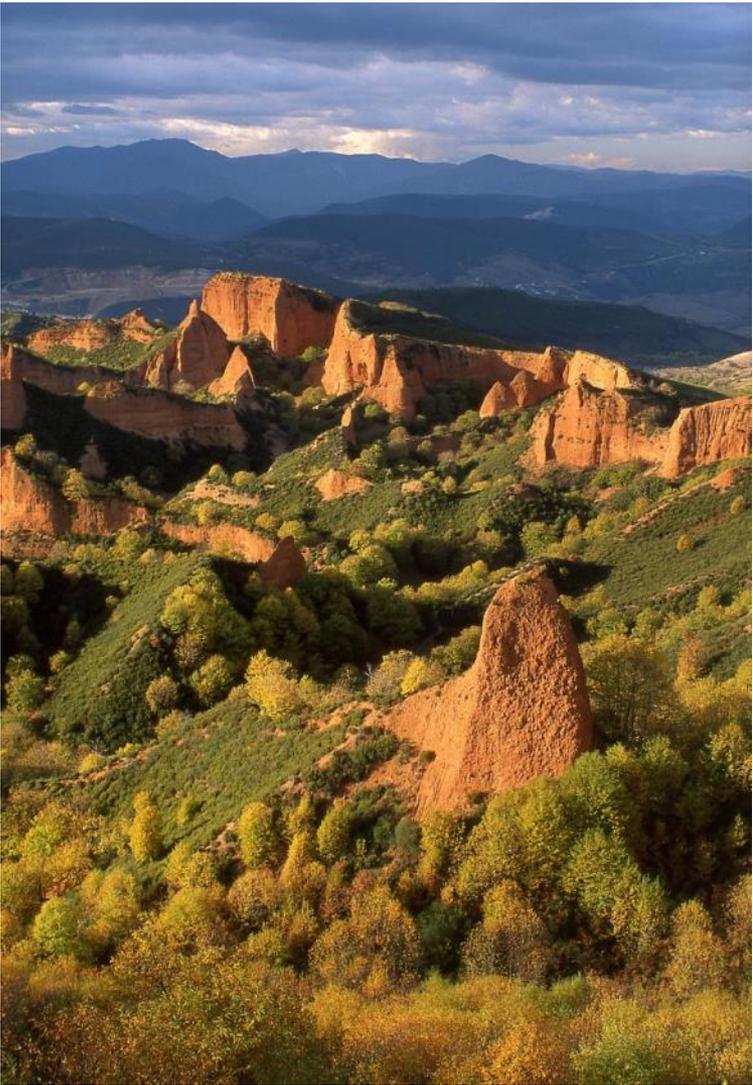


# EXAMPLES OF GEOMORPHIC RECLAMATION ON MINED LANDS IN SPAIN: FROM PIONEERING CASES TO THE USE OF THE GEOFLUV METHOD



**José F. Martín Duque**

Complutense Univ. of Madrid, Spain  
Restauración Geomorfológica

**Nicholas Bugosh**

GeoFluv, Parma, OH



# COLLABORATORS

Saturnino de Alba, Luis Balaguer, Juan Vicente Campillo, Avelino García, Rosa M. Carrasco, Andrés Díez, María Fera, Cristina de Francisco, Néstor Hernando, Cristina Martín, José M. Nicolau, Sara Nyssen, Javier de Pedraza, Miguel A. Sanz, Lázaro Sánchez, Luis del Riego, Jorge Ramón Travieso, María Tejedor, Ignacio Zapico...  
and many many more, to be seen at:



<http://www.restauraciongeomorfologica.com>

Oblique aerial photographs by:



**PAISAJES ESPAÑOLES**, S.A.

Fotografías Aéreas

# Reclamation of mined lands in Spain

- Compulsory from 1982
- Specific Law for Rec. of coal mining in 1984
- Current (new) Law from 2009
- Traditional practises are dominant (terraces, artificial ditches, short-sightseeing visual impact correction —visual screens—), and regulators and practitioners are not up-to-date of the best available knowledge
- In this framework, our group has developed a few examples of Geomorphic Reclamation on Mines



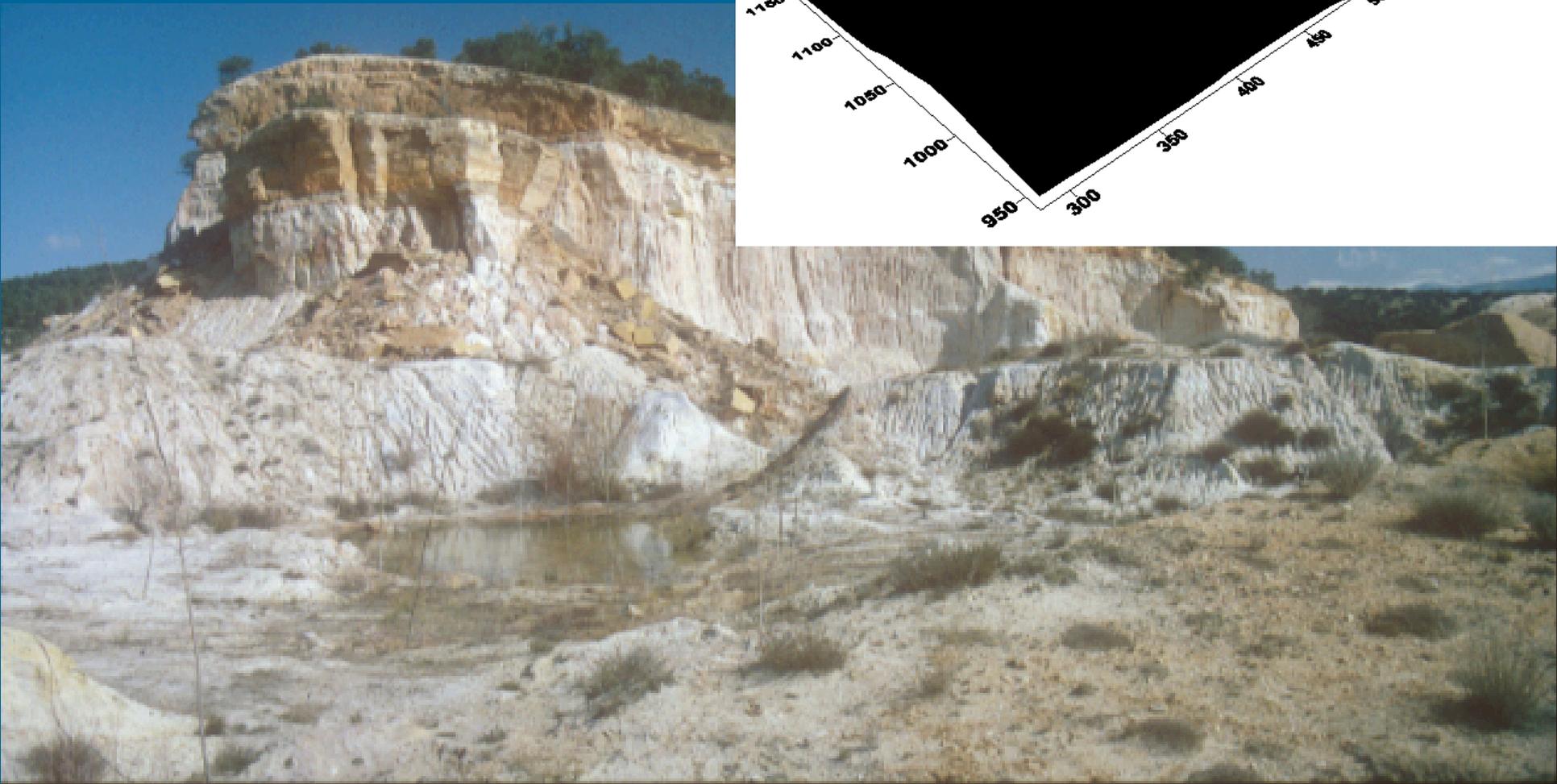
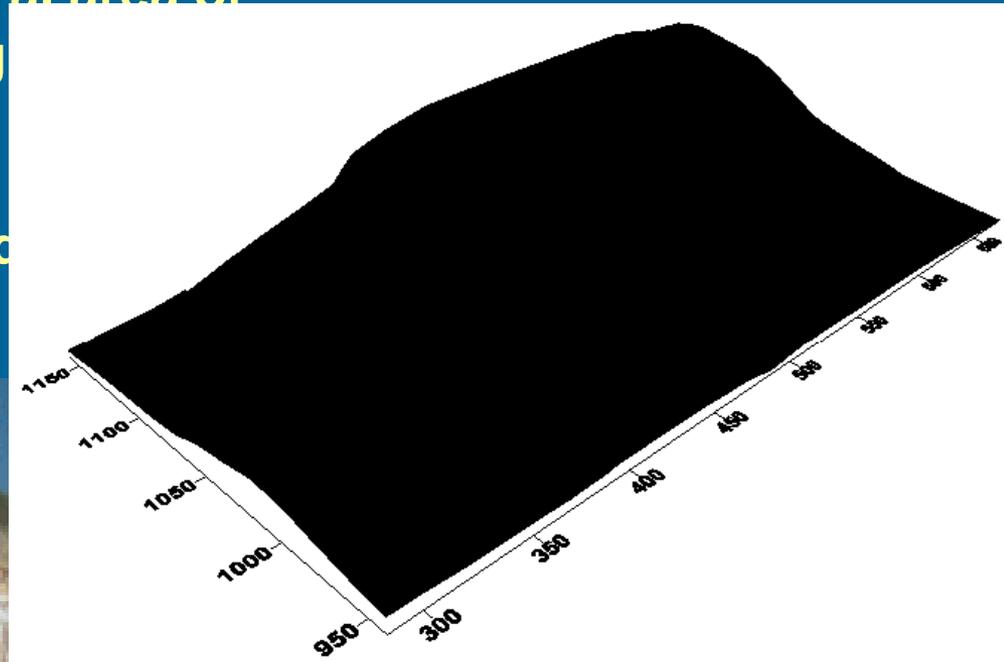
# 1) LA REVILLA (SEGOVIA)

Design - 1994  
Construction - 1995

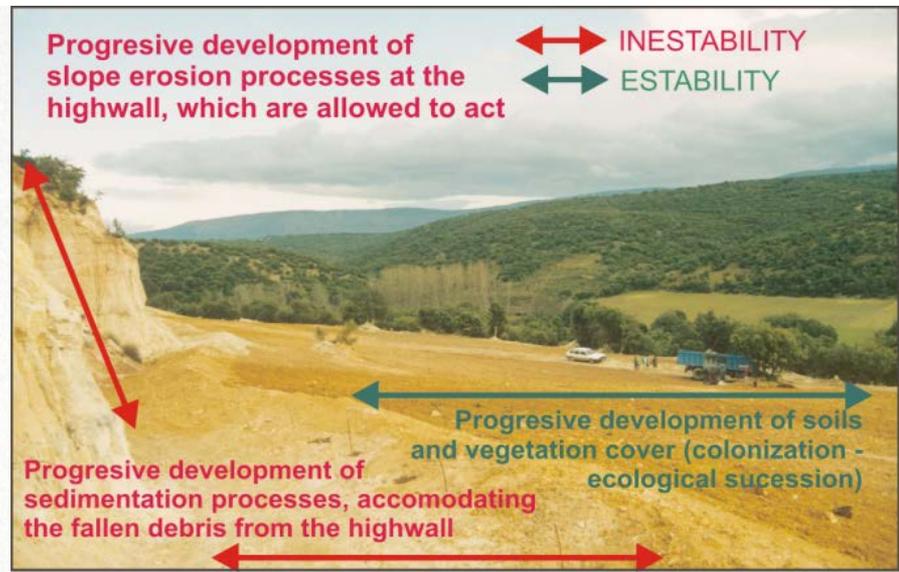
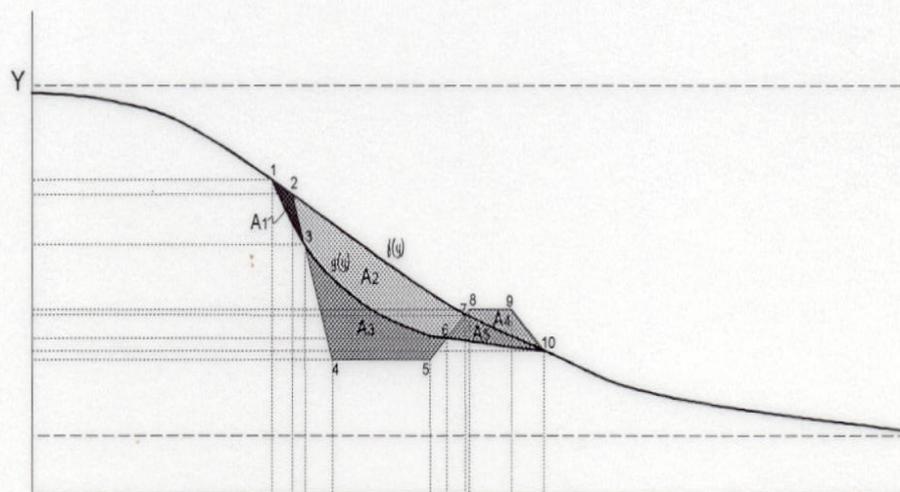
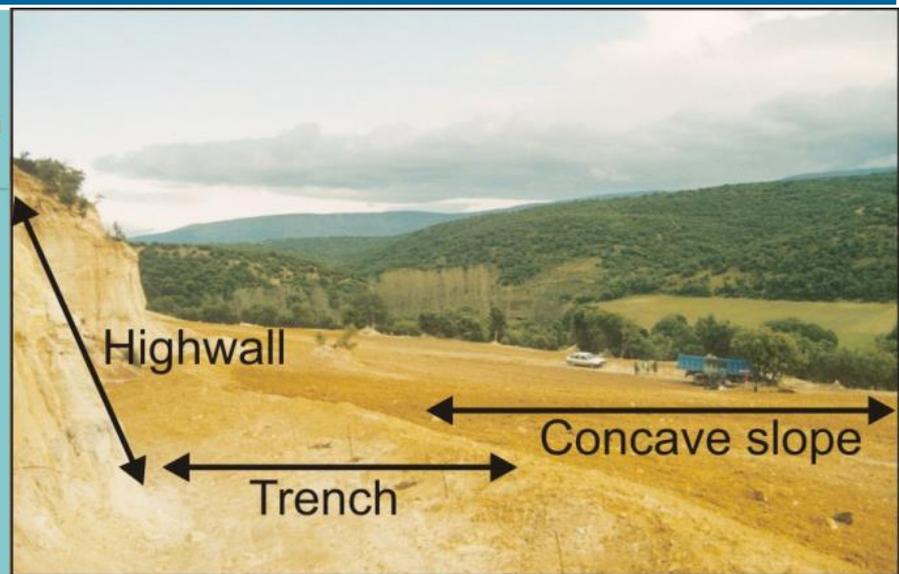
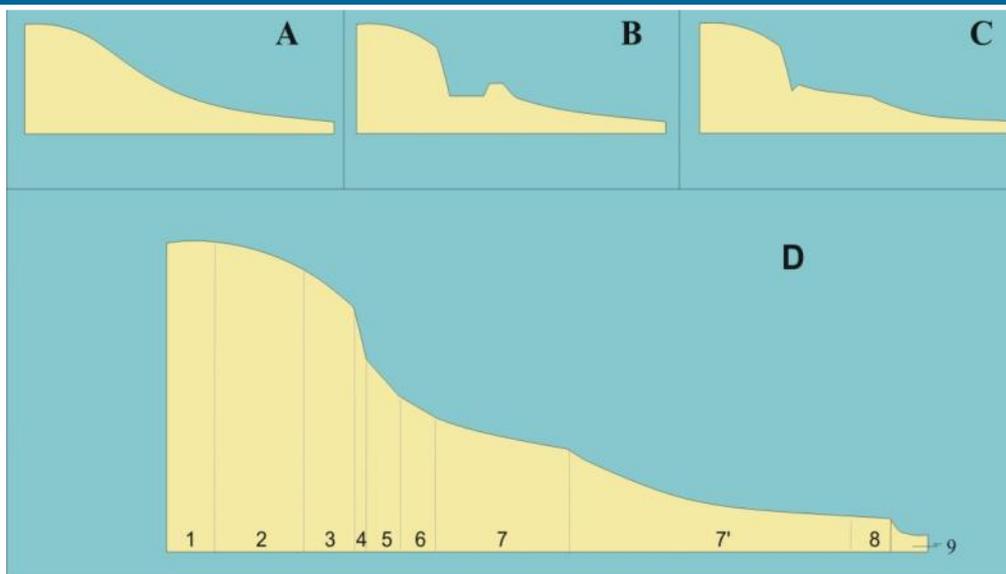


**PROBLEM – Degraded land in a rural area of Central Spain, characterized by high ecological and landscape quality.**

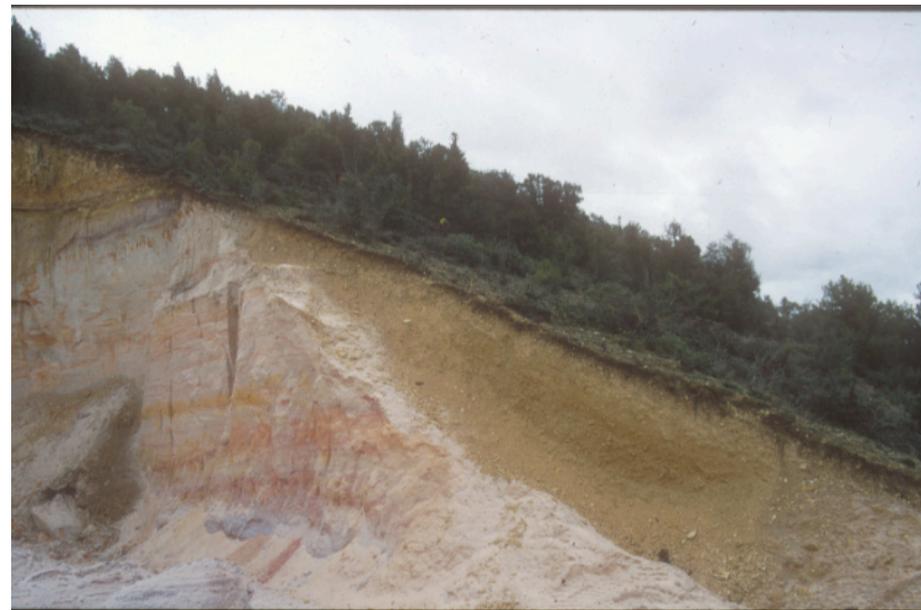
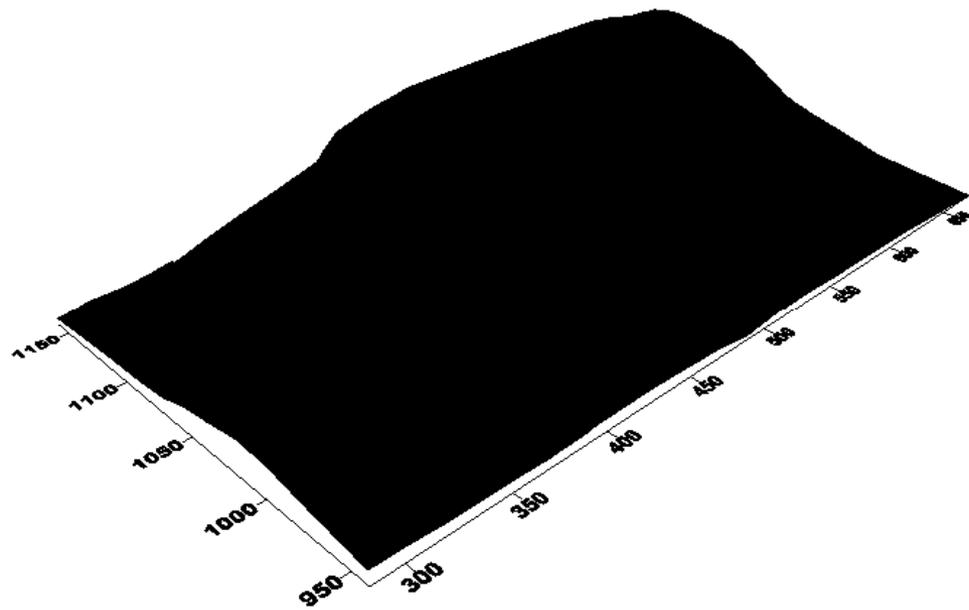
**Geomorphic instability, erosion and off-site effects**



# SOLUTION – restoration and management of ecologic processes through landform design, following a “highwall-trench-concave slope” geomorphic reclamation model



# CONSTRUCTION AND RESULTS



# CONSTRUCTION AND RESULTS



1996



1995

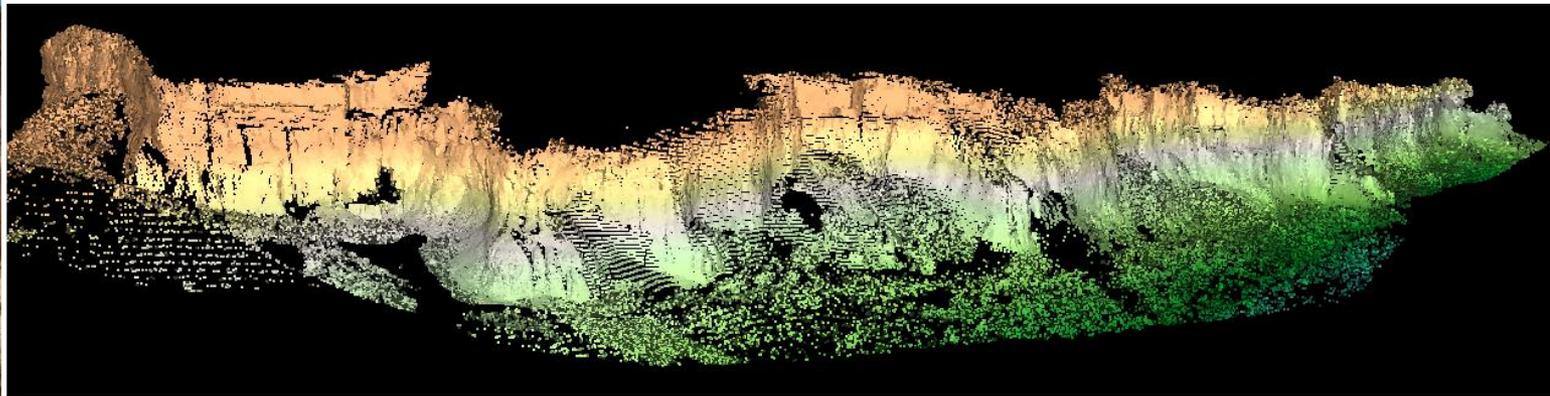
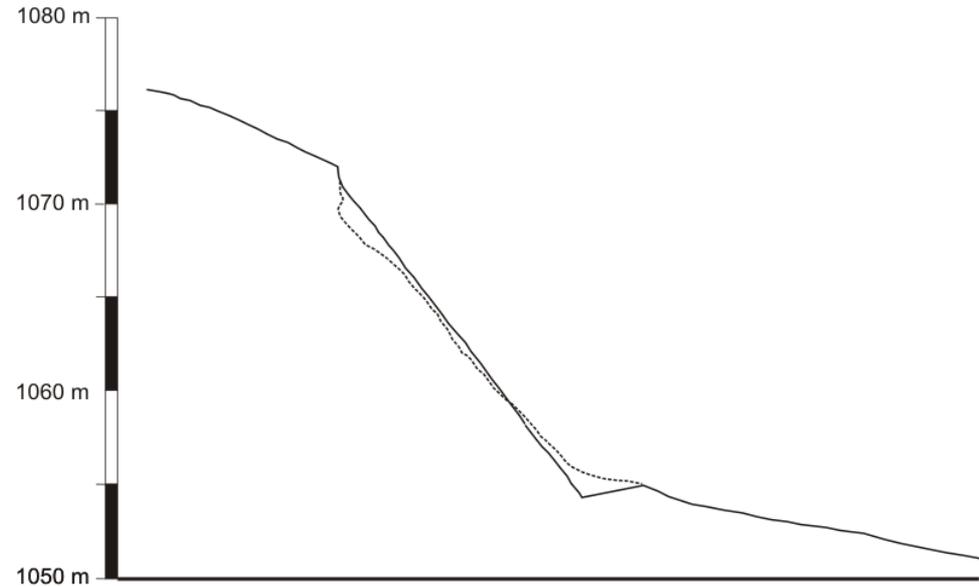


2004



2006

# MONITORING AND RESEARCH - slope-focused (2D), demonstrates the success of the highwall solution, but evidences the lack of a drainage network (3D)

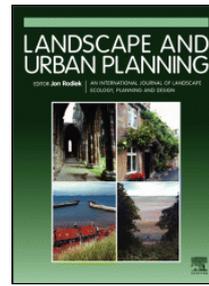
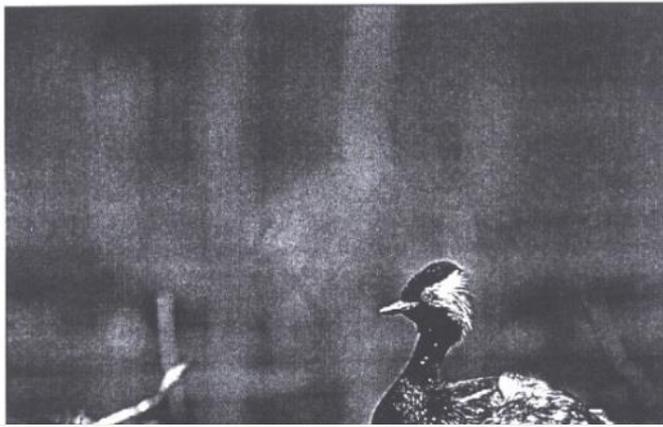


## Restoration Award '98

*Dedicated to nature*

*Der Natur gewidmet*

*Hommage à la Nature*



Landscape and Urban Planning 42 (1998) 1–14

LANDSCAPE  
AND  
URBAN PLANNING

### A geomorphological design for the rehabilitation of an abandoned sand quarry in central Spain

J.F. Martín Duque<sup>a,\*</sup>, J. Pedraza<sup>a</sup>, A. Díez<sup>b</sup>, M.A. Sanz<sup>a</sup>, R.M. Carrasco<sup>b</sup>

<sup>a</sup> Department of Geodynamics, Faculty of Geology, Universidad Complutense, Ciudad Universitaria s/n, 28040 Madrid, Spain

<sup>b</sup> Department of Environment, Faculty of Sciences, Universidad Europea de Madrid, Villaviciosa de Odón, 28670 Madrid, Spain

Received 11 August 1997; received in revised form 28 January 1998; accepted 31 March 1998

EARTH SURFACE PROCESSES AND LANDFORMS  
*Earth Surf. Process. Landforms* 35, 531–548 (2010)  
Copyright © 2010 John Wiley & Sons, Ltd.  
Published online 13 January 2010 in Wiley InterScience  
(www.interscience.wiley.com) DOI: 10.1002/esp.1950



### Restoring earth surface processes through landform design. A 13-year monitoring of a geomorphic reclamation model for quarries on slopes

J.F. Martín-Duque,<sup>1\*</sup> M.A. Sanz,<sup>1</sup> J.M. Bodoque,<sup>2</sup> A. Lucía<sup>1</sup> and C. Martín-Moreno<sup>1</sup>

<sup>1</sup> Department of Geodynamics, Faculty of Geology, Complutense University of Madrid, Spain

<sup>2</sup> Department of Mining and Geological Engineering, Castilla La Mancha University, Toledo, Spain

Received 10 March 2009; Revised 27 August 2009; Accepted 5 October 2009

\*Correspondence to: José F. Martín Duque, Department of Geodynamics, Faculty of Geology, Complutense University, C/José Antonio Novais 8, 28040 Madrid, Spain. E-mail: josefco@geo.ucm.es

## 2) LA HIGUERA (SEGOVIA)

Design - 2008  
Construction - 2008

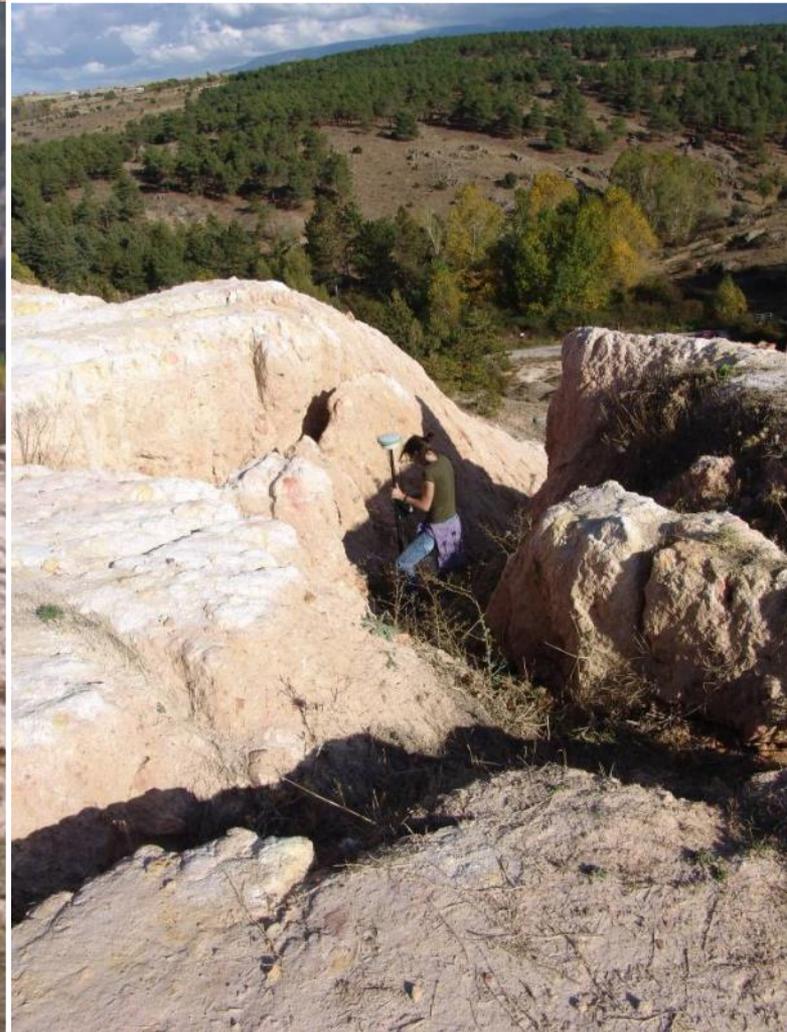
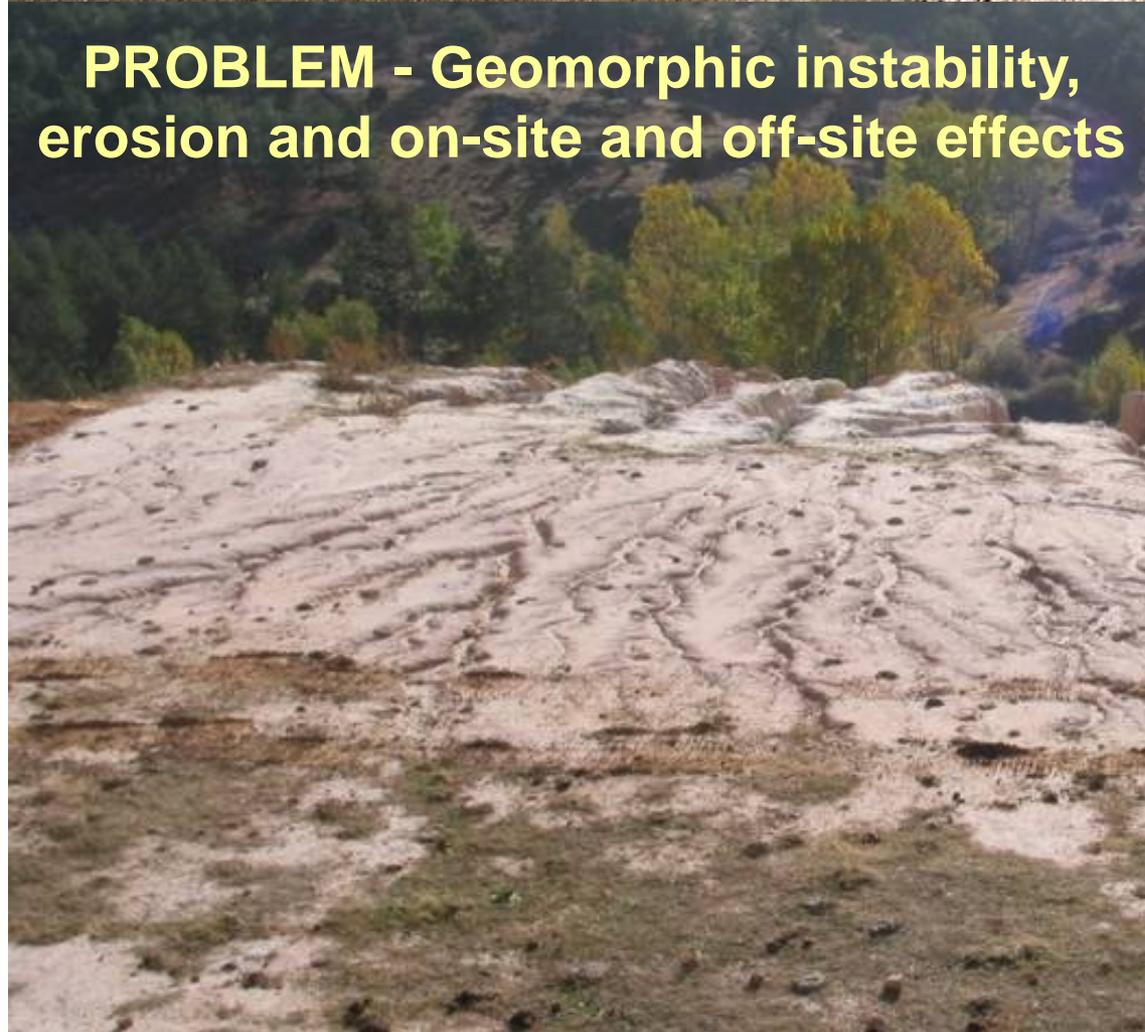


**PROBLEM – Degraded land in a rural area of Central Spain, characterized by high ecological and landscape quality**

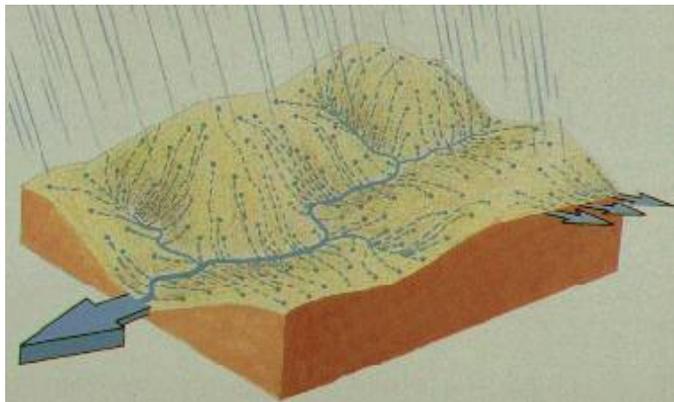
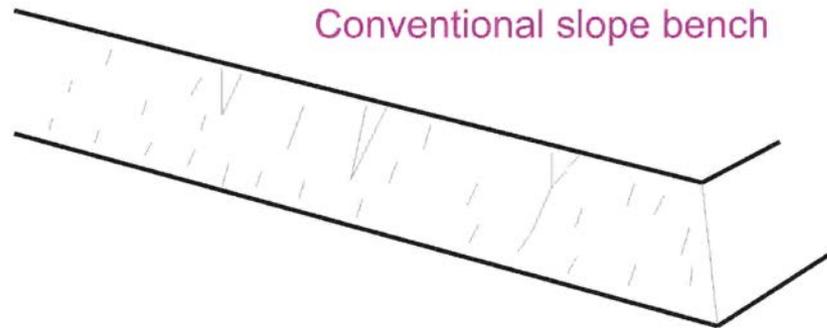
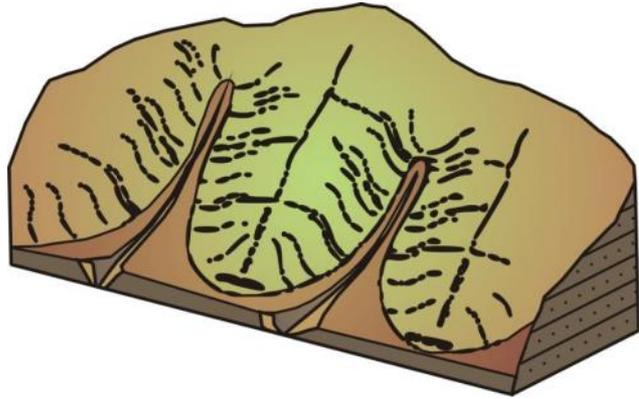




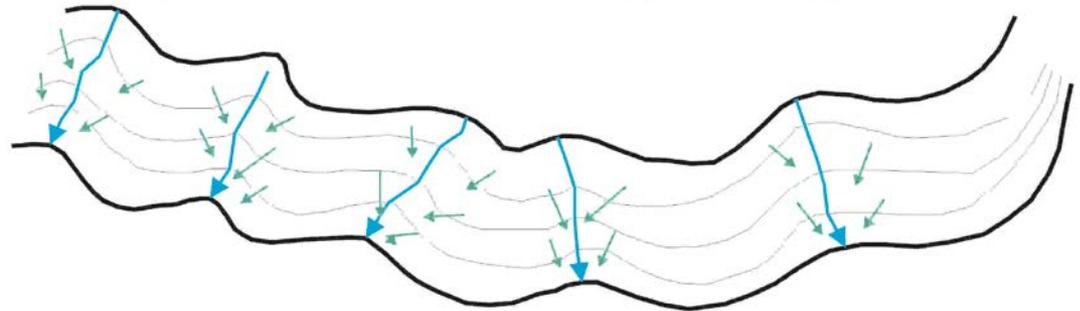
**PROBLEM - Geomorphic instability, erosion and on-site and off-site effects**



# SOLUTION – restoration and management of processes through landform design, following a “small slope watersheds” model (...playing by ear, 1)

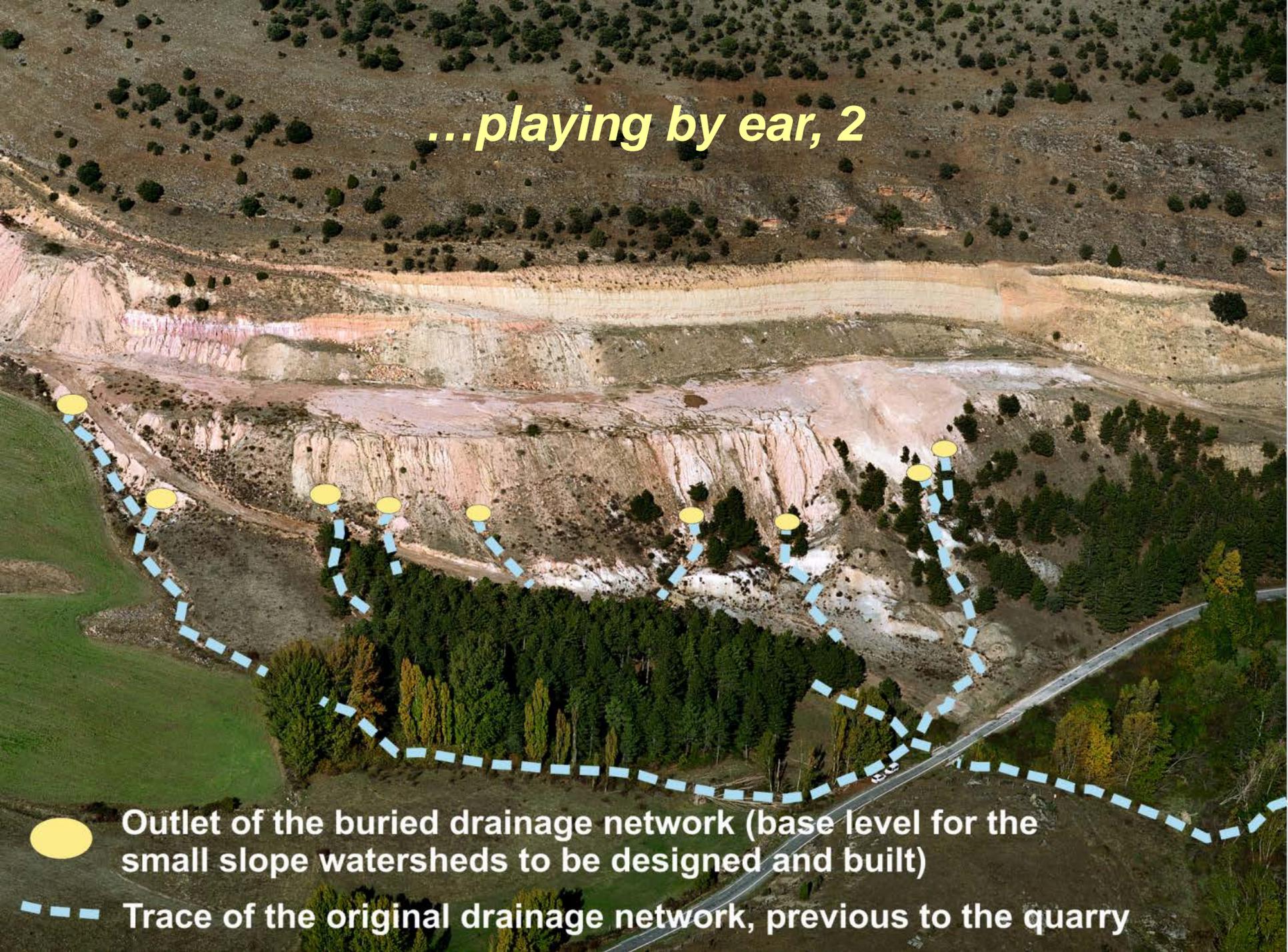


Proposal of reclamation building small slope watersheds



Adapted from: Schor HJ & Gray DH. 2007.  
*Landforming. An environmental approach to hillside development, mine reclamation and watershed restoration.* John Wiley and Sons, Hoboken.

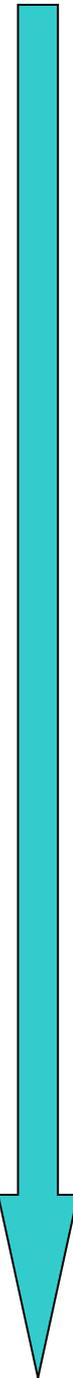
*...playing by ear, 2*



 Outlet of the buried drainage network (base level for the small slope watersheds to be designed and built)

 Trace of the original drainage network, previous to the quarry

# CONSTRUCTION AND RESULTS



# CONSTRUCTION AND RESULTS



May 5, 2014

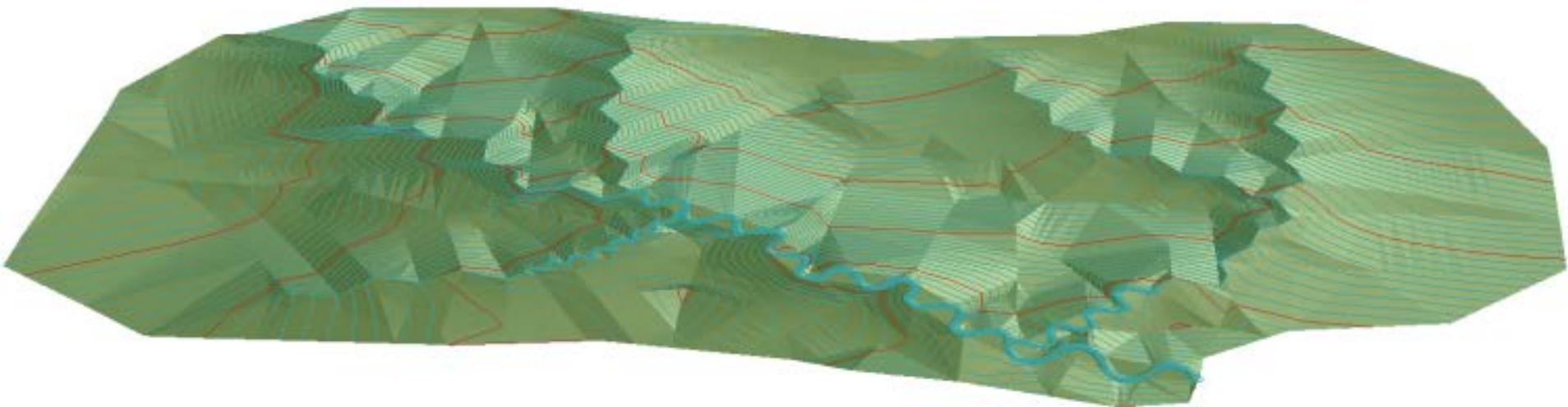
# MONITORING AND RESEARCH: very low sediment yield from the reclaimed areas

Measured sediment yield at two sediment ponds from December 2008 to June 2010



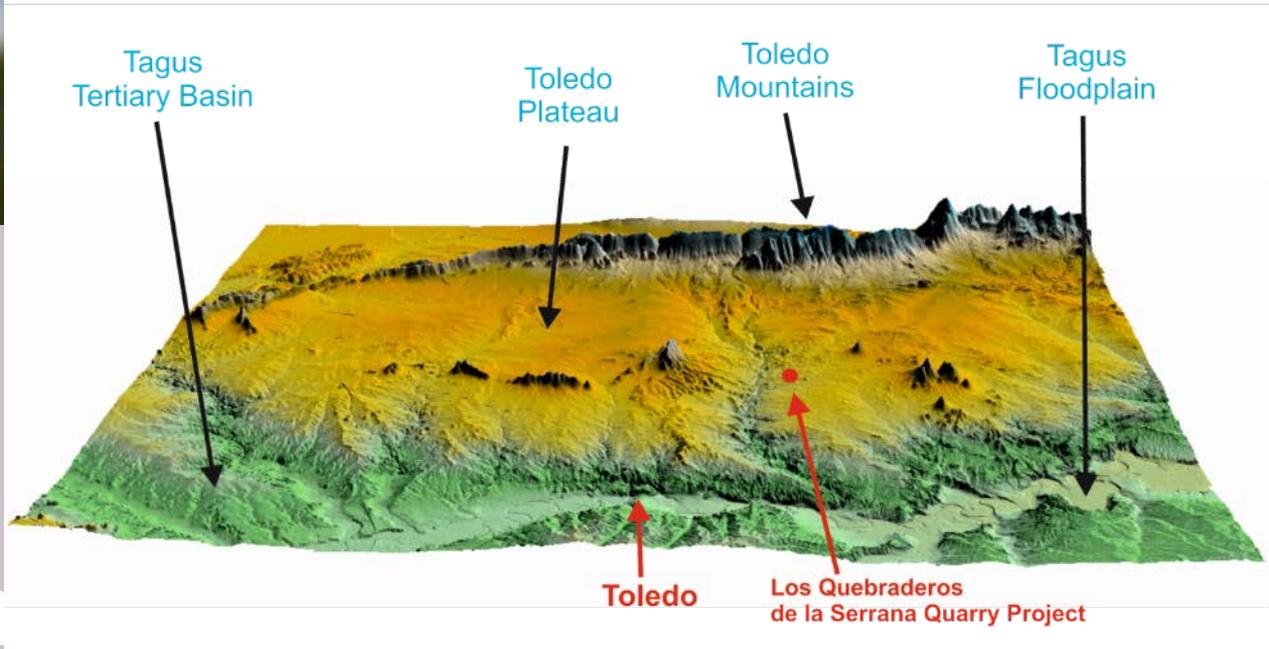
POND	Mass (kg)	Area (m <sup>2</sup> )	Rate (Mg ha <sup>-1</sup> year <sup>-1</sup> )
Pond 1 (no grazing)	2372.26	10.282	1.54
Pond 2 (grazed area)	1620.04	4.111	2.62

**FROM 2009, THE WORK OF OUR GROUP ON GEOMORPHIC RECLAMATION ON MINED LANDS OF SPAIN IS BASED ON GeoFluv™ (METHOD) AND USES NATURAL REGRADE (SOFTWARE) TO MAKE THE DESIGNS**

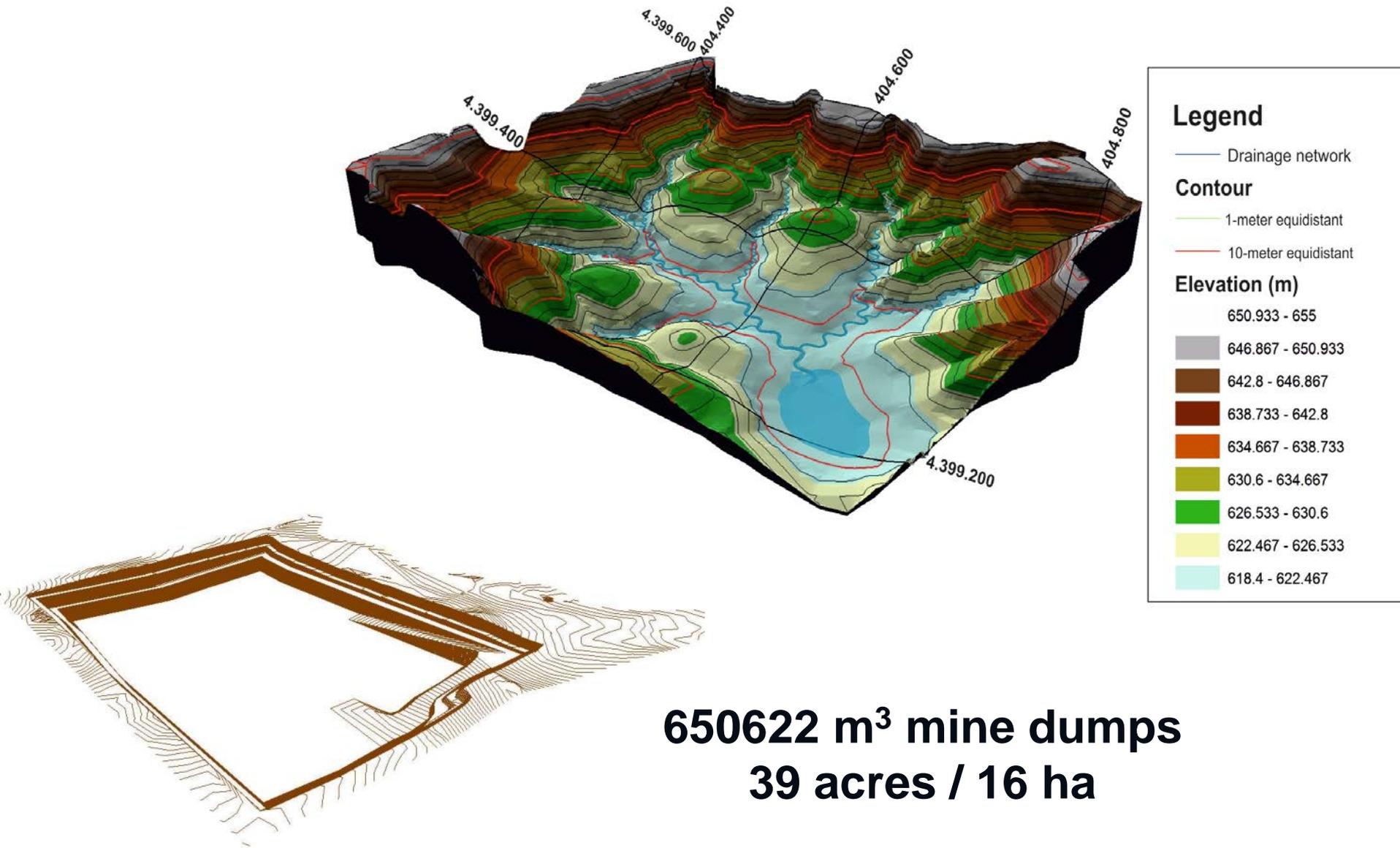




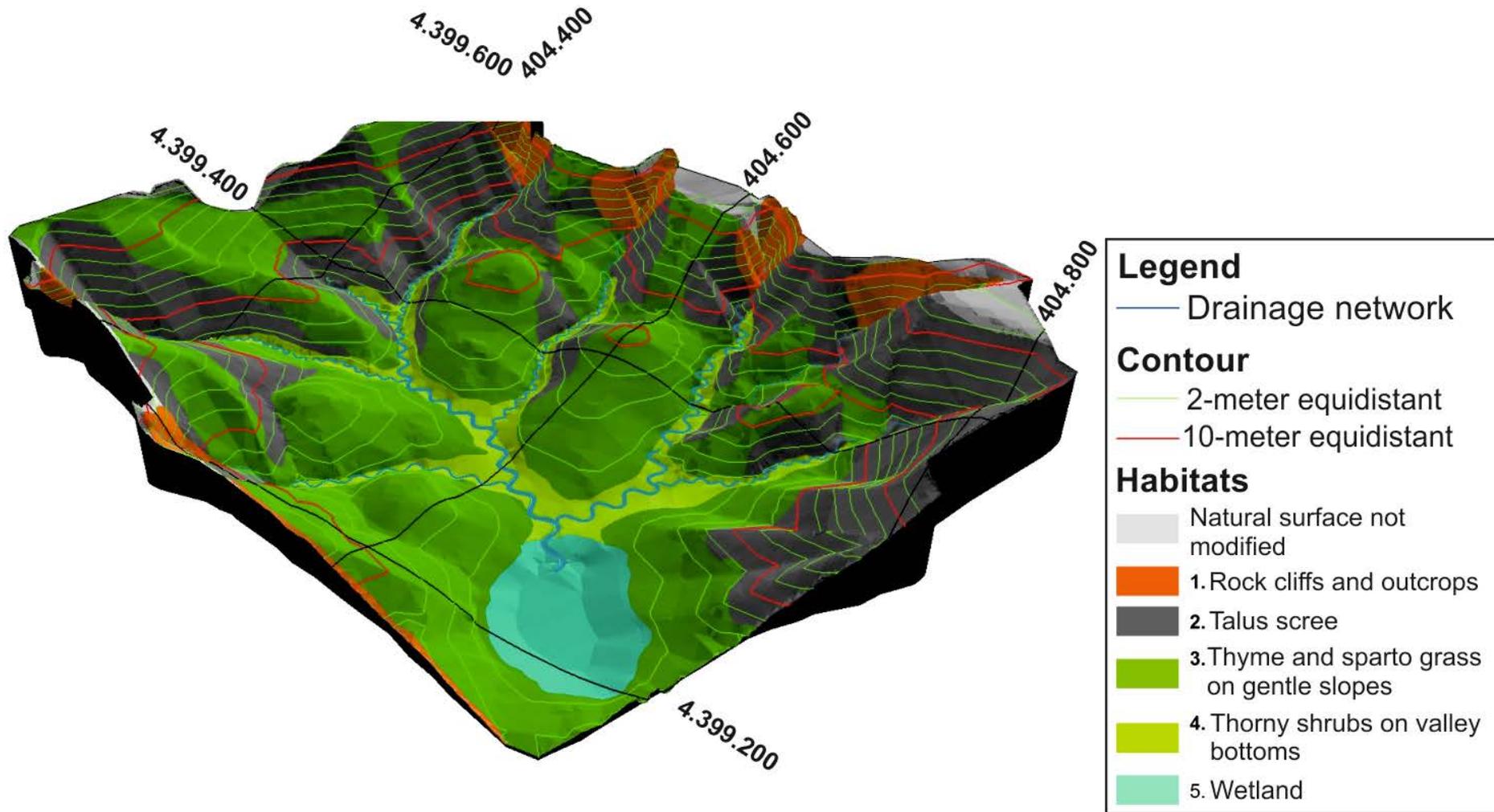
**PROBLEM – slate quarrying project in important Iberian (or Spanish) Imperial Eagle habitat (bird of prey on the verge of extinction – classified as critically endangered by the IUCN). The regulators did not authorize a previous project with a traditional reclamation approach**



# SOLUTION – a GeoFluv geomorphic reclamation design which replicates colluvial slope landforms...



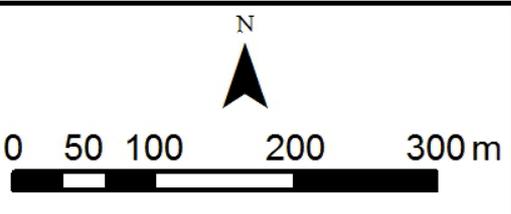
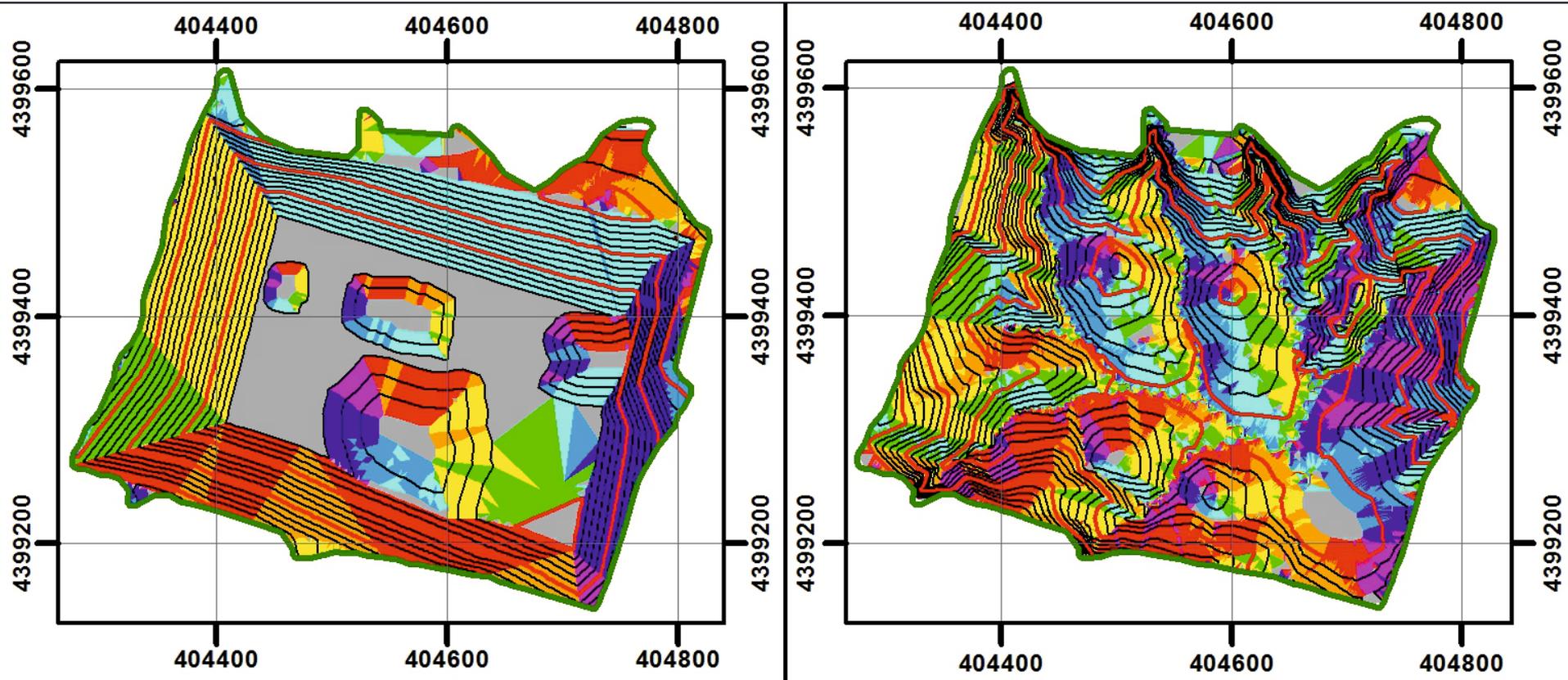
**SOLUTION – ... which are the basis for reconstructing rabbit habitats, which form the foundation of the Spanish Imperial Eagle's foodweb. PROJECT APPROVED. NOT A SINGLE PUBLIC ALLEGATION!**



# Traditional reclamation

*versus*

# GeoFluv reclamation



## Legend

- Equidistant contour 2 m
- Equidistant contour 10 m
- North
- Northeast
- East
- Southeast
- South
- Southwest
- West
- Northwest
- Flat

## 4) SOMOLINOS (GUADALAJARA)

1<sup>a</sup> Phase: Design and construction - 2011  
2<sup>a</sup> Phase: Design and construction - 2013

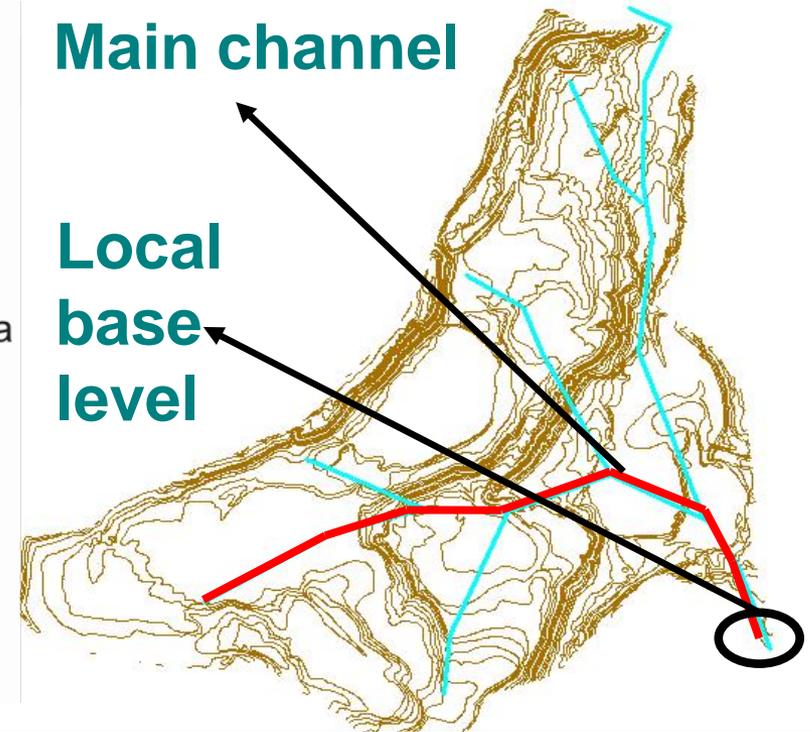
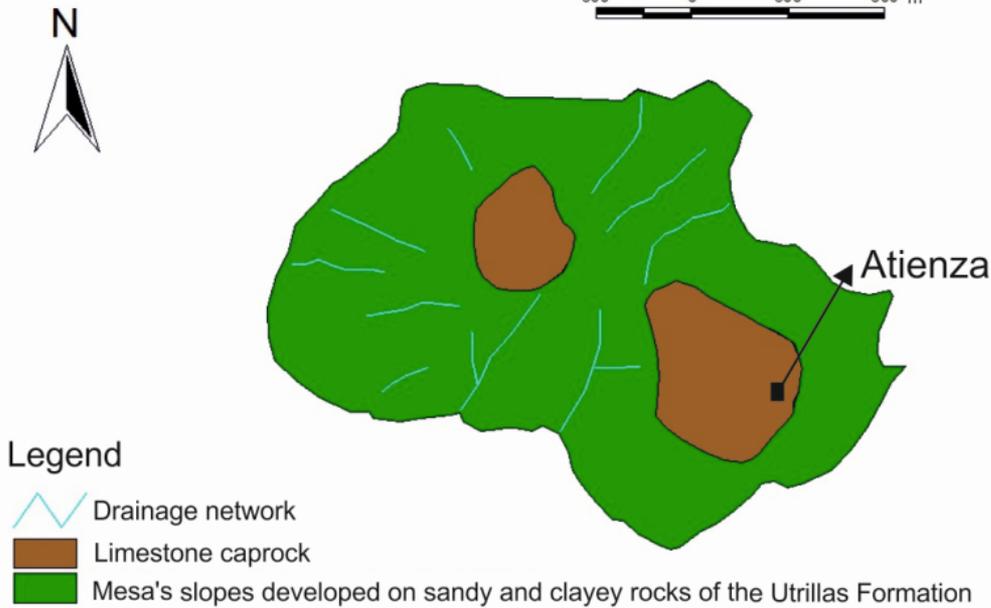




**PROBLEM – Degraded land in a rural area of Central Spain, characterized by high ecological and landscape quality, very close to a picturesque hamlet. Geomorphic instability, erosion and on-site and off-site effects**

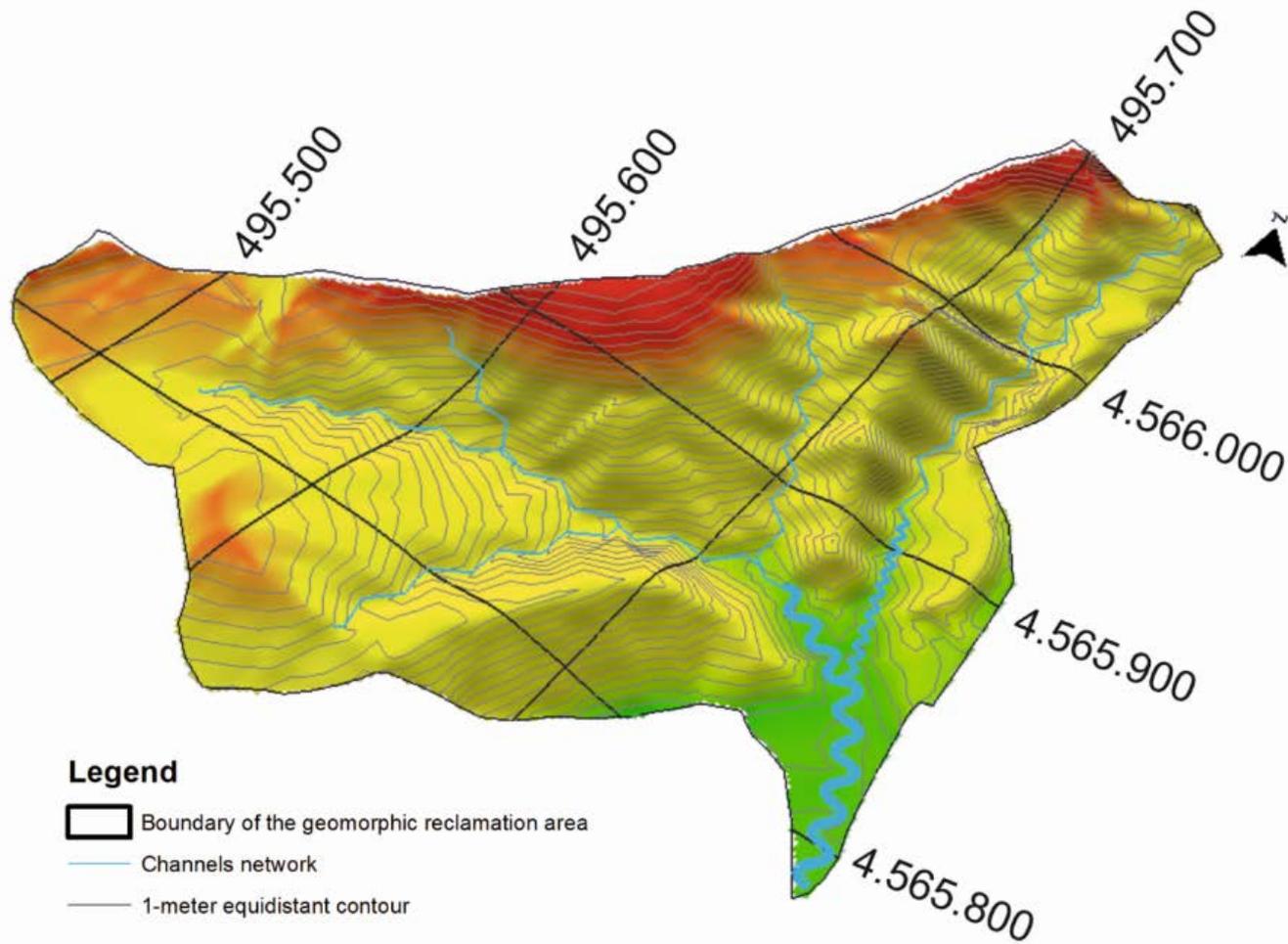
**Hydrological impact:  
off-site effects...  
from a quarry  
considered to be  
reclaimed by the  
regulators**





<b>INPUTS</b>	<b>Units</b>	<b>Value</b>
<b>Runoff coefficient</b>	<b>For one unit</b>	<b>0.3</b>
<b>2 year, 1 hour, precipitation</b>	<b>cm</b>	<b>1.84</b>
<b>50 year, 6 hour, precipitation</b>	<b>cm</b>	<b>8.52</b>
<b>Drainage density</b>	<b>m/ha</b>	<b>80</b>
<b>A channel reach</b>	<b>m</b>	<b>12.58</b>

# SOLUTION – GeoFluv design replicating stable reference landforms



## Legend

-  Boundary of the geomorphic reclamation area
-  Channels network
-  1-meter equidistant contour

## Elevation of the geomorphic reclamation area

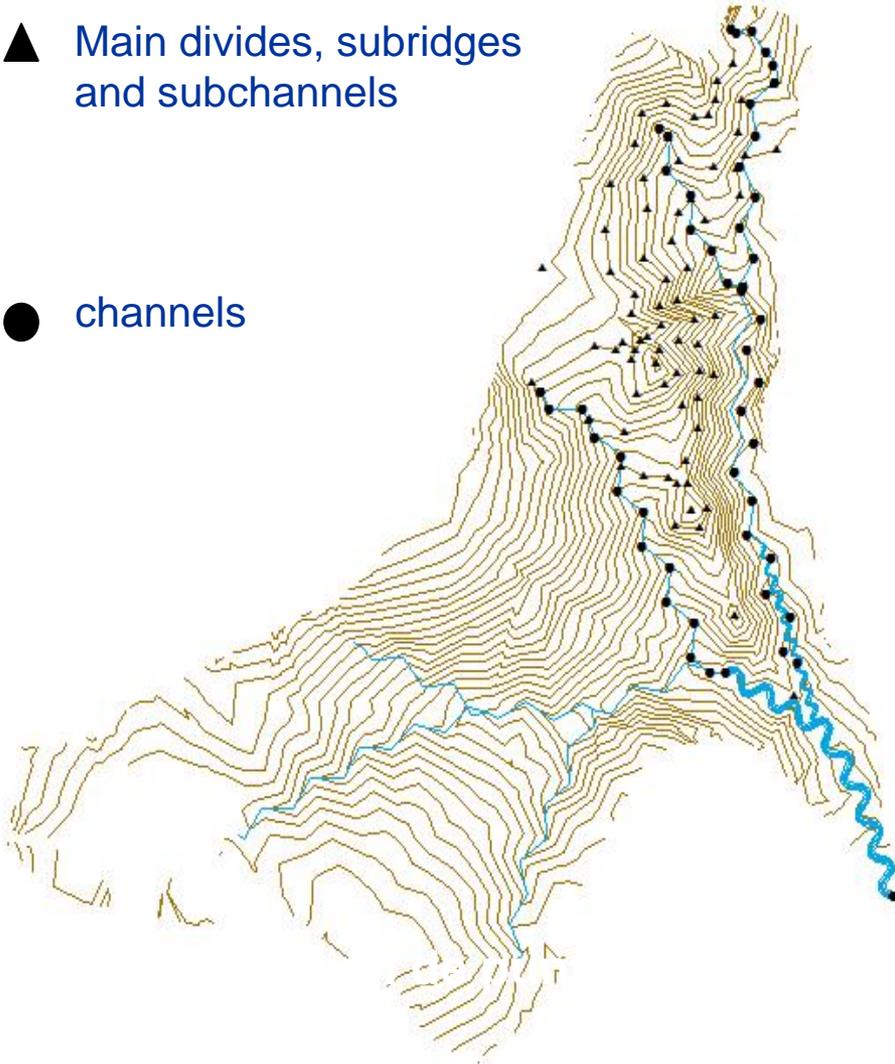
-  High : 1257.18 m
-  Low : 1224.09 m

# Construction used survey and stake

GPS machine guidance may also be used

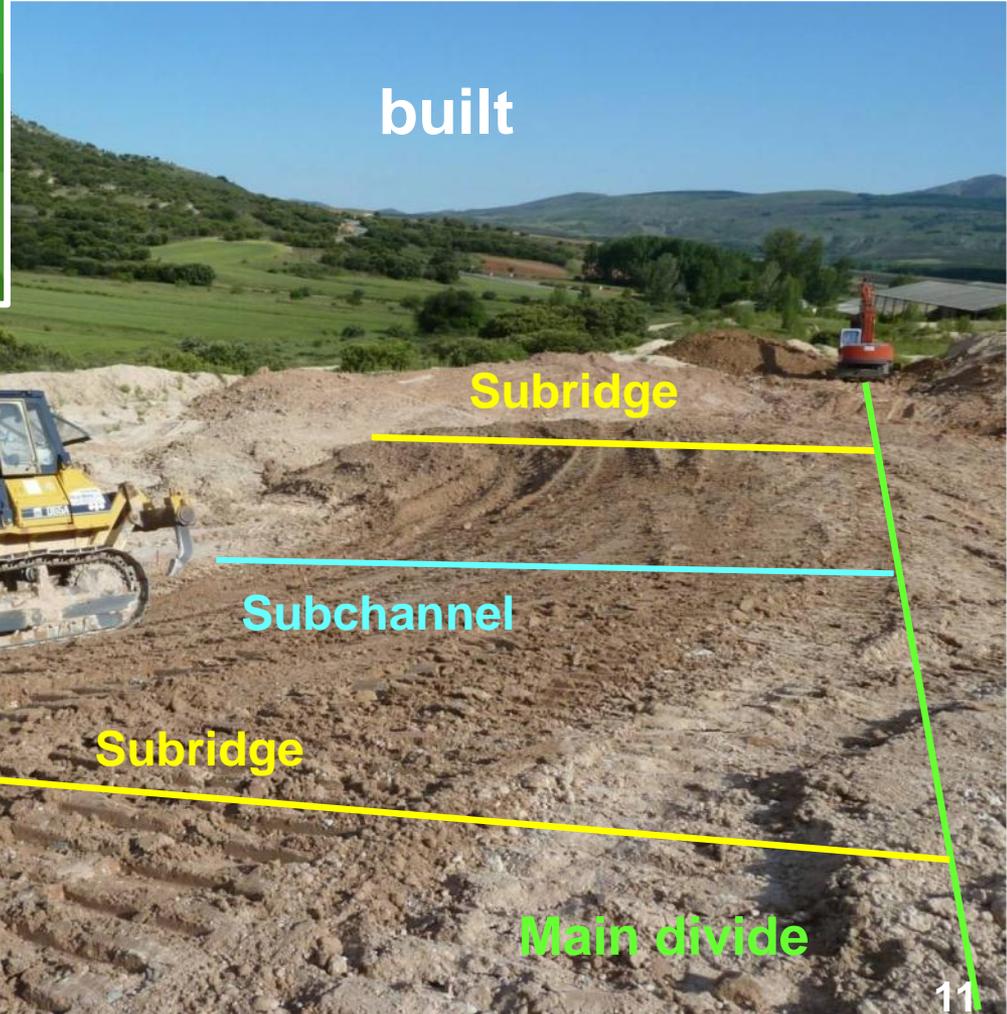
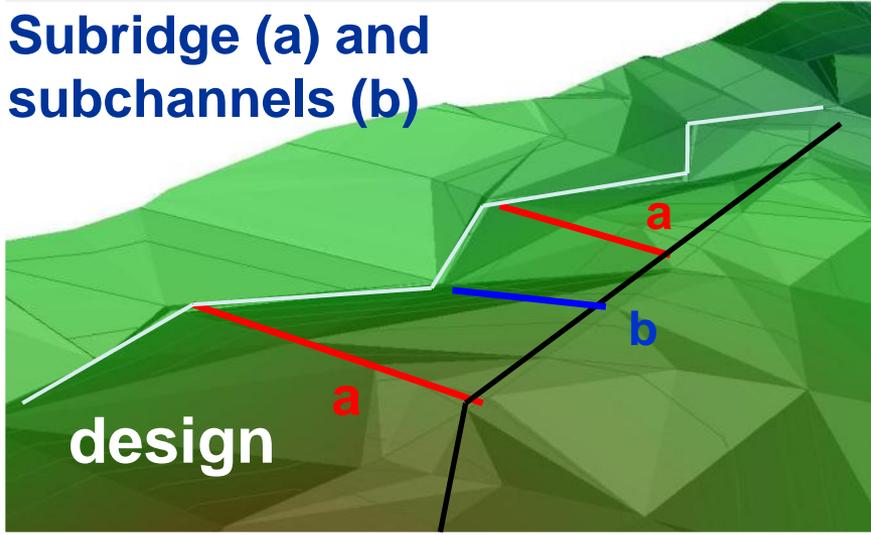
▲ Main divides, subbridges  
and subchannels

● channels



# Construction – Level 3 Training helped operators

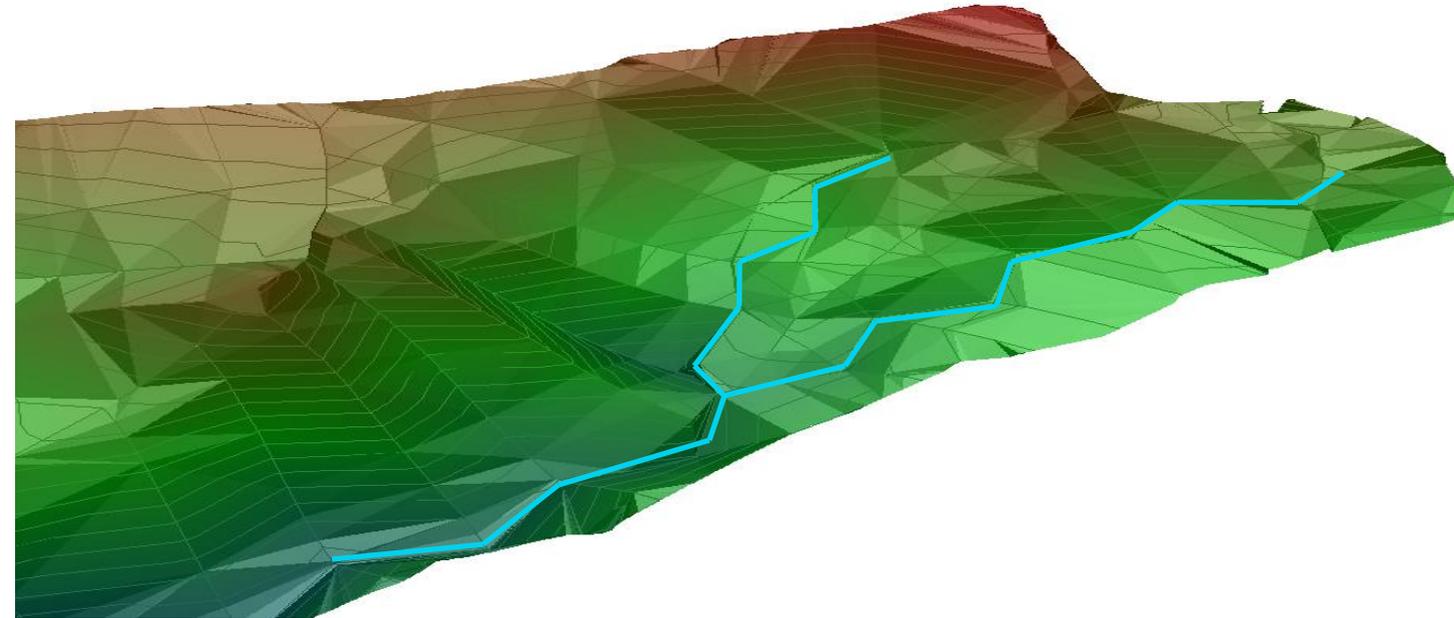
Subridge (a) and subchannels (b)



# CONSTRUCTION AND RESULTS



# First GeoFluv reclamation built in EUROPE (2011)



# CONSTRUCTION AND RESULTS



# CONSTRUCTION AND RESULTS



# CONSTRUCTION AND RESULTS

15 acres / 6.2 ha



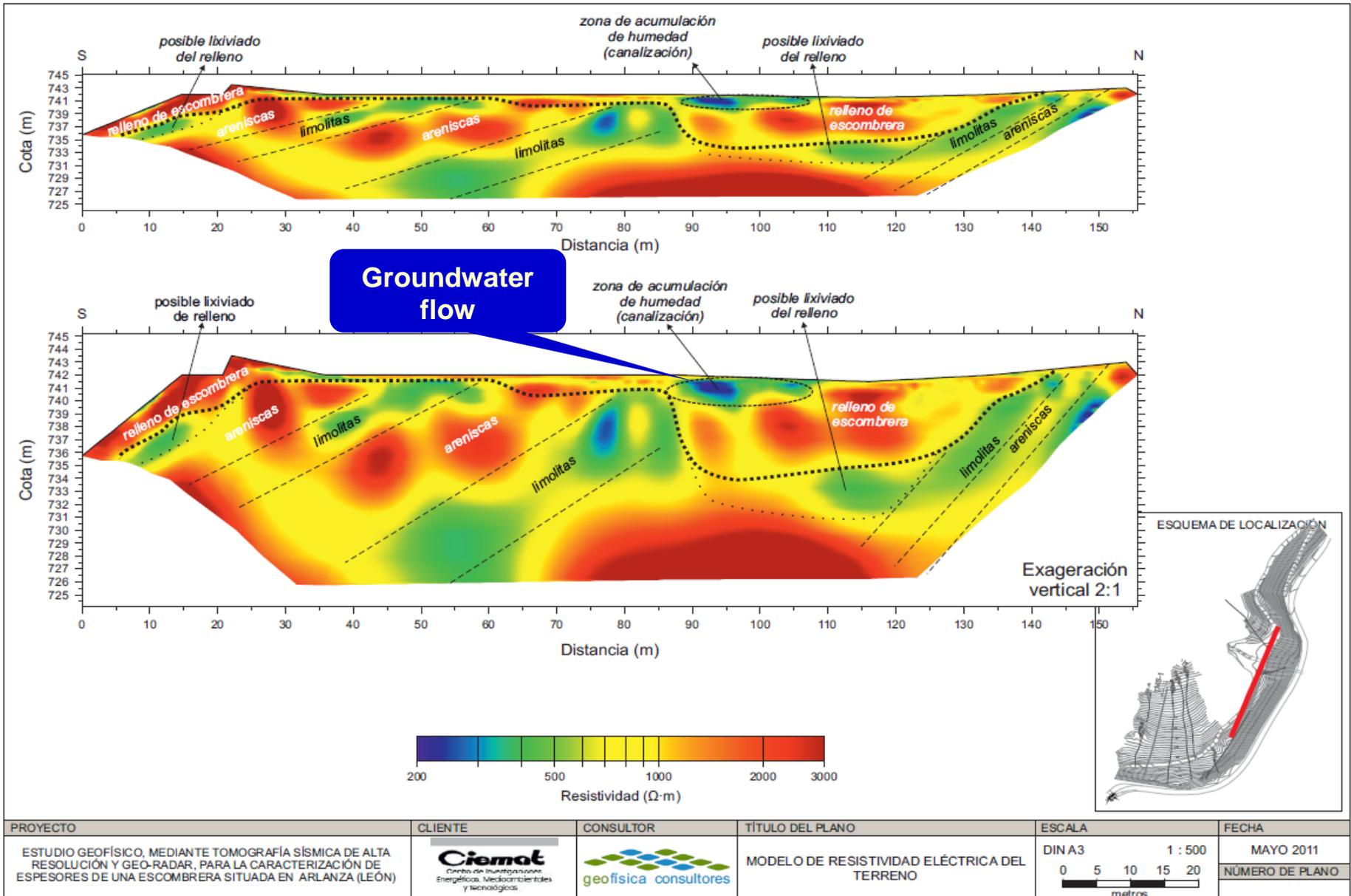
## 5) ARLANZA (LEÓN)

Design - 2011

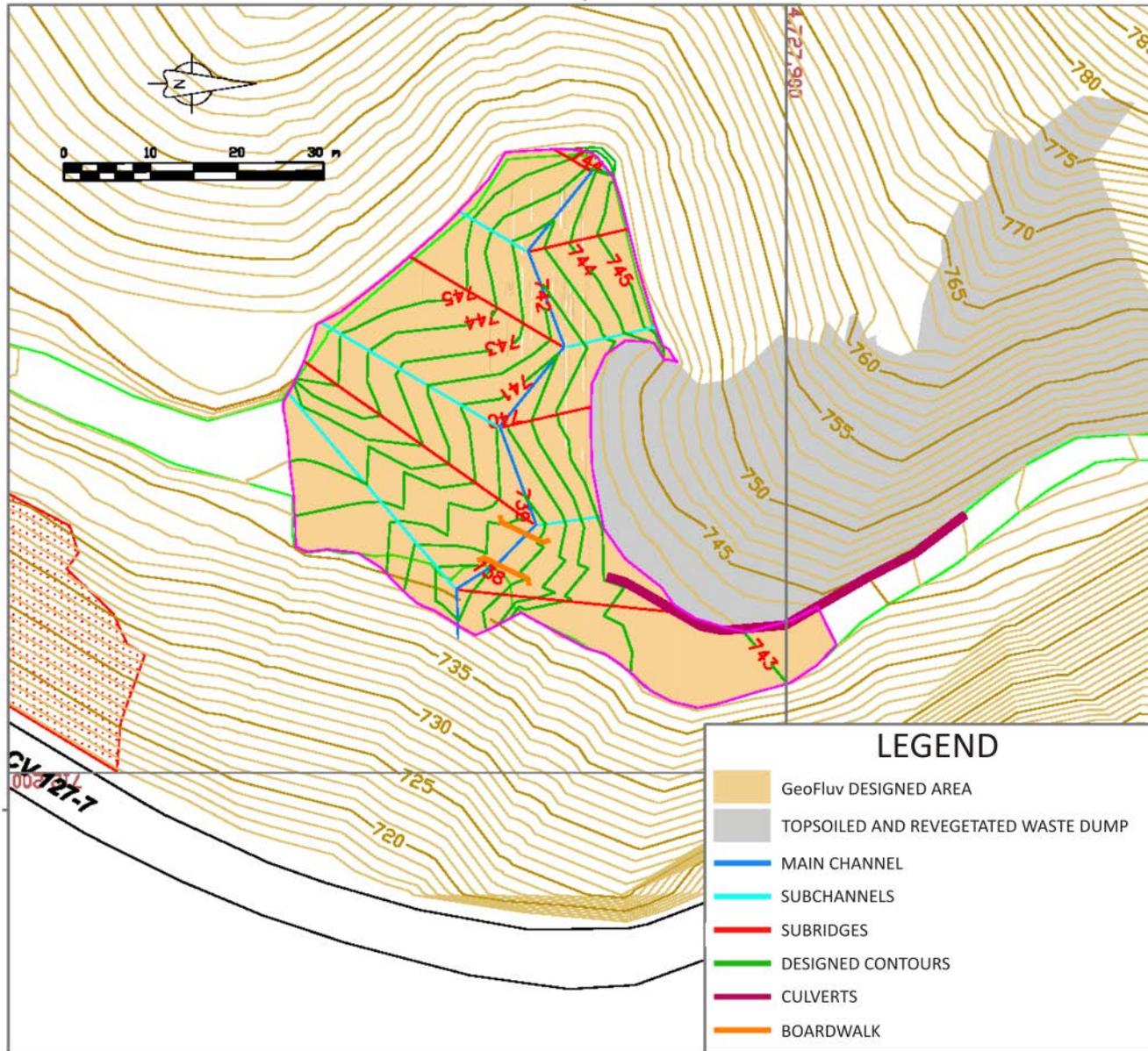




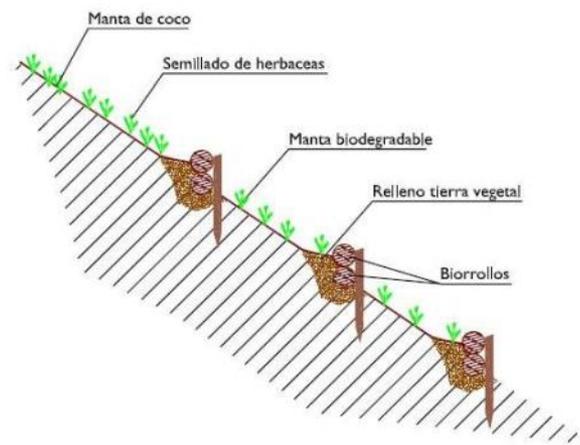
# ... and the artificial drainage does not work



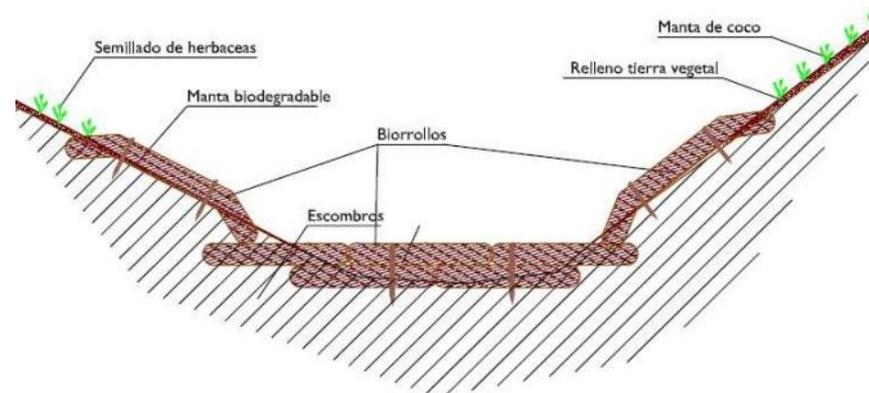
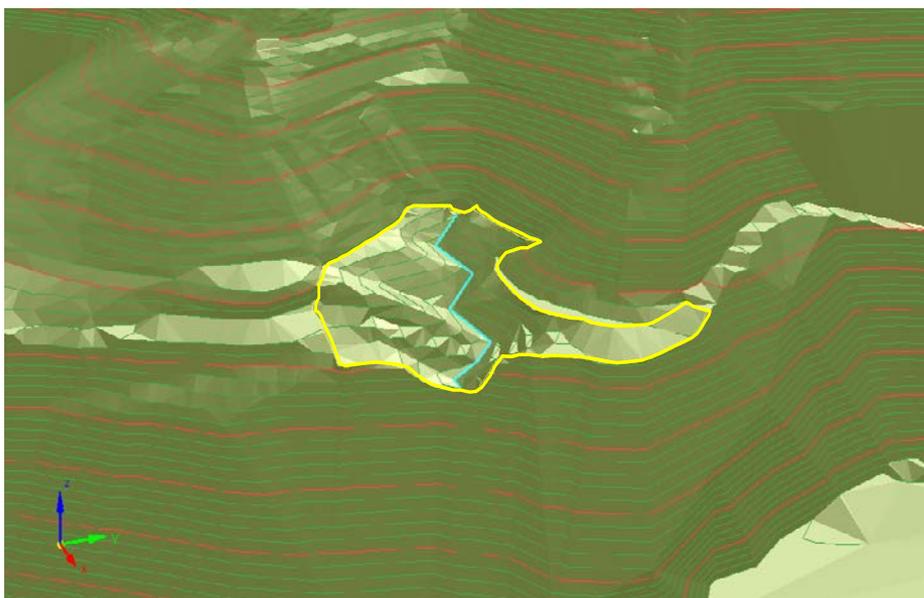
# SOLUTION – Restoring the hydrological connectivity (GeoFluv)



# GeoFluv geomorphic reclamation *versus* Bioengineering



SECCIÓN A-A'



SECCIÓN B-B'

## 6) EL MACHORRO (GUADALAJARA)

Design and construction  
2012

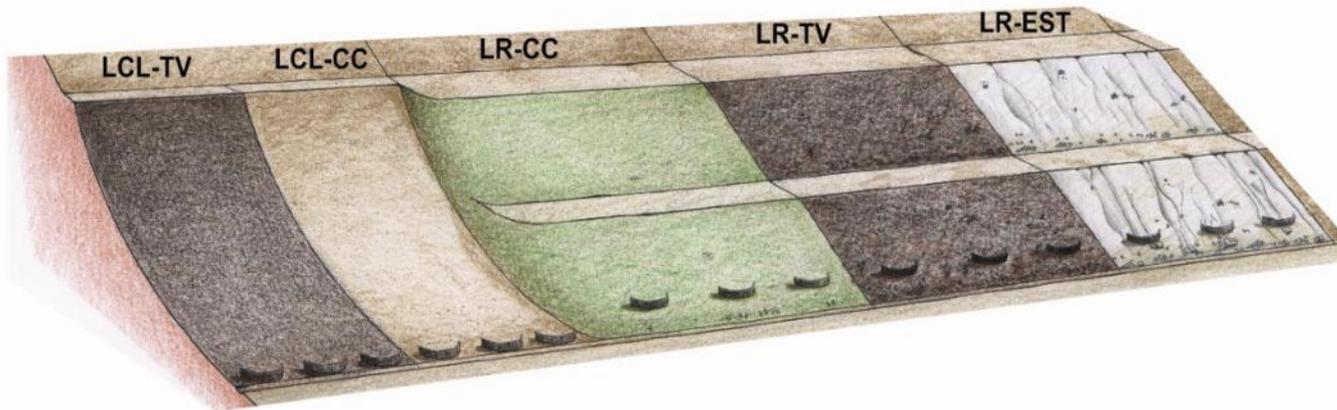


**PROBLEM – kaolin mine in a highly challenging site . . .  
. . . at the edge of a Natural Park and extremely vulnerable to  
water erosion**



**88 acres / 36 ha**

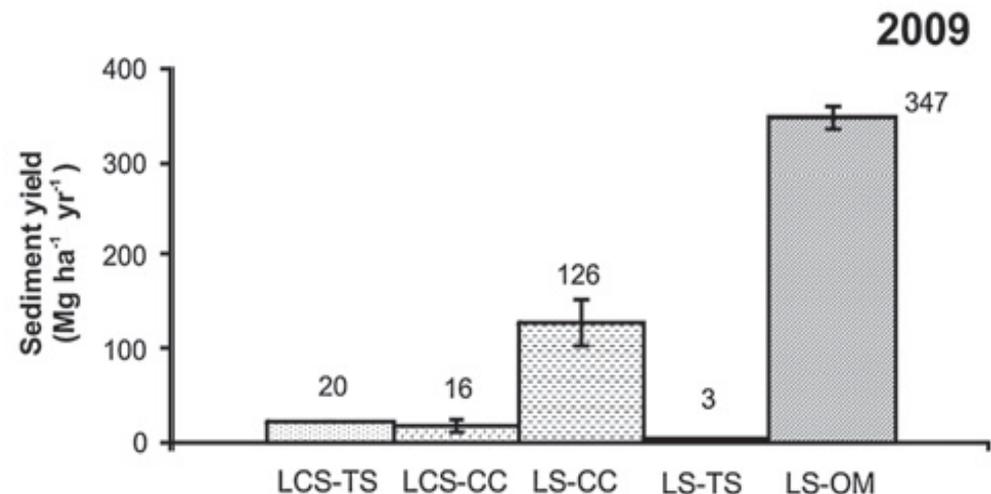
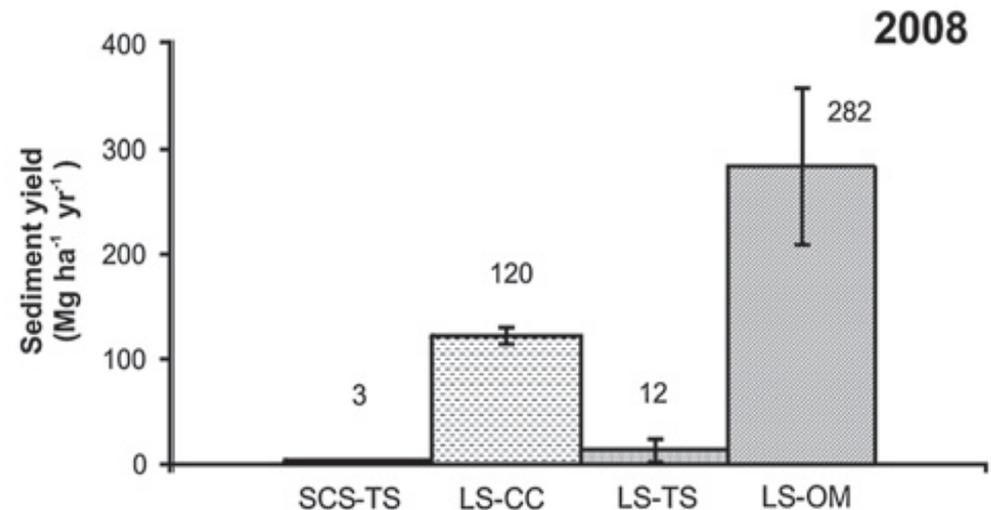
**SOLUTION (1<sup>ST</sup> PHASE) – simple modification of topography (concave) and surface soil cover (topsoil) of the traditional terraced landforms covered with subsoil; quantification of sediment yield of 5 treatments, by means of sediment fences, for two water years: 2008-2009 and 2009-2010**



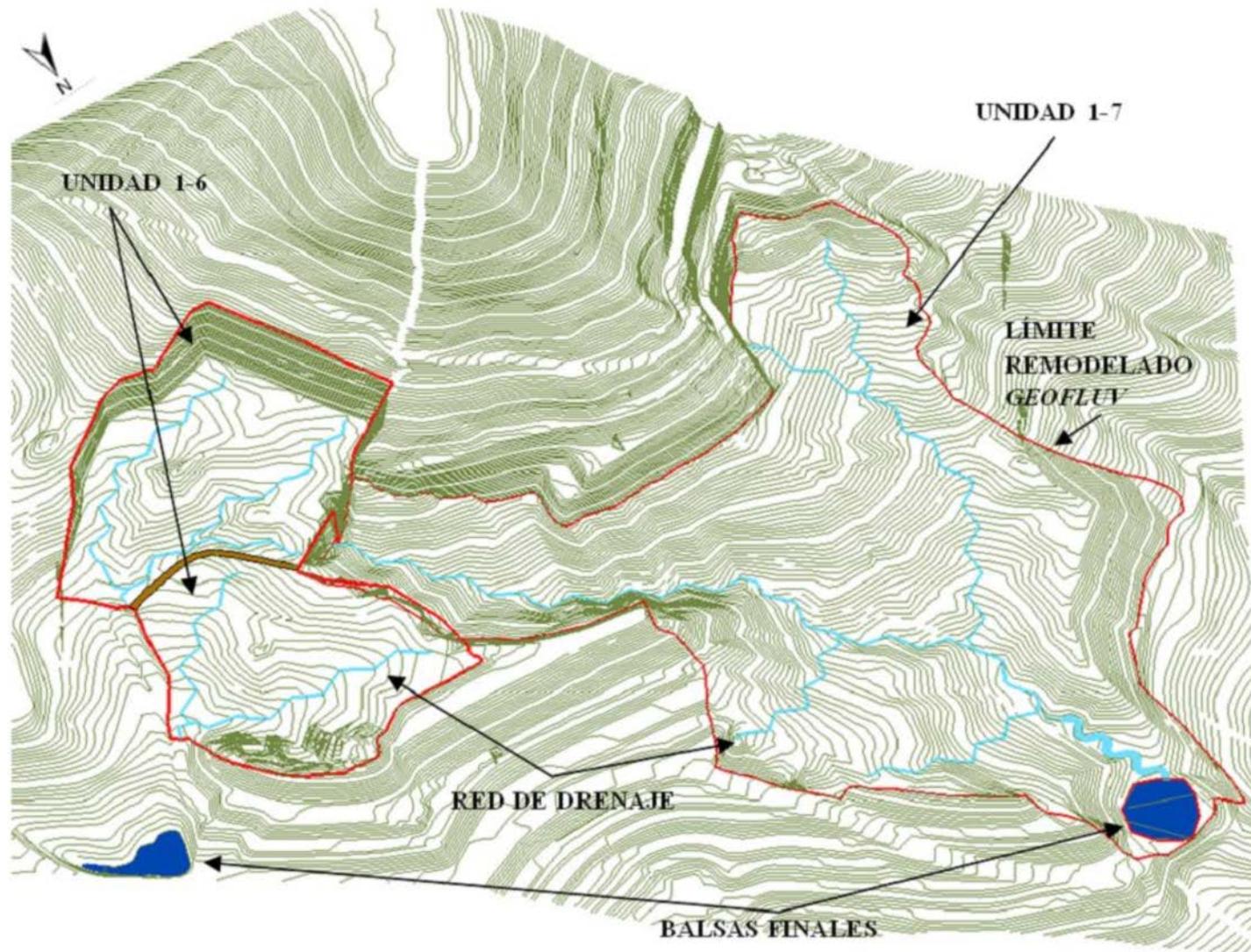
# RESULTS (1<sup>ST</sup> PHASE) – concave slopes yielded much less sediment than linear slopes; topsoiled slopes yielded much less sediment than subsoil-covered slopes

## LAND DEGRADATION & DEVELOPMENT

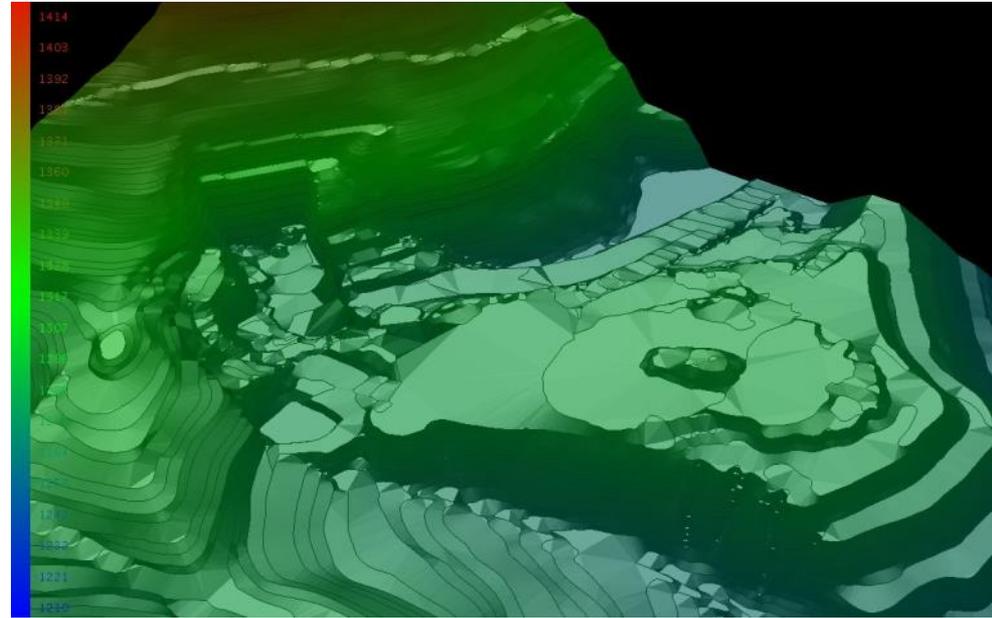
Martín-Moreno, C., Martín Duque, J.F., Nicolau, J.M., Hernando, N., Sanz, M. and Castillo, L. 2013. Effects of topography and surface soil cover on erosion for mining reclamation. The experimental spoil heap at El Machorro mine (Central Spain). Land Degradation & Development (in press), DOI: 10.1002/ldr.2232



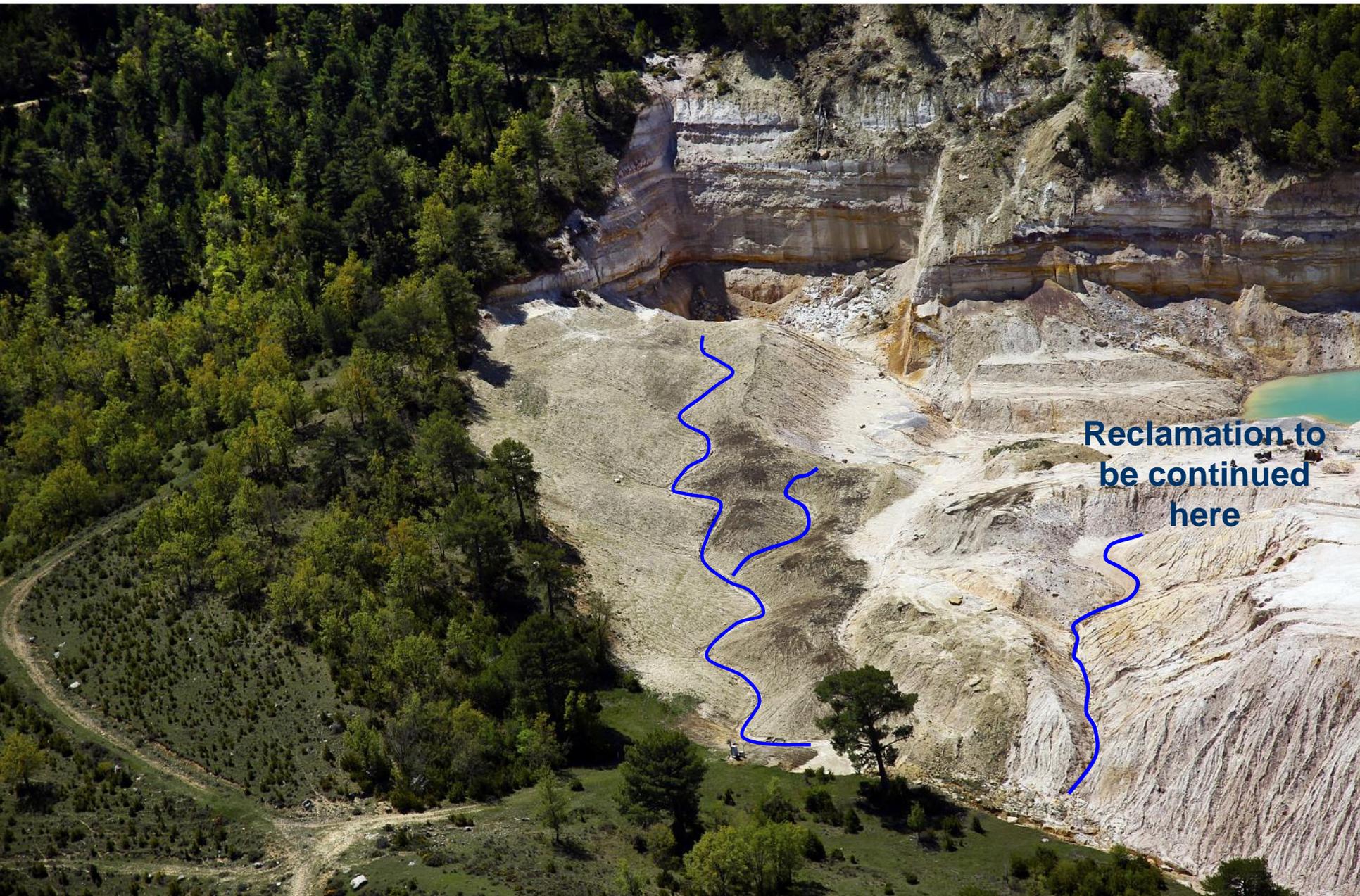
# SOLUTION (2<sup>ND</sup> AND DEFINITIVE PHASE) - building stable landforms and maximizing landscape and ecological integration by means of a GeoFluv approach



# CONSTRUCTION AND RESULTS



# CONSTRUCTION AND RESULTS



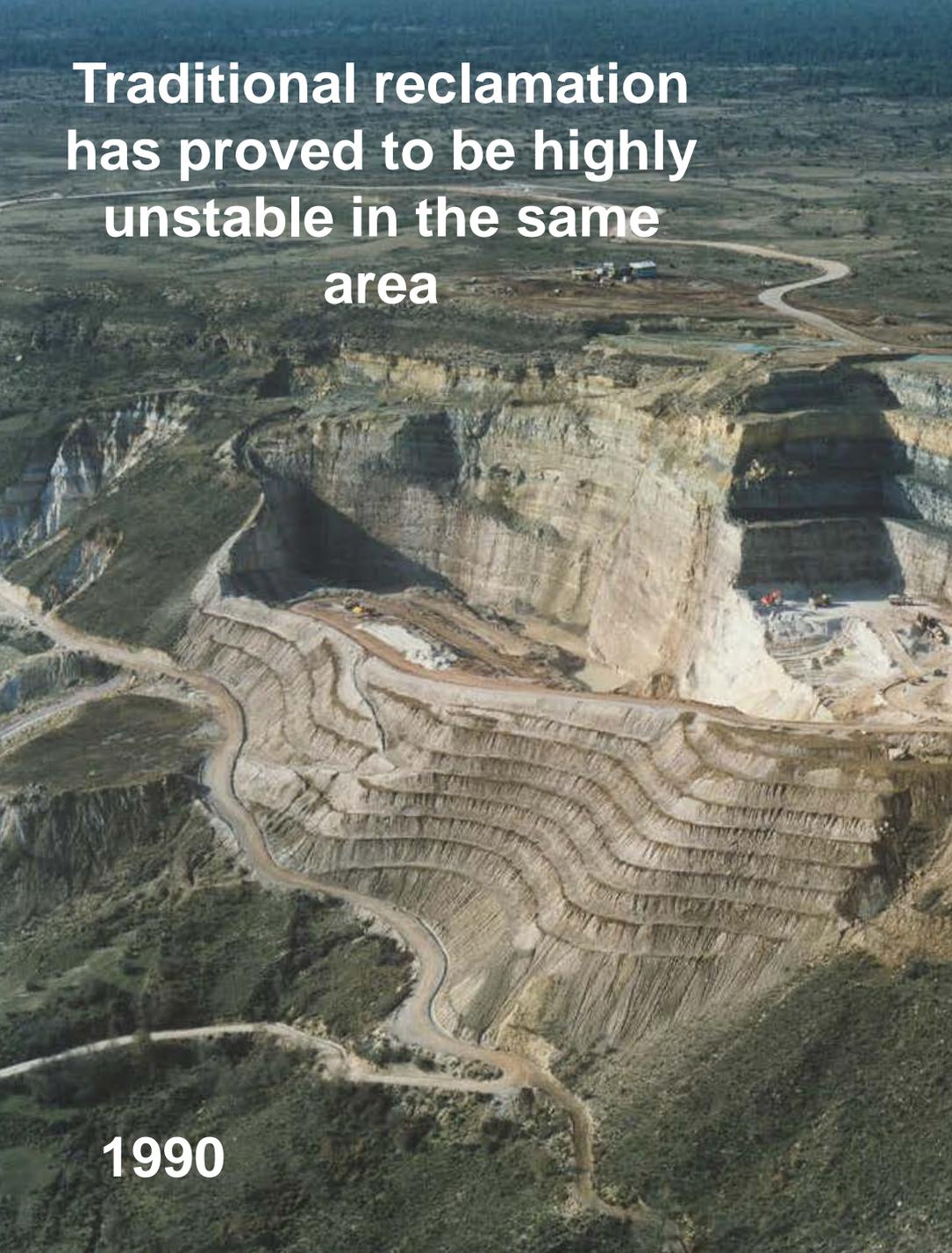
Reclamation to  
be continued  
here



# GeoFluv geomorphic reclamation *versus* traditional reclamation



**Traditional reclamation  
has proved to be highly  
unstable in the same  
area**



**1990**



**2007**



**2010**



More than 800000 € have been spoiled in building ineffective check dams downstream of the mines

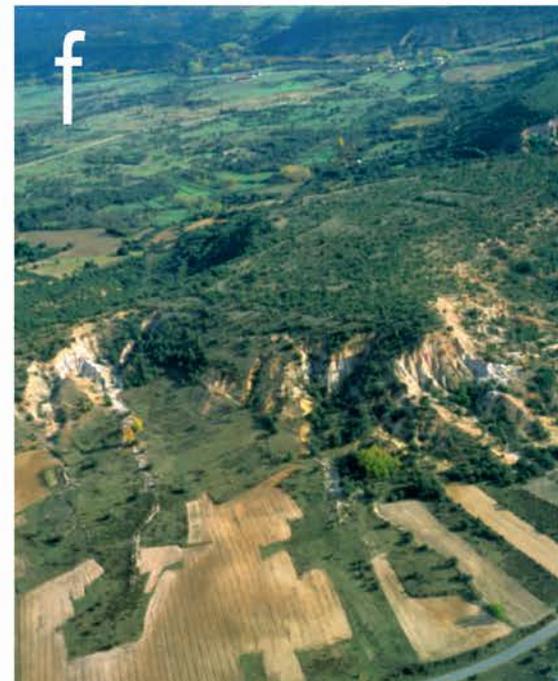
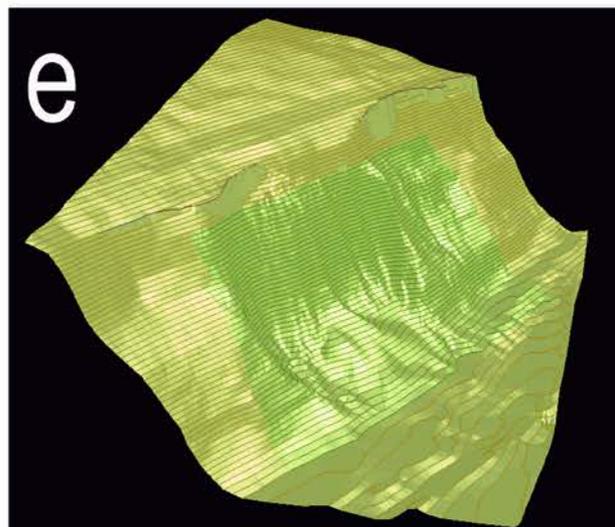
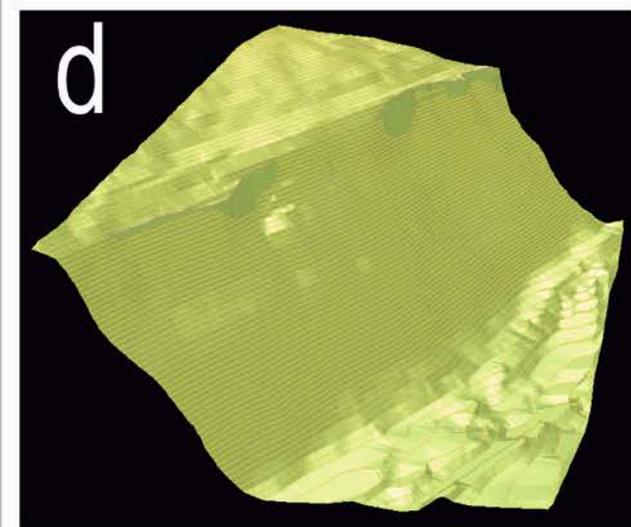
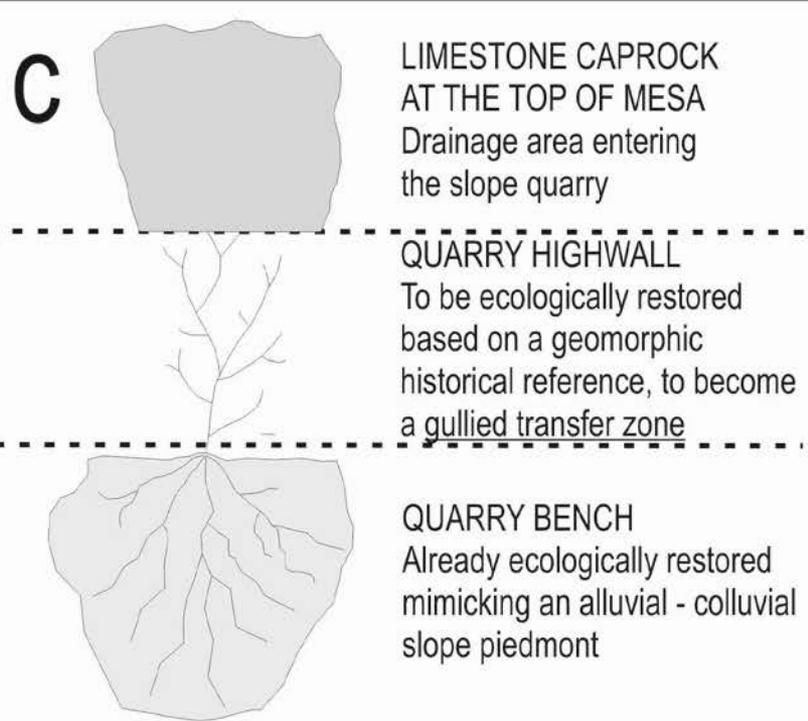
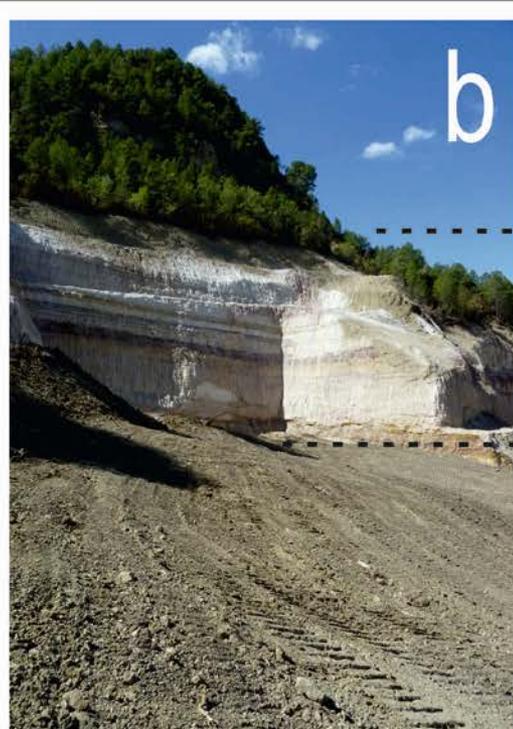
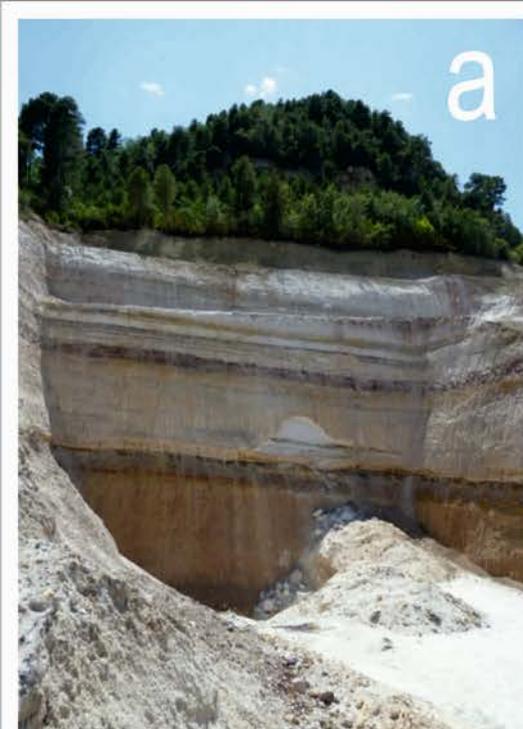


# GeoFluv geomorphic reclamation *versus* traditional reclamation









# Optimum 'stitching' with the environment



# CONSTRUCTION AND RESULTS

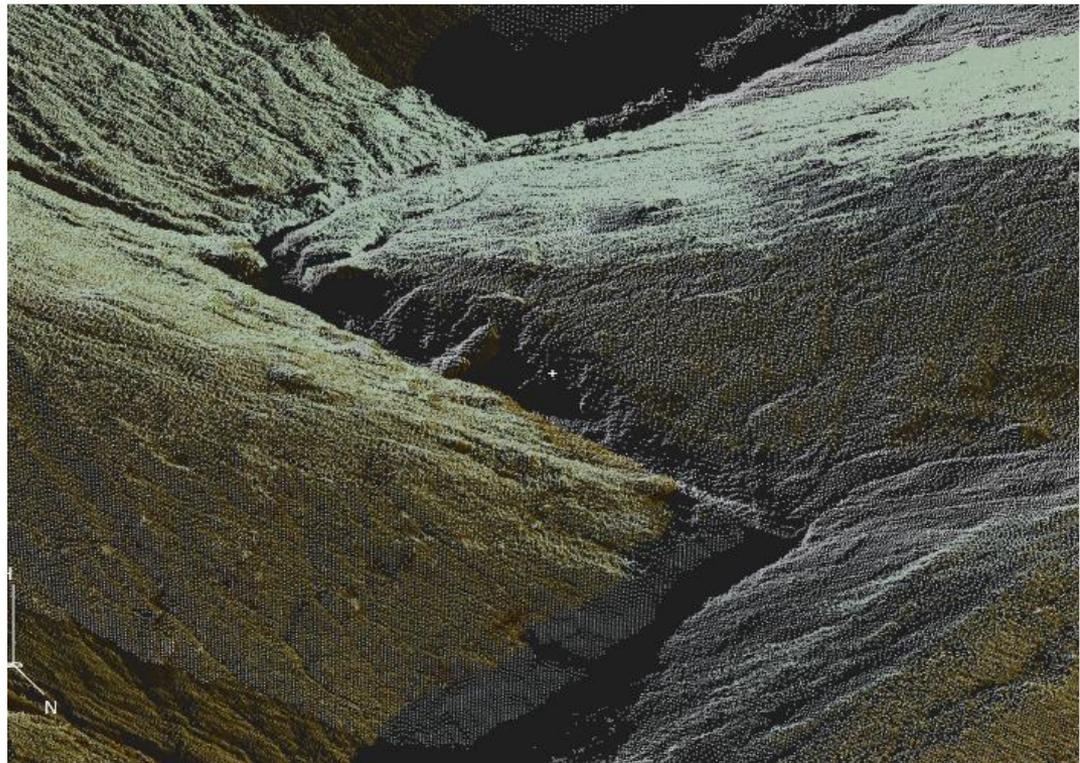
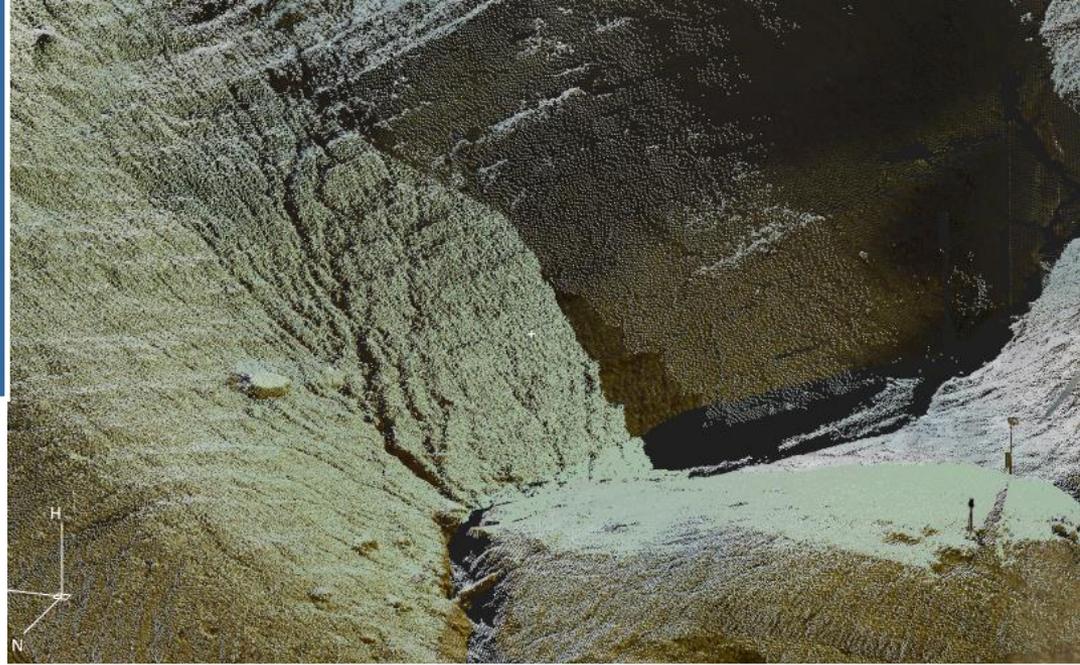


# CONSTRUCTION AND RESULTS

# MONITORING AND RESEARCH – quantifying the hydrological and erosive response of the GeoFluv geomorphically restored areas (flume, pressure sensor, turbidimeter)



# MONITORING / RESEARCH: Quantification of erosion by using TLS and Multistation



# 7) MARÍA JOSÉ (GUADALAJARA)

Design - 2012  
Construction - 2013



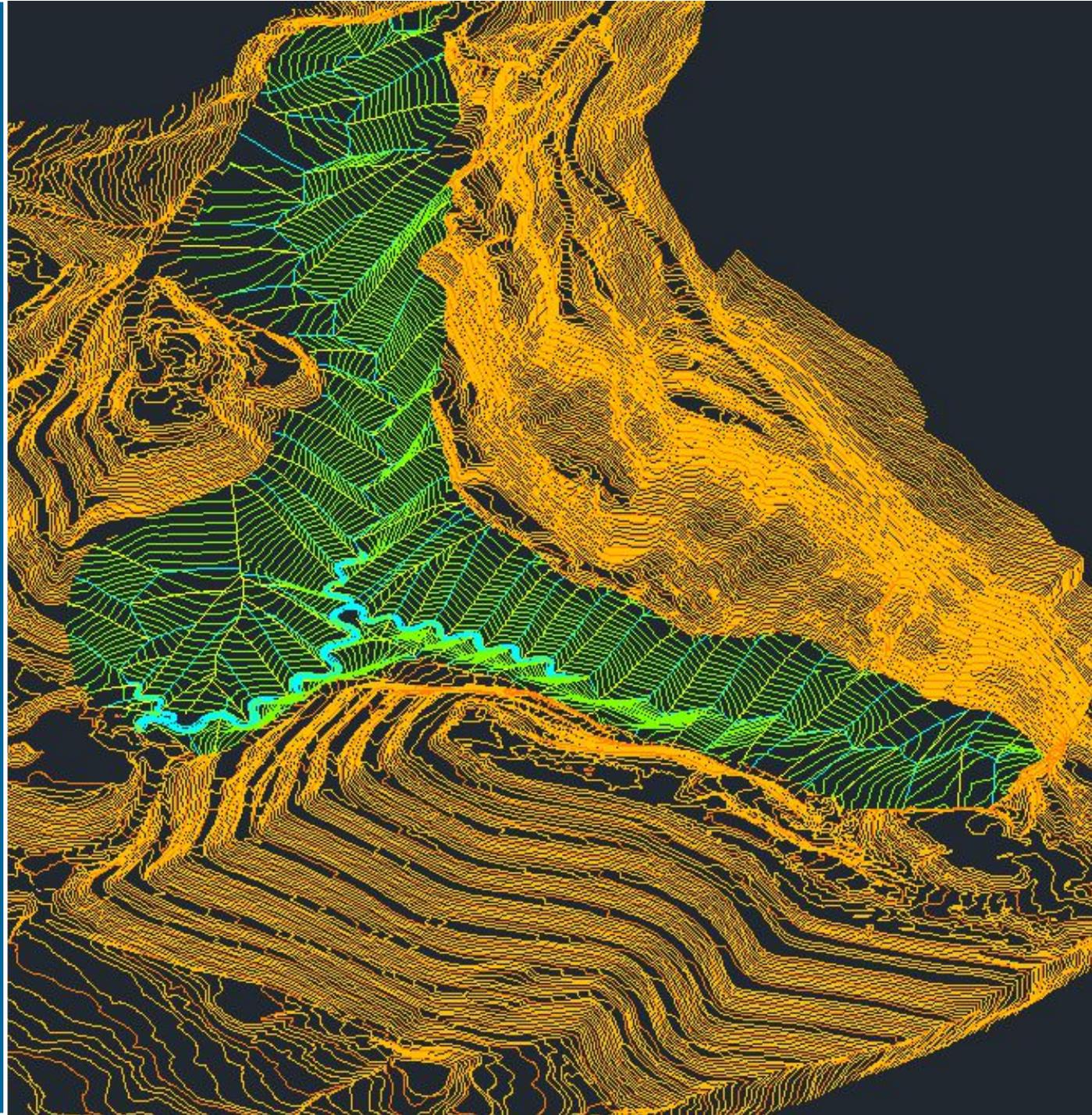
**PROBLEM – same as El Machorro, but with a traditional approach of reclamation since 1965 (severe physiographic transformation)**

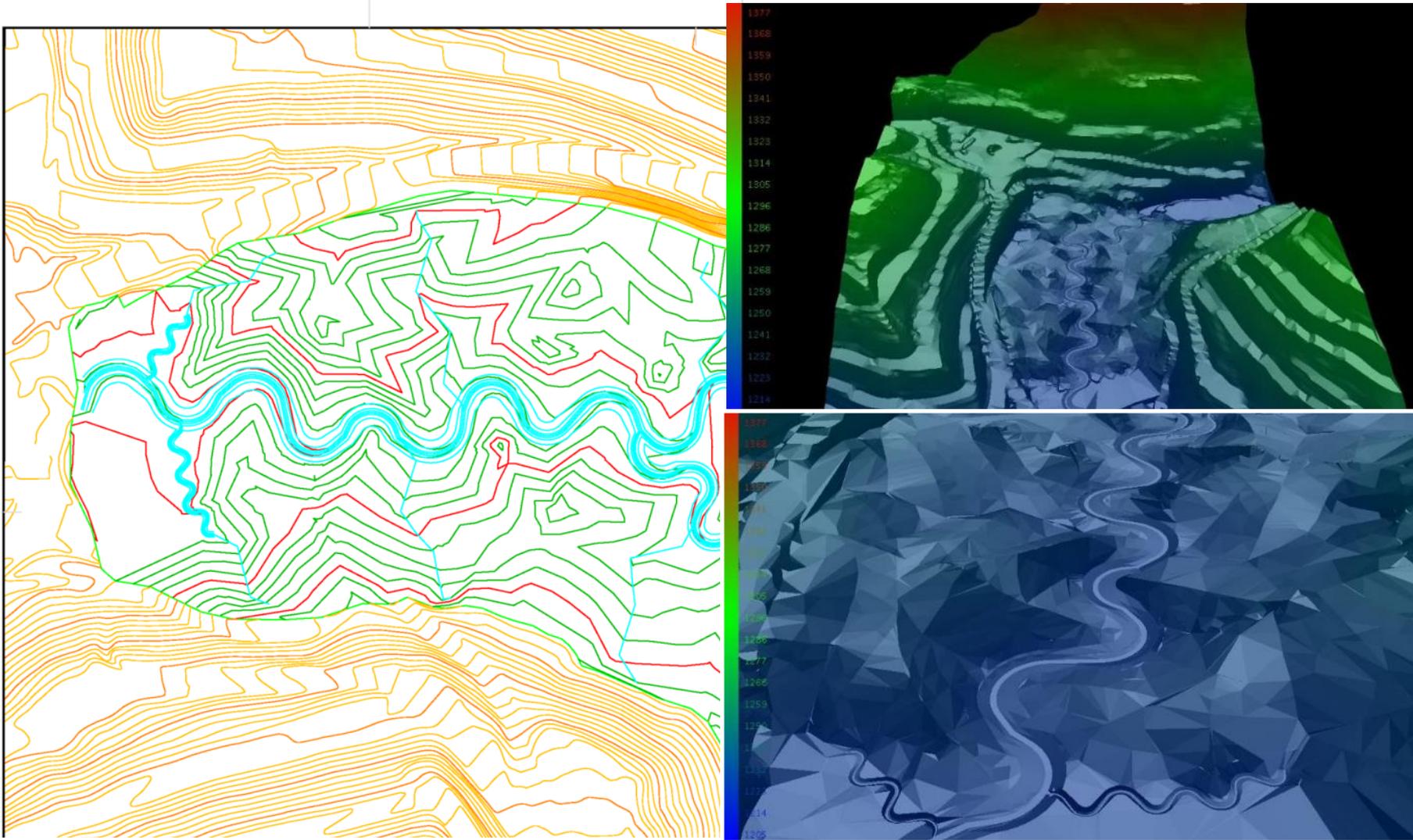


## SOLUTION

GeoFluv  
regrade /  
reshape of the  
valley made by  
the mine  
(between the  
highwall and the  
waste dumps)

CONCEPTUAL  
DESIGN  
FOR 34 ACRES  
/ 14 ha





**SOLUTION - GeoFluv regrade / reshape of the valley created by the mine (between the highwall and the waste dumps) – 6 acres / 2.5 ha CONSTRUCTIBLE DESIGN**

# CONSTRUCTION AND RESULTS



***And an example of how things should not be done: the builders did not respect the base level altitude!***

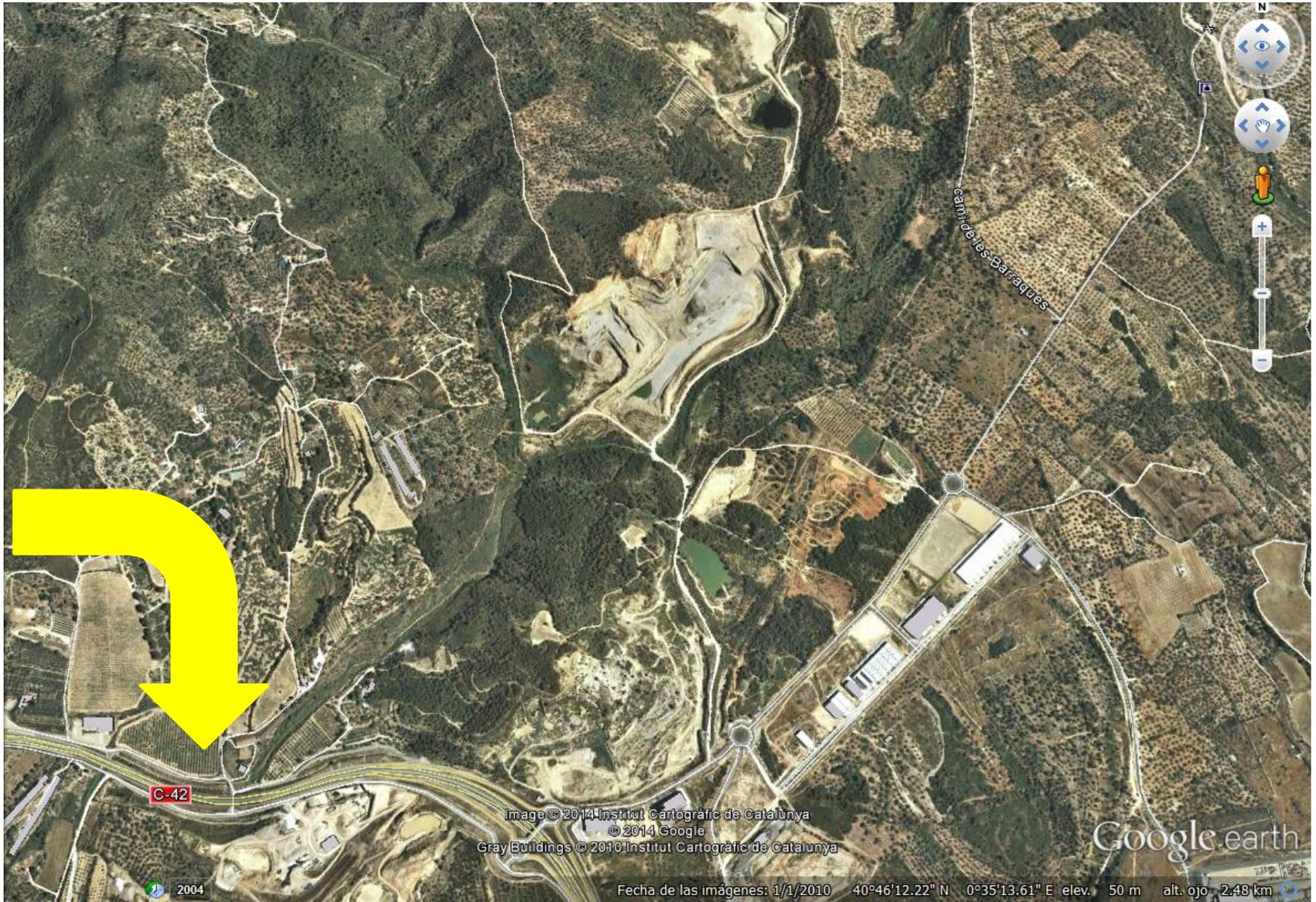


## 8) CAMPREDÓ (TARRAGONA)

Design - 2013  
Construction – 2014 / 2018



# PROBLEM – in addition to the land degradation by mining, there are nearby problems of flooding caused by a highway

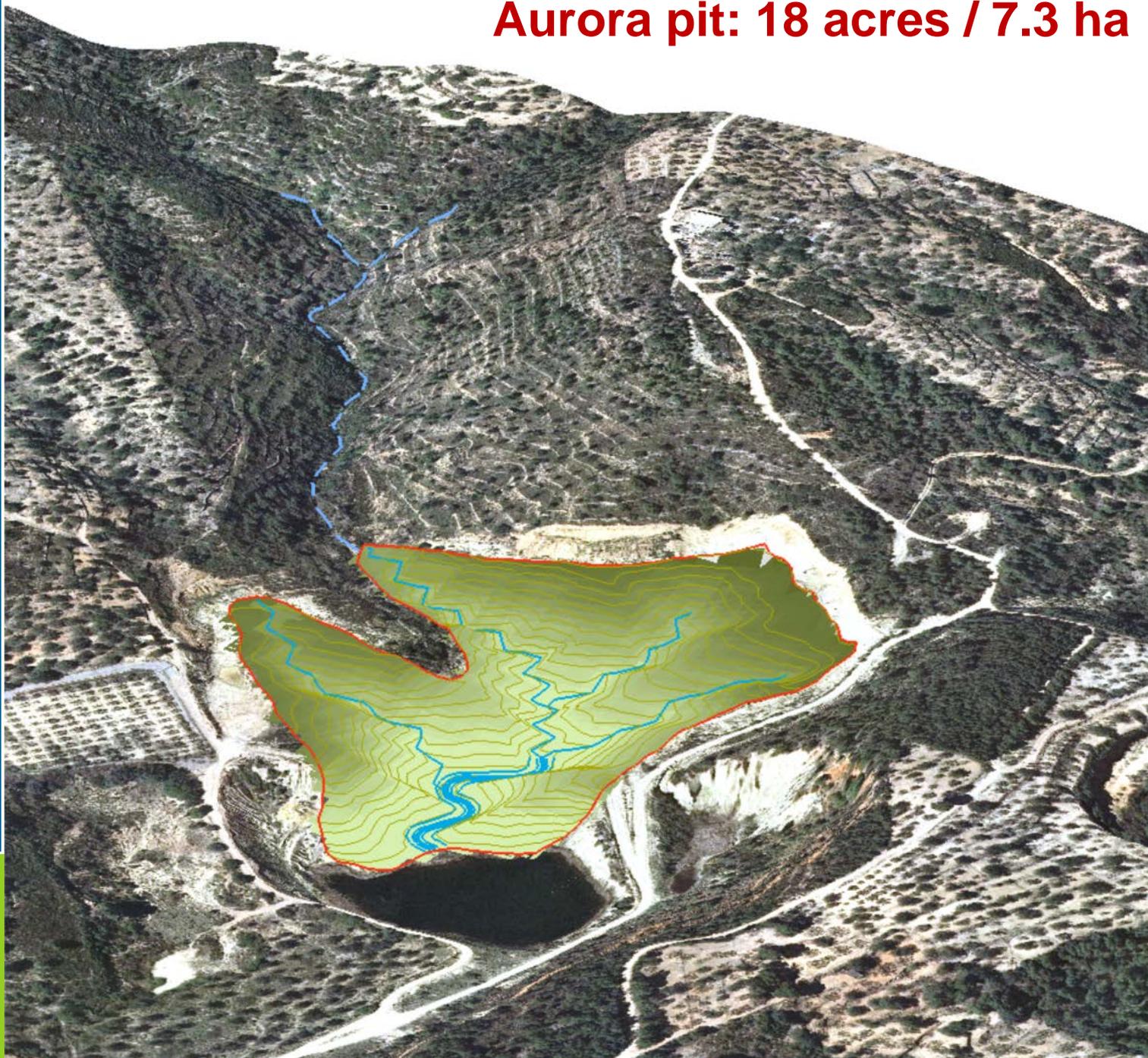


# SOLUTION

GeoFluv-  
based  
designs for

- 1) Restoring valuable and threatened habitats;
- 2) Restoring the hydrological connectivity

**Aurora pit: 18 acres / 7.3 ha**

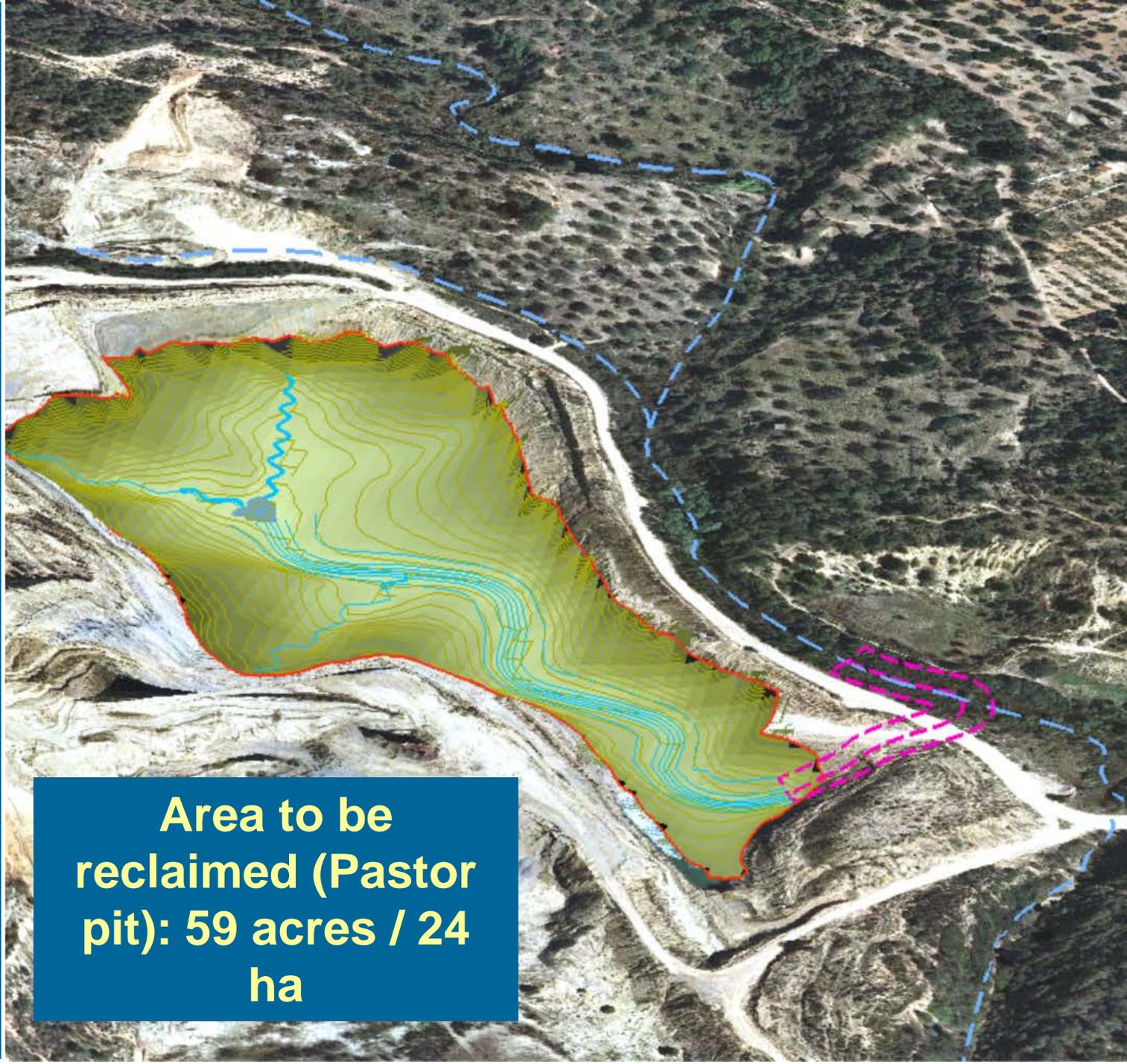


## SOLUTION

GeoFluv-  
based  
designs for

1) Restoring  
valuable and  
threatened  
habitats;

3) Use the pit  
as a natural  
“storm surge  
basin” of an  
area of 689  
acres / 279  
ha



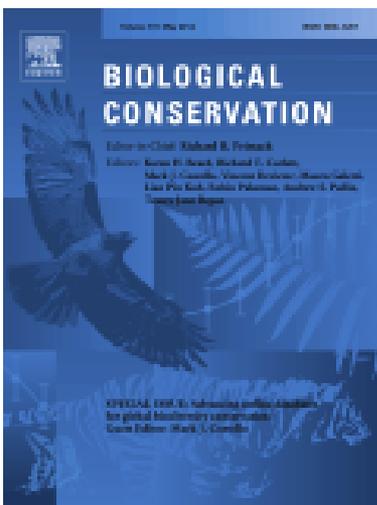
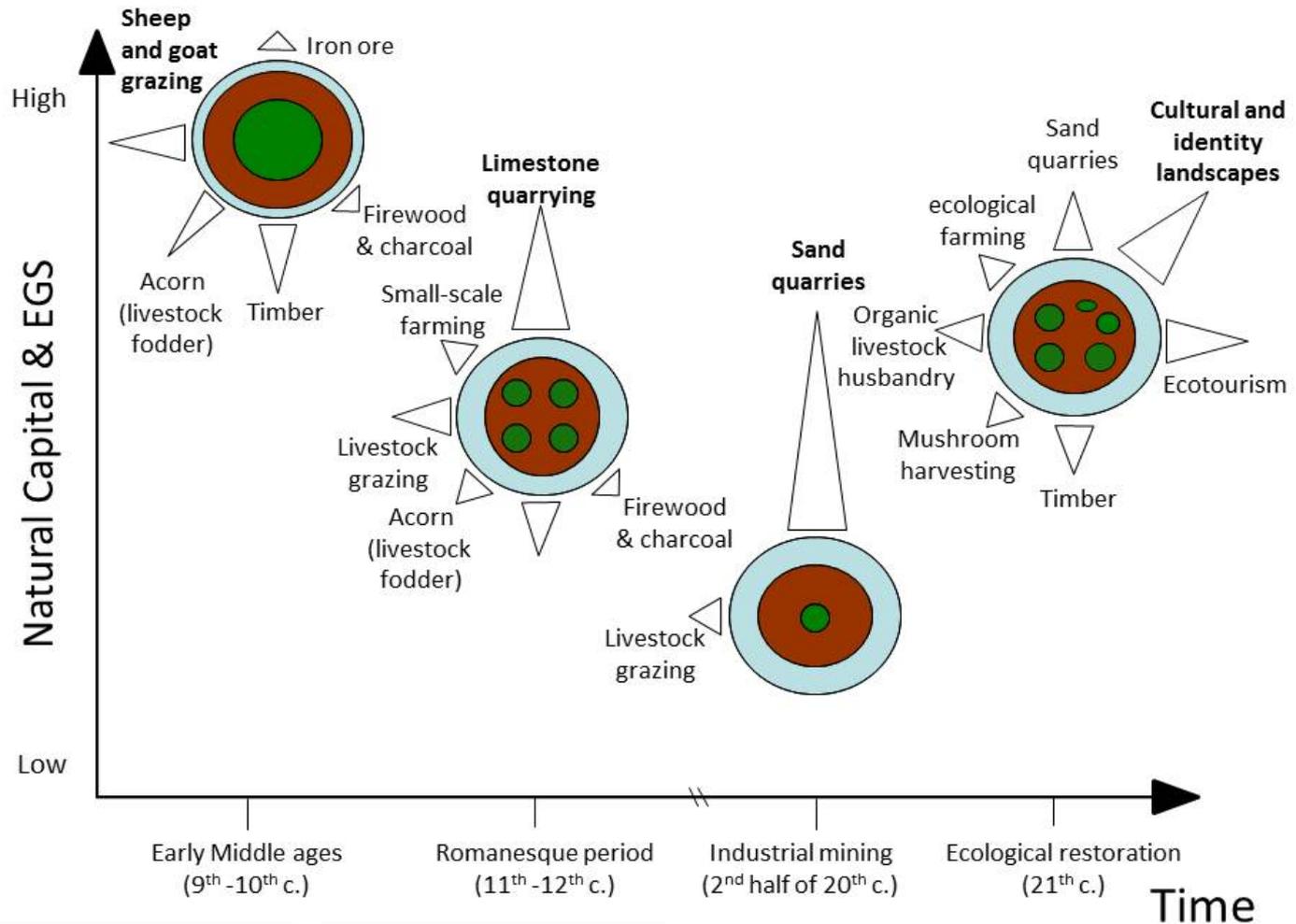
Area to be  
reclaimed (Pastor  
pit): 59 acres / 24  
ha

## **In Spain, Geomorphic Reclamation on Mined Lands, in general, and mainly because of the use of the GeoFluv method, is:**

- **Providing a HIGH STABILITY, from the short to the long term, to the reclaimed landforms, balancing their runoff and sediment yield with the surrounding environments and eliminating maintenance**
- **Restoring lost hydrological connectivity and helping to reduce the effects of flooding**
- **Helping to restore some of the most valuable and threatened habitats in Europe (Natura 2000 network)**
- **Despite the small area of most of the reclaimed lands, they are having a high influence as demonstrative examples for a change in Mining Reclamation practise**
- **Achieving a remarkable high acceptance among local communities and regulators, making mining feasible in places where this activity was seen as not viable (as at the very edge of protected areas, for example)**

# Geomorphic reclamation in Spain is also restoring Ecosystem Goods and Services (EGS)

Balaguer, L, Escudero, A., Martín-Duque, J.F., Mola, I. & Aronson, J. 2014. The historical reference in restoration ecology. Biological Conservation (in press)



- **Mainly throughout the work of our group, and by using the GeoFluv method, SPAIN is leading the field of Geomorphic Reclamation o Mined Lands in EUROPE**
- **At RESTAURACIÓN GEOMORFOLÓGICA, we provide: university teaching, courses of updating for regulators and mining industry, consultation and research**

<http://www.restauraciongeomorfologica.com>

Thank you very  
much indeed for  
your attention

