Identification of the reference and limitations

(Action A3)

LIFE16 ENV/ES/000159 TECMINE

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CONTENT

ABSTRACT

This report includes a description of the methodology carried out to search for a reference area (regarding stable landforms). This reference area is useful to obtain some parameters required by the Natural Regrade software and, therefore, to carry out the geomorphic designs following the GeoFluv method. All that for the Fortuna mine.

The first section describes the characteristics that the reference area must meet to be stable, then the different parameters required by the Natural Regrade software are explained. After those tasks, the methodology used to perform the search of the reference is explained. This methodology includes: 1) office work; 2) field work; and 3) rainfall data analysis. Subsequently, the results obtained and a brief discussion about them are included, as well as the final inputs used to design the geomorphic restoration. Finally, in the conclusions section, the limitations found are discussed, as well as the works that we still continue to obtain an adequate reference area for mines with a similar physiographic setting than the Fortuna mine.

1. INTRODUCTION

As it is known, one of the methodologies that will be tested in this demonstrative LIFE project is GeoFluv.

The GeoFluv method, created by Nicholas Bugosh, Principal of the GeoFluv company (www.geofluv.com) is implemented in the Natural Regrade software (http://www.carlsonsw.com/solutions/mining-solutions/natural-regrade/). This method for land reclamation is based in hillslope and fluvial geomorphic principles, and it has been applied mostly at open pit (surface) mine restoration. GeoFluv – Natural Regrade designs complex landforms structured according to a drainage network, having functional channels 'stitched' with convex – concave slopes. These designed landscapes should be stable in the long-term as well as functional, allowing the development of self-sustainable vegetal communities. Therefore, these landforms should be adapted to the current climatic and physiographic conditions at the site.

It is important to highlight that GeoFluv has been included in the Directive 2006/21/EC on the management of waste from extractive industries, considering it as one the **Best Available Techniques for mine restoration by the European Commission**.

As it was explained in the *State of the Art of Mine Restoration Techniques* (deliverable of Action A1), the procedure of GeoFluv implementation includes:

1- finding a suitable reference area with stable landforms and acquiring inputs from them;

2- designing landforms and drainage networks, it means, the final landscape to be restored;

3- building the planned landscape; and

4- monitoring the hydrological and erosive – sedimentary response of the reclaimed watersheds

1.1 Scope of the document

The aim of this report is to explain the procedure carried out to find out the reference area, necessary to apply the GeoFluv method (step 1, previously mentioned).

The objective was to find this reference in an area close to the Fortuna mine, assuring this way that the reference was perfectly adapted to local climatic conditions.

1.2 Structure of the document

This report has been structured following the different steps carried out to seek the reference area. Additionally, a first section, entitled background, has been included to describe the characteristics of the areas where GeoFluv will be applied and the characteristics that the reference should have.

Therefore, this document includes:

- Background
- Methodology and Rainfall analyses
- Results and discussion
- Inputs used to do the GeoFluv designs
- Conclusions and further work

2. BACKGROUND

2.1 Areas of GeoFluv implementation

LIFE TECMINE is going to be implemented in the Fortuna mine, property of the Sibelco mining company. This mine is located in the Ademuz Municipality, Valencia Region, Spain (Fig 2.1).

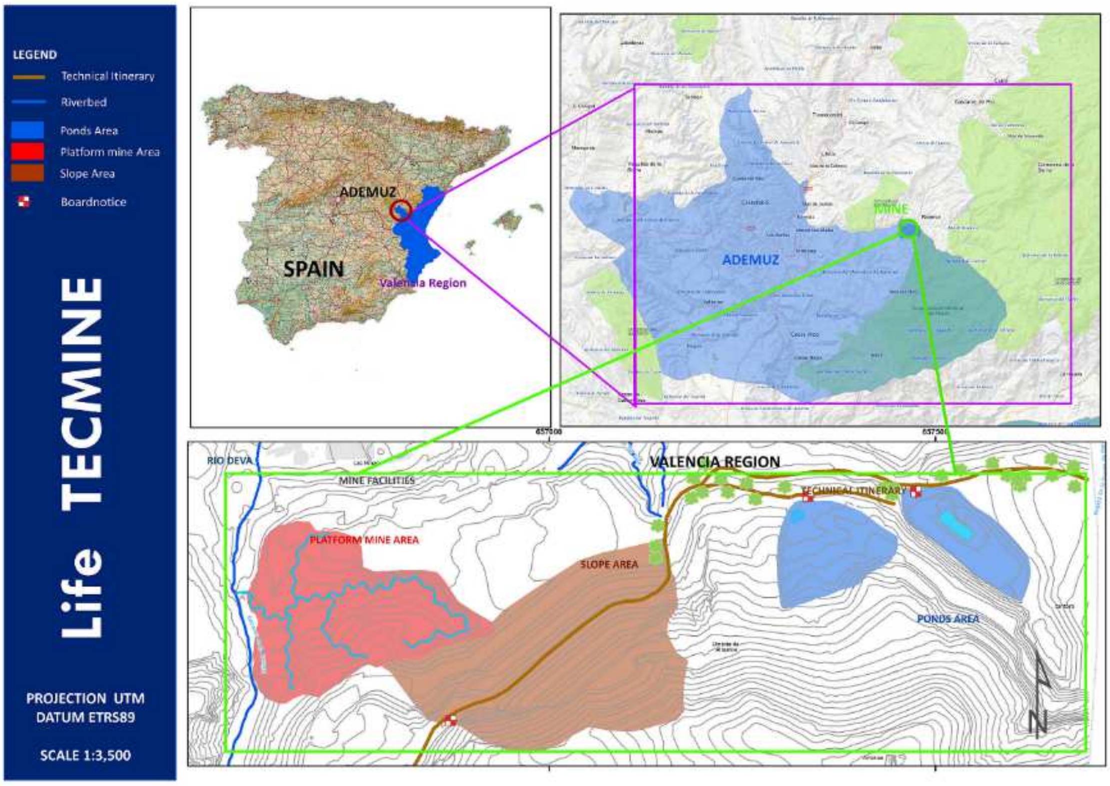

Figure 2.1. Location of LIFE TECMINE and Fortuna mine

In the Fortuna mine, mineral deposits that belong to the local stratigraphic units of Albian age (Facies Utrillas and Weald) are exploited. These deposits are characterized by the intercalation of successive layers of kaolinite-feldspathic white sand, separated by red clay levels. This geological series has a thickness of more than 100 m, containing 7 available layers of sand, whose thicknesses range from 4 to 15 meters. Over these layers of industrial interest, there are a number of fairly well organized strata ranging from calcarenitic and sandstone to calcareous lithology. This set of carbonate facies has been assign to the Cenomanian age.

Physiographycally, the Fortuna mine is located in a long, steep slope —more of 160 meters of difference from the top of the slope to the bottom— with north aspect orientation. Previously to mining operations, this slope was used for agriculture purposes and a series of agricultural terraces were built (see Fig 2.2). Some parts of the slope were not topographically modified, remaining in "natural" conditions. These "natural" slopes are covered by colluvium substratum, on which soils and vegetation develop. Therefore, it is important to cover the restored are with this material, thus local vegetation is adapted to and grow more easily on it.

Figure 2.2. Aerial photograph of 1956 of the area where the Fortuna mine is located (red circle). It is possible to observe a series of agricultural terraces built on the slopes.

Specifically, GeoFluv is going to be applied on two areas of the Fortuna mine: 1) a platform mine area and 2) a highwall-slope area (see Fig 2.3). The new restored landscapes will be built using mine spoils or overburden materials. These unconsolidated materials are mainly composed by gravels, sands, clays and rock fragments.

Figure 2.3. Oblique aerial photography of the Fortuna mine. Red circles indicate the two areas where the GeoFluv method is going to be applied.

2.2 Reference characteristics

The ideal reference area should be located in the vicinity of the mine which is going to be restored. By this way, it is assured that the reference is adapted to local climatic conditions. Additionally, the reference area should be developed on materials similar to those which are going to be used to build the designed landscapes (mine overburden or spoils), it is to say, unconsolidated detritic materials (gravels, sands, clay). On these materials, a well-developed drainage network should be identified, in order to measure the different inputs required by the Natural Regrade software (see section 2.3). The reference area should also have rounded small hillslopes and low gradient, with convex-concave slopes, drawing the smooth and stable landscapes that we want to replicate (see Fig 2.4).

One most common setting where it is possible to find this kind of suitable landscapes is fluvial terraces. Fluvial terraces have been built by rivers and streams that have transported and settled sediment of different size, from cobbles to gravels, sand and clay. If the fluvial terraces are stable, on them, a drainage network is developed, connecting the runoff of surrounding slopes to the lowest point of the valley, the river. Furthermore, soils and vegetation are also developed on the fluvial terraces surface.

Figure 2.4. Example of a GeoFluv reference area developed on a fluvial terrace. It is possible to observe the drainage network that connects the slopes to the main valley, the smooth and rounded hillslopes and the convex-concave shape profile slopes. Example used as reference area for the GeoFluv reclamation of La Plata mine.

Another places where it is possible to find this kind of landscapes, suitable for reference areas of Fortuna mine, are undulating plains and hills developed on Utrillas and Weald Facies. As it has been explained before, the Utrillas and Weald Facies are composed by different layers of gravels, sands and clays, and they are exactly the same kind of materials available in the mine to build the restored landscapes. The difference is that during the mining works, these materials have been excavated and mixed, and they have lost their natural cohesion. Therefore, what it is needed to find landscapes developed with analogue conditions. Therefore, we decided to focus on fluvial terraces and undulating plains and hills of the Utrillas and Weald Facies, because they are more similar to the materials that we find in the Fortuna mine.

2.3 Inputs required by the Natural Regrade software

The Natural Regrade software requires three types of inputs or settings:

- Topographic characteristics of the area where the restoration is going to take place
- Morphometric inputs from a stable reference area
- Rainfall and hydrological data

Table 2.1 reports a list of the inputs/setting required by the software and Figure 2.5 shows some examples of the measurements that are needed to make, in order to obtain the inputs. To obtain these parameters, a combination of fieldwork and photographs and digital elevation model analyses are needed.

Table 2.1

Inputs/settings required by Natural Regrade software

	Description	Units
Topographic conditions of the design area	Base level elevation	m.a.s.l.
	Slope at the mouth of the main valleys bottom channels	%
Morphometric inputs from a stable reference area	'A' channel reach – type of channel with slope> 0.04, according to Rosgen (1994)	m
	Width-to-Depth (range) - type of channel with slope > 0.04 and < 0.04, according to Rosgen (1994)	m
	Sinuosity (range) - type of channel with slope > 0.04 and < 0.04, according to Rosgen (1994)	m
	Maximum distance from ridgeline to channel's head	m
	Drainage density	m ha^{-1}
	Angle from subridge to channel's perpendicular	degrees (°)
Rainfall and hydrological data	2-yr 1 h rainfall	cm
	50-yr 6 h rainfall	cm
	Runoff coefficient	-
	Maximum stream velocity	m s^{-1}

Source: Natural Regrade software

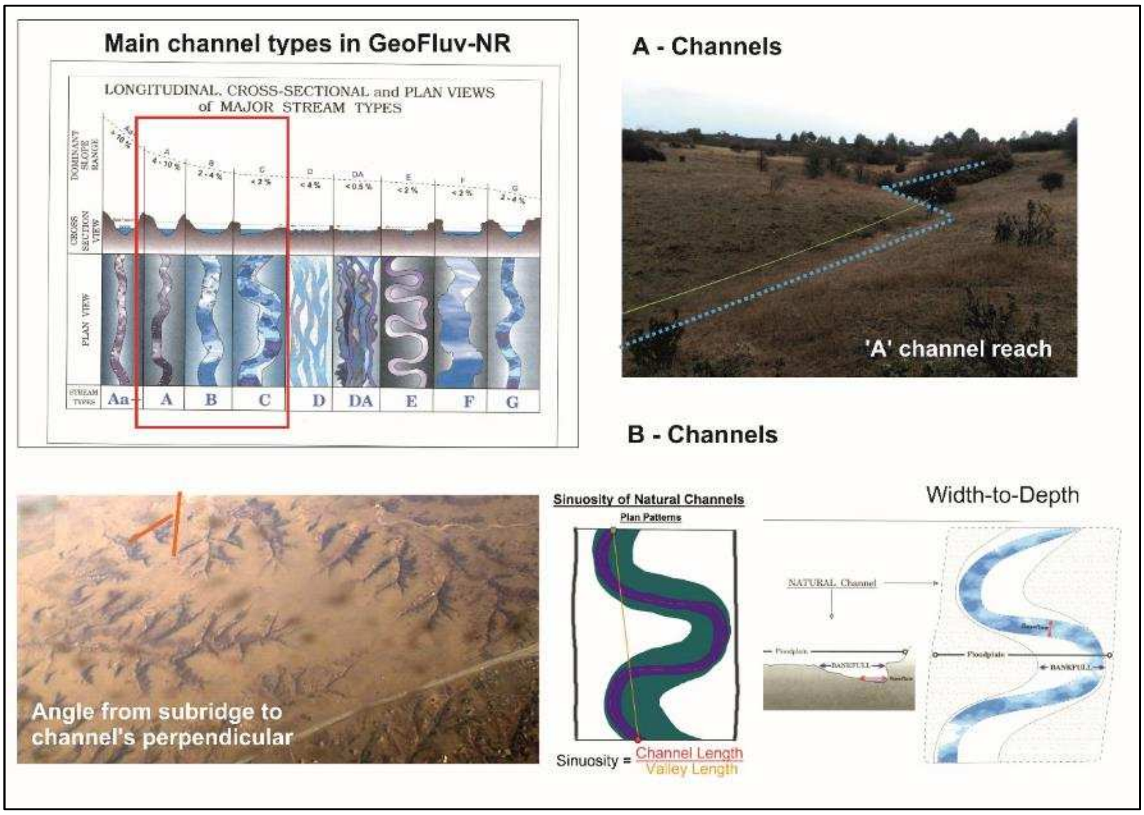

Figure 2.5. Main channel types in GeoFluv-Natural Regrade and some parameters that need to be masured in the reference area.

3. METHODOLOGY AND RAINFALL ANALYSES

The methodology used to seek the reference area for the LIFE TECMINE project followed two main steps. The first one was made in the office, by using GIS software (see section 3.1). The second step was fieldwork, where some places selected during the first step were visited and checked (see section 3.2). Additionally, rainfall analyses were carried out to obtain rainfall parameters required by Natural Regrade software (section 3.3).

3.1 Office work

In order to find out the reference area, a systematic process was followed. To do this, ArcGIS and Google Earth Pro software were used.

The process consisted on analysing and overlapping different layers of information (see explanation and Fig 3.1):

- Geology
- PNOA ortophotos
- Digital Terrain Models
- Drainage network
- Slope analyses

As it has been explained before (section 2.2), we were interested in fluvial terraces and undulating plains and hills on Utrillas and Weald Facies materials. Therefore, the first step was to map these lithologies. To do this, 1:50000 scale geologic maps (MAGNA series from the Geological and Mining Institute of Spain (IGME, in Spanish), http://info.igme.es/cartografiadigital/geologica/Magna50.aspx) were simplified, drawing only those lithologies we were interested in.

After that, the created shape layers were overlapped on most updated available orthophotos. These photos were downloaded from the National Geographic Institute (Instituto Geográfico Nacional, IGN, in Spanish); http://centrodedescargas.cnig.es/CentroDescargas/index.jsp). By doing this, it was possible to check if the mapped areas had the appropriated characteristics: "natural" smooth landscapes with a drainage network developed on them. Here, the Google Earth Pro software was found to be a useful tool, because it allowed observing the selected areas in three dimensions view. Therefore, a combination of both tools, ArcGIS and Google Earth, was applied.

Then, slope analyses were made, in order to check that the selected area had slope gradients lower than 35%. Additionally, drainage network and watershed analyses were also made. To carry out these analyses, the Digital Terrain Models (DTM) of each area were needed. Digital Terrain Models with 5-m grid spacing, available at IGN website (http://centrodedescargas.cnig.es/CentroDescargas/locale?request_locale=en), were used.

Once all of these steps were followed, a few group of small areas were pre-selected. The next step was to check the most suitable areas to make direct observations of them by fieldwork.

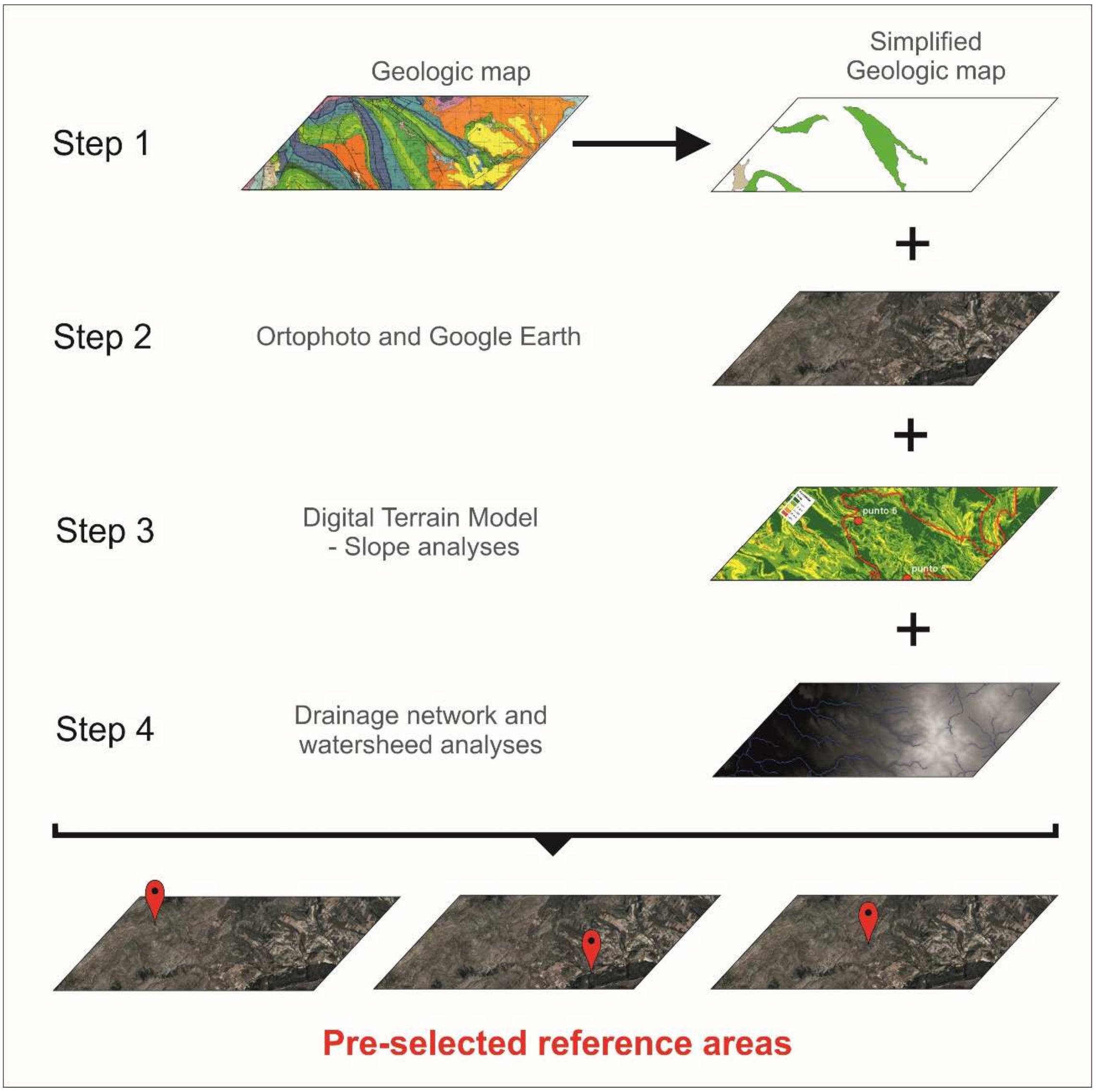

Figure 3.1. Procedure followed in the office to find the reference area.

3.2 Fieldwork

Once few areas have been pre-selected, fieldwork is necessary to check whether those areas are appropriated or not. If any of those areas have the characteristics we are looking for, some parameters could be measured in the field. Table 3.1 shows the parameters or inputs measurable in the field.

Table 3.1

Inputs/settings required by the Natural Regrade software, measurable in the field

	Description	Units
Morphometric inputs from a stable reference area	'A' channel reach – type of channel with slope> 0.04, according to Rosgen (1994)	m
	Maximum distance from ridgeline to channel's head	m
	Width-to-Depth (range) - type of channel with slope > 0.04 and < 0.04, according to Rosgen (1994)	m

3.3 Rainfall analyses

As it has been explained before (see section 2.3), the Natural Regrade software also requires rainfall data. Specifically: i) the volume of precipitation equivalent to one hour rainfall for a return period of two years (2-yr, 1-h rainfall); and ii) the volume of rainfall equivalent to six hours precipitation for a return period of 50 years (50-yr, 6-h rainfall).

In order to obtain this rainfall information, the data registered by the National Agency of Meteorology (*Agencia Estatal de Meteorología*, AEMET, in Spanish) in its weather stations network was analysed.

Firstly, it was necessary to ask for the data available in the weather stations close to the area of restoration. Table 3.2 includes a summary of the weather stations located nearest to the Fortuna mine.

Table 3.2

Weather stations located in the vicinity of the Fortuna mine (altitude about 1100 m a.s.l)

	Code	Altitude	Distance (km)	Register	Completed years
CAMARENA DE LA SIERRA (DGA)	8374	1310	9	1991-2018	25
SESGA	8382E	1150	11	1984-2018	31
ADEMUZ-AGRO	8381B	708	12	1987-2017	24
ADEMUZ	8381	742	13	1956-1967	9
ADEMUZ - X	8381X	705	13	2008-2018	6
TORRIJAS	8462	1359	19	1956-2004	45
SANTA CRUZ DE MOYA	8383	763	20	1956-2018	58

Source: elaborated from AEMET information

The chosen weather station was Sesga (8382E), for having a similar altitude than the Fortuna mine (and therefore with similar weather conditions). Additionally, it is only 11 km far from the mine, and it has a wide record range, which includes recent years.

Firstly, monthly and annual mean precipitation was calculated from the Sesga weather station data (see Table 3.3). The annual mean precipitation for the restored area is 507, 7 mm, being the months of May and October the ones which recorded higher precipitation values, 61,4 and 56,6 mm respectively.

Table 3.3

Monthly and annual mean precipitation (in mm) of the area of Fortuna mine. Mean values calculated from the Sesga (8382E) weather station data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
SESGA (8382E)	36,4	32,6	38,3	56,0	61,4	41,5	24,7	27,2	47,8	56,6	48,5	38,1	**507,7**

Source: elaborated from AEMET data

After that, Intensity-Duration-Frequency curves (IDF curves) were calculated. The IDF curves are a graphical representation of the probability that a given average rainfall intensity will occur (see Table 3.4 and Fig. 3.2). Once intensities have been calculated for each return period (frequency) and time of duration, it is necessary to multiply them by the duration of the event (1 and 6 hours) and make the appropriated units conversion to obtain rainfall values required by the Natural Regrade Software.

Table 3.4

Intensity (mm h^{-1}) according to the IDF curves of Sesga (8382E) weather station. In red, intensity values necessary to calculate the rainfall volume required by Natural Regrade software.

Frequency (yrs)	Duration (min)												
	5	10	15	20	25	30	35	40	45	50	55	60	360
2	75,0	48,8	38,0	31,8	27,7	24,7	22,5	20,7	19,2	18,0	17,0	**16,1**	5,3
5	88,4	57,6	44,8	37,5	32,7	29,2	26,5	24,4	22,7	21,3	20,0	19,0	6,3
10	100,1	65,2	50,7	42,5	37,0	33,0	30,0	27,7	25,7	24,1	22,7	21,5	7,1
25	118,1	76,9	59,8	50,1	43,6	39,0	35,4	32,6	30,3	28,4	26,8	25,4	8,4
50	133,8	87,1	67,8	56,7	49,4	44,2	40,1	37,0	34,4	32,2	30,3	28,8	**9,5**
100	151,6	98,7	76,8	64,3	56,0	50,0	45,5	41,9	38,9	36,5	34,4	32,6	10,7
500	202,6	131,9	102,6	85,9	74,8	66,8	60,8	55,9	52,0	48,7	45,9	43,5	14,4

Source: own elaboration

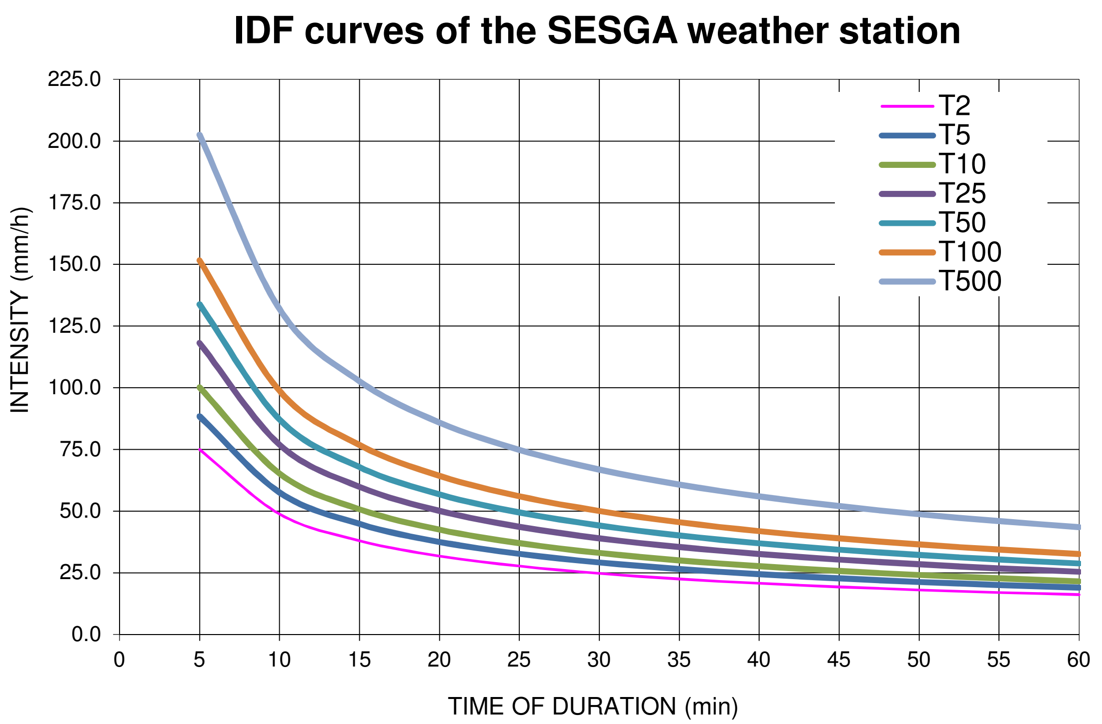

Figure 3.2. IDF curves calculated from the Sesga (8382E) weather station data. T = return period, frequency (in years). Observe that 6 hours (360 minutes) duration is not included in the graph, due to space limitation.

4. RESULTS AND DISCUSSION

4.1 Office work

During the office work, a total of six areas were pre-selected, four of them on fluvial terraces and two on Utrillas and Weald Facies (see Fig. 4.1). The pre-selected reference areas on fluvial terraces were named as "terraza" (terrace in Spanish) and followed by a number (i.e. Terrazas_1). To name the pre-selected areas on the Utrillas and Weald Facies, the name of the nearest village was used (i.e. El Cubillo).

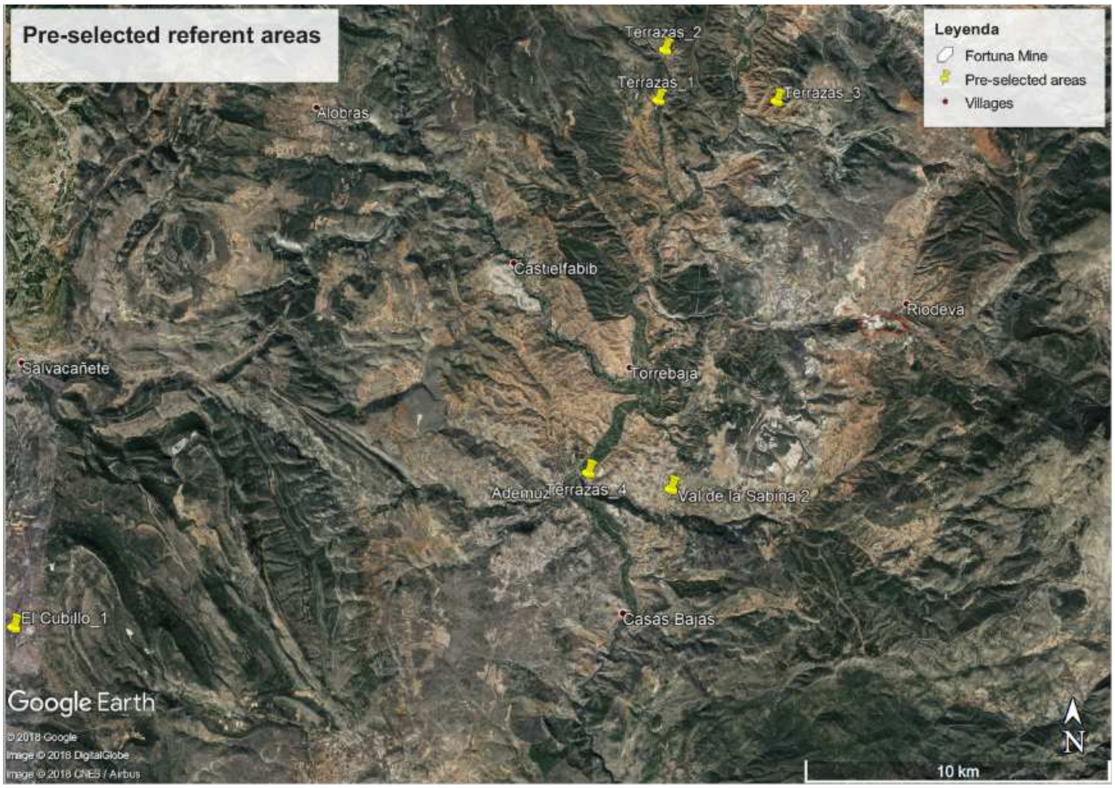

Figure 4.1. Aerial orthophoto with the pre-selected reference areas.
(Source: own elaboration in Google Earth Pro)**.**

Observing these pre-selected areas on Google Earth or PNOA orthophoto, they seemed to match the requirements for being considered as a reference area. However, by observing them in detail, we realized that most of the land surface had been transformed by humans, historically, existing innumerable agricultural lands. Therefore, only two areas, with less land transformation, were selected for fieldwork.

4.2 Fieldwork

The fieldwork consisted on visited the pre-selected areas named "Val de la Sabina_2" and El Cubillo_1. The former is very close to Val de la Sabina Village, and only 9 km distance from the Fortuna mine. Theoretically, this area, developed on the Utrillas Facies, seemed to be ideal. However, field visits revealed also a deeply human-modified area, with high slope gradients (see Fig. 4.2). Summing up, this area was rejected as a potential reference one.

Figure 4.2. Val de la Sabina_2, pre-selected reference area. It is possible to observe steep slopes on the Utrillas Facies, with agricultural lands in the lower slopes. Therefore, the “natural” landforms and their “natural” drainage network do not exist anymore.

The second visited place was El Cubillo_1, in a small and flat valley, but no drainage network was recognised. While driving through this landscape, it was observed other areas that seemed to be potential for reference areas, which were visited. One of these areas is included in Figure 4.3. In this case, the landscape was smooth, with rounded hills, but the small valleys were also transformed for agricultural purposes, and it was not possible to recognise any drainage network.

Figure 4.3. An example of a 'smooth' landscape, which lower areas have been modified for agricultural purposes.

Therefore, none of the visited places resulted as an appropriated reference area. The landscape had been highly modified by humans on them, and therefore, the natural characteristic that we were looking for could not be found.

In short, there is a significant limitation for the GeoFluv-Natural Regrade application on our highly transformed Mediterranean landscapes.

4.3 Rainfall analyses

Table 4.1 includes the results obtained after doing the rainfall analyses. These values are the ones used to carry out the GeoFluv designs for areas 1 and 2 at the Fortuna mine.

Table 4.1
Rainfall reference values obtained from Sesga (8283E) weather station (AEMET)

	Description	Units	Value
Rainfall inputs	2-yr 1-h rainfall	cm	1,6
	50-yr 6-h rainfall	cm	5,7

5. INPUTS USED TO CARRY OUT THE GEOFLUV DESIGNS

Due to the fact that it has not been possible to find out a good reference area, and the need to carry out the GeoFluv designs before August 2018, it has been decided to use available suitable data for equivalent reference areas.

Therefore, the inputs required by the Natural Regrade software that have been finally used correspond to an existing suitable reference area in the Alto Tajo region (see Zapico *et al.*, 2018). This reference area is also located in the Iberian System, and on the Utrillas Facies, about 100 kilometres (in a straight line) from the Fortuna mine. Therefore, it is considered to be a suitable reference area for obtaining inputs to be used for the GeoFluv designs of the Fortuna mine.

The inputs of the Alto Tajo region that will be used in the TECMINE project are Morphometric, while the Topographic inputs and the Rainfall characteristics are those of the LIFE TECMINE project area. Table 5.1 shows the values of the inputs used and Figure 5.1 portraits a reference image of the Alto Tajo Region. These values have been already published (Zapico *et al*., 2018).

Table 5.1
Inputs/settings used to carry out the GeoFluv designs of the Fortuna mine. m a.s.l. = metres above sea level.

	Description	Units	Values
Topographic conditions of the design area	Base level elevation	m a.s.l.	941 (area 1) 998 (area 2)
	Slope at the mouth of the main valleys bottom channels	%	7,8 (area 1) 9,6 (area 2)
Morphometric inputs from a stable reference area	'A' channel reach – type of channel with slope> 0.04, according to Rosgen (1994)	m	16.6
	Width-to-Depth (range) - type of channel with slope > 0.04 and < 0.04, according to Rosgen (1994)	m	-
	Sinuosity (range) - type of channel with slope > 0.04 and < 0.04, according to Rosgen (1994)	m	-
	Maximum distance from ridgeline to channel's head	m	37
	Drainage density	m ha^{-1}	110
	Angle from subridge to channel's perpendicular	degrees (º)	5
Rainfall and hydrological data	2-yr 1 h rainfall	cm	1,6 (Sesga) 2,15 (Alto Tajo)
	50-yr 6 h rainfall	cm	5,7 (Sesga) 8,92 (Alto Tajo)
	Runoff coefficient	-	1,3
	Maximum stream velocity	m s^{-1}	1,37

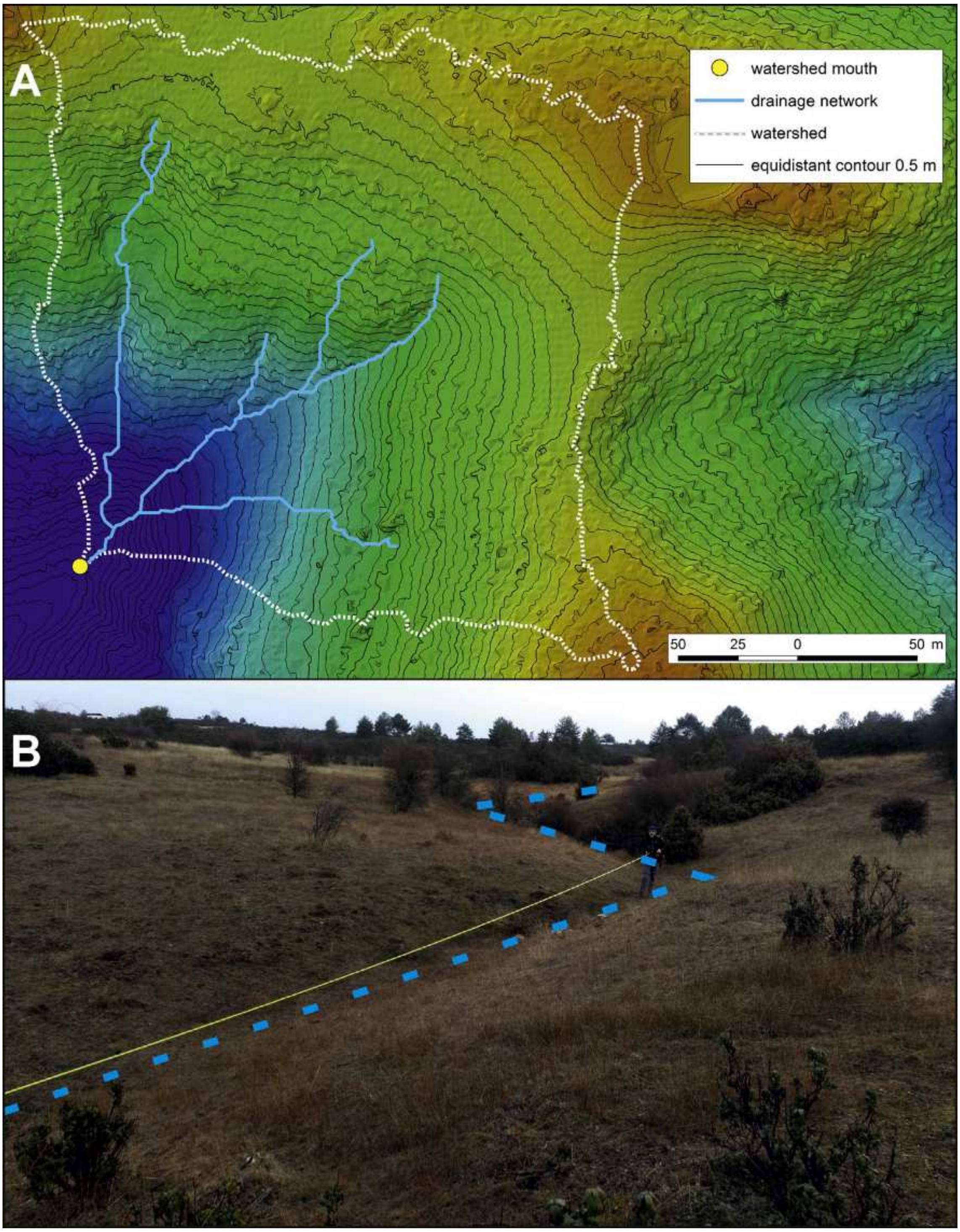

Figure 5.1. Reference area used for designing the geomorphic reclamation of Fortuna mine. A) map of one of the watersheds used to obtain inputs, such as drainage density, with the drainage network overlain on a TIN file obtained from LIDAR data of PNOA (2009). B) ground photo of the area, showing measurements of morphometric parameters of channels. Source: Zapico et al. (2018).

6. CONCLUSIONS AND FURTHER WORK

After the completion of this Action, one of the main conclusions obtained is the difficulty of finding a suitable reference area in the vicinity of the Fortuna mine, in particular, and in Mediterranean landscapes (in general), which have been highly modified by human activities throughout history. This fact represents a limitation, although it can be solved by the few suitable areas that have been already found, and by the experience of the use of the method worldwide.

However, it is considered that the applied methodology is appropriate for finding suitable reference areas for other situations, since it is a systematic and objective procedure, which allows covering large areas in a first phase of search (the so-called office work) and focusing only on a few areas to be visited and for the realization of fieldwork.

This action is considered finished, and the inputs from the Alto Tajo area are considered suitable. However, the search for a suitable reference area that could be a contribution of the TECMINE project, for similar mines, will be continued within a Master's Thesis, that is being developed under our direction. Once it is finished, it will be distributed among the TECMINE personnel. For this Master Thesis, we have decided to expand the search area to the Teruel mining basins, where there are large flat and undulating areas developed on the Utrillas and Weald Facies.

7. REFERENCES

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