Content corresponding to the related oral paper presented at the 2014 OSM National Technical Forum: *Advances in Geomorphic Reclamation at Coal Mines*, Albuquerque, New Mexico, May 20-22. Office of Surface Mining, Reclamation and Reinforcement (OSM), Department of Interior, United States.

EXAMPLES OF GEOMORPHIC RECLAMATION ON MINED LANDS IN SPAIN. FROM PIONEERING CASES TO THE USE OF THE GEOFLUV™ METHOD

José F. Martín Duque
Department of Geodynamics, Complutense University (UCM) and Institute of Geosciences, IGEO (CSIC, UCM), Madrid, Spain

Nicholas Bugosh
GeoFluv, 2205 North Avenue, Parma, Ohio, 44134, USA

Abstract

This paper describes eight examples of truly geomorphic reclamation on mined lands of Spain, as solutions for complex environmental problems. The first one, *La Revilla* (Segovia province), was designed in 1994 and constructed in 1995. It considered 2D slope processes in its design, and allowed the definition of a specific geomorphic model of mining reclamation, which we called "highwall-trench-concave slope". A 13-year monitoring period of the reclaimed area proved the success of that approach at meeting its defined objectives. The second example, *La Higuera* (Segovia province), designed and built in 2008, replicated a series of small catchments on a clay contour quarry, being innovative with respect to the existing topographic solutions for mining reclamation in Spain up to that date.

From 2009 we started to spread a geomorphic approach for the reclamation of mined lands by applying the GeoFluv™ (method) through the Natural Regrade software (Carlson). Thus, six more noticeable cases have been already designed since that year, with three of them being partially or totally constructed. Each of them has its own particularities and contributions, becoming innovative geomorphic solutions to existing environmental (ecological, social and economic) problems. The *Quebraderos de la Serrana* example (Toledo province) allowed a local company to get permission for slate quarrying in a highly ecologically vulnerable area; before that, the permission for extracting rocks had been rejected with a conventional reclamation approach. The *Somolinos* case is, to this date, the most complete geomorphic reclamation in Spain, and the first one in Europe to have been built by using the GeoFluv method. This restoration has healed a degraded area of about six hectares at the outskirts of the Somolinos hamlet, in a valuable rural landscape of the Guadalajara province. The *Arlanza* example (Leon province) shows a design which proposes to restore the hydrological connectivity of a coal mine dump which blocked a valley. The *Machorro* and *María Jose* examples (Guadalajara province) are allowing kaolin mining to be compatible with the preservation of protected areas at the edge of the Upper Tagus Natural Park, in highly vulnerable conditions for water erosion. Finally, the *Campredó* case (Tarragona province) shows an agreement between a mining company, the academia, and the Catalonian Agency of Water, to combine a high standard of geomorphic reclamation with solving problems caused by flooding downstream of a clay mining area. Additional information on these examples and about the state of art of the Geomorphic Reclamation practice in Spain can be found at http://www.restauraciongeomorfologica.es.

Introduction

Geomorphic reclamation is still a very young discipline, applied science and engineering technique. The ground-breaking book *Geomorphology of Disturbed Lands* (Toy and Foster, 1987) called attention to the possibilities and advantages of incorporating geomorphic principles into disturbed land reclamation. BHP Billiton began using the GeoFluv design method at its La Plata Mine in 1999 and the federal Office of Surface Mining (OSM) held an *Alternatives to Gradient Terraces* conference in Farmington (New Mexico) in 2000, where the method's application at the nearby La Plata Mine was explained (Bugosh, 2000). Numerous tours of the La Plata reclamation and application at its sister project, the San Juan Mine over the following years, helped to introduce others to the new method. Bugosh joined Carlson Software in 2003 to make his calculation-intensive method into a user-friendly computer software module that was released in 2005 as Carlson Natural Regrade. In 2004, OSM awarded the San Juan Coal Company a National reclamation award and recognized it with Best of the Best Reclamation status for its fluvial geomorphic reclamation using the new method. The reclamation using the new system at these mines now dates back a decade and a half, and the projects there are the largest constructed to date; as a result the area has hosted interactive fluvial geomorphic reclamation forums, from 2006 through the present.

At this moment, geomorphic reclamation is not well known and developed outside the United States, but reclamation designers have been trained in the GeoFluv method in Australia, Canada, Chile, Mexico, South Africa and Spain, and demonstration projects are underway there. In this framework, Spain can claim to have been pioneering in both the design and construction of mining geomorphic reclamation in the mid-1990s (see Martín Duque et al., 1998), and in the key contribution to the specific literature in this field (Martín Duque et al., *op.cit*., Nicolau and Asensio, 2000; Nicolau, 2002, 2003). From 2009 the work of our group of *Restauración Geomorfológica* in Spain is mostly based on the GeoFluv™ (method) and uses Natural Regrade (software) to accomplish geomorphic reclamation (see Martín Duque and Bugosh, 2013).

This paper describes eight examples of truly functional geomorphic reclamation on mined lands of Spain. Figure 1 shows their location within the peninsular Spain.

Figure 1. Location of the described eight cases of geomorphic reclamation on mined lands of the peninsular Spain. Pioneering cases (without the use of GeoFluv): 1, La Revilla; 2; La Higuera. GeoFluv cases: 3, Quebraderos de La Serrana; 4, Somolinos; 5, Arlanza; 6, Machorro; 7, María José; and 8, Campredó.

Examples

Pioneering cases

La Revilla (Orejana Municipality, Segovia Province, Castile and Leon Autonomous Community)

The environmental problem to be solved at La Revilla was a common one caused by many quarries in Spain (and worldwide). Mining activity transformed and degraded land in a rural area characterized by high ecological and landscape quality. Geomorphic instability and water erosion (with on-site and off-site effects) were common at this site. Therefore, social opposition by local communities was evident. The core of a solution that would tackle all those harms at the same time was thought to be a geomorphic mining reclamation design, which was carried out in 1994 and constructed in 1995. This example considered the 2D slope processes in its design (see Martín Duque et al., 1998) and allowed definition of a specific geomorphic model of mining reclamation that we called “highwall-trench-concave slope” (Figure 2). In addition to a topographical complex design, this reclamation included a reinstatement of the surficial deposits (carbonatic colluvia) upon the restored topography. Finally, the area was tilled and seeded.

A 13-year monitoring period of that geomorphically reclaimed area (see Martín Duque et al., 2010a), and its continuation until today, has proved the success of that approach. This example is described in very detail at Martín Duque et al. (1998, 2010a) and we therefore refer to those papers for a more in-depth information about this case.

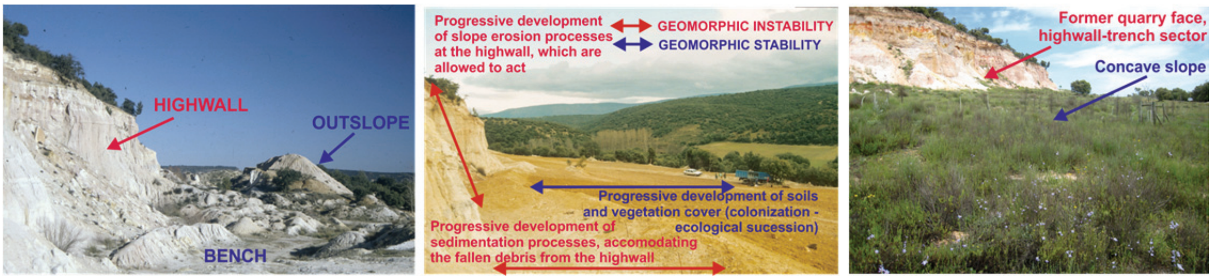

Figure 2. Left (January 1995), main landforms created by the exploitation of La Revilla quarry. Center (February 1995) — the landform design proposed two different zones for managing surface slope processes; the image shows them immediately after they were built. The right picture (May 2006) shows the landscape evolution at the two referred zones; the accommodation of fallen debris at the trench and the geomorphic stability at the concave slope can be clearly seen. All the details about the geomorphic design, cut and fill balance, and other relevant information are explained at Martín Duque et al. (1998).

La Higuera (Espirdo Municipality, Segovia Province, Castile and Leon Autonomous Community)

The environmental disturbances at La Higuera were very similar to those explained for La Revilla. Therefore, it was diagnosed that the solution should be a geomorphic-based reclamation, which was designed and built in 2008, restoring a series of small catchments on a clay contour quarry (Figure 3).

This approach was innovative with respect to the existing topographic solutions for mining reclamation in Spain up to that date (see Martín Duque et al., 2010b), because it considered a watershed approach, restoring the transformed drainage network by linking each buried channel with its base level and reestablishing, approximately, the original watershed areas. However, it did not yet incorporate all the complexity of the GeoFluv method, as this example was accomplished before we 'found' it in Spain. As in La Revilla, original surficial deposits (and former soils) were replaced on top of the built landforms. In this case, after verification of a suitable soil quality and seed dispersal, no revegetation was made. The spontaneous vegetation colonization and succession which have occurred at the reclaimed area since 2008 prove the success of that decision. A two-year measuring of the sediments yielded by the restored watersheds to two sediment ponds showed values of 1.54 Mg $ha^{-1}yr^{-1}$ for a non-grazed area and 2.62 Mg $ha^{-1}yr^{-1}$ for a grazed one. These values are similar to those of nearby non-mined lands, showing the short-term success of the approach. However, there are uncertainties about its long-term stability, because some fundamental principles (such as stable longitudinal profiles of the channels) were not considered.

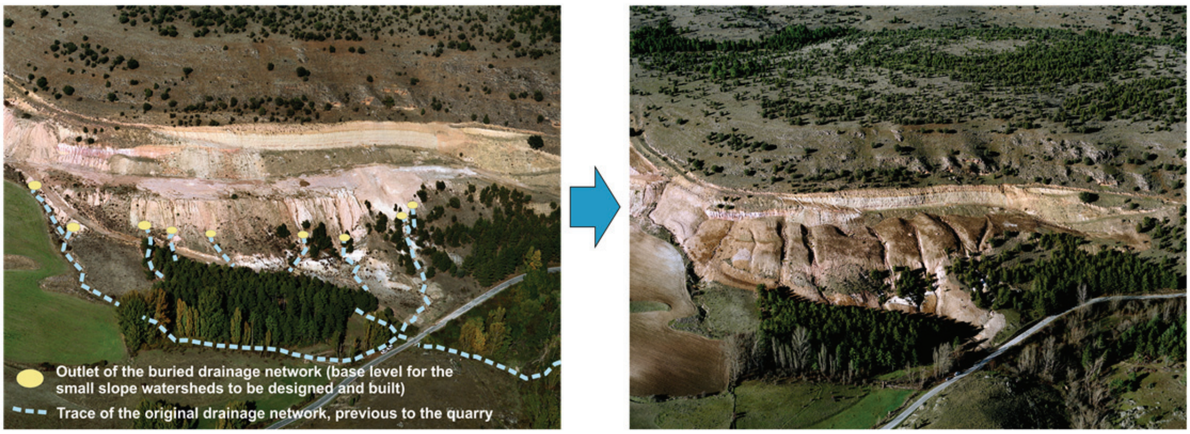

Figure 3. Left, oblique aerial photo of La Higuera quarry (October 2008) showing the outlets of the buried drainage network, as a key factor for the geomorphic reclamation. Right, image just after the geomorphic reclamation was completed (January 2009).

<u>GeoFluv cases</u>

La Revilla example showed us that functional, natural slopes are not just simple 2D concave slopes. They are much more complex in three dimensions. Later on, the La Higuera case revealed that, despite its short-term success, fluvial geomorphic design should not be 'guesswork' or an approximation. In 2009, our Spanish group working in geomorphic reclamation 'found' the GeoFluv method, and discovered that it was based on sound scientific fluvial geomorphology. Among others, it allows designing both 3D fluvial networks separated by stable functional slopes that mimic the natural landscape, including 3D complex concave profiles, tackling therefore the shortcomings of our two first examples. Consequently, from 2009 the work of our group on *Restauración Geomorfológica* in Spain is mostly based on the GeoFluv^{TM} (method) and uses Natural Regrade (software) to make the designs. Because each scenario has its own particularities, we describe imaginative (but always scientifically sound) adaptations of the method, producing innovative geomorphic solutions to challenging environmental problems, in addition to tackling erosion resistance.

The GeoFluv method is a specific, patented method of fluvial geomorphic landform design that is the 'heart' of the Natural Regrade software. It is an empirical method, in that it uses geomorphically mature local reference landforms. Particular measurements taken from these reference areas define how the reference landforms have responded over thousands of years to erosive forces. These measured values are used as inputs to the GeoFluv design method. When the designer collects the local inputs and uses them according to the method, the designer has a high degree of confidence that the reclamation will perform similar to the stable, mature landform from which the measurements were collected (see Bugosh, 2009; Bugosh and Epp, 2014).

Los Quebraderos de La Serrana (Noez Municipality, Toledo Province, Castile – La Mancha Autonomous Community)

Los Quebraderos de La Serrana is a slate quarrying project located in a habitat classified as 'important' for the Iberian Imperial eagle (bird of prey on the verge of extinction, and classified as critically endangered by the IUCN). Because of that, the regional environmental regulators did not authorize a previous version of this project, based on a traditional mining reclamation approach. A compromise between the company and the Administration allowed a search for a solution that would make the mining activity compatible with the preservation of the Iberian Imperial eagle. A GeoFluv geomorphic reclamation design which replicated colluvial slope-piedmont transition landforms revealed that it would allow the restoration of suitable habitats for the conservation of this bird of prey. Going even further, it was demonstrated that the post-mined landscapes would have a higher biological diversity than the pre-mined ones. Mainly, rabbit habitats (blending both staple food and shelter) which form the foundation of this eagle's foodweb (see Figure 4) would increase. On October 9th, 2011, the project received authorization, without having had a single public objection.

This example, described in detail at Zapico et al. (2011, 2013) has very important implications. First, as far as the mining sector is concerned, it makes it evident that the change between using the best available knowledge for reclamation (in this case GeoFluv) can make the difference between having or not economic activity. Second, as far as the environmental administration is concerned, it demonstrates that a post-mined landscape, geomorphically restored, can have a higher biological diversity than a pre-mined one. Third, putting all the focus in a scientifically based solution reduces social conflicts.

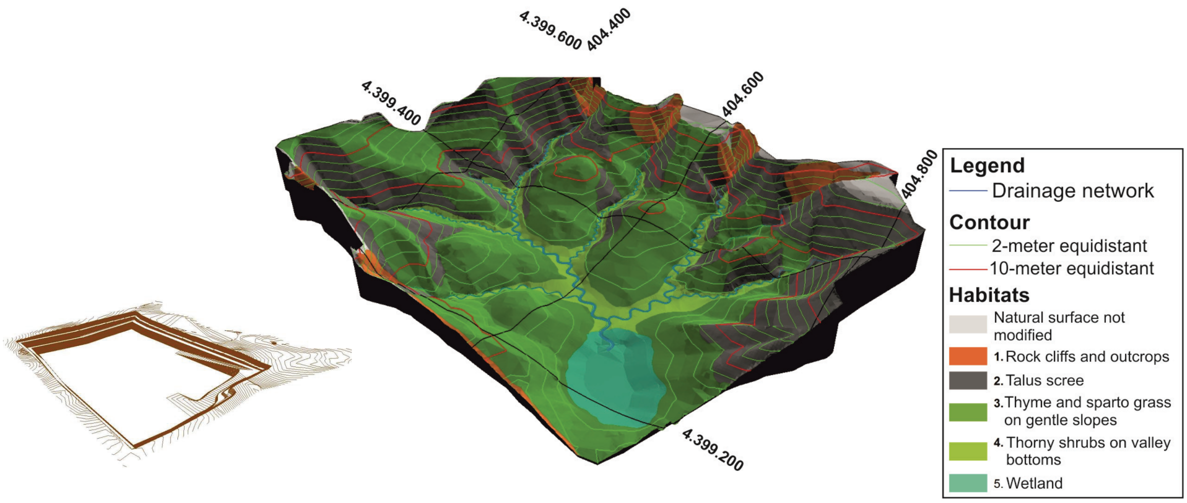

Figure 4. The small figure at the lower left corner shows the morphology of the projected quarry pit (16 hectares —39 acres— of surface, 30 m of depth, with an estimated volume of spoils of 650622 m^3). The main figure shows the GeoFluv design draped by the projected habitats upon it.

Somolinos (Somolinos Municipality, Guadalajara Province, Castile – La Mancha Autonomous Community)

The Somolinos quarry is situated at the North of the Guadalajara Province, in the vicinity of the small village of Somolinos (1240 m a.s.l.). The high ecological and landscape value of this area is reflected by its location among a Site of Community Importance (SCI) and a Special Protection Area for Birds (SPAB), both within the European Natura 2000 Framework (a catalogue of the most valuable habitats in Europe), and by its vicinity to two protected areas—a Natural Monument and a Natural Park.

This quarry was already reclaimed in 2008 following a traditional approach—broad stepped platform (with sediment pools within them), linked by short rectilinear slopes. No topsoil was applied upon the regraded surfaces, leaving the uncohesive sands exposed with tree and shrub plantings intended to control erosion. In 2011, the platforms and the rectilinear slopes showed severe erosion (see Fig. 5.1), the pools were almost filled by sediments, and the planted vegetation was totally inefficient controlling erosion. After extreme precipitation events, runoff from this quarry contaminated pristine riparian ecosystems downstream with suspended sediments. Once again, we assessed the use of GeoFluv as the best solution to both stabilizing the area and enhancing its ecological and landscape value, by replicating stable 'natural' reference landforms. The geomorphic design is represented by figure 5.2.

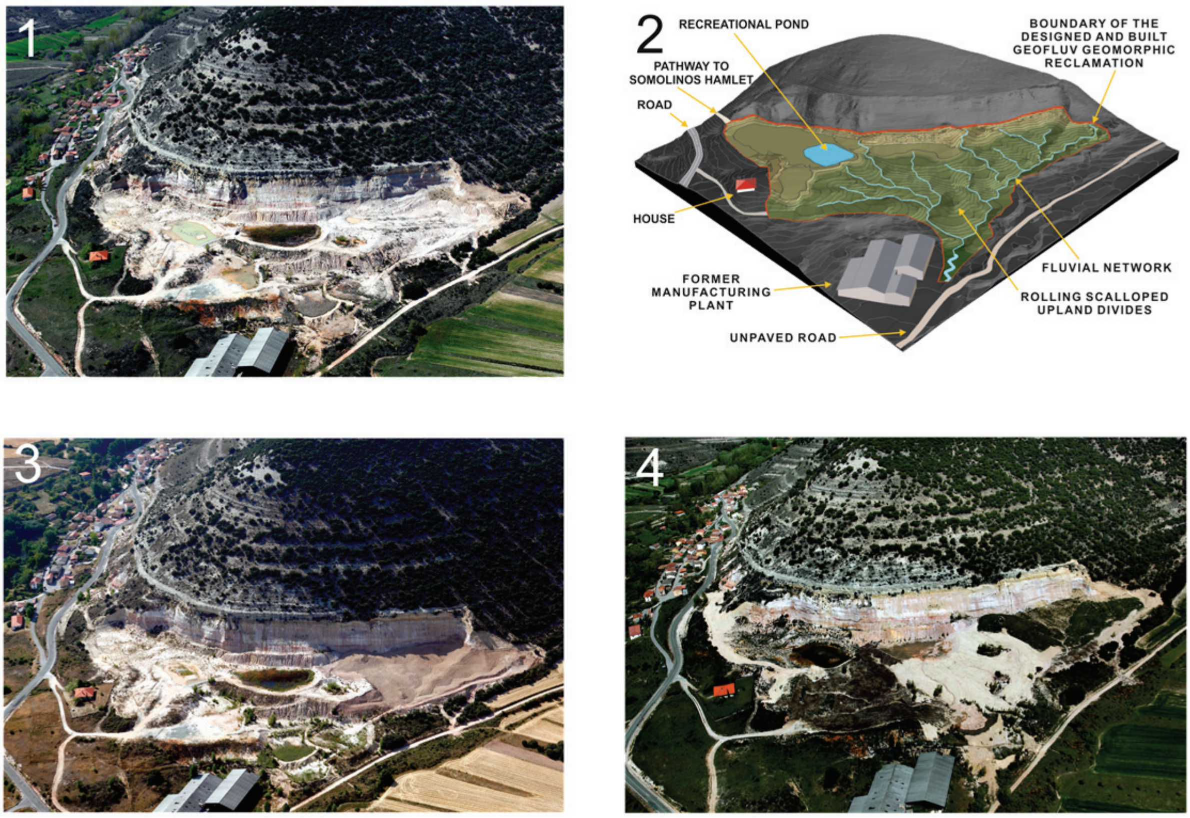

Figure 5. (1) The Somolinos quarry (6.2 hectares, 15 acres) before its geomorphic reclamation, in April 2011; the image shows evident signs of water erosion, without vegetation and soil. (2) 3D view of the geomorphic design, showing reference elements for their identification at the aerial photos. (3) Result of the first phase of geomorphic reclamation (June, 2011). (4) The quarry in May 2014, after completion of the reclamation; the area reshaped in June 2011 is now covered with grasses. The dark reclaimed area (between the former manufacturing plant and the recreational pond) has been fertilized with manure. The light central area is draped with colluvium, which has been seeded.

The designed landforms consist of: (a) a short alluvial plain with a meandering fluvial channel of less than 4% of gradient; (b) zigzag fluvial channels with gradient higher than 4%; (c) rounded interfluves, the slopes of which have a 'scalloped' topography, composed of subwatershed ridges and sub-channels (or swales). Along the divides of these ridges, small saddles were also designed. The existing spoils at the Somolinos quarry, sand and clay, were the only materials considered in the cut and fill balance.

The only available cover material at the surroundings of the quarry for topdressing was the carbonatic colluvium which originally draped the extracted mined material, which was chaotically disposed at the edge of the derelict area; no true soil was present. The available volume would allow replacing a 20 cm depth over all the regraded area. The replacement of this carbonatic colluvium would replicate the surficial deposits' structure of the original slopes, and it has therefore a sound ecological basis. Finally, the reclaimed surface would be subject to different soil and vegetation treatments (partially fertilized with manure and partially seeded).

The designed measures were implemented in two phases. Figure 5.3 shows the result of the building of the first geomorphic reconstruction (topography plus topsoiling) phase, in June 2011. This reconstructed surface was *circa* 1 ha, located at the Northern area, being the first GeoFluv construction in Europe. 42 days after finishing the geomorphic reconstruction, on August 12th, 2011, an intense storm hit on the reclaimed area. The recorded intensity captured by the radar images was between 32 and 64 mm h^{-1} (1.26 and 2.52 in h^{-1}). Despite such high intensities, an assessment of the reconstructed area showed that it remained very stable in terms of soil erosion after the summer storm, even when no vegetation at all was yet established. However, the sandy surfaces of the contiguous still un-reclaimed areas suffered severe erosive processes. Details of the Somolinos geomorphic reclamation up to the end of 2011 are described at Martín Duque et al. (2012). Finally, during the autumn of 2013 and winter of 2013-2014, the landform construction was completed (Figure 5.4).

Arlanza (Bembibre Municipality, León Province, Castile and Leon Autonomous Community)

The environmental problems to be solved here were created by a coal waste dump clogging a small valley with a watershed of 73 ha (180 acres) in the coal-mined region of El Bierzo, Northwest Spain. There is an artificial core drain within the dump, but it has not worked properly, as evidenced by a high resolution seismic tomography and georadar. On the other hand, gully erosion has started on the dump surface, affecting a nearby road (which links the Noceda town with the highway A-6) and a main fluvial course (Noceda River), both downstream of the dump (see Figure 6 left).

The geomorphic solution to this problem consisted of a GeoFluv design to restore the hydrological connectivity between the valley and its mouth to the Noceda River. This initiative complements a broader ecological restoration project for this area (García and Cantó, 2010). Despite the small size of the design, there are several contributions of this project that deserve to be highlighted:

(1) the use of an alluvial cone as a geomorphic reference for the design, which we consider a suitable adaptation to the new conditions imposed by an unconsolidated 'deposit' (waste dump) clogging the mouth of a tributary 'carved' on consolidated rocks;

(2) the *ad hoc* modification of the A-reach channel distances (but maintaining the designed main channel longitudinal profile), in order to adapt the sub-watershed valleys and sub-watershed ridges layout to existing physiographic conditions (springs, existing lateral valleys and ridges) and man-made structures (mine entrance —pithead—, wall and pathway) surrounding the dump. This example is described in detail at Francisco et al. (2013).

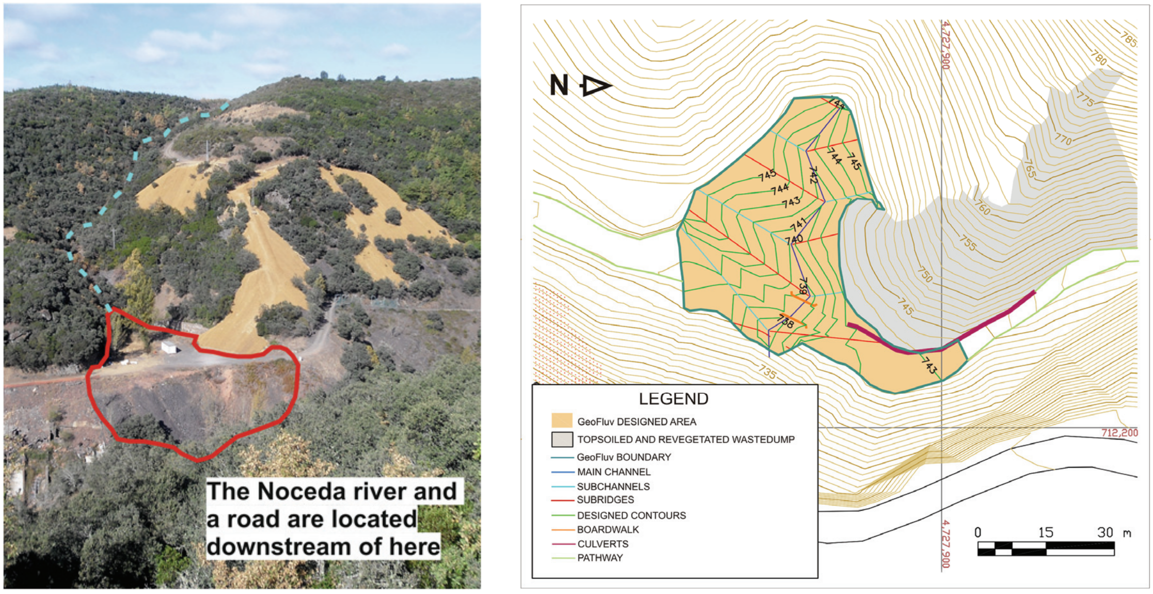

Figure 6. Left, the red line is the boundary of the coal waste dump clogging the valley, which fluvial channel is marked by the dashed blue line. The ocher areas correspond to ecological restoration in coal dumps following the method described at García and Cantó (2010), which did not need geomorphic reclamation. Right, GeoFluv design for restoring the hydrological connectivity.

El Machorro (Poveda de la Sierra Municipality, Guadalajara Province, Castile and La Mancha Autonomous Community)

We consider El Machorro geomorphic reclamation as the most challenging one of those described here, because of: the high gradients of this slope mine; its physiographic position at the edge of a mesa rim, with 400 m of difference in height between the mesa and the valley floor; the very high erodibility of its sandy spoils; the high erosivity of the precipitation in the area; and the location of the mine at the brink of one of the most outstanding Natural Parks of Spain (Upper Tagus), with pristine fluvial ecosystems. Further information appears at: Martín-Moreno et al. (2013, 2014), Nyssen et al. (2013) and Balaguer et al. (2014).

El Machorro mine has typical highwall-bench slope quarry topography (see Figure 7, left). The on-going traditional reclamation approach consists of a terraced truncated pyramid form constructed at the outer bench and separated from the highwall in an attempt to provide a visual screen for the latter (see Figure 7 left). Sediment pools are placed to minimize the sediment emissions to the nearby fluvial network. However, current maintenance and monitoring works at the mine show that the spoil heaps erode repeatedly forming gullies, and the sediment pools fill very often. This causes high maintenance costs. Initially we experimented to improve the terraced landforms by means of concave slopes and adequate topsoiling (see Martín-Moreno et al., 2013). Finally, the suitable reclamation solution is based on the GeoFluv method, adapted to the local physical environment setting, to make compatible mining in these very difficult environmental conditions. Figure 7 right shows the beginning of the reclamation works and Figure 8 provides the whole geomorphic framework.

Figure 7. Left, oblique aerial view of the area of El Machorro mine where the GeoFluv reclamation is starting to be applied. This picture show the traditional terraced reclamation approach —with the experimental area in the lower right corner— and the beginning of the GeoFluv reclamation works. Right, image covering the area of the yellow rectangle of the left that shows an already reclaimed area (central zone, with brown–ocher colors and blue line of fluvial network), blended with the natural surroundings (to its left); the short blue line to the right shows the area where the reclamation is continuing, in this case excavating a valley in the pre-existing terraced spoil heap.

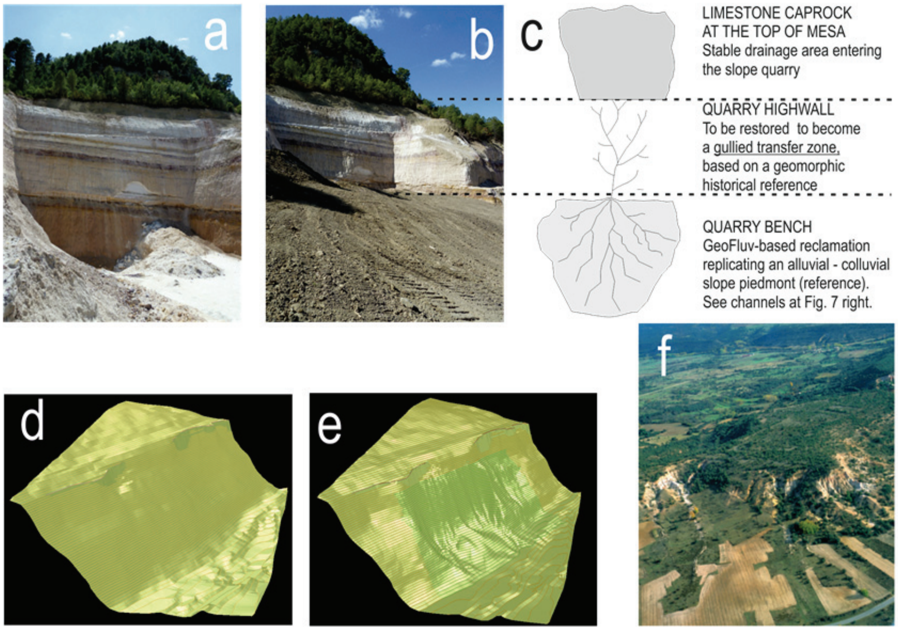

Figure 8. GeoFluv-based reclamation model for El Machorro. a) Typical highwall-bench slope quarry topography at a mesa hillslope (see figure 7 left, as it is the same area). b and c) Details of the three zones of the model (see Figure 7 right, as it is the same area); at the top, a stable and permeable limestone caprock will yield limited runoff downstream; the highwall is proposed to be shaped to mimic the sand gullies of the region, functioning as a hydrological transfer zone from the caprock mesa to the GeoFluv reclaimed area at the slope basis (former quarry bench); this GeoFluv reclaimed area uses as a reference an alluvial–colluvial piedmont, with a main channel designed to convey the bankfull and flood discharges corresponding to the whole watershed. d) 3D model of the highwall current surface. e) 3D model of the highwall design, to be built by scratching excavator works, based on the contour pattern of the existing gullies in the region, to ensure that it becomes a hydrological transfer zone subjected to low erosion (due to its almost vertical topography and protecting horizontal caprock, meeting the terms of mining safety regulations). f) Oblique aerial view of the reference landscapes of the model, in which the gullies have a human induced origin, being therefore historical geomorphic references (see Balaguer et al., 2014).

Summing up the proposed solution: the spoil heaps are being regraded to GeoFluv design at the bench, and the highwall is proposed to be shaped to mimic the sand gullies of the region, acting as a functional hydrological transfer zone from the limestone caprock mesa to the GeoFluv reclaimed area at the slope basis (former quarry bench).

María José (Poveda de la Sierra Municipality, Guadalajara Province, Castile and La Mancha Autonomous Community)

The María Jose example complements El Machorro one in a broad initiative between the Spanish mining company CAOBAR and the Direction of the Upper Tagus Natural Park, both of which are seeking to make kaolin mining compatible with ecosystem preservation at the edge of the Upper Tagus Natural Park, in conditions very susceptible to water erosion.

The María José mine started in 1965. Since then, it has created a profound physiographic transformation, actually shaping a truly main valley (2 in Figure 9) between the highwall (1 in Figure 9) and an outslope terraced waste dump (3 in Figure 9). This mine manages the on-site sediment and water properly, by means of a cascade of sediment pools (4 in Figure 9 is the most downstream one). Despite of this, and because of the location of the mine at the edge of a protected area, it was possible to get European funding to change from the ongoing traditional approach of mining reclamation to the *Best Technology Currently Available* (BTCA) in that field, this being considered the GeoFluv method. Given the starting point physiographic conditions, we considered that the most realistic solution was to design a 'natural' valley for the already man-made valley created by the mine between the highwall and the outslope-terraced waste dump, with a broad main meandering channel draining it. The two images at the right of Figure 9 show the first phase of construction of this valley (see Figure 9 caption for complementary explanation).

Figure 9. The María José mine created a man-made valley (2 at the left image) between the highwall (1 at the left image) and the outslope-terraced waste dump (3 at the left image). This landform has no local physiographic analogy. We proposed reshaping that valley to one more compatible with the nearby natural ones by using the GeoFluv method. The right images show details of the first phase of construction (zone 2a at the left image), with a main meandering channel (B type of the Rosgen classification). The 2b zone will be reclaimed following the same pattern.

Despite the adequacy of the solution, the construction of the design by an outside contractor was not totally well performed. Specifically, as it can be seen at the upper right image, the slopes do not reflect the designed convex-concave slope, but just convex ones. Also, the sub-watersheds are not real swales, but more close to ditches. Additionally, the base level elevation (the mouth of the reclaimed area to a pond) was not respected, and it was built about 1.5 m above, on unconsolidated materials. This caused immediate channel erosion to correct the channel's longitudinal profile to a stable profile and reach equilibrium. These contingencies demonstrate that the GeoFluv method needs expert guidance at all of its phases, and this was not fulfilled, in this case, at the construction process.

Campredó clay quarries (Tortosa Municipality, Tarragona Province, Catalonia Autonomous Community)

This example includes the geomorphic reclamation of a mining area of about 80 hectares (197 acres). The landscape to be restored was transformed by clay quarries for the cement industry, located at the Campredó decentralized municipal entity near the Ebro delta in Catalonia. This project will be developed in two quarries (Aurora and Pastor) of the CEMEX cement company and it is co-funded by the European environmental program called LIFE+. Additional information about the project can be accessed at http://www.cemexrestaura.com/.

Again, the environmental problems associated with the mining land transformation here are common: loss of hydrological connectivity and effects on nearby valuable ecosystems, landscapes and habitats. In addition, there are problems caused by flooding to a highway downstream of this area, although not caused by mining (as most of the quarried areas are closed pits). However, the GeoFluv-based designs intend to provide simultaneous solutions (see Figure 10). Thus, by proper landform design, we intend to: 1) restore valuable and threatened habitats; 2) restore the lost hydrological connectivities; 3) use the largest quarry pit as a natural "storm surge basin" of a watershed with an area of 279 hectares (689 acres), in collaboration with the Catalonian Agency of Water.

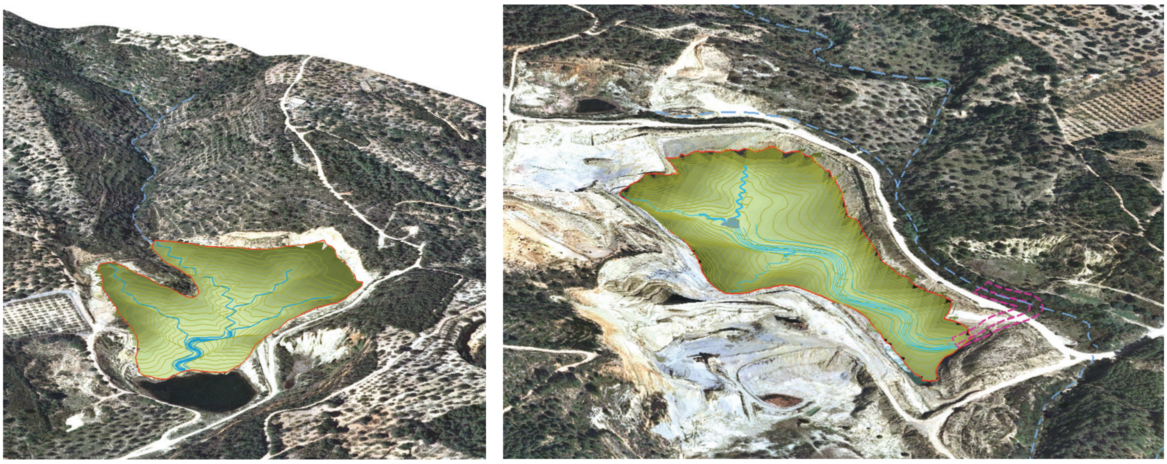

Figure 10. Left, proposed GeoFluv solution for the Aurora quarry (7.3 hectares, 18 acres); as it can be seen, the designed area hydrologically connects a stream with an existing pond (dark area). Right, the Pastor quarry pit has been designed to play the role of a natural "storm surge basin" of a watershed with an area of 279 ha (689 acres); the dashed pink line represents the bypass from the Rocacorba stream to the pit. The main contribution of this design is that the "storm surge basin" will be a natural landscape, restoring 24 ha (59 acres). In addition to the explained solutions, in both cases the geomorphic reclamation will be the basis for restoring valuable and threatened habitats.

Concluding remarks

There is a worldwide tendency in which social and legal pressures on mining companies are driving them to use the *Best Technology Currently Available* (BTCA) for the reclamation and restoration of the lands affected by their activities. In our interpretation, even in those countries or regions where this situation still does not occur, it will happen in the near future.

Mining reclamation in Spain is still dominated by traditional approaches, most of which neither solve landform stability problems nor do they achieve acceptable standards by people and regulators. In this framework, the geomorphic approaches to mining reclamation, in general, and specifically through the use of the GeoFluv method, are providing the referred BTCA. A creative use of the geomorphic approach to mining reclamation is addressing in Spain many other problems in addition to erosion resistance. We list here some of their already proven advantages (from the eight described cases):

- there is a higher stability, from the short to the long term, of the reclaimed landforms and landscapes, balancing their runoff and sediment yield with those of the surrounding environments, usually eliminating maintenance;
- lost hydrological connectivities are being reinstated;
- the combination of landform stability and high topographical diversity upholds the reestablishment of a high biological diversity, restoring even habitats of endangered species (such as the Iberian Imperial eagle) and European protected habitats;
- an effective restoration of ecosystem goods and services is promoted;
- the restored landscapes blend seamlessly with the surrounding environment;
- geomorphic reclamation has a remarkable high acceptance among local communities, regulators and some mining companies, as it is demonstrating that mining can be viable in places where this activity was seen as not sustainable (as within the Iberian Imperial eagle habitat or at the very edge of protected areas, such as the Upper Tagus Natural Park);
- geomorphic reclamation can help to mitigate the effects of natural hazards.

In a more conceptual framework, we dare to claim that there cannot be a truly ecological restoration of mined lands without geomorphic reclamation. The main reason behind this assertion is this: surface mining imposes a severe transformation of bedrock, landforms, surface hydrology and groundwater (outside soils, vegetation…). Therefore, only if a proper understanding of that dire transformation is made, and a geomorphic design and construction address the management of the hydrogeomorphic processes to occur in the area, the reclamation will be vulnerable and incomplete. The GeoFluv method provides a suitable tool to accomplish that.

Acknowledgements

The eight described cases of geomorphic reclamation in Spain are a summary of almost 20 years of work. Therefore, many people and organizations need to be thanked. The GeoFluv examples have been developed in collaboration with (in alphabetical order): Cristina de Francisco, Néstor Hernando, Cristina Martín Moreno, José M. Nicolau, Sara Nyssen, María Tejedor and Ignacio Zapico. We developed excellent teamwork with (arranged by cases): Rosa M. Carrasco, Andrés Díez, Javier de Pedraza, Luis Polo and Miguel A. Sanz (*La Revilla* case); María Feria, Luis Balaguer and Carlos Polo (*La Higuera* case); Juan Vicente Campillo, Javier Oria, Luis Balaguer and the staff of *Construcciones Lozoya* (*Los Quebraderos de La*

Serrana case); the *Ayuntamiento de Somolinos* (Rafael Anchía and Jose Anchía), Saturnino de Alba, Luis Balaguer, the *Consejería de Agricultura de la Junta de Comunidades de Castilla – La Mancha* (specifically Ruth Delgado and the enviromental rangers), Francisco J. Delgado and *Construcciones y Excavaciones Félix Moya* —Ángel Moya y Jesús Fernández— (*Somolinos* case); Avelino García, Luis del Riego, Jorge Ramón Travieso, CIUDEN and README (*Restauración Ecológica de Áreas Degradadas por la Minería en España,* http://readme.org.es/) (*Arlanza* case); CAOBAR, Lázaro Sánchez and the staff of both the Upper Tagus Natural Park and the Guadalajara and Castile – La Mancha mining and environmental administrations (Machorro and María José case); and all the people involved in the ECORESTCLAY Project (http://www.cemexrestaura.com/en/) (*Campredó* case).

It is outstanding that four of the six GeoFluv cases (including the only three ones being built so far) have been developed at the Castile – La Mancha Autonomous Community of Spain, where we found the highest enthusiasm about this method of geomorphic reclamation at the Mining and Environmental administrations (both at regional and provincial levels). At these built examples, *Construcciones y Excavaciones Félix Moya* and CAOBAR have demonstrated the highest possible performance and professionalism. All the oblique aerial photos have been taken by Paisajes Españoles. Since 2009, these initiatives have been a part of two research projects of the Spanish Ministry of Science and Technology: *Establecimiento de criterios hidrogeomorfológicos para mejorar la restauración ecológica y la integración ambiental de la minería a cielo abierto* (CGL2009-14508-C02-01), and *Mejora de la eficiencia ecológica y económica de las restauraciones mineras mediante reconstrucciones geomorfológicas que favorecen el control hidrológico* (CGL2010-21754-C02-01). A more complete list of collaborators can be seen at www.restauraciongeomorfologica.es. At this website, we provide additional information related with university programs, courses of updating for regulators and mining industry, consultation and research related with GeoFluv and geomorphic reclamation.

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