

C1: Topography and hydrology monitoring

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1. Introduction

This section presents the work carried out and the results obtained in relation to Action 2 "Rill erosion survey".

This action aimed to continue erosion monitoring in order to (1) measure the evolution of the rills network and identify erosion rates once the system has stabilised and (2) monitor the evolution of the abrupt Geomorphic ("herringbone") restoration, in case any treatment is necessary.

During the Life Tecmine period, the rill erosion was monitored, which is reported in the report "C. Monitoring of the Impact of the Project actions. Action C 1.1 Monitoring of topographic evolution and erosion rate". This can be used as a reference document in order to interpretate the After Life results.

The After Life actions envisaged were as follows:

- Rills field-sampling once a year (2023 and 2024). Data analysis and reporting.
- Photographic monitoring of "herringbone" and erosion in GeoFluv Small and Large and Report (2023 and 2024).

Objective 1 could not be addressed due to lack of economic budget. Although it has not been possible to carry out a quantitative assessment of the rills, a qualitative assessment has been made through photographic monitoring.

Objective 2 has been addressed by photographic monitoring carried out on 06.12.23 and 05.06.2025.

2. Results

2.1. Qualitative (photographic) rills survey

The observations made in the units identified in the Tecmine report are presented. These are as follows:

- Eastern GeoFluv (=Conventional GeoFluv without tree holes): no rill networks had been developed in 2021 and 2023. No rills have been found in 2025 either, as shown in the figure 1.
- Western GeoFluv, "Conventional GeoFluv with tree holes": Rill network was underdeveloped in 2021 (rill density: 0.16 m/m²). Photographs and field observations indicate that the rills have become non-functional in some areas as vegetation has developed. No new rills have been developed in 2023 and 2025. See figures 2 and 3.
- In Western GeoFluv, the restored zone with overburden substrate evolved from 0.24 to 0.32 m/m² in rill density between 2020 and 2021. These were densities well below the 0.60-0.70 m/m² that are considered the threshold above which erosion prevents vegetation development in restored mining areas very similar to Fortuna quarry

(Moreno de las Heras et al, 2009; 2011). Observations made in December 2023 and 2025 indicate a stabilisation of the erosive forms. The development of vegetation was poor in 2023 due to the poor quality of the soil. However, in 2025 plant cover is much higher because of the good environmental conditions in 2025's spring. See figure 4.

Overall, the observations made in 2023 and 2025 point towards no increase in the number of rills and no increase in the size of rills. This is what we expected since Hanckok et al. (2016) showed how erosion rates in restored mining areas reach the highest values in the first year after restoration -when rill networks are formed- and decrease exponentially until stabilizing in the fourth year.

2.2. Qualitative (photographic) monitoring of the abrupt GeoFluv ("herringbone")

The most critical area from an erosion point of view is the "Abrupt Geomorphological Restoration area" where, on the one hand, the upstream erosion in the main channel of "herringbone" is really important, affecting 77.4% of the length of the channel in 2021. And on the other hand, rill network density is very high, closed to the maximum tolerable rates for plant community can develop (0.60-0.70 m/m²). This is why this area needs specific monitoring.

Figure 5 shows the evolution of the erosive forms over the years with images from 09.10.2019; 07.02.2020; 17.03.2021; 11.02.22, 06.12.23 and 05.06.2025. After the formation of the first drainage network and rills in 2019, a significant growth of the main channel and rills is observed in 2020 (tropical storm "Gloria" occurred in 19-21.01.2020). Erosion actively progressed in 2021 (storm "Filomena" occurred in 05.01.2021). In 2022, no major changes were observed. In 2023 and 2025 there was a widening of the main channel and its tributaries by side walls falling and river bed wedging. Vegetation continues developing in this erosive environment: both, herbaceous and shrub cover have increased significantly in 2025.



Figure 1. Panoramic view of Eastern GeoFluv (=Conventional GeoFluv without tree holes) in 05.06.2025. No rill system has developed and vegetation is not limited by erosion. The photo above is of the western side and the photo below is of the eastern side.



Figure 2. Panoramic view of Western GeoFluv “Conventional GeoFluv with tree holes” in 05.06.2025. Photographs and field observations indicate that the rills have become non-functional in some areas as vegetation has developed. No new rills have been developed. The photograph above corresponds to the lower part of the basin and the one below to the upper part.





Figure 3. Detail of Western GeoFluv “Conventional GeoFluv with tree holes”. This is the main constructed slope with concave and convex forms. Rills formed in 2019 (photograph above) are not visible in the photograph intermediate (December 2023). Photograph below (June 2025) shows vegetation covering 100% of soil surface.





Figure 4. Western GeoFluv, the restored zone with overburden substrate. There is no difference in the number and size of the rills between the top photograph (February 2022) and the intermediate photograph (December 2023), which indicates a stabilisation of the erosive forms. Rills density in 2022 was about 0.32 m/m^2 , below the $0.60\text{-}0.70 \text{ m/m}^2$ that is considered the threshold above which erosion prevents vegetation development in restored mining areas very similar to Fortuna quarry (Moreno de las Heras et al., 2009; 2011). Observations made in June 2025 (photograph below) shows higher plant cover due to the mild spring time.







Figure 5. Evolution of the erosive forms in abrupt Geomorphic ("herringbone"). The images from top to bottom correspond to 09.10.2019; 07.02.2020; 17.03.2021; 11.02.22, 06.12.23 and 05.06.25. The explanation of the erosive evolution can be found in the text.

3. Conclusions

The qualitative observations made on the network of rills throughout the restoration of the Fortuna quarry indicate a stabilisation of their evolution over time, as well as a compatibility with the development of vegetation.

The evolution of erosional forms in the abrupt ("herringbone") is still active. In 2025 the main channel and tributaries have continued the widening and deepening process. However, vegetation development (both, herbaceous and shrub species) on the slopes has been very significant in 2025, which indicates that erosion is not impeding vegetation establishment.

In general, the erosion monitoring in the After Life period of TECMINE confirm that if proper geomorphic restoration is made, following orthodox principles, such as honouring channel concavity profile and linking with base level, avoiding runon, and a proper cover of soils and vegetation is made, the system is stable. However, gully erosion is clear in the herringbone solution. We interpret that there are several reasons for that, being the main that this solution is not a proper geomorphic (GeoFluv design). It was more a compromise solution, that did not show the expected results. After the TECMINE project, LIFE RIBERMINE project proposed a solution of scalloped hillslopes for a similar physiographic setting, with proper soil and vegetation cover, and in that case, is showing clear stability from the first year (Hancock & Martín-Duque, 2024). Therefore, life TECMINE served to find a proper solution in LIFE RIBERMINE. The solution is, for similar physiographic settings, for the future, proper geomorphic scalloped hillslopes can be designed and built, and if properly covered with soils and vegetation, they will remain stable.

4. References

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