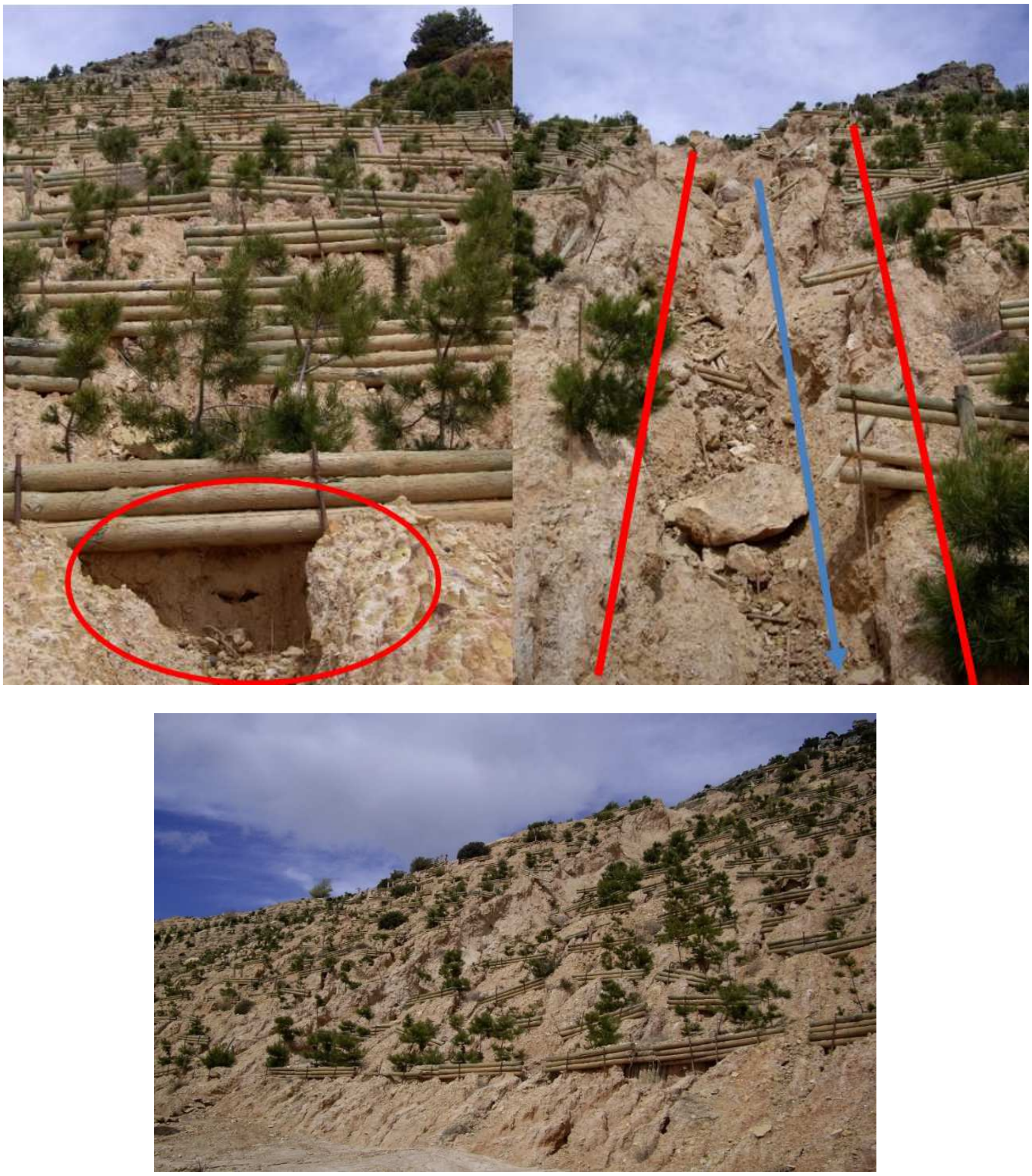

Figure (53). Fascines have failed to stop the erosion of the slope. Municipal District Alpuente, Valencia.

In the same way, another mining restoration was conducted with slopes more than 20 meters high and steep slopes. Few months after restoration, rains produced terraces failure like the ones showed in figure 53.

Figure (54). Fascines displaced by rain. Municipal District of Higueruelas, Valencia.

Not all the restorations have led to failures.

There are also many valid and desirable actions to reproduce, like the one in figure 55 where a rocky mulch over sterile has been able to maintain vegetation and moisture

Figure (55). Revegetation on rocky mulch in the upper area of the restoration. Municipal District of Andilla, Valencia.

Figure (56). New sprouts on rocky mulch. Municipal District of Higueruelas, Valencia.

Drip irrigation and organic aids (such as mud) has favoured the implantation of vegetation on a batter/berm morphology.

Figure (57). New sprouts. Municipal District of Sagunto, Valencia.

Figure (58). Drip irrigation of vegetation at toe of the slope. Municipal District Alicante, Alicante.

There are successful bioengineering techniques able to retain unconsolidated sandy or gravel materials in high slopes:

Figure (59). Bioengineering techniques used on the slope. Municipal District of Jérica, Castellón.

After several years of restoration work, the use of bioengineering has made it possible to control erosion and the establishment of vegetation.

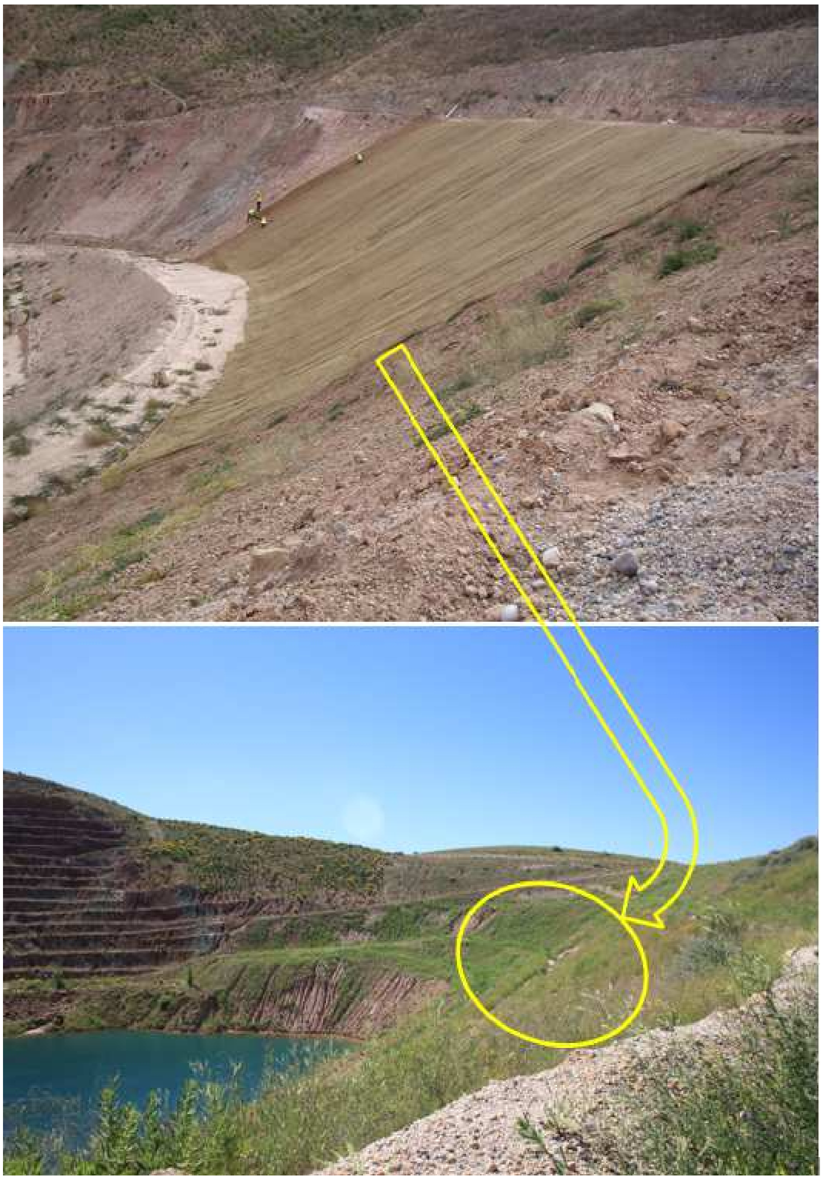

Figure (60). Bioengineering in slopes. Municipal District Higueruelas, Valencia.

In view of the above, we must ask ourselves what can be done? What techniques, tools and software do we have?

Not all restoration experiences have failed. Some of the successful ones have incorporated elements of bioengineering or substrates. In the future, it will be crucial to favour hydrological processes taking into account the climate of the area and the nature of the substrates. To do this, it is vital to observe the nature of the water cycle in hydrological basins and their capacity to evacuate both normal and extraordinary flows, without the need for artificial elements, like berms, ditches or downspouts

A suitable geomorphological restoration is essential, where ecological processes are encouraged and activated. **(JF Martín Duque and JM Nicolau Ibarra - Conference on mining restoration. Valencia 2016).**

Replication of natural systems reduces the risk of accelerated erosion and enables self-healing erosion control system. (**Geomorphic approach for design of sustainable drainage systems for mine land reclamation -Sawatsky & Beckstead 1996)**

In the design of future restorations, it is essential to obtain a wise management of runoff. The introduction of non-naturalized elements (concretes, bolts, meshes) should be avoided. A better integration in the landscape should be sought -avoiding geometric designs like straight sides, rectangular and bevelled angles- trying to recreate the natural shapes of the surrounding landscape.

On this topographic design, we will be able to carry out the different actions that allow us to properly handle the substrates and enable adequate designs and subsequent revegetation.

It is necessary to use erosion calculation tools (USLE, RUSLE, Number of Curve, etc.) and know how to dimension the sediment control structures. We will have to provide our mining restoration design with a long-term stable relief, estimate the transmission of sediment to natural basins and streams using predictive models and assess changes in water quality.

The vast majority of the restorations carried out to date, base their new topography on the reshaping of the operating profile, converting it again into a batter/berm profile with smaller angle and heights. In addition, ditches are always planned for surface water drainage and access roads to the areas of the exploited void, storage and installations. It is very common to find pyramid-like creations in final dumps, some have great height and even if they do not seek to cover a lot of surface. They affect large areas, for example in marble, the unsaleable material can reach more than 90% of the deposit. In all cases, the problems described are maintained, generating immature topographies, with high rates of erosion and low retention capacity substrates and low water supply to revegetation. (**J.F. Martín Duque UCM y J.M. Nicolau Ibarra UZAR – Jornada sobre restauración minera. Valencia 2016**).

Since companies are consuming their resources without the desired results, there are few rules to consider in future designs. First thing to do is to avoid the concentration of runoff and to prevent it from entering through the top of the slopes, the main cause of rills and gullies creation, and prevent head ward erosion. It is necessary to provide a certain concavity to the slopes and make a good study of the roads to prevent them from accelerating erosive processes.

Substrates will also help us manage water, especially by increasing rough surfaces. Wright et al, -USA, 1978- already pointed out that the practice of building slopes with a "smooth" appearance, giving the impression of a "good finish" was fatal for installation of vegetation, being the roughest surfaces, with less attractive appearance, those that favour water infiltration, decrease water flow in the drainage network and allows vegetation settlement.

Evans & Hancock, proposed in the a document, called "Landform Design for Rehabilitation" * Department of the Environment of Australia's 1998, that it would be desirable to develop practical and efficient approaches to nature, using "best available techniques", creating a topographic design in restorations as a flexible vision and part of a whole, as a direct part of mining operations.

The final restoration involves possible changes in the design of the exploitation and surfaces affected by dumps.

Earthworks constitute 90% of the cost of restoration so it is important to minimise these movements by supporting us with computer tools that allow integration into the surrounding landscape.

This document proposes new geomorphological solutions where it is essential to consider the following topics;

1. Rebuild the drainage network in the new topographic conformation
2. Define the baseline level, avoiding the risk of erosion and sedimentation downstream
3. That the longitudinal general profile of the fluvial network is concave
4. Designing concave-convex slopes
5. Visual integration into the landscape
6. Ecological connectivity
7. To relate elements of the exploitation (ramps, roads, accesses, dumps) with the future restoration
8. Wetlands
9. Replication of natural forms (mountains, valleys, slopes, etc.)

There are usually rock fronts in clay and sand mines, with great differences in height, and which make us review other methodologies such as integration with maximum stability in rocky cut slopes.

These precepts are already being used mainly on road slopes in France. The Talus Royal method (Paul Royal - www.geniegeologique.fr) can achieve maximum stability through the "printing" of cut slopes already evolved within the landscape creating an attractive naturalized polychromy. It allows us to identify the discontinuities of the rocky massifs and their instability, to understand this unstable pattern, to know the erosive and evolutionary response and to incorporate the response to the final design. **(Ecological restoration of areas affected by transport infrastructure. (Chapter 2 -Geomorphological and Hydrological Considerations - Dr. José F. Martín Duque et al)**

Figure (61). Talus Royal on the road. France.

Figure (62). Rock instabilities. Municipal District of Enguera, Valencia.

Mine site rehabilitation is becoming more sophisticated, through improved knowledge as well as advances in technology. Computer-based landscape evolution and soil erosion models are tools that can greatly assist mine rehabilitation. **(Hancock & Willgoose – Sustainable mine rehabilitation. 25 years of the SIBERIA landform evolution and long–term erosion model)**

Software is usually used with designs of regular and geometric shapes, far away from the existing geographical features. Programs such as MDT, INROADS, Autodesk CIVIL on CAD platforms are widely known for topographical work, but there are other more specifically mining programs such as Carlson Surface Mining, Vulcan, Surpac, Gemcom, Mincon, Geovia, among others.

Programs for hydrological evaluation such as SEDCAD, Rivermorph, RUSLE or HEC-HMS, allow to obtain hydrological evaluation models

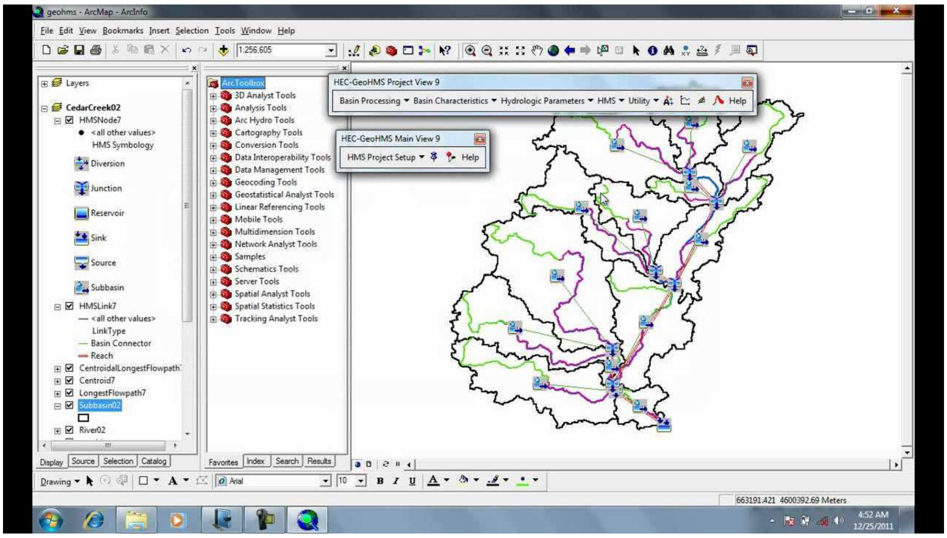

Figure (63). Software HEC-HMS

Computer-based landscape evolution and soil erosion models are tools that can greatly assist mine rehabilitation.

Siberia (http://www.telluricresearch.com/) allows us to analyse the evolution of geomorphology and erosion over long periods, and has been used in the Australian mining industry for over 25 years.

By observing the evolution of landscape and erosion, we will obtain a predictive model, which helps the Australian administration to analyse the final restoration. (Hancock & Willgoose - Sustainable mine rehabilitation. 25 years of the SIBERIA landform evolution and long-term erosion model).

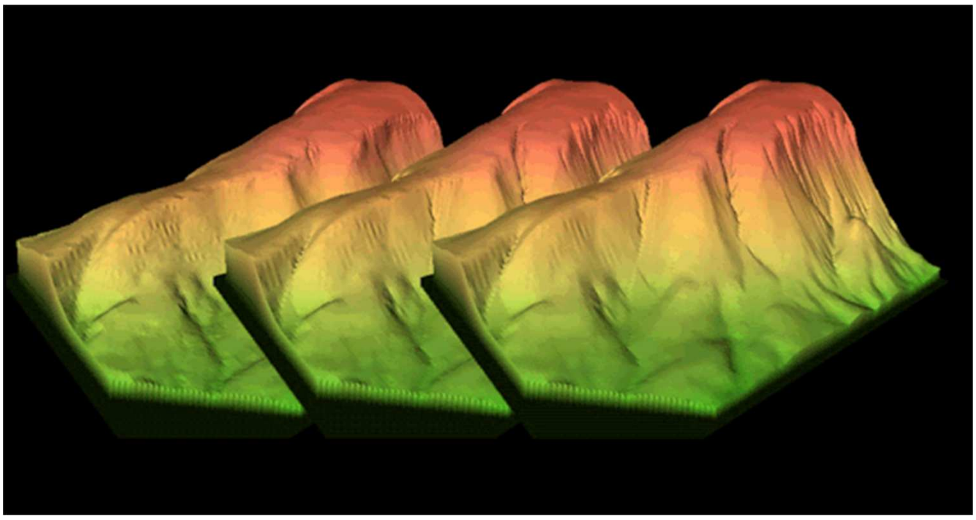

Figure (64). Simulation of Siberia Telluric Research

Special mention should be made of the solution created by Nicholas Bugosh (www.geofluv.com), with his method called GEOFLUV, implemented in the NATURAL REGRADE software (http://www.carlsonsw.com/solutions/mining-solutions/natural-regrade/), which is marketed by CARLSON Many of the criteria described above are met, allowing the reconstruction of the drainage network, defining the base level and the overall longitudinal concave longitudinal profile. It also helps us to design concave-convex slopes replicating the natural forms of the environment.

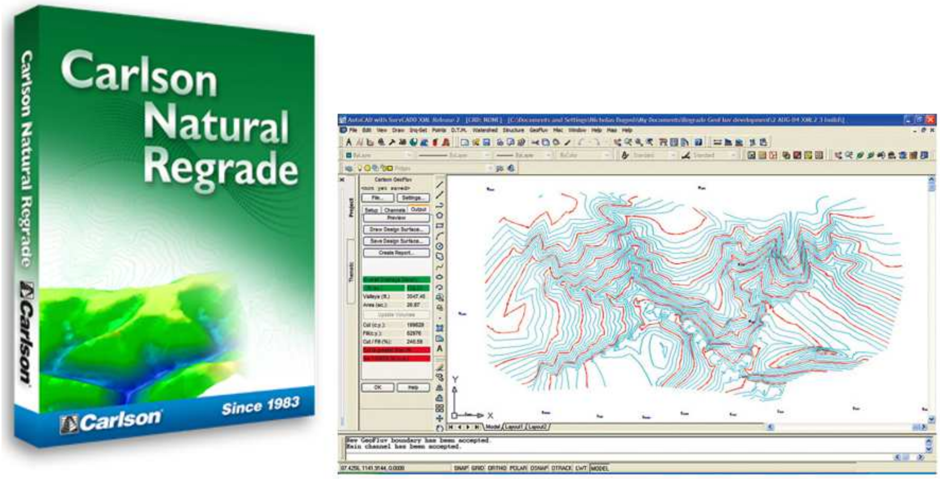

Figure (65). Software Natural Regrade.

Hence, Geofluv is a fluvial geomorphic method for land reclamation, which allows designing the landforms to which the land would naturally evolute under actual climatic and physiographic conditions at the site. The resulting slopes and stream channels have long-term stability because they are in balance with the local conditions, and are a reclamation alternative to traditional uniform slopes with terrace and concrete ditches and culverts. (**The Geofluv Method for Mining Reclamation: Why and how it is applicable to Clouser Plans in Chile – Bugosh, Martín-Duque, Eckels -2016**).

The procedure includes:

- Finding a suitable reference area with stable landforms and acquiring inputs from them
- Designing two first-order stream watersheds
- Building the planned landscape
- Monitoring the hydrological and erosive–sedimentary response of the reclaimed watersheds.

This process is in itself a contribution to global advancement of reclamation best practices, because there are very few geomorphic-based mining reclamation examples, and even fewer that include their multiannual (**Geomorphic reclamation for reestablishment of landform stability at a watershed scale in mine sites: The Alto Tajo Natural Park, Spain – Zapico, Bugosh, Martín-Duque, Laronne, Ortega, Molina, Martín-Moreno, Nicolau, Sánchez-Castillo**).

With this method we can simultaneously obtain different benefits from economic and social, to aesthetic and ecological, allowing the greatest possible sustainability.- **(The Remodelling of the land in the ecological restoration of the space affected by mining activities: from the use of**

geomorphological criteria to the Geofluv - N. Bugosh, J Fco Martín-Duque- Ponferrada method. Leon. May 2012).

We can conclude that there are currently partial approximations of geomorphology, through forecasts or predictions of erosion, also through CAD drawings such as Geofluv-Natural Regrade. However, it does not seem enough to cover every topic. We will have to combine and add designs for areas with a great difference in height and others for the escarpments or rock banks very common in the Valencian geology.

The final objective will be to know, use and integrate the different computer tools and calculation systems, in an appropriate way that covers all the aspects mentioned above, as opposed to the traditional geometric-linear geomorphology.

There are currently several examples in different countries, such as USA, Australia and Spain, but none in Valencia Region, which will be mentioned in the case studies of this document.

It is interesting to follow and review the new approaches proposed in geomorphological restoration, comparing them with the examples of restoration that have been partially or totally produced in more than 80 locations in the Region of Valencia, as shown in figure 65.

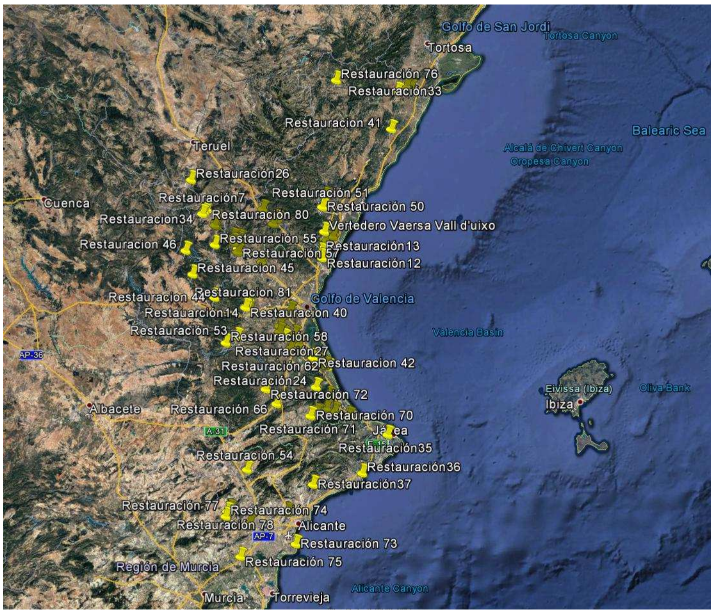

Figure (66). Total or partial restorations locations in the Valencia Region

VEGETATION RESTORATION

Back in 1989, López Jimeno et al. described in their "Manual de Restauración de Terrenos y Evaluación de Impactos Ambientales en minería" -Guidelines for land restoration and environmental impacts evaluation in mining - the "conventional techniques" used in restoration of land affected by mining works.

Relating to these traditional techniques that are still in use, the new approach of technical and scientific studies is based on the ecological knowledge of emerging ecosystems, whose functioning is little known at present (Valladares y Gianoli 2007).

According to Temperton et al. (2004), the knowledge of rules that control colonisation, assembly of species and succession of communities in slopes will allow to extract useful conclusions and to draw general guidelines for restoration of these degraded ecosystems. Ultimately, the colonization of an area and the resultant community of plants depends upon three main groups of factors: a) seeds availability, b) environmental conditions and c) plant-to-plant interactions, known in turn as the three great "ecological filters" that determine the assembly rules of species

According to studies conducted by Keddy (1992), Weiher and Keddy (1999), only those species that belong to the group or pool of local species capable to go through a series of filters will be able to establish themselves successfully. The size of the local pool is progressively reduced to a subset of species of the original pool according to its ability to reach the zone by means of scattering (dispersal filter), to adapt to environmental conditions (abiotic factors filter) and to compete with the other settled plants (biotic interactions filter).

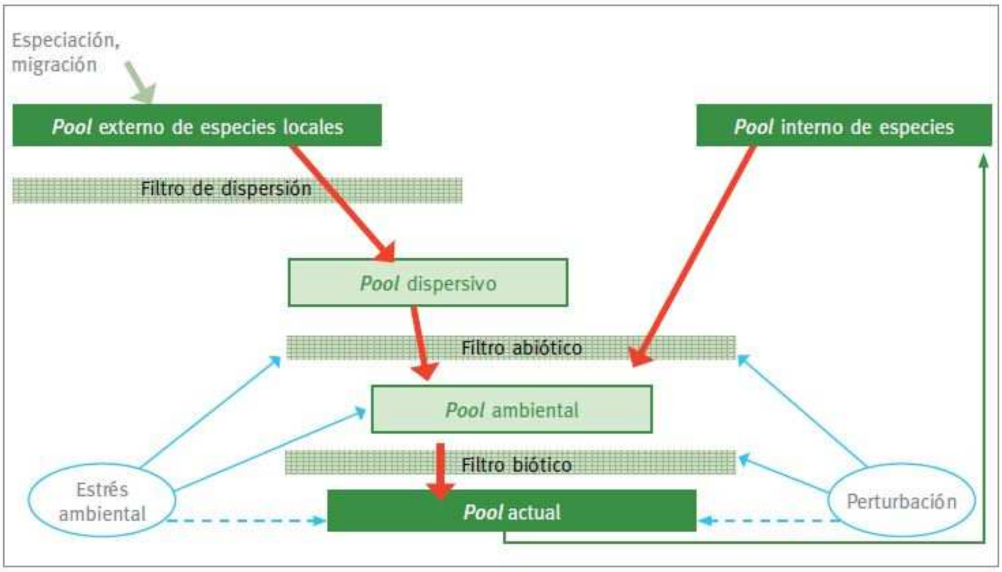

Figure (67). Dynamic model of filters that control the process of species assembly in a plant community. Modified from Fattorini and Halle (2004).

The intensity and relative influence of the filters changes throughout the succession, while geographic dispersion and abiotic factors have a greater weight in early stages of the succession, plant-to-plant interactions acquire higher importance in later stages (Fattorini and Halle 2004; Figure 67).

Current research suggests that effective actions or restoration measures based on the conscious manipulation of ecological filters can be proposed in order to accelerate or direct the process of plant colonization. It is not always necessary to intervene in the restoration process, however, the poor abiotic conditions of the slopes prevent, in most cases, a passive restoration, since the climatic, topographical, ecological and soil conditions are very unfavourable.

Based on the results obtained by several research groups, following are different types of actions, to counteract the effect of the filters, favouring the entry and establishment of the plants :

a) *Seeds availability*

The presence of areas of natural vegetation near slopes that act as seed sources can help to mitigate the effects of the dispersal filter, since it favours the spontaneous entry of species from the surrounding vegetation and accelerates the processes of colonisation on the slope. The closer the slopes are to the surrounding vegetation matrix, the greater the arrival and availability of seeds on the slope.

Bochet et al. (2007) recommend that during the implementation of linear restoration works, a natural vegetation band of at least 20 m width at the head or foot of the slopes should be maintained as far as possible, as it contributes to improving the results of active restoration projects by accelerating the colonisation process. In the absence of natural vegetation, other measures such as the addition of topsoil or hydroseeding may be applied.

b) *Soil improvement and seed bank.*

Abiotic limitations can be overcome by the application of mulches (Brofas y Varelides 2000), fertilisers (Petersen et al. 2004), organic amendments,(de Ona y Osorio 2006) or topsoil (Balaguer 2002).

The topsoil has the function of mitigating the poor abiotic conditions of the soil due to its higher content of organic matter and microorganisms and provides the slope with seeds through the natural seed bank contained in the soil. A large number of studies in very diverse environments, such as Tormo et al. (2007) obtained on the slopes of the N-330 in Utiel (Valencia) that, during at least the first two years, the vegetation cover on slopes where topsoil was provided was higher than on control slopes without topsoil added. It took three years for untreated plots to reach average plant cover values equivalent to those recorded in the first year in plots with topsoil.

However, in this region with severe climatic conditions, the vegetation cover achieved in the first year after the application of topsoil (35%) is not enough to ensure efficient erosion control in the event of heavy rains (Gyssels et al. 2005; Brochet et al. 2010a).

According to Balaguer (2002), the success of the application of topsoil can be very variable depending on its handling during the removing, stockpiling and spreading out operations.

Mola et al. (2011) demonstrate that, with actual topsoil management practices, the contribution of seeds to slopes through the natural seed bank contained in topsoil is low.

On the other side, according to Traba et al. (2006), it is confirmed that in different ecosystems of acidic Mediterranean environments, most of the viable seeds are found in the first 5 cm of soil depth. Other studies in desert ecosystems or mining quarries support these observations, pointing out that 80-90% of viable seeds are found in the topsoil, that is to say, in the first 2 cm (Tacey and Glossop 1980; Kemp 1989).

In addition, research indicates that soil thickness influences seed germination, with an optimal depth of 2 cm or less (Andrade et al. 1997; Torma and Hodi 2000; Traba et al.2004). These studies show that excessive soil thicknesses of more than 10 cm can even inhibit the germination of seeds or the emergence of sprouts.

In short, and in conclusion, these data indicate that, in order to achieve optimum performance of the seed bank in the topsoil, superficial removal of the soil to be cleared (first 5 cm, instead of 20-25 cm recommended by projects) should be carried out at the end of the summer and before the first rains. In addition, a very shallow layer of topsoil should be applied (5 cm instead of 30-35 cm recommended usually by projects). However, appropriate machinery is needed to ensure the removal of this thin layer of topsoil.

c) *Selection of species adapted to the conditions of the area to restore.*

Unfortunately, the species selected for hydroseeding are usually limited to a small number of species available on the market (commercial species), and are recommended indiscriminately for any geographical, soil or climatic scenario (Balaguer 2002).

On the other hand, one of the common mistakes is the use of native species in hydroseeding, regardless of their ability to adapt to abiotic conditions on slopes. In this sense, the term 'native species' should refer to those species that are native but associated with environments and ecological conditions similar to those of the slopes, and not to forest formations or those at the highest level of development characteristic of the region.

However, the success of hydroseeding depends largely on an appropriate selection of the species to be sown.

As an alternative to these problems, Paschke et al. (2000); Prach (2003); Tinsley et al. (2006) propose the use of local species, after being tested in different environments by experimental sowing, that are better established than the commercial species used in standard mixtures. However, the theory of ecological filters ensure that the use of 'local' species (from the external local pool) does not always guarantee the success of revegetation as experienced by Tormo et al. in 2006.

Therefore, Bochet et al. (2010b) propose a species selection methodology, based on the idea that those species capable of spontaneously and abundantly colonising slopes are suitable species, that they are adapted to the local conditions of the slopes and that ,therefore, present certain guarantee of success for the revegetation of these slopes.

The selection process is divided into two phases. First, the identification through floristic inventories of the species that successfully colonize the slopes and, secondly, the validation of the selection process through small-scale experimental sowing with the identified species. This second phase is also important to rule out competition problems between species selected for blending (Matesanz and Valladares 2007).

Applying this method to slopes in the Requena-Utiel region, Bochet et al.(2010b) identified 41 of the species in the external local pool as being capable of spontaneously and successfully colonising at least one of the four types of slopes studied (northern fill , southern fill, , northern cut, southern cut). In the validation phase, hydroseeding on N-330 embankments (Utiel, Valencia) demonstrated increased vegetation establishment with a mixture of seeds of species selected from that list of 41 species 'successful colonizers' compared to a mixture of seeds of commercial species commonly used in this region for slope revegetation (NTJ 08H 1996).

The vegetation cover densities were 4 to 15 times higher, for at least the first four years, for the mixture of local species selected with this method.

Clearly, this method ensures the success of the species selected only for ecological conditions and habitat type similar to those of the areas inventoried. However, since species are capable of overcoming filters due to their functional characteristics, the identification of functional traits associated with the success of slope colonizing species could be useful for the development of effective technical criteria for species selection in a wide range of environmental conditions (Cano and Montalvo 2003; Karim and Malik 2008).

For example, Cano and Montalvo in 2003 proposed an integrated categorization of the plants of the communities of cut slopes of granitic substrates in the province of Pontevedra, Spain, including an evaluation of the aptitudes of the types found for erosion control.

The results of the assessment show seven different types of plants, which are discriminated based on their attributes related to environmental suitability, aerial protection, underground protection, persistence and aesthetic value.

This classification system shows that 96% of the species that colonize cut slopes are low demanding in terms of nutrients and have good protective skills against erosion (high surface protection and rapid horizontal growth). However, 48% of the species recommended for the restoration of these environments have a low to very low overall protective value, either because they are not adapted to the general conditions of the slopes or because they do not provide enough surface protection

These results and the low percentage of common species (13%) between spontaneous and recommended colonising species suggest poor knowledge of adapted species, limited commercial availability and inadequate selection criteria.

ESPECIES	DISPERSIÓN	DS	DN	TS	TN
Alyssum simplex	Barócora	+	+	+	+
Anacyclus clavatus	Balística	+	+	+	+
Avena barbata	Anemócora	+	+	+	+
Bromus rubens	Anemócora	+	+	+	+
Centaurea aspera	Zoócora	+	+	+	+
Cichorium intybus	Balística	+	+	+	+
Convolvulus arvensis	Barócora	+	+	+	+
Diplotaxis erucoides	Barócora	+	+	+	+
Euphorbia serrata	Mirmecócora	+	+	+	+
Hordeum murinum subsp. leporinum	Anemócora	+	+	+	+
Sonchus oleraceus	Anemócora	+	+	+	+
Scabiosa simplex	Anemócora	+	+	+	+
Bromus tectorum	Anemócora		+	+	+
Crepis vesicaria	Anemócora		+	+	+
Erodium cicutarium	Barócora		+	+	+
Calendula arvensis	Zoócora			+	+
Carduus pycnocephalus	Anemócora			+	+
Filago pyramidata	Anemócora			+	+
Medicago minima	Zoócora			+	+
Plantago albicans	Barócora			+	+
Scorzonera laciniata	Anemócora		+		+
Silene nocturna	Balística		+		+
Reseda phyteuma	Balística	+		+	
Pallenis spinosa	Anemócora	+		+	
Eryngium campestre	Anemócora	+	+		
Carthamus lanatus	Anemócora				+
Crepis foetida	Anemócora				+

ESPECIES	DISPERSIÓN	DS	DN	TS	TN
Foeniculum vulgare subsp. piperitum	Barócora				+
Linaria simplex	Balística				+
Papaver rhoeas	Balística				+
Senecio gallicus	Anemócora				+
Senecio vulgaris	Anemócora				+
Avena sterilis	Anemócora			+	
Erodium ciconium	Barócora			+	
Erodium malacoides	Barócora			+	
Hirschfeldia incana	Barócora			+	
Reseda undata	Barócora			+	
Aegilops geniculata	Zoócora		+		
Aegilops triuncialis	Zoócora		+		
Genista scorpius	Barócora	+			
Santolina chamaecyparissus subsp. squarrosa	Balística	+			

DN: desmonte norte, DS: desmonte sur, TN: terraplén norte, TS: terraplén sur. Mecanismos de dispersión: anemócora: por el viento; barócora: por la gravedad; zoócora: por los animales, excepto por las hormigas; mirmecócoras: por las hormigas; balísticas: por 'catapulta'. Modificado a partir de Bochet *et al.*, 2010b.

Table 1. List of species and their respective dispersion mechanisms, which spontaneously and abundantly colonise the different types of slopes of the A3 motorway between the towns of El Rebollar and Venta del Moro (Valencia). This area is characterized by a semi-arid continental climate and a limestone loam substrate

c) Study and analysis of plant-to-plant interactions for restoration.

According to Maestre et al. (2001), herbaceous species, initially promoted in restoration for their rapid growth and potential to prevent erosion, could facilitate the establishment of woody species, or even other herbaceous species, leading to increased diversity and coverage of slope communities. However, herb-herb interactions in these environments are completely unknown, and the few studies on herb-woody interactions suggest that competition is more important than the facilitating facet in these environments (Soliveres et al).

d) Dichotomous key for decision-making.

Matesanz et al. (2006) creates a useful tool, in the form of a dichotomous key, to assist in decision making for the restoration of road slopes. The key identifies five main criteria for decision-making (climate, soil, type, slope slope and proximity of natural vegetation zones).

Based on the studies of Valladares et al, 2004 and Bochet et al, 2010, one of the greatest challenges for the future is the restoration of cut slopes with steep slopes (>27º and above all >45º), in which spreading of topsoil is very difficult and the application of hydroseeding is not successful. The success of the restoration of these slopes depends on making changes in the macrotopography, reducing the slope inclination, morphology and length of the slopes, or in the microtopography, increasing the roughness of the soil and creating areas of less compaction, before any complementary restoration measures are applied to facilitate the establishment of vegetation.

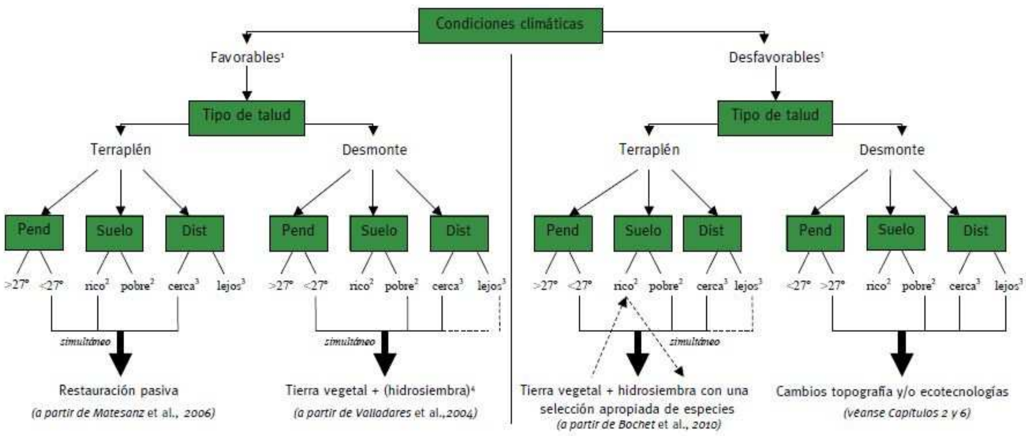

Figura 22. Clave dicotómica para la toma de decisiones en la restauración de taludes de carretera. Los criterios a tener en cuenta aparecen en los recuadros verdes: condiciones climáticas, tipo de talud, ángulo de la pendiente (Pend), condiciones del suelo (Suelo), y distancia a la vegetación natural circundante (Dist). Las líneas punteadas derivan de extrapolaciones indirectas.

1 Umbral de condiciones climáticas 'favorables/desfavorables': las condiciones climáticas son desfavorables a partir del momento en que existe un periodo largo en el que el crecimiento vegetativo no es posible o está fuertemente limitado por la sequía. Este punto crítico se da cuando hay más de tres meses seguidos de sequía o cuando la precipitación media anual es inferior o igual a 350 mm (en la Península Ibérica, condiciones de ombroclima semiárido o árido según Rivas Martínez 1983).

2 Umbral de suelo 'rico/pobre': un suelo es considerado pobre a partir del momento en que los 10 cm de tierra del talud que quedan expuestos a soportar la colonización vegetal están compuestos de tierra mineral que nunca ha estado expuesta a meteorización previamente (material litológico puro o tierra proveniente de horizontes de suelo no superficiales) o si existe una limitación edáfica especial (salinidad, contaminación, etc.).

3 Umbral de distancia del talud a la flora natural 'cercana/lejana': la vegetación natural se considera cercana en un intervalo de entre 0 m y mínimo 150 m desde el talud. Estos resultados se basan en el trabajo de Bochet *et al.* (2007a) en el que los autores no encuentran una limitación importante a la colonización por falta de propágalos en un intervalo 0 a 150 m desde el talud, aunque sí encuentran una segregación de las especies de acuerdo con su mecanismo de dispersión, viéndose favorecidas aquellas especies que se dispersan a larga distancia.

4 Valladares *et al.* (2004) consiguen buenos resultados con este tratamiento combinado de tierra vegetal + hidrosiembra. No obstante, podría ser que el único tratamiento de extendido de tierra vegetal fuese suficiente (y la hidrosiembra innecesaria) para alcanzar resultados similares.

As general conclusions and based on different studies based on the scientific method, effective restoration measures based on the manipulation of these filters have been proposed for different climatic, topographical, edaphic and landscape scenarios.

Before making any decision on a restoration project, and whenever possible, it is advisable to carry out a study of the environmental variables that condition the area to be restored (climate, soil, topography, flora, proximity to natural vegetation, etc.). This prospecting will make it possible to guide the choice of the most appropriate measures and to guarantee their viability and profitability in terms of cost/benefit.

However, although intervention is not always necessary, any action that favours spontaneous processes of colonisation, regeneration and succession will lead to more sustainable ecosystems in the long term.

Conventional techniques for spreading over topsoil and/or hydroseeding can provide satisfactory results if their performance is optimised by appropriate topsoil management and/or appropriate selection of the species.

Finally, revegetation of steep slopes remains a major challenge for the future. There is also a need for greater knowledge of the evolution of slope communities in the medium and long term.

SOIL QUALITY

In every process of quarry recovery and especially in the dry Mediterranean, there must be a balance between the development of vegetation cover and the ability of the substrate to support it during critical periods. This balance must be established within the short and long-term objectives. These interactions must therefore be taken into account in the design of the restoration, which are particularly important in the Mediterranean basin because of limited water availability and high risk of erosion in autumn (Josa et al 2012).

Lei et al (2016) analyse the main environmental problems in mining areas such as air pollution, water acidification, reduction of soil quality, loss of biodiversity and destruction of the landscape. They suggest the use of a 'natural' landscape and technology strategy in the ecological restoration of the mine. This is known as ‘ecological engineering’ (Kalin, 2004). This discipline aims to apply knowledge of natural biological systems to achieve human (industrial) objectives in a self-sustaining natural environment. Being effective in the long term, as it provides a balance of natural and human values. Restoration strategies that stimulate biotic interactions and promote internal control of ecosystem processes will be most beneficial in the practice of long-term restoration. (Li & Heutschi, 2011).

Mining soils have been degraded by industrial activity. A a feature of degradation is the lack of organic matter compared to adjacent natural areas (Larney & Angers, 2012).

Various techniques are used in order to restore soil quality. They that have been widely studied and next are reviewed in this work in order to obtain recommendations that may be useful for the development of the project. The techniques used are:

- Implementation of organic amendments
- Irrigation application
- Revegetation

Organic amendments have been proved ideal for accelerating soil regeneration processes. In this sense, Larney & Angers (2011) have carried out a study in the province of Quebec (Canada) in which they analyze how organic amendments affect the physical, chemical and biological properties of soil, focusing their study on how the type of organic amendment, as well as its application rates, improve soil and biomass production.

Organic amendments include livestock manure, bio-solids, waste products from pulp and paper mills, wood residues and crop residues. All these wastes are produced in abundance and can be widely used in soil restoration. With world's population steadily increasing, there will be a surplus of organic amendments available as the demand for food, fuel, fibre, urban bio-solids or manure from intensive livestock farming increases. There is also a rise in degraded soils that may act as receptors of these materials and are the ones that benefit most from improving soil quality.

These authors propose future research on the role of organic amendments in the restoration of degraded lands as a first step towards the recovery of a self-sustaining ecosystem in the long term. They propose the following lines of research:

- Compensations between high rates of organic amendments vs. low rates of repeated organic amendments over several years.
- Soil overload with nutrients or contaminants, especially in relation to water quality.
- Study of nutrient dynamics, such as phosphorus release and immobilization.
- Mechanisms of soil genesis after the incorporation of organic amendments, such as the creation of organo-mineral complexes.
- Economic analyses on the long-range transport of organic amendments for restoration purposes.
- Life cycle analysis, carbon footprints and global impacts on greenhouse gas emissions from the use of organic amendments in restoration.

Jorba et al (2008) have evaluated the effect of compost and irrigation on the erosion rates, vegetation cover and response of woody sprouts in a limestone quarry in the Garraf Massif (Barcelona, Spain). They discuss the effect of the introduction of woody species on diversity, as well as the role they play as a dispersal nucleus and their subsequent expansion.

They start from the premise that in the revegetation of quarries, the use of species best adapted to drought, both climatic and edaphic, should be considered, as their water requirements are lower and do not compromise natural colonization (Josa et al 2012).

From their study, they conclude that the use of organic amendments and irrigation increases the grassland cover, which has a positive effect from a "fast" green integration point of view that determines the reduction of erosion. However, if grassland cover is dense, it can compromise the establishment of key components of the reference ecosystems because the composition and structure is very different from the natural environment.

These authors recommend establishing a design of alternative or complementary actions, other than the extensive use of organic amendments, such as establishing periodic brushings to control the development of grasses in tree micro-basins, an alternative to make grasses and ligneous plants compatible (Chaney et al. 1995; Casselman et al. 2006). As well as a more localised application of irrigation to avoid excessive herbaceous growth, for example, drip irrigation in plantations.

Oliveira et al (2011) demonstrated, in a limestone quarry in SW Portugal (Serra da Arrabida), the problem of soil loss in Mediterranean quarries and showed that a low quality substrate is often unsuitable for revegetation since it limits the establishment of plants that are also subject to recurrent drought stress. They applied substrate improvements with the addition of NPK fertilizers, water-retaining polymers, mycorrhizal inoculums and combinations of these, to three species of plants *Ceratonia siliqua*, *Olea europaea var sylvestris* and *Pistacia lentiscus* three years old. Its growth was evaluated for 8 years.

The results obtained show that low availability of nutrients is one of the main restrictions for the growth of the species. The addition of fertilizer significantly improved plant survival in the short term. However, when assessing the long-term effects, this effect is limited and it is difficult to justify its application due to the economic and environmental costs of its implementation.

On the other hand, the species studied have a high survival capacity and show that they are suitable for revegetation as long as the conditions are similar. However, they recommend that research be carried out with other native species to help improve the quality of restorations in Mediterranean environments.

Due to the monitoring carried out, it has been shown that the slight short-term beneficial effects of some of the treatments tested do not have any major advantages for the plants. They keep the door open to the evaluation and/or study of the possible benefits obtained by reducing the costs with the application of mycorrhizal inoculum or hydrogel in a limestone quarry in a Mediterranean environment.

Luna et al (2016) carried out a restoration experiment in limestone quarries in the Sierra de Gádor (in the province of Almería, Spain), taking as a premise that one of the starting conditions for the recovery of ecosystems is the development of soils with enough organic matter content to be functional. They used as a reference of soil quality, those adjacent to the area to be restored.

In their study they wanted to test the effect of two factors; organic and mulch amendments, and on each factor, three levels. For organic amendments, three levels were considered: (a) thermally dried sewage sludge from urban waste water (b) urban sewage sludge; and (c) with no treatment. In addition, for mulch the levels considered were a) mulch of fine silica gravel from a nearby quarry; b) wood shavings mulch from *Pinus halepensis* and c) no mulch.

This study provides a snapshot of the microbiological and biochemical properties of soil five years after the start of the restoration process, confirming the benefits of low-cost restoration strategies, such as the addition of organic amendments (compost and sewage sludge) and mulch (gravel and wood chips), in quarries in semi-arid climates. Organic amendments combined or not combined with mulch improved soil functionality and microbial biomass, especially compost treatments that showed the values closest to those of the reference soils. However, increases in soil functionality and microbial biomass cannot be associated with changes in microbial diversity. In addition, the bacterial and fungal communities were different in each of the treatments and in the reference soils.

Despite the fact that the advantages of the application of these amendments have been proved, the results indicate that five years after restoration are still not enough to find a correlation between the composition and functionality of the microbiological communities in the restored areas and the reference soils. More studies are needed to draw rigorous conclusions. Above all, because communities are severely affected by environmental changes and climate fluctuations (Fierer and Jackson, 2006).

To restore soil quality, the most studied and used method is revegetation, especially the planting of hyperaccumulating plants, which stabilizes the bare area and minimizes the problem of contamination (Wong, 2003; Zu et al., 2004), being a realistic approach to mine recovery (Yang et al., 2010).

Lei et al (2016) have shown that the combination of tree species and crop diversification plays an important role in the restoration of all aspects (physicochemical, biological, biochemical and molecular) of these degraded lands, where reforestation improved the soil efficiently (Singhet al., 2012).

The choice of species is very important, with native species being the first choice. At the same time, the state and effects of fauna and microorganisms must be considered, and they play a critical role in the restoration of a functional ecosystem (Cristescu et al., 2012), so that plant, animal and microbial communities must be rebuilt in mining areas.

Despite the development of mining restoration techniques in recent decades, restoration failures remain significant (Haigh, 2000). One of the least studied aspects is the succession of species in the restored areas. This would facilitate the evolution towards ecosystems that provide stability and facilitate the regeneration of fundamental ecological processes (Sänger and Jetschke, 2004).

Short-term monitoring of plant composition is a necessary but insufficient predictor to evaluate the evolution process (Herricka et al., 2006). Long-term monitoring is essential. Remote sensing (RS) and Geographic Information System (GIS) technologies are used (Lei et al, 2016).

Moreno-de las Heras et al (2008) to evaluate heritage trends and their trajectories, have studied 87 slopes with different ages and restoration treatments in the province of Teruel, Spain. They analyse factors, mechanisms and processes involved in succession through the measurement of topographic variables, restoration techniques, local disturbances and erosion.

It should be noted that, on artificial slopes, the incipient development of the soil favours runoff and limits rainfall infiltration (Ward et al., 1983; Guebert & Gardner, 2001). In some cases, this extra flow of soil flows from the top and promotes soil erosion, drastically affecting plant dynamics (Moreno-de las Heras et al., 2005).

Restoration practices have evolved considerably in recent decades. On the one hand, the design of the terrain's shape has shifted from landscapes based on platforms and ditches to structured basins with gentle slopes and watercourses (Nicolau, 2003). On the other hand, the use of topsoil instead of coating materials. In his study Moreno de las Heras et al. 2008 have found a great variety of plant communities and successional trajectories.

The main driving forces behind the succession of vegetation were the initial conditions in relation to soil quality, revegetation treatments and the environmental scenario, as well as climatic conditions and proximity to the source of propagules. With their study, Moreno et al (2008) have identified the key factor that drives the process of evolution:

- The distance to the seed source
- Soil erosion caused by landslides from the top of restored slopes. This is an important driving force in the succession of vegetation on restored slopes in dry Mediterranean environments, severely restricting plant establishment, probably due to increased water stress, as well as physical disturbances caused by soil erosion.

- Incorrect revegetation practices. A mixture of non-native species is usually used, sowing grasses of herbaceous and leguminous plants that are rarely followed by a plantation of shrubs and/or tree species.

- The use of non-native, fast-growing species that limit vegetation dynamics. In this case, local alterations such as the appearance of fungal diseases and especially the grazing of sheep on herbaceous populations may favour the transition to more diverse shrub communities.

Moreno et al (2008) from the results obtained extract the following practical considerations:

- Pay special attention to the selection of a substrate, it must be free of important physicochemical substances (extreme pH and toxicity).

- Preserve uphill protective structures (canals and berms) that control flows from the top of the restored slopes

- Avoid revegetation with fast-growing non-native species to avoid inhibition of spontaneous colonization.

In ecosystem restoration, it may take more than 15 years to achieve ecosystem functioning comparable to an unmodified ecosystem. Therefore, a reliable short-term method of evaluation and monitoring is needed to ensure that the restoration is on the right track (Waterhouse et al, 2014). In this sense, soil microbial communities can serve as indicators of the current state of the ecosystem, because microbes respond relatively quickly to environmental changes.

At an active open pit mine located on the East Coast of New Zealand, Walter et al (2014) assessed impacts to microbial communities using three different restoration methods in both cost and restoration effort. When the restored sites were 5 years old or younger.

The restoration methods tested were:

- Direct Vegetation Transfer (DTV), also called 'habitat' or 'community translocation', is the removal and relocation of intact vegetation and soil cover or clods for rehabilitation purposes (Rodgers et al.2011).

- The use of treated bio-solids spread out for subsequent planting and

- The untreated ones that are also spread out for later planting

Impacts on soil microbial communities were assessed by measuring microbial biomass, dehydrogenase activity, community physiological profile and functional diversity measured by the use of carbon substrates.

The study shows that both the direct transfer of vegetation and the addition of bio-solids as restoration methods benefit microbial communities by channelling resources towards ecological restoration, while the same does not apply to untreated and replanted areas. In all cases compared to unaltered soils and/or habitats.

This study has also shown that soil microbial communities are a valuable tool for assessing the progress of restoration, and that ecosystem restoration can begin in a relatively short time after investment in an appropriate restoration strategy, ultimately benefiting from plant and animal recolonization.

GUIDELINES

Listed below are a number of guides and manuals published to date on restoration and landscape integration of mining activities.

Carabassa, V., Ortiz, O., Alcañiz, J.M., (2012). Evaluación y seguimiento de la restauración de zonas afectadas por minería. Generalitat de Catalunya. Departament de Territori i Sostenibilitat. Direcció General de Qualitat Ambiental.

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EUROGYPSUM (2010) Biodiversity Stewardship in Gypsum Quarrying: our Best Practices

European Commission (2009). Reference Document on Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities.

European Commission, (2010) EC Guidance on: Undertaking non-energy extractive activities in accordance with Natura 2000 requirements http://ec.europa.eu/environment/nature/natura2000/management/docs/neei_n2000_guidance.pdf

Fernández Rubio (2007). Rehabilitación de Espacios Mineros – Experiencia española. Universidad Politécnica de Madrid.

ICMM – INTERNATIONAL COUNCIL ON MINING & METALS (2006). Good Practice Guidance for Mining and Biodiversity. www.icmm.com.

Jorba, M., Vallejo, R., (2010). Manual para la restauración de canteras de roca caliza en clima mediterráneo. Departament de Medi Ambient i Habitatge de la Generalitat de Catalunya.

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Several authors (2010). Guía para evaluar EIAs de Proyectos Mineros. Alianza Mundial de Derecho Ambiental (ELAW), Eugene OR 97403.

Several authors (2013). Multiple Land Use Framework. Standing Council on Energy and Resources. (SCER). Australia. Government of Australia.

Several authors (2016). Rehabilitación de Minas. Programa de Practicas Líderes para el desarrollo sostenible de la Industria Minera. Australian Government, Department of Industry, Tourism and Resources.

Several authors (2014). Guía Metodológica para la tramitación ambiental de las actividades extractivas en la Comunidad Foral de Navarra y Guía de buenas prácticas. Gobierno de Navarra. Departamento de Desarrollo Rural, Medio Ambiente y Administración Local.

Several authors (1989). Manual de restauración de terrenos y evaluación de impactos ambientales en minería. Ingeniería Geoambiental. Instituto Tecnológico y Geominero.

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Whitebread-Abrutat, P. H. (2012). Exploring World Class Landscape Restoration. Winston

CASE STUDIES

The extractive activity leaves abundant signs of its activity in the territory. However, its restoration and enhancement may contribute to the economic development of depressed populations, through museums or parks. We have the following examples:

PARQUE MINERO DE RIOTINTO, Huelva. Andalucía, Spain

http:/www.riotintodigital.es/links.html

LAS MÉDULAS, El Bierzo, León. Castilla-León, Spain

https://es.wikipedia.org/wiki/Las_M%C3%A9dulas

MINA DE CABÁRCENO, Penagos. Cantabria, Spain

https://www.parquedecabarceno.com/info/informacion-del-parque#.Wo_-BoPOVGE

MINA DE AZUFRE DE LIBROS (Sulfure mine), Teruel. Aragón, Spain

https://www.heraldo.es/noticias/suplementos/2015/03/09/la_nueva_vida_poblado_minero_350477_314.html

MINA DE UTRILLAS Teruel. Aragon, SPAIN

http://parquemineroutrillas.com/

MINA DE CARBÓN AS PONTES. La Coruña. Galicia, Spain

http://www.elmundo.es/elmundo/2013/09/16/natura/1379362130.html

MINA DE ORO DE BERGANTIÑOS (Gold mine), La Coruña, Galicia. Spain

https://elpais.com/ccaa/2012/05/13/galicia/1336929841_218321.html

EDEN PROJECT St Blazey, Cornualles. UK

http://www.edenproject.com/

Following are several cases of geomorphological restoration applying GEOFLUV. A geomorphological solution is used in mines restoration changing a degraded area into a rural landscape of configuration and dynamics similar to the existing ones.

Country	Mina	Municipio	Distric
Spain	La Revilla	Orejana	Segovia
Spain	La Higuera	Espirdo	Segovia
Spain	Cantera de Somolinos	Somolinos	Guadalajara
Spain	Quebraderos de la Serrana	Noez	Toledo
Spain	El Machorro	Poveda de la Sierra	Guadalajara
Spain	María José	Poveda de la Sierra	Guadalajara
Spain	Escombrera de Arlanza	Bembibre	León
Spain	Aurora	Campredó	Tarragona
Spain	Pastor I	Campredó	Tarragona
Spain	Nuria	Poveda de la Sierra	Guadalajara
Portugal	Mina do Lousal	Grándola	Setúbal
USA	La Plata		New Mexico
USA	San Juan		New Mexico
USA	El Navajo		New Mexico
USA	El Segundo		New Mexico
USA	Swastika Mine	Ratón	New Mexico
USA	Limestone quarry	Tijeras	New Mexico
USA	Limestone quarry		Colorado
USA	HardRock Mine	Leadville	Colorado
USA	Minehaha slurry	Sullivan country	Indiana
USA	Coal Mine	Gallup	New Mexico
USA	Coal Mine		Arizona
USA	Sand Mine	Jackson country	Wisconsin
USA	Coal Mine		Wisconsin
USA	Uranium Mining	Riverton	Wyoming
Chile	El Indio		IV Región
Colombia	SATOR	Puerto Libertador	Córdoba
Australia	Mangoola		New South Wales
Australia	Bengalla	Muswellbrook	New South Wales
Australia	MT Owen Mine	Hunter Valley	New South Wales
Australia	Mt Arthur Colliery	Hunter Valley	New South Wales
Australia	Glendell Coal Mine	Ravensworth	New South Wales
Australia	Tasman mine	West Wallsend	New South Wales
Australia	Liddell Colliery	Ravensworth	New South Wales
Australia	MTW	Singleton	New South Wales

Source: (http://www.landformining.igeo.ucm-csic.es/es/content/restauraci%C3%B3n-geomorfol%C3%B3gica-minera)

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