Natural Water Retention in the Ramabujas Stream catchment near Toledo

The road to reduce peak flows and increase infiltration

February 2025

Contents

1. Introduction

While central and eastern Spain are traditionally known for their dry summers and generally low rainfall, these regions are increasingly experiencing more extreme rainfall events. In particular, slow-moving DANA storm systems — officially referred to as upper-level isolated depressions — are characterized by intense rainfall and high total precipitation, often resulting in widespread flooding. During the most recent DANA event on October 30th, 2024, the regions of Valencia, Castilla-La Mancha, and Andalusia experienced significant damage, with many lives lost.

On September 3rd, 2023, the Toledo region, among others, was struck by a DANA storm that brought more than 100 mm of rainfall in less than 8 hours. One of the areas most severely impacted by this extreme flooding was the Arroyo de Ramabujas catchment (Figure 1). Widespread flooding occurred in the centrally located town of Nambroca and the downstream industrial district of Santa María de Benquerencia. Agricultural fields were heavily damaged by erosion, resulting in large amounts of sediments that were carried downstream, damaging buildings and streets. This storm demonstrated that the integrated drainage system — comprising both natural streams and artificial canals and culverts — was inadequate for providing flood protection during such extreme events.

As climate change intensifies, not only heavy rainfall but also droughts are expected to become more frequent and severe. Industries in water-intensive sectors, such as the Suntory fabric located at the downstream end of the Ramabujas catchment, are particularly vulnerable to water shortages. By investing in Nature-based Solutions (NbS) to enhance water retention in the catchment, Suntory contributes to ensure a more reliable and stable water supply. To reduce the exposure of the Ramabujas catchment to both flooding and water scarcity, this report seeks to address two critical questions:

1) How can flood protection be improved in the Ramabujas catchment during DANA-type events?
2) How can the water footprint of the Suntory fabric be minimized to reduce pressure on local water resources (800.000 m^3 per year)?

This report provides an integral water system analysis of the Ramabujas catchment and examines the potential for implementing Nature-based Solutions to enhance flood resilience and water retention.

The water system analysis comprises a combination of GIS analysis, satellite image analysis and their integration with field observations and meteorological data. Ultimately, the findings aim to help mitigate flood and drought risks while ensuring sustainable land and water management for both the local population, the farmers and industrial activities in the region.

This study focusses on Nature-based Solutions without losing sight of obvious technical measures. Nature-based Solutions address societal challenges through actions to protect, sustainably manage, and restore natural and modified ecosystems, benefiting people and nature at the same time (IUCN).

The results of this study are presented on the interactive website: https://media.stroming.nl/ramabujas/#

***Figure 1:** Topographical map of the Arroyo de Ramabujas catchment in the region Castilla – La Mancha near Toledo (central Spain). Two small villages (Nambroca and Las Nieves) are located within the catchment. The industrial district Santa María de Benquerencia, home to the Suntory factory, is located in the most downstream area of the Ramabujas catchment, near its confluence with the stream Tagus.*

2. The Ramabujas Stream catchment

2.1 Topography, geology, slope and soil

The Ramabujas catchment has an elongated shape, stretching approximately 16 km in length and 5 km in width, covering an area of about 67.6 km² (Figure 2). The southern (upstream) boundary is marked by the Sierra de Nambroca mountains, where peak elevations reach up to 944 meters above sea level. In the north (downstream), the confluence of the Ramabujas and Tagus streams occurs at an elevation of 454 meters, resulting in a total elevation difference of 490 meters.

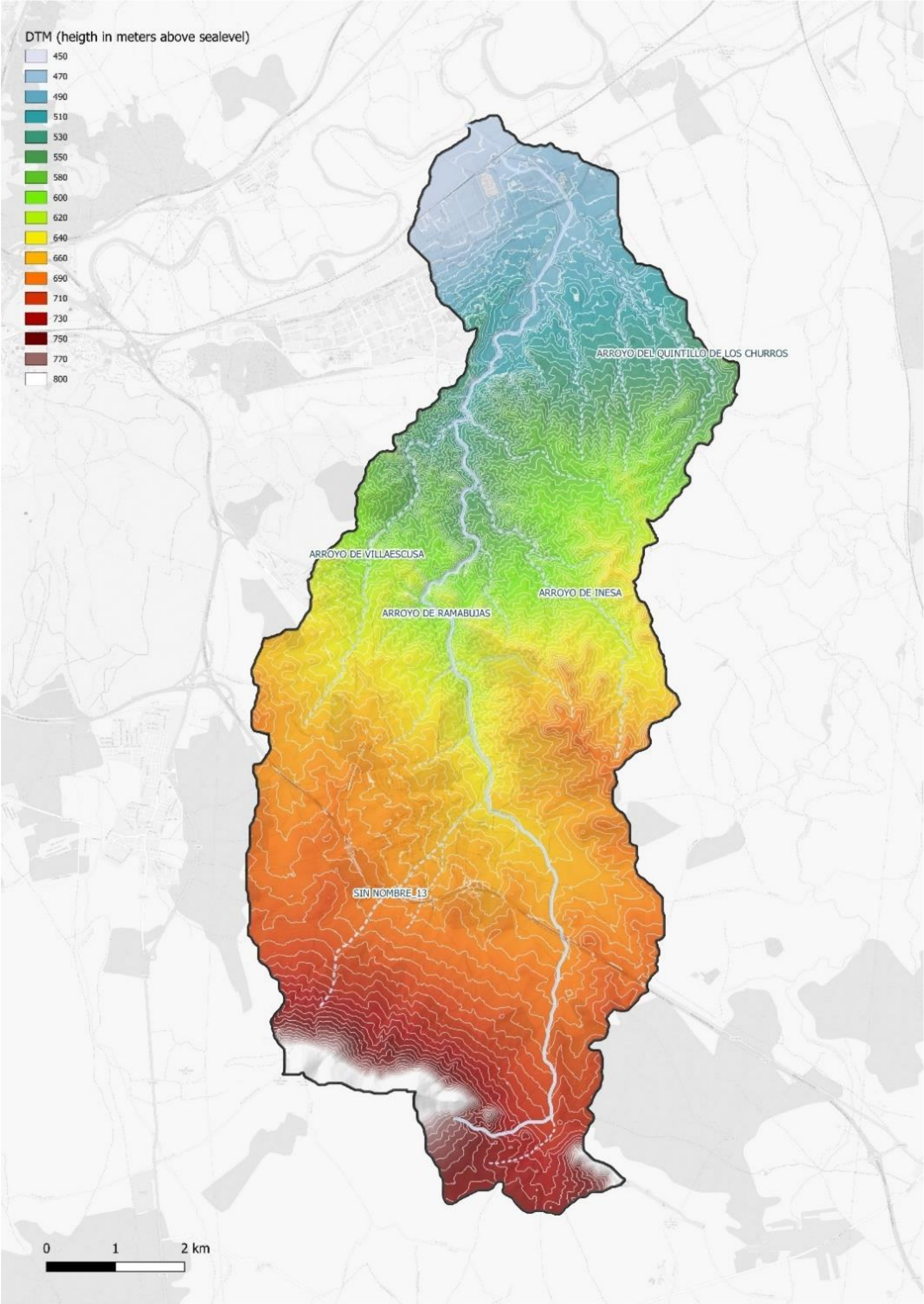


Figure 2: *Digital Elevation Map of the Ramabujas catchment (2 m resolution).*

The southern (upstream) three-quarters of the watershed are dominated by exposed igneous and metamorphic rocks (of Pre-Hercynian age), which are found at or near the surface (Figure 3). Locally, these basement rocks are covered by hillslope deposits and alluvial fans, especially along the flanks of the Sierra de Nambroca, or by Miocene fluvial sands and conglomerates in parts of the eastern region. The northern (downstream) quarter of the catchment is characterized by Miocene sands and conglomerates, along with Pleistocene to Holocene hillslope, alluvial fan, and stream terrace deposits.

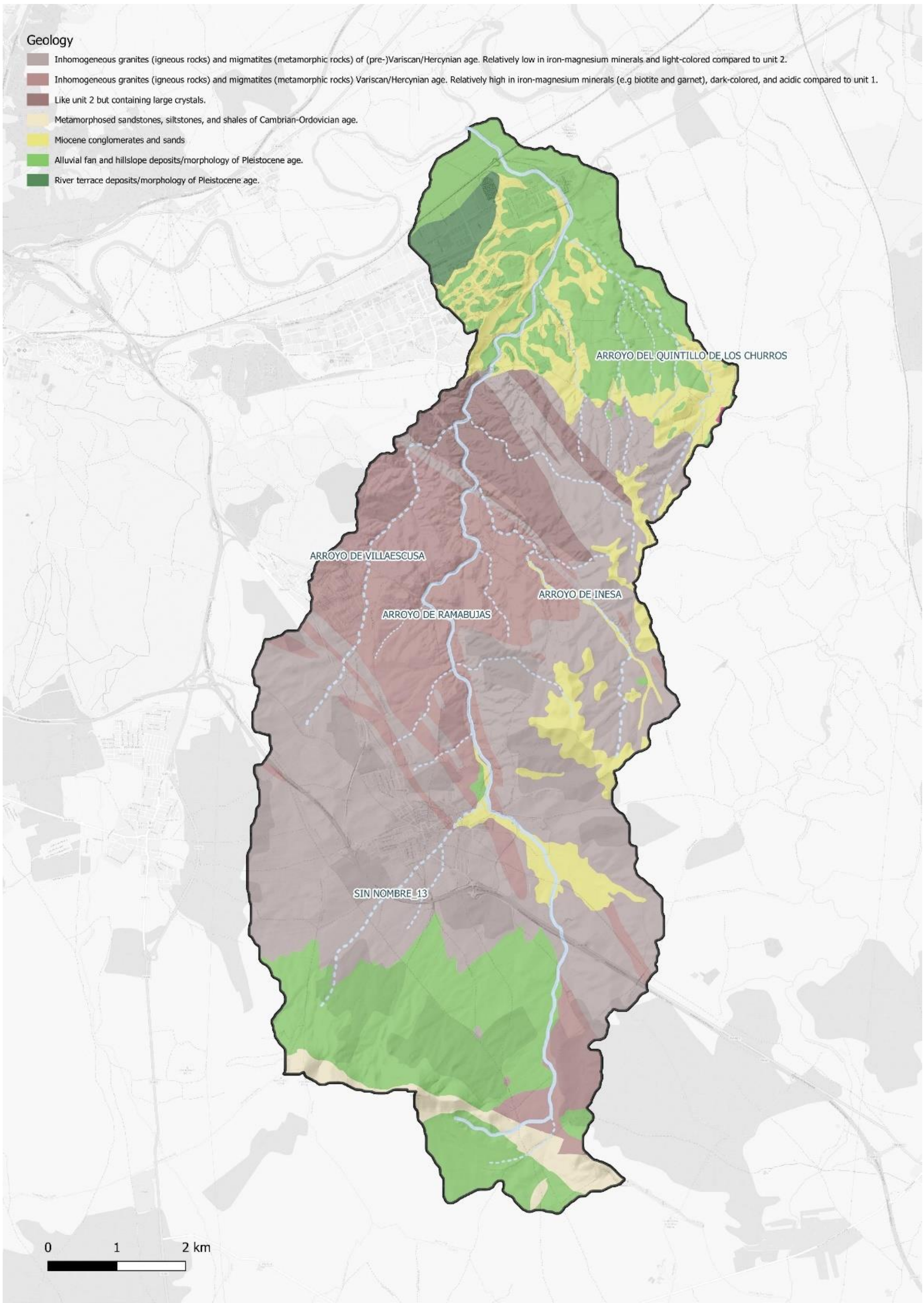


***Figure 3:** Geological map of the Ramabujas catchment.*

As shown in Figure 4, most of the catchment has moderate slopes, with gradients ranging from 5 to 15%. Upstream and downstream there are relatively flat areas, with slopes less than 5% steepness. Steeper areas are found along the flanks of the Nambroca Mountains and in the central part of the catchment, where topographic gradients range from 10 to 30%, and can locally exceed 50%. In the central part, this pronounced relief is primarily the result of channel incision, although geological variations also influence the topography in some areas (Figure 5B). In the flatter upstream section, no distinct channel morphology is observed. In contrast, the downstream area features stream channels embedded within broad alluvial valleys (Figure 5A).

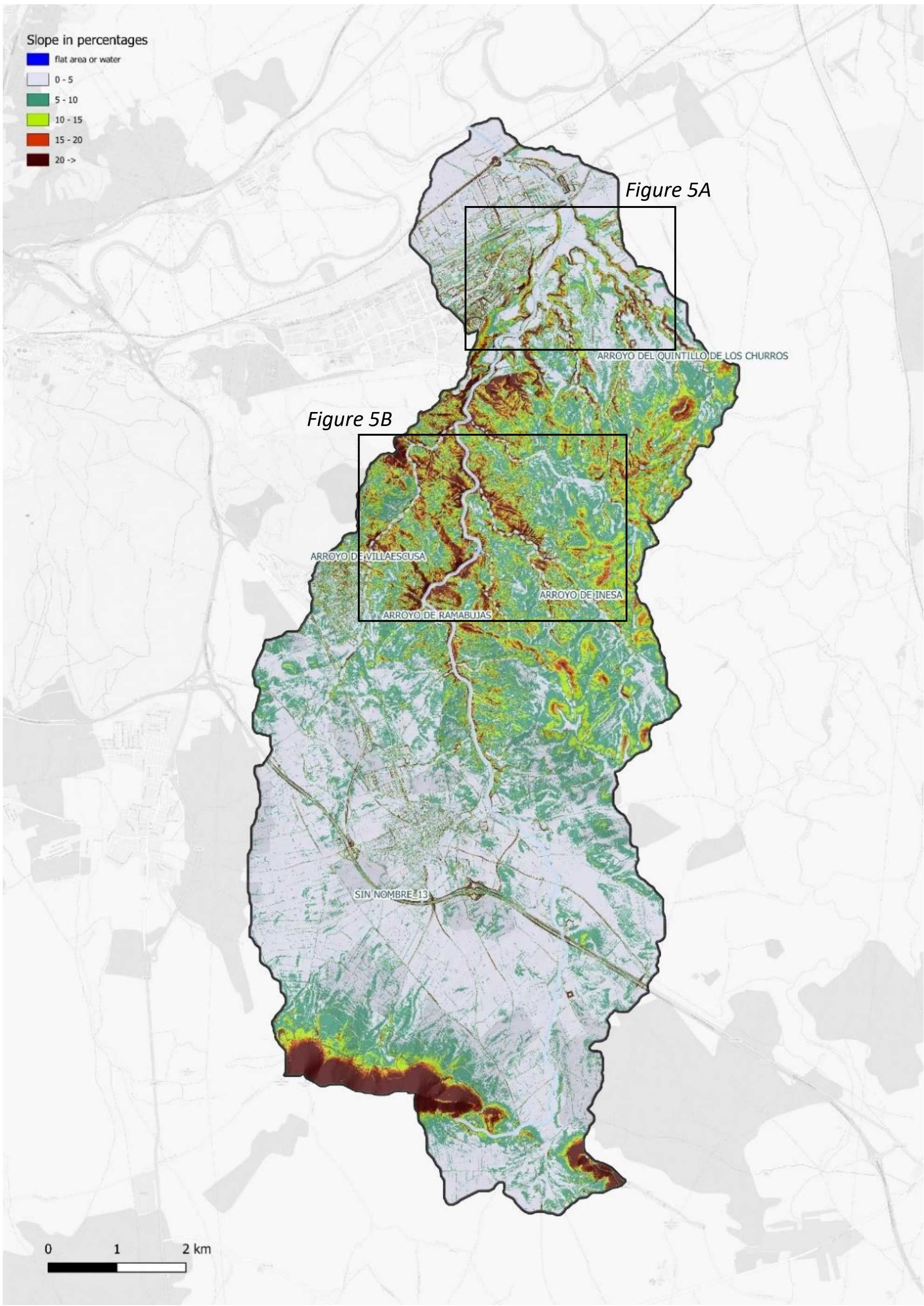


Figure 4: *Slope map (%) of the Ramabujas catchment (derived from the 2-m digital elevation model).*

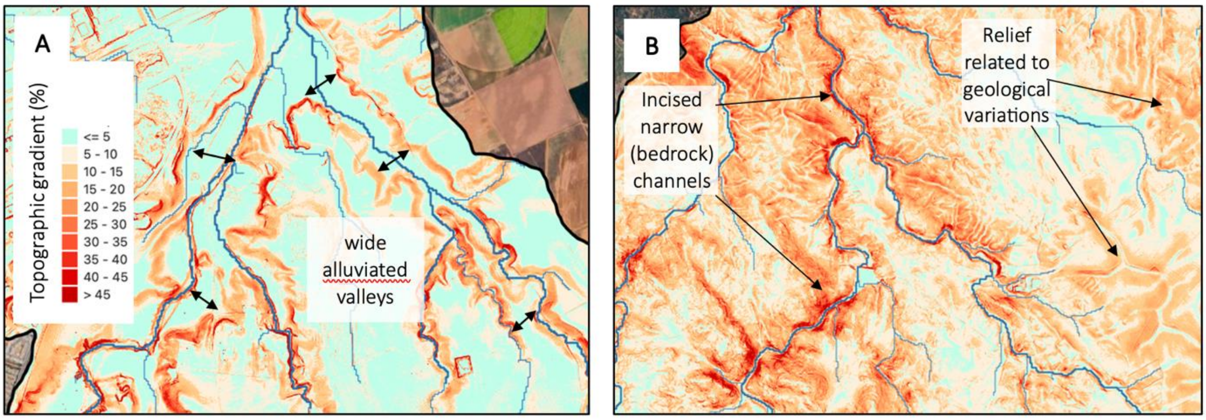


Figure 5: *Characteristic valley morphology in the downstream (A) and central areas (B) of the Ramabujas catchment (see Figure 4 for localities).*

According to the soil map, the Ramabujas catchment is characterized by the presence of two main soil orders: *Inceptisol* and *Entisol* (Figure 6). These soils are characterized by weak (in case of *Inceptisol*) to minimal (*Entisol*) horizon development, reflecting the human-induced disturbance of the landscape. Deforestation and agricultural activities have strongly enhanced erosion across the watershed, leading to the loss of nutrient- and organic-rich horizons. Locally, sediment deposition from upstream further disrupts soil formation, preventing the development of more mature soil profiles.

Among the *Inceptisols* there are two soil classes differentiated: *Haploxerepts*, especially observed in the central part of the catchment, have weakly developed profiles and no significant calcium carbonate accumulation (Figure 6). *Calxerepts***,** dominating the upstream part of the catchment**,** have similar profiles but notable accumulation of calcium carbonate, making them more alkaline.

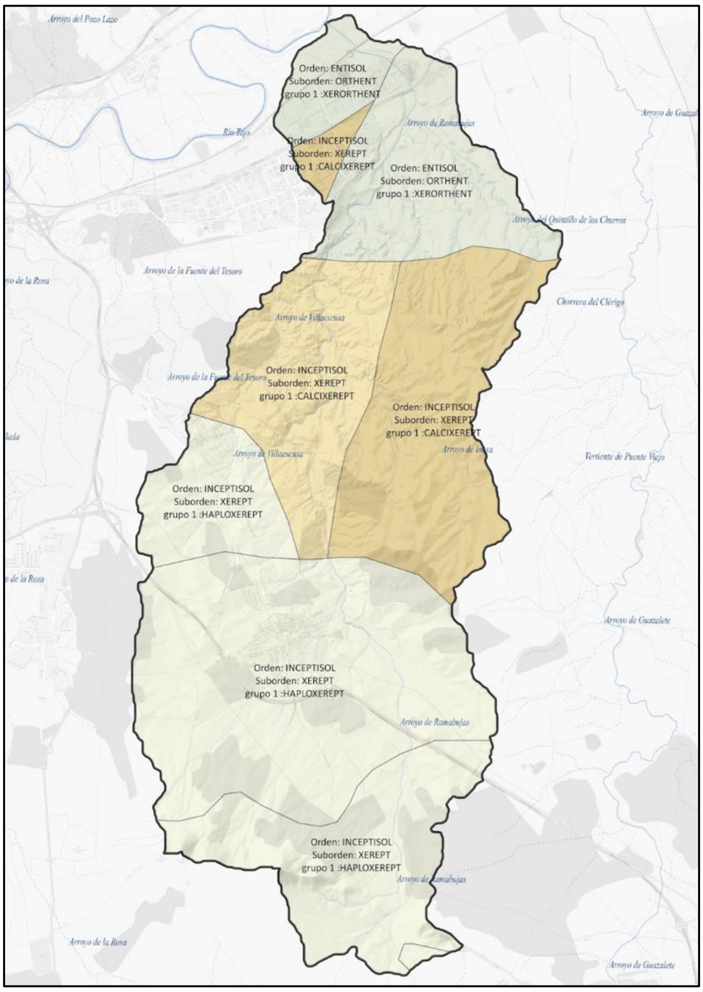


Figure 6: *Soil map of the Ramabujas catchment.*

2.2 Water system

The Ramabujas drainage network as shown in Figure 7 was calculated from 10-meter resolution digital elevation data. The drainage network consists of the main stream, *Arroyo de Ramabujas*, along with its primary tributaries: *Arroyo de Villaescusa*, *Arroyo de Inesa* and *Arroyo del Quintillo de los Churros*. This drainage system is characterized by ephemeral flow, with water typically present only after rainfall events. For most of the year, the streams are dry. Therefore, especially the headwaters of the drainage network shown in Figure 7, illustrate the direction of surface runoff more accurate in case of a rain event.

Figure 7: *Drainage network of the Ramabujas stream catchment derived from 10-m DEM.*

A notable feature of the Ramabujas drainage system is its partial obstruction by east-west oriented highways and railroad (Figure 8). To facilitate the passage of water underneath these elevated structures, runoff is directed through culverts. At these localities, the calculated drainage network was adjusted manually to account for passage through these culverts. Manual adjustment was also needed for the two artificial canal structures, one around/through the village of Nambroca, and the other one crossing the industrial terrain of Santa María de Benquerencia (Figure 8).

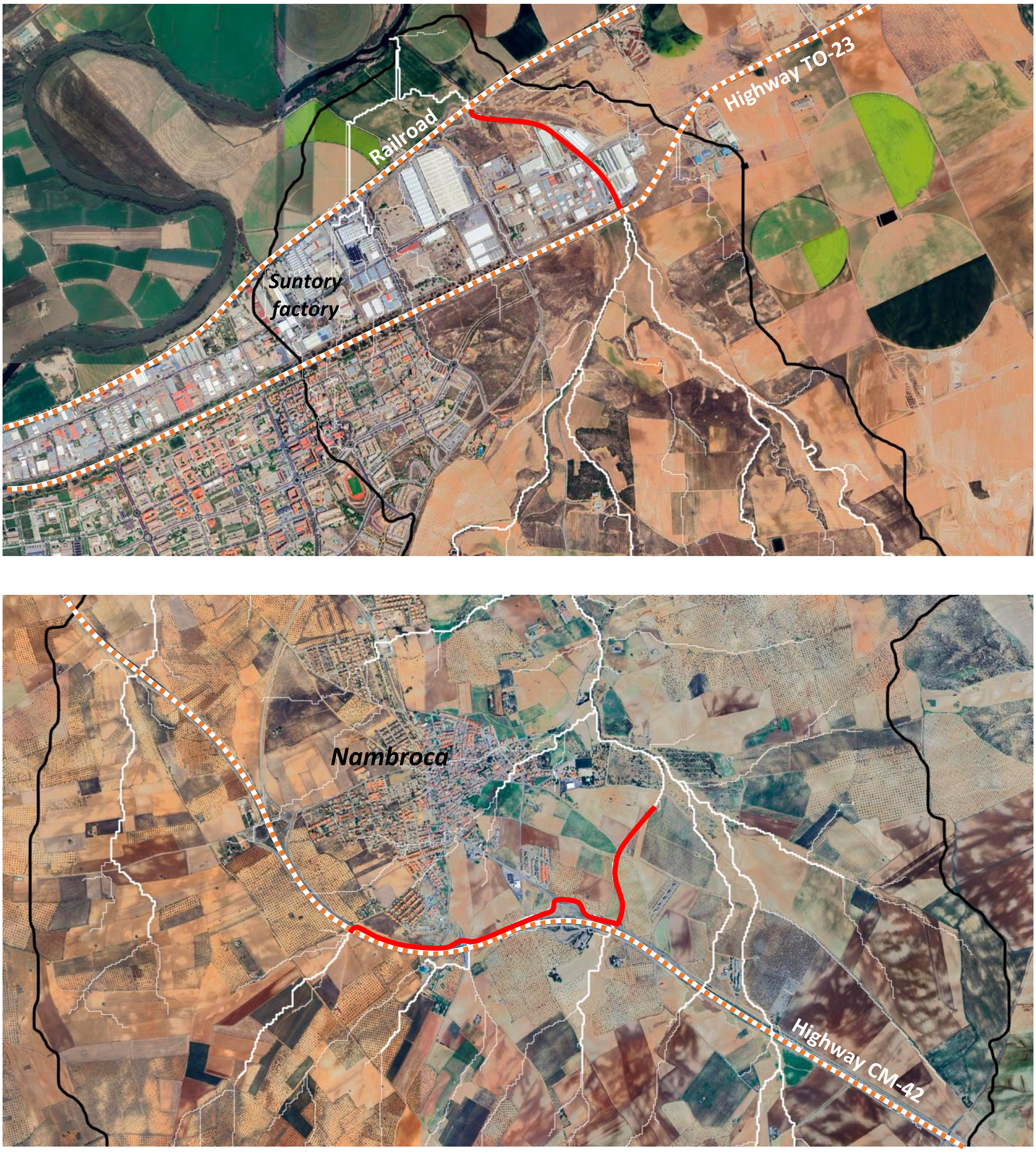


Figure 8: *Culverts (where drainage lines cross the railroad and two highways) and artificial canals (red lines) in the industrial area of Santa María de Benquerencia (top), and around the village of Nambroca (bottom).*

2.3 Land use

In the Ramabujas catchment, three types of agricultural land use dominate: olive groves, arable land, and fallow land (Figures 9 and 10). Various crops are grown in the fields, mainly winter wheat. After harvesting these crops in spring (~April), the fields typically remain fallow for the remainder of the year. In the olive fields, soils remain uncovered year-round, often lacking undergrowth such as grasses and herbaceous plants.

Figure 9: *Olive groves (left) and wheat plots (right) are the dominant agricultural land uses in the Ramabujas catchment.*

Figure 10: *In the central part of the Ramabujas catchment natural areas are more common.*

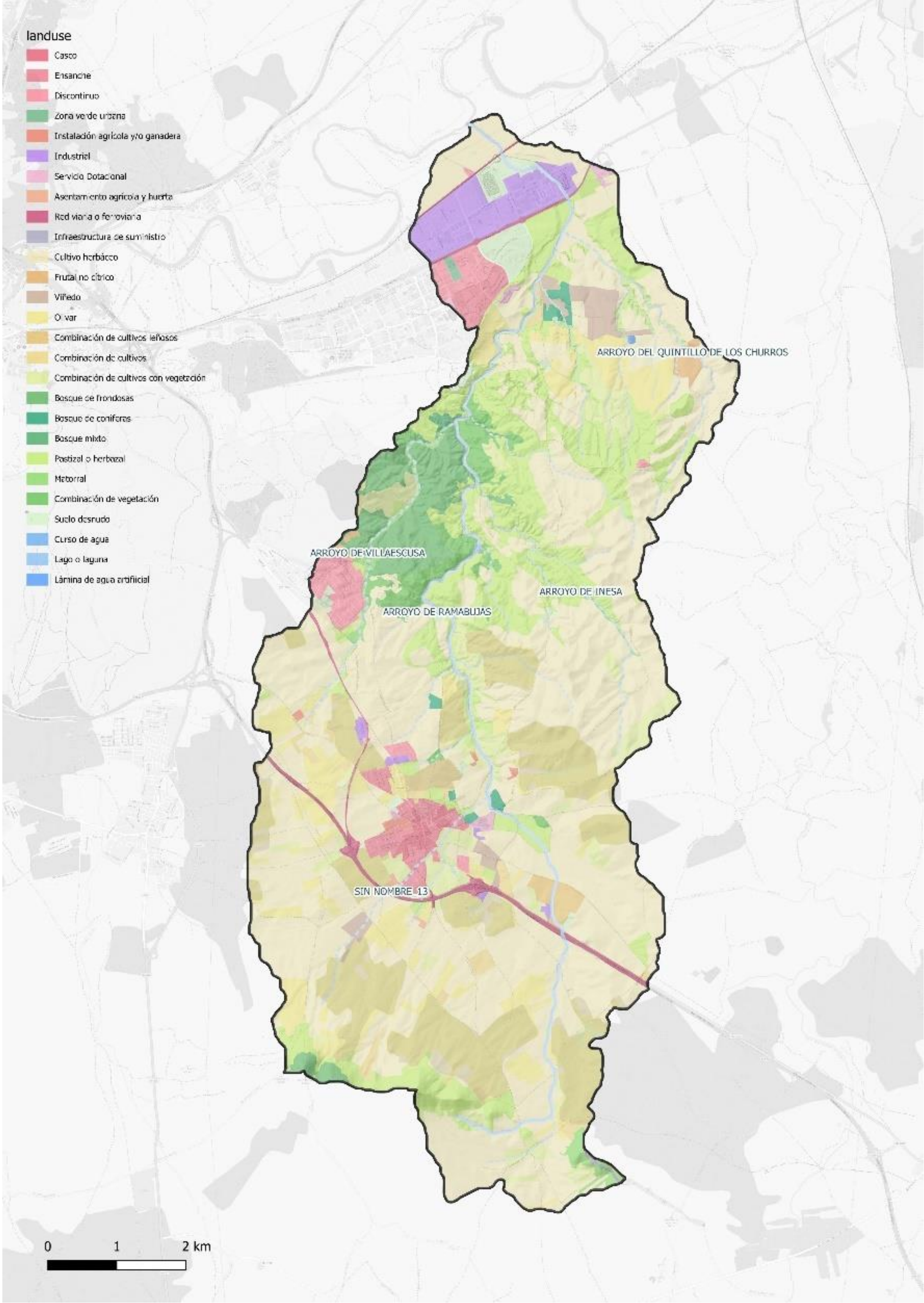


Figure 11: *Land use map Ramabujas catchment according to SIOSE 2014.*

Forest cover in the catchment is limited. Only in the central-western part of the catchment a significant area of deciduous or mixed forest is situated. This forest is relatively sparse, consisting mainly of low trees with a significant amount of shrubbery.

Although the level of urbanization in the Ramabujas catchment is low, the built-up areas are still susceptible to flooding and contribute to it. The centrally located village of Nambroca lies at the confluence of several tributaries of the Ramabujas, and the development in this area has largely ignored the potential impacts of extreme rainfall. The village is located just downstream of the CM-42 highway.

Downstream of the TO-23 highway, the area is dominated by the industrial site of Santa María de Benquerencia. The Suntory plant is located in the northwestern corner of the Ramabujas catchment.

Figure 12: *A significant percentage of the catchment remains fallow each year due to CAP conditions for soil recovery (top). Street in the village of Nambroca, north of the CM-42 highway (bottom left) and the Suntory factory in the industrial zone north of the TO-23 highway (bottom right).*

2.4 Vegetation cover analysis based on satellite images

Sentinel-2 satellite imagery from 2017-2024 was used to analyse land cover patterns and changes within the Ramabujas catchment (https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S2_SR_HARMONIZED). Since runoff generation and flow velocities in this area are largely influenced by vegetation cover, the *Normalized Difference Vegetation Index* (NDVI) was employed to differentiate between barren land and areas covered by various types of vegetation. The NDVI is a widely used remote sensing index that quantifies vegetation health and density, that varies between 0 and 1 and where higher values indicate denser or healthier vegetation.

One of the sub-catchments in the central-eastern part of the Ramabujas catchment (see Figure 15 for location) was used as a test region to examine how the NDVI fluctuates seasonally and across different years, comparing highly degraded agricultural land (e.g. field #3 in Figure 13) with densely vegetated (semi-)natural land (e.g. field #5 in Figure 13).

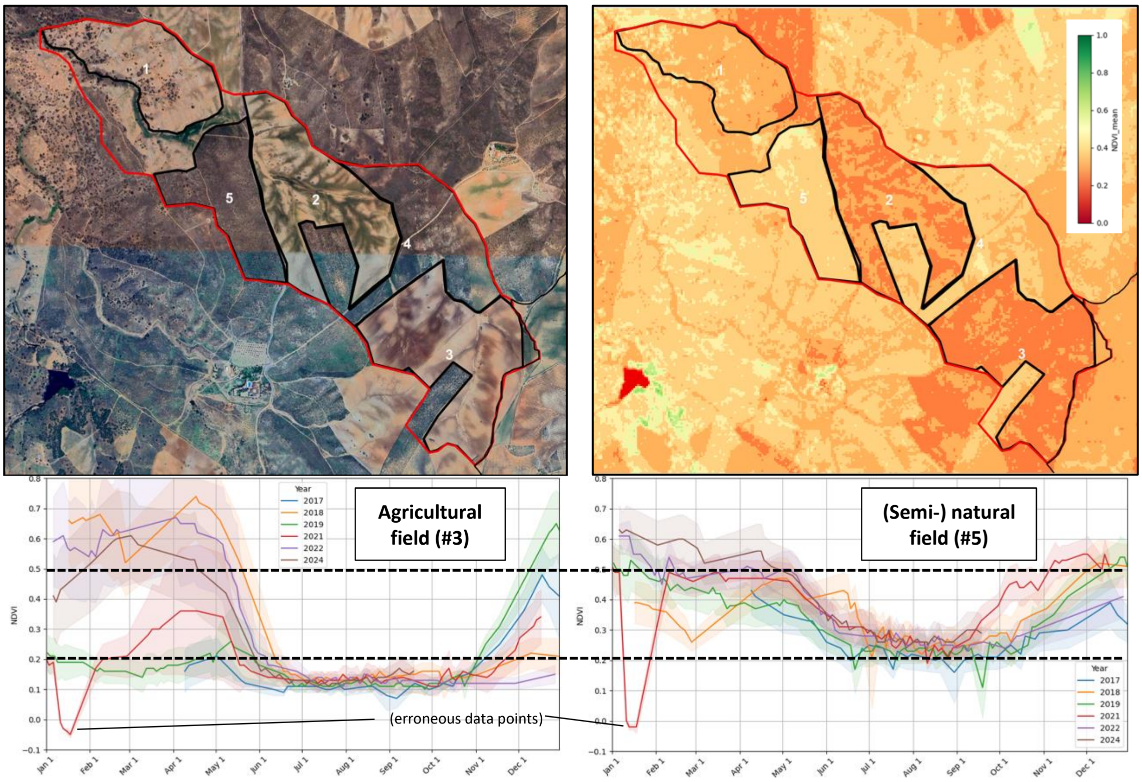
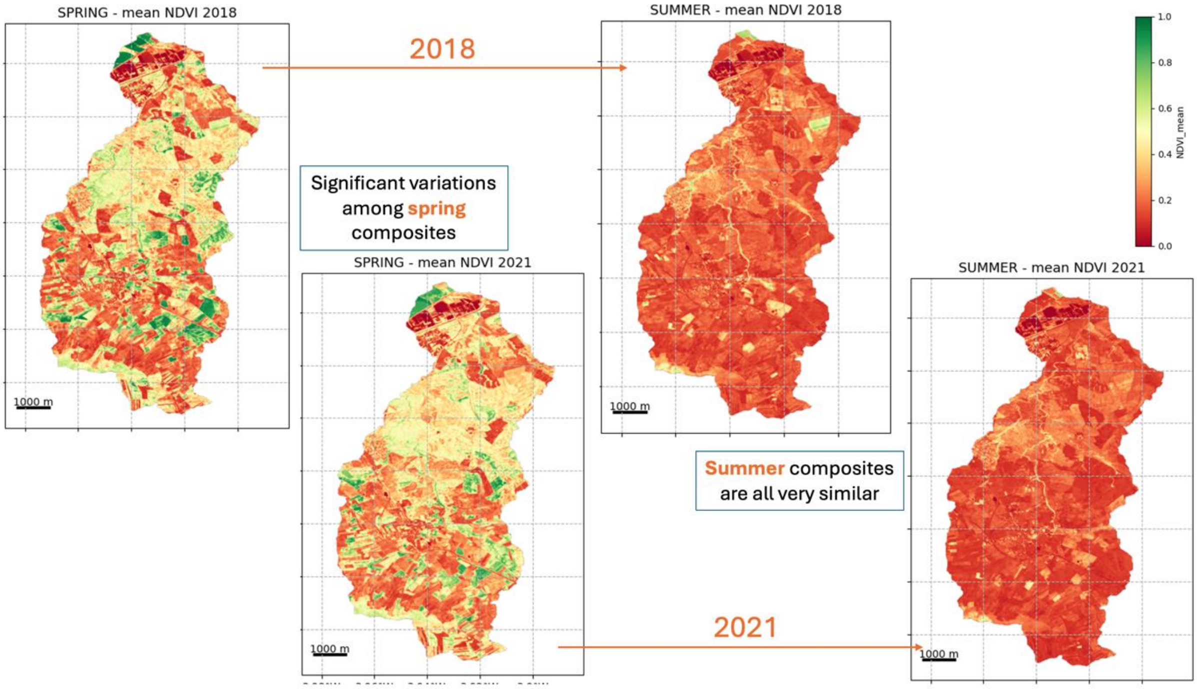


Figure 13: *Test region in central-eastern Ramabujas that was used for exploring NDVI timeseries (see Figure 15 for location of this area). For each of the five fields (see numbers 1-5) the mean NDVI was calculated for all available satellite images and this data was plotted against time. To demonstrate the differences between barren agricultural land and natural land, the timeseries of fields #3 and #5 are shown in the 2 graphs at the bottom (see text for explanation). The top left figure is a Google Satellite image for showing what the different fields look like. The top right figure shows the mean summer NDVI for the region based on all available images.*

As shown in Figure 13, the natural land (field #5) exhibits relatively high NDVI values (~0.4 to 0.6) during winter and early spring (January-April), and lower NDVI values (~0.2 to 0.3) during the summer months of July and August. Year-to-year comparisons of the NDVI patterns reveal a consistent seasonal cycle, reflecting the summer-winter contrast in precipitation and potential evaporation, and so the availability of water (see section 3). The observed variability from year to year is primarily driven by differences in weather conditions.

In contrast, the NDVI curves for the agricultural land (field #3) reflect land use practices rather than natural vegetation dynamics (Figure 13). Due to the highly degraded condition of this land, there were several years with no crop production, as indicated by consistently low NDVI values throughout both winter and summer (e.g., in 2017, 2019, and 2012). In other years (e.g., 2018, 2022, and 2024), the land was used to grow winter grains, resulting in a distinct NDVI pattern: high values (~0.5–0.7) from February to April as the crops matured, followed by a sharp decline in NDVI to around ~0.1–0.15 from July to October, reflecting the complete absence of vegetation cover post-harvest. The seasonal and annual NDVI fluctuations in the test region served as a reference for interpreting NDVI signals across the Ramabujas catchment.


SPRING - mean NDVI 2018

SUMMER - mean NDVI 2018

SPRING - mean NDVI 2021

SUMMER - mean NDVI 2021

Significant variations among spring composites

Summer composites are all very similar

Figure 14: *Examples of mean NDVI composite maps for the spring months (based on all available Sentinel-2 images from March and April) and summer months (July and August images) for the years 2018 and 2021.*

Characteristic of the NDVI time series from fields with either natural vegetation or agricultural crops is the distinct NDVI contrast between spring (or pre-harvest) and summer (or post-harvest). In spring, fields with active vegetation (both natural and agricultural) typically show higher NDVI values, which are represented by yellowish or greenish colors in the mean spring NDVI maps (Figure 14, left). This contrasts with the summer NDVI maps (Figure 14, right), where these same fields often appear red, indicating a sharp decrease in

NDVI values as crops are harvested or vegetation becomes less vigorous during the hotter months. In contrast, fallow fields, which have little to no vegetation throughout the year, do not exhibit the same spring-to-summer NDVI contrast. These fields remain barren, showing low NDVI values (typically red) in both the spring and summer maps, as there is no significant vegetation growth in either season.

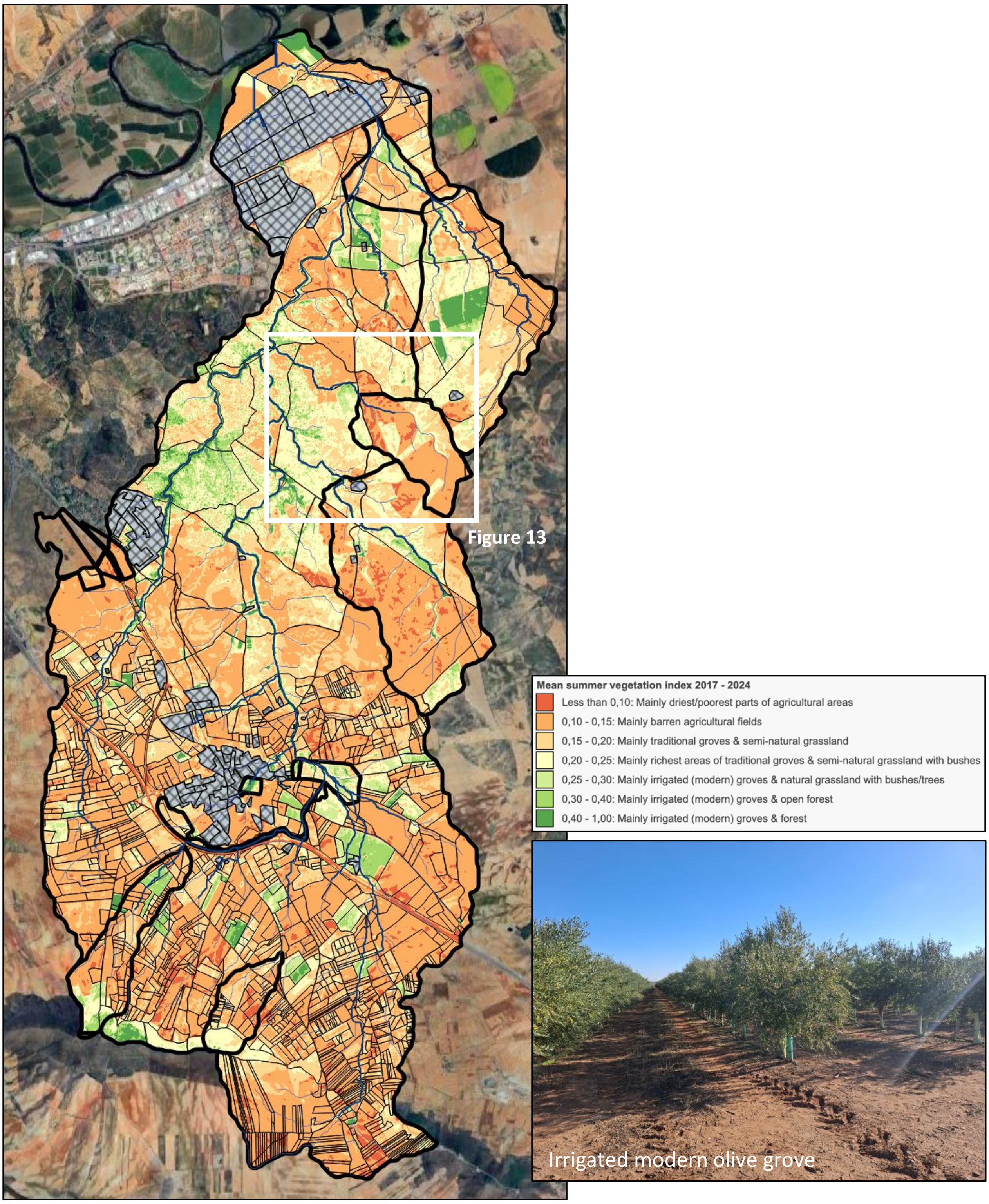


Figure 15: *Mean (2017-2024) NDVI summer composite image. The picture shows an irrigated modern olive grove, the only type of field turning green on the summer NDVI map, besides natural lands.*

The mean NDVI maps in Figure 14 were created based on all Sentinel-2 images from spring months March and April, or by means of all images from summer months July and August. The maps in Figure 14 were produced for each year individually, while the map in Figure 15 shows mean summer NDVI values based on all years together. This map nicely demonstrates that most of the catchment consists of bare agricultural land and paved surfaces (NDVI < 0.20). Only natural areas and irrigated modern olive/almond groves with high tree density appear green in the summer NDVI map, indicating healthy vegetation under Mediterranean summer conditions (NDVI > 0.25).

Based on the spring and summer NDVI analysis, an additional map (Figure 16) was derived to show the number of years (out of 8 years; 2017-2024) each field remained completely barren, without vegetation cover throughout the entire year. While most fields in this area are barren for part of the year—especially during the summer—the fields highlighted in Figure 16 contribute more significantly to land degradation. This map first identifies fields that have been barren for (almost) all years (deep red color), which are primarily traditional olive/almond orchards with low tree density and a characteristic 'barren soil' NDVI signal. However, of particular concern are the many fields that are barren for 4-6 years (yellow-orange colors). These fields are rarely used for crop production but are still plowed regularly, to meet EU Common Agricultural Policy (CAP) conditions, driving ongoing erosion with little economic value.

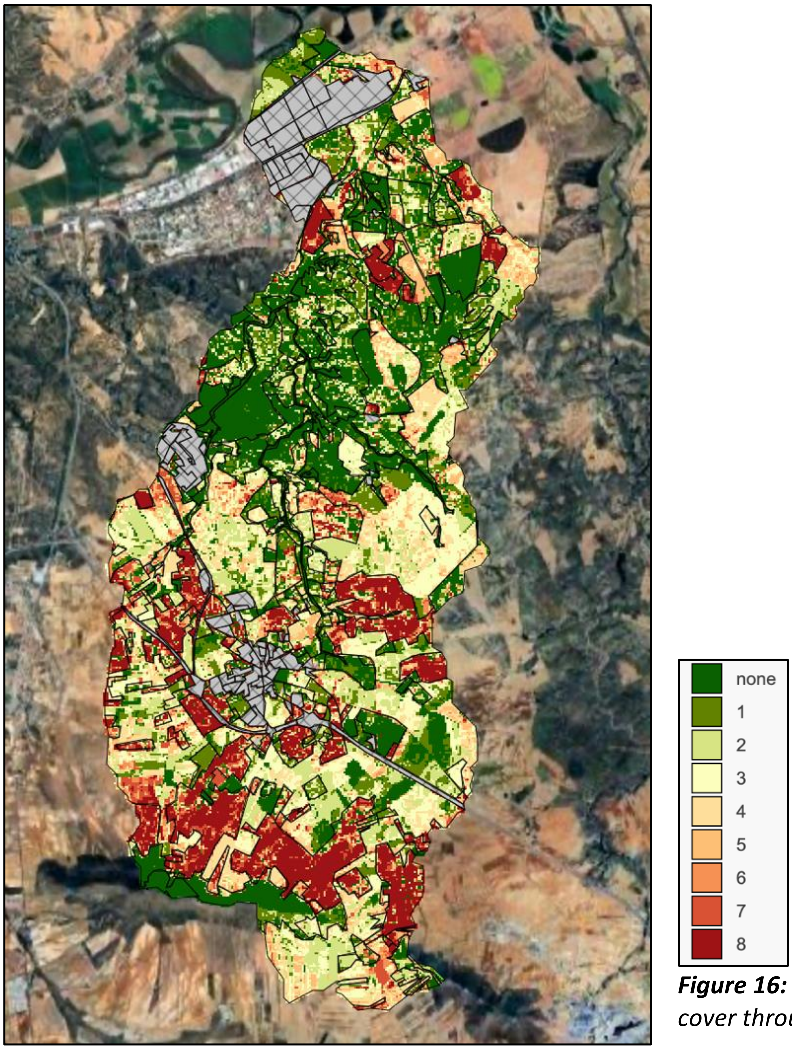


Figure 16: *Number of years without vegetation cover throughout the entire year.*

3. Rainfall and flooding in the Ramabujas catchment

3.1 Annual average rainfall and seasonal variability

Precipitation data for the Ramabujas region over the past 10 years was sourced from the Copernicus Climate Data Store ('ERA5 hourly data on single levels from 1940 to present'; https://cds.climate.copernicus.eu/datasets). ERA5 combines model outputs and global weather observations to produce a consistent and accurate atmospheric record. Due to its relatively coarse spatial resolution (0.25° x 0.25°), extreme rainfall values are generally lower than those reported by local weather stations (for example, the relatively low daily total of 47 mm for the Dana event on September 3, 2023, as shown in Figure 17). However, because rainfall events are often spread over longer durations, total precipitation amounts still align closely with local records. As such, this dataset is well-suited for long-term precipitation analysis. Over the past 10 years, the average annual precipitation in the Ramabujas catchment was approximately 425 mm.

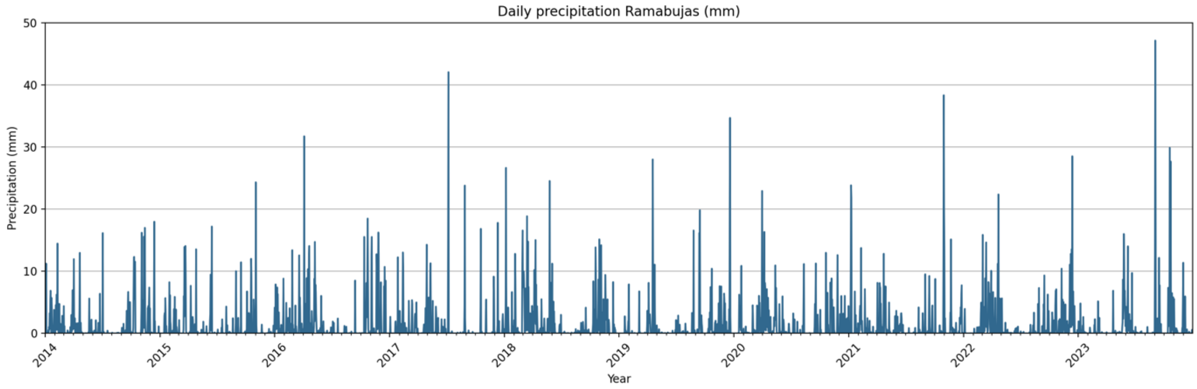


Figure 17: *Daily sums of hourly ERA5 total rainfall data 2014-2023.*

Rainfall is relatively consistent during the winter months, with two primary wet periods: (March-)April and October(-November). In contrast, during the summer months (especially June, July, and August) dry conditions prevail (Figure 18).

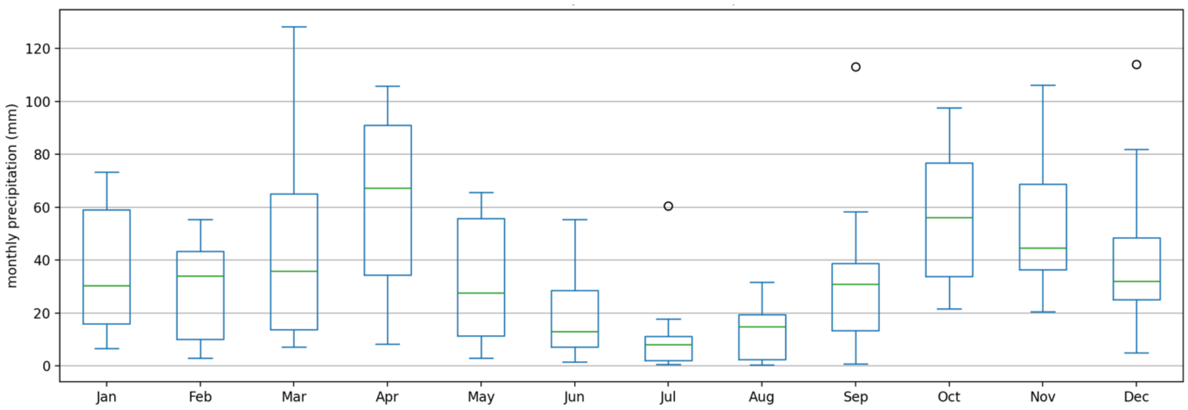


Figure 18: *Seasonality in precipitation (based on ERA5 dataset, 2014-2023).*

3.2 Rainfall and flooding during DANA September 3rd, 2023

Local weather stations report that the DANA event from September 3rd, 2023, brought close to 100 mm of rainfall to the Ramabujas catchment, with peak intensities exceeding 100 mm per hour. During this brief period of intense rainfall, surface runoff caused severe erosion and flooding in the villages and industrial areas. It is most likely that the zone with high precipitation moved from south to north over the Toledo region with local variation in intensity and duration.

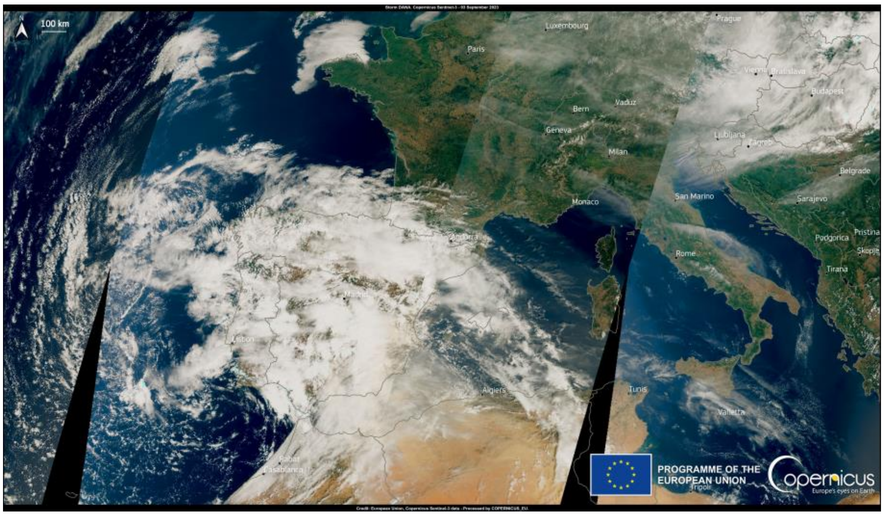


***Figure 19:** DANA seen from the Copernicus Satellite on the 4th of September 2023.*

The official weather data from the Toledo weather station (AEMET) mirrored the rainfall pattern observed by the private weather station network https://www.wunderground.com. The main difference is the timing of the rainfall. The peak of the DANA event in the AEMET data occurred around 6 PM, while the Wunderground network recorded the peak between 8 and 9 PM (Figures 20 and 21).

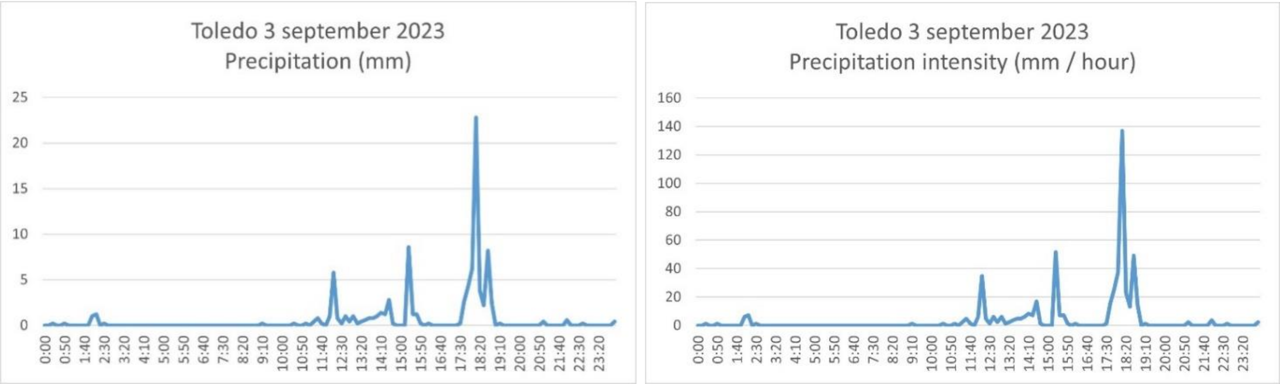


***Figure 20:** Precipitation (left) and precipitation intensity (right) in Toledo on September 3rd, 2023, based on AEMET 10 minutes observations. Two smaller peaks were followed by a large peak with high intensity rainfall. Total amount of precipitation was 90,2 mm with a peak intensity of 137 mm / hour. The peak of the event took place around 6pm.*

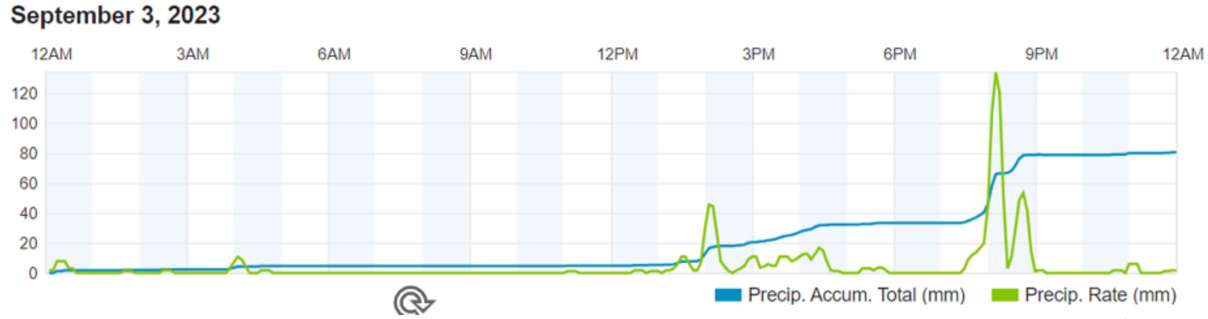


Figure 21: *Total precipitation (blue line) en precipitation intensity (green line) in Toledo on September 3rd, 2023, based on Wunderground observation. Total amount of precipitation recorded was 80 mm with a peak intensity of 134 mm / hour. The biggest difference is the time of the peak of the event recorded around 8pm, 2 hours later than the peak in the AEMET data. Other Wunderground stations in the area recorded the peak of the event also between 8 and 9 pm. Most likely the peak of the event was around 8pm.*

During the DANA 2023 event, the culvert under the TO-23 highway was unable to efficiently discharge the water from the Ramabujas catchment, leading to the formation of a lake (see Figure 22). As the water level in the lake reached the height of the highway (484.5 meters), flooding began on the highway and spread into the nearby industrial area. A reconstruction of the lake's size suggests that approximately 28 hectares were flooded, with a total volume exceeding 900,000 m^3 of water (Figure 22).

In terms of timing, flooding began around 9:15 pm in the village of Nambroca (Figure 23), and by 10 pm, the industrial zone—including the Suntory factory—was heavily inundated as water levels surpassed the height of the TO-23 highway (Figure 23). Given the short time gap between the peak of the DANA event and the flooding in the industrial zone, it is likely that the downstream subcatchments contributed the majority of the floodwaters.

Figure 22: *Based on the DEM (Digital Elevation Model) a reconstruction could be made of the lake that emerged during DANA (lake is visible in the left drone image from the day after). More than 900.000 m3 of water was temporally stored on area of 28 ha (bottom).*

Los autobuses de Toledo, colapsados por la DANA: "Ha sido una tragedia" - ENCLM

"Fortunately, only material damage was caused. At the worst moment of the flooding, three people from the cleaning service were working at the headquarters of Unauto and had to climb to the first floor to literally save their lives. The fear was great on Sunday night, because the water flooded so much that at 22:00 it 'exceeded the height of the buses, which is three meters' The DANA destroyed the headquarters of Unauto, which is located a few meters from the Ramabujas stream."

Figure 23: *Flooding in the village of Nambroca on 3 September 2023 around 9:15 PM (Left). Flooding of Toledo bus terminal at the industrial site downstream of the Ramabujas stream on the same day at 10 PM (Right).*

4. Field observations and key story lines of the Ramabujas

Based on the desk-top water system analysis presented in previous chapters, a field campaign was conducted from October 27th to 30th, 2024. The main aim was to observe some of the key hydrological and morphological processes in the Ramabujas catchment. Based on this data integration, we present here the story of the Ramabujas through seven story lines, covering the main sixteen field sites visited from upstream to downstream (Figure 24).

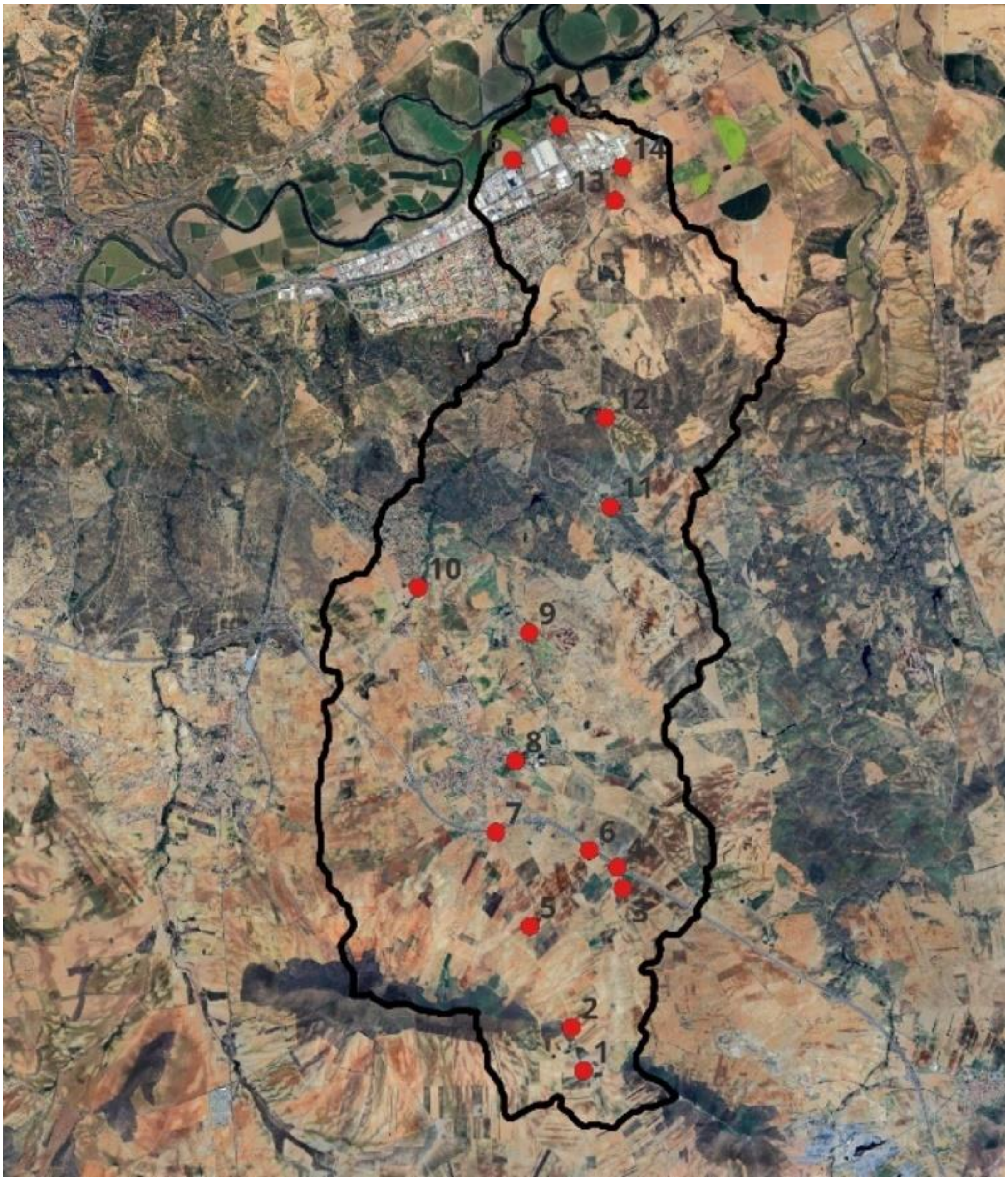


Figure 24: *Locations of the field sites in the Ramabujas catchment. Locations and pictures can be found on the website: https://media.stroming.nl/ramabujas/#*

4.1 Land degradation in the upstream Ramabujas catchment (sites 1-6)

The most upstream area of the Ramabujas is located between the Sierra de Nambroca mountains and highway CM-42 (field sites 1 and 2; **39°46'35.5"N 3°56'06.8"W**). The soils are shallow, with stone and rock layers close to the surface. In this area, the continuous loss of sediments and organic matter from fallow land is a key concern.

The height difference between the natural field and the arable land demonstrate how intense erosion is occurring (Figure 25 right picture).

Site	Geology	Slope	Land use	Key observation
1 & 2	Metamorphosed sandstones and granites, shallow layer of hillslope deposits	Gentle slopes mostly between 0 – 5 % and 5 – 10 % (Apart from the steeper mountain ridge)	Arable land, olive fields, abandoned almond fields, sparce natural vegetation	Continuous land degradation

Figure 25: *Continuous land degradation results in the loss of fine sediments (left) and organic material (right).*

Figure 26: *Abandoned almond fields (right) are more effective at preserving the soil through the protection of natural vegetation compared to the nearby olive groves (left).*

Figure 27: *Sparse natural vegetation acted as a retention area, slowing the flow of water during the DANA event (left). The height of the water is indicated by the floodmarks on the trees (right).*

Site 3: 39°46'53.7"N 3°55'14.8"W

If we follow the Ramabujas from sites 1 and 2 to the CM-42 Highway (site 3), floodmarks indicate high, but no extreme, discharges during the DANA 2023 event (5 m³/sec). The landscape was able to retain a significant amount of water coming from the upstream area. In this part of the catchment, the streambed of the Ramabujas is often unrecognizable in the field, as it runs through arable land and is therefore neglected as a stream.

Site	Geology	Slope	Land use	Key observation
3	Granites and hillslope deposits	Gentle slopes mostly between 0 – 5 %	Arable land & olive fields	-Ramabujas is not recognized as a stream -Area with high but no extreme water discharges

Figure 28: *The course of the Ramabujas can be distinguished by the light green colour, the streambed is one with the arable land (left). 100 meters upstream the Ramabujas is not recognizable at all as erosion tracks are being erased and the streambed is ploughed (right).*

Site 4

Two connected culvert constructions allow the main channel of the Ramabujas to cross both the CM-42 highway and the secondary road running parallel to it. The culvert beneath the secondary road was nearly filled with water and sediment, but the water level remained below the road surface. The secondary road itself contributed significant amounts of water to the stream. DANA discharge is estimated to have been ~5 m^3/sec.

Figure 29: *Ramabujas stream flows through a culvert under the highway (left) and bumps into the embankment of the secondary road (top right), where it flows 30 meters west through 3 small culverts to continue its way downstream (bottom right).*

Site 5: 39°45'57.3"N 3°57'13.5"W & 39°46'34.4"N 3°56'07.0"W

Further to the west several streams flow northward from the mountain ridge toward the highway. This area is characterized by severe erosion and surface runoff. Erosion begins in the steep slopes near the mountain ridge and is intensified by the bare fields of olive and almond trees further downstream.

Site	Geology	Slope	Land use	Key observation
5	Alluvial fan and hillslope deposits	Steep slopes close to the mountain ridge (10 – 20%) Decline in steepness in the downstream direction (0 – 10 %)	Olive fields, almond fields and arable land	Severe erosion and surface runoff due to (bare) olive and almond fields

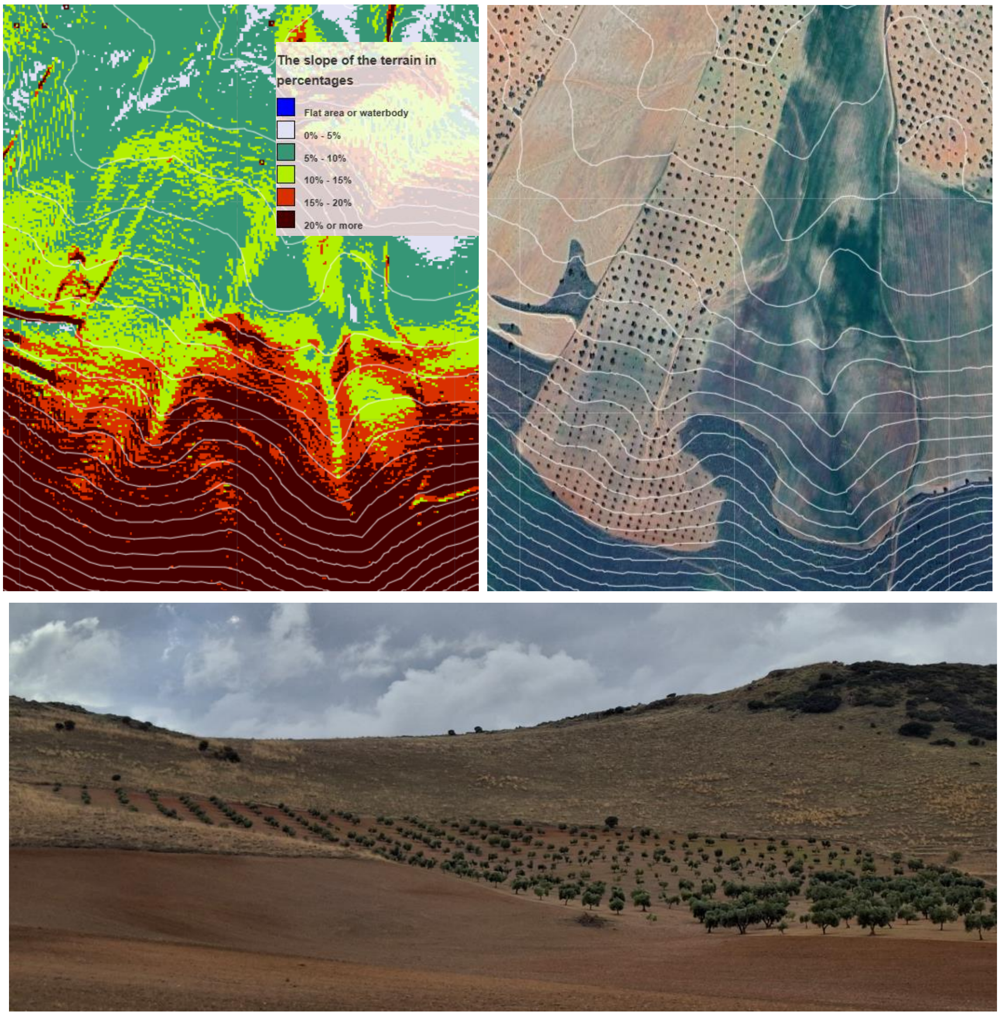


Figure 30: *Olive fields on the northern slope of the mountain ridge. Slope percentages up to 20% make the area vulnerable to soil erosion and surface runoff.*

Figure 31: *Severe erosion tracks through almond fields (left). Upstream olive fields are vulnerable for surface runoff (right)*

Figure 32: *Ploughing of the olive fields removes the protection of grasses and herbs, leaving the soil fallow and reducing the infiltration capacity due to weather conditions.*

Site 6: 39°47'10.4"N 3°55'32.0"W

The runoff from this section of the upstream area contributed more to the downstream discharge than the main channel of the Ramabujas itself. Floodmarks on two linked culvert constructions indicated high water levels (3 meters) on the upstream side of the highway (site 6; circa ~10 m^3/sec during DANA). While the water was able to pass through the first culvert, it was obstructed by the smaller second culvert beneath the secondary road. As a result, the secondary road became flooded, and water discharged into the olive field downstream.

While the culverts are typically sufficient during average rainfall events, some of these structures turn out to be inadequate during extreme storm events. Especially considering the fact that these structures tend to become blocked by debris and sediment, radically reducing their capacity or even completely stopping the further passage of water.

Figure 33: *Flood marks under the highway revealed high water levels (3 meter) at the upstream side of the highway.*

Figure 34: *The smaller culvert under the secondary road couldn't handle the amount of water. The road flooded and water continued its way downstream through the olive field. Flood marks can be seen at the trunk of the trees.*

Figure 35: *Surface runoff from paved and unpaved roads (field sites 6 & 7) contributed to the high discharge during DANA. Roads turned into streams.*

4.2 Flood risk in Nambroca & Las Nieves (sites 7 and 8)

Nambroca, a municipality with a population of 4,500, is partly located on several smaller stream streams (39°47'54.2"N 3°56'20.2"W). To protect the village from flooding, an artificial canal was constructed parallel to the highway to divert water away from the area. However, during the DANA event, the canal was unable to discharge all the incoming water from the culverts. The canal breached at two locations, and parts of the village were flooded, as shown in the figure below.

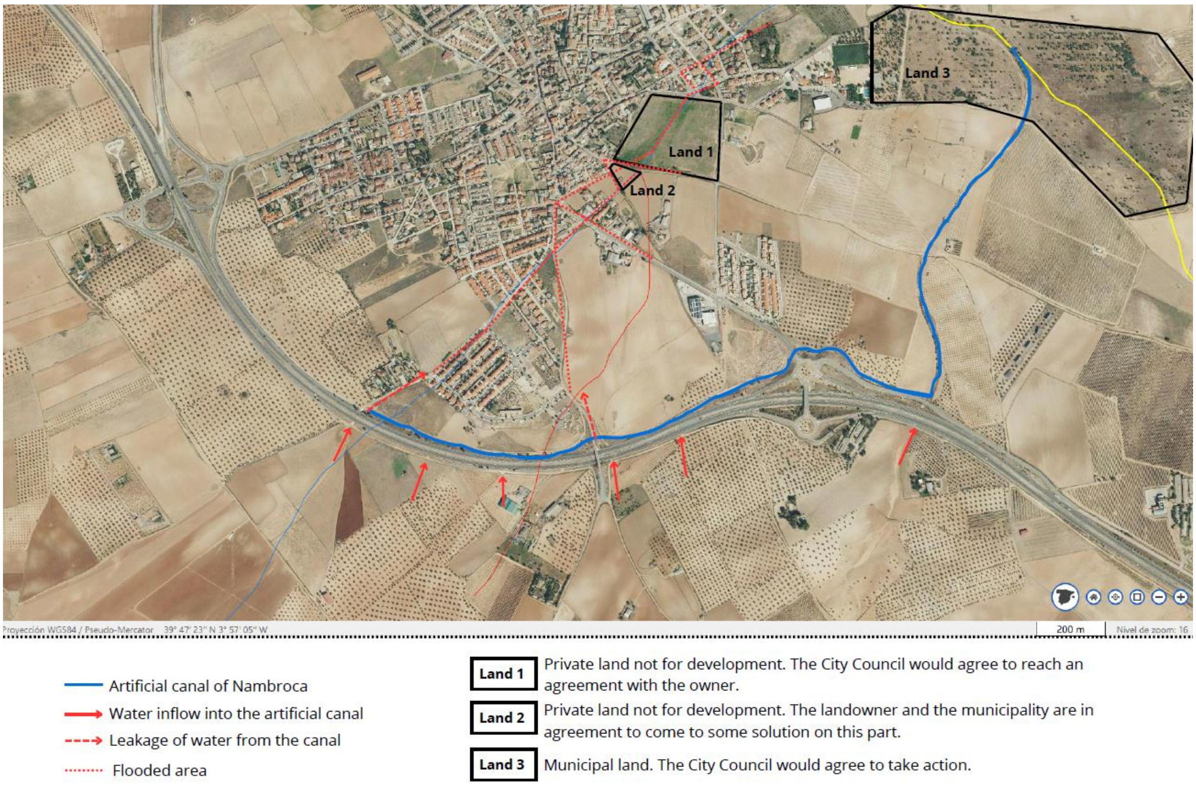


Figure 36: *Flood map of Nambroca during DANA 2023.*

Figure 37: *The artificial canal, build to protect the village, was not able to discharge the incoming water and breached at two locations.*

Figure 38: *Calle de la Fuente turned into a stream during DANA 2023, flooding several streets and houses.*

In Las Nieves (39°49'44.5"N 3°58'00.1"W), during DANA events, mudflows enter the village from the west (Figure X). The area west of Las Nieves, which includes olive fields and arable land, is part of the municipality of Toledo and is characterized by a large percentage of bare soil.

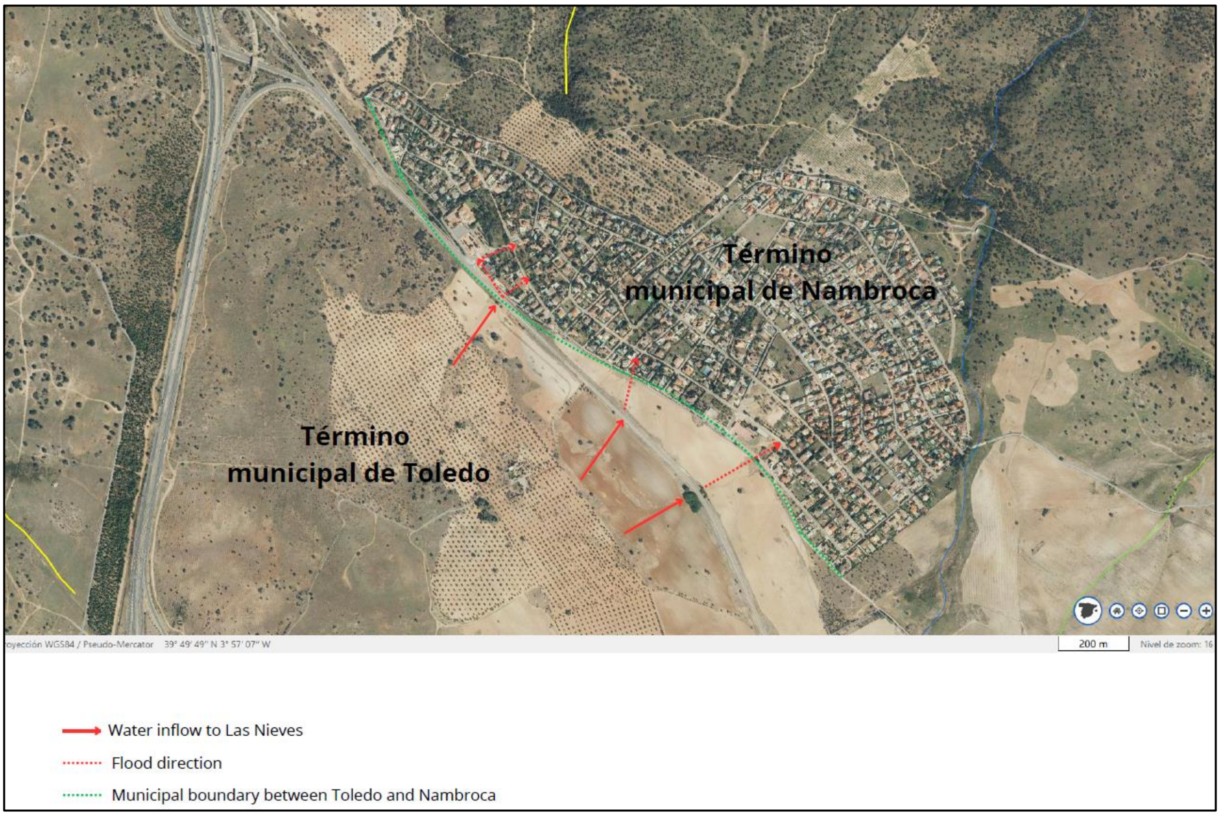


Figure 39: *Flood map of Las Nieves during DANA 2023.*

Figure 40: *Satellite image of Las Nieves after DANA 2023 (left) and flood damage in the village (right).*

4.3 Natural stream Arroyo de Villaescusa (site 9)

East of the village of Las Nieves, the Arroyo de Villaescusa flows through a natural stream valley (39°49'19.0"N 3°57'23.1"W). Natural stream valleys are common to the incised streams of the Ramabujas catchment The vegetation in these valleys helps retain and delay the flow of water during high discharge events.

Figure 41: *Natural valley of the Arroyo de Villaescusa flows east of Las Nieves in a natural valley (left), surrounded by a natural riparian zone (right).*

4.4 Water quality downstream of Nambroca (site 10)

Downstream of Nambroca, the Ramabujas becomes an incising stream flowing through a natural valley. During our visit water was running through the streambed. The smell and colour of the water could indicate that wastewater from Nambroca might be discharged untreated in the Ramabujas. 39°48'57.4"N 3°56'12.6"W

Figure 42: *The Ramabujas flows through a natural valley downstream of Nambroca. The water quality during low discharges might be under pressure due to discharge of sewage water.*

4.5 Severe erosion and high DANA discharges in northern sub-basins (sites 11-12)

Based on field observations and satellite images taken shortly after DANA 2023, it can be concluded that the northern sub-catchments contributed significantly to the total water discharge during this event. Severe erosion occurred in the fallow fields, adding large amounts of sediments to the floodwater (39°50'44.9"N 3°55'24.5"W).

Site	Geology	Slope	Land use	Key observation
12	Granites and metamorphic rocks with shallow soils	Moderate to steep slopes between 5 – 20 %	Arable land, forested land and fallow fields	-Floodmarks show high discharge during DANA -Erosion tracks visible on satellite images and in the field -Large area of fallow fields

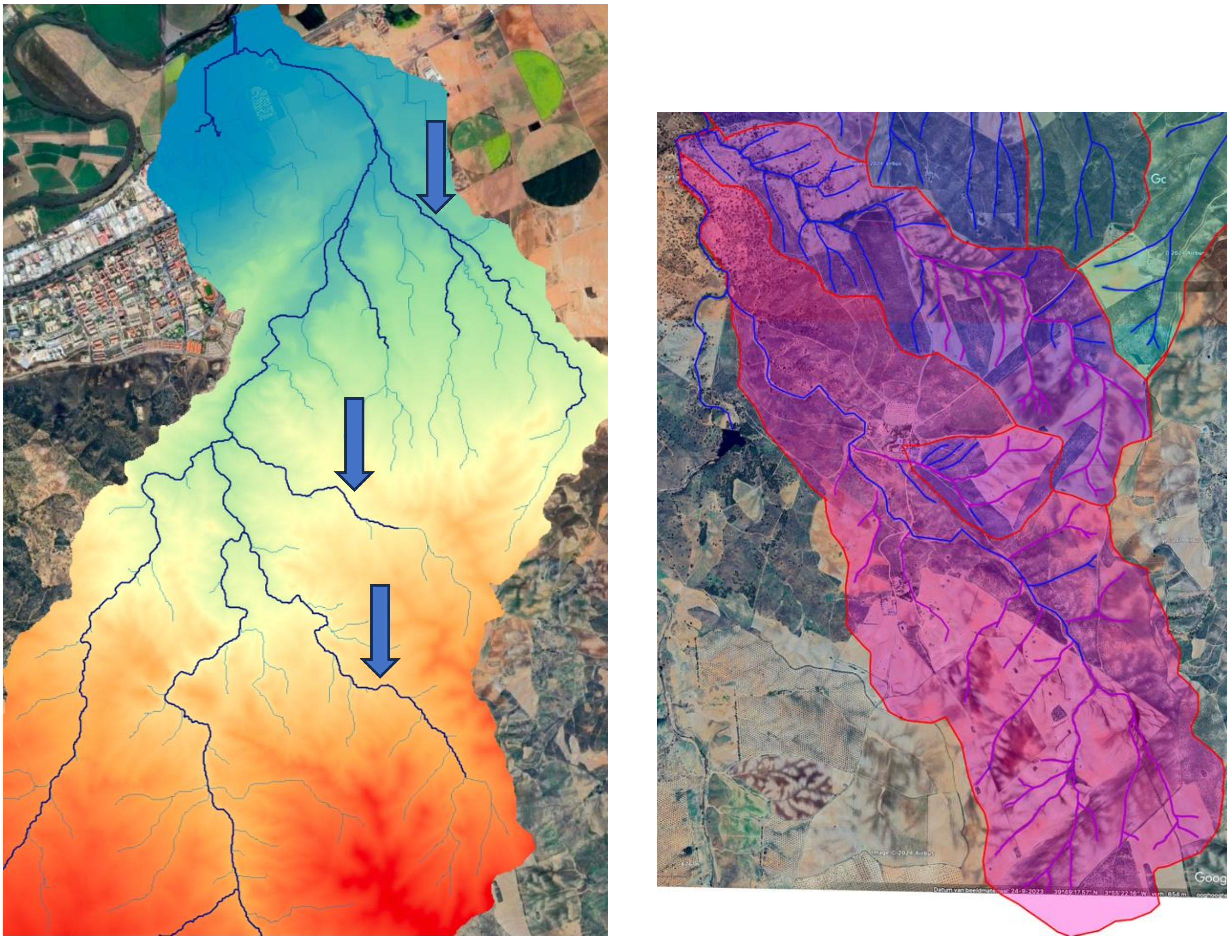


Figure 43: *Three sub-catchments vulnerable to erosion and high discharge in case of a DANA event (Left). For two of them, purple lines show runoff routes with signs of erosion as observed in the field (right).*

Figure 44: *Ploughed erosion tracks on fallow fields visible in a satellite image taken two weeks after DANA 2023 (left). Floodmarks indicating high water levels during DANA 2023 (right).*

Figure 45: *Streambed amidst fallow land (Left) Fresh erosion tracks highlight the vulnerability of this area to soil erosion and surface runoff (Right).*

4.6 Water retention in downstream Ramabujas (sites 13)

In the downstream area of the Ramabujas, just before it enters the industrial zone, the main stream and its tributaries converge to flow as a single stream underneath the TO-23 highway. During DANA 2023 a large lake formed due to the obstruction caused by the highway. When the lake reached its maximum capacity both the highway and the industrial zone were flooded.

This downstream area features a distinct geological structure, consisting of a mixture of Miocene sand and stone layers, along with alluvial deposits from the Pleistocene era (Figure 46).

Figure 46: *Alluvial deposits forming an aquifer layer (left), Conglomerate layers of sand and stone are vulnerable to erosion (right).*

Site	Geology	Slope	Land use	Key observation
13	Miocene conglomerates & Alluvial deposits	Low slope areas (0 – 5 %) with some steep ridges	Arable land & Vineyard western side of the area is designated for future development	-This area functions as an aquifer -Severe erosion near steep ridges -A vineyard is situated in a stream bed - Ramabujas obstructed by improvised dam - During DANA a lake emerged with an volume of over 900.000 m3 and an flooded area of 28 ha.

Alluvial deposits creating an aquifer

The alluvial deposits of sand and clay form an aquifer layer that allows water from the Ramabujas to infiltrate. This area has the potential to serve as a water retention area for the Ramabujas (Figure 47).

Figure 47: *In the afternoon of 30 October 2024, the small discharge in the Ramabujas (left) was completely infiltrated 2 kilometres downstream (right).*

Vineyard in a stream

The area where the Arroyo del Quintillo de los Churros forms its delta and flows into the Ramabujas is in use as a vineyard. During DANA 2023, the upstream section was flooded by the Arroyo del Quintillo de los Churros, as evidenced by the large amounts of sand deposits. The downstream area of the vineyard was flooded by the Ramabujas when it became part of the large lake.

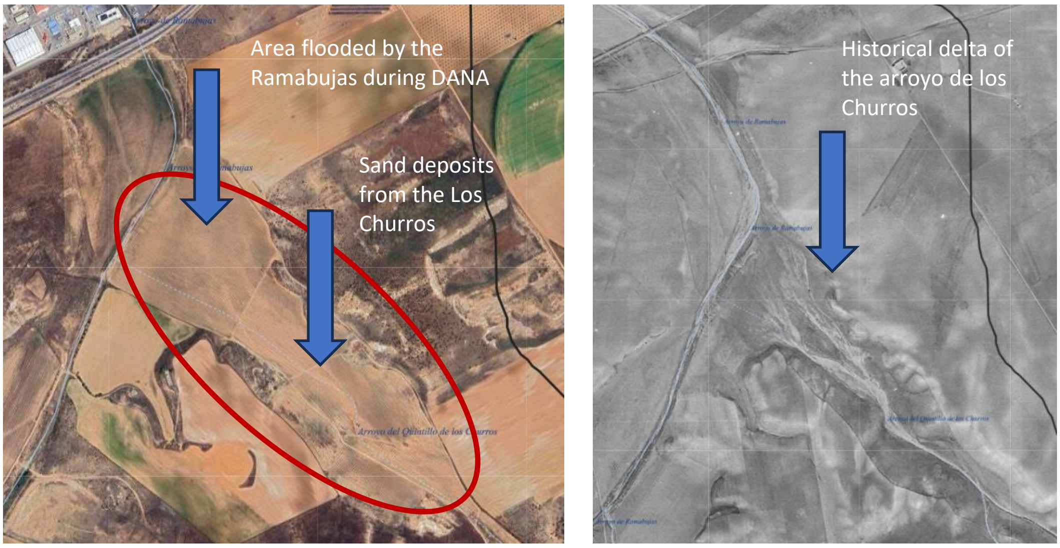


Figure 48: *The vineyard is situated on the confluence of the Arroyo del Quintillo de los Churros and the Ramabujas stream. During high water discharges the area is flooded from both streams (Left). In the historical aerial photo of 1956, the delta of the Arroyo del Quintillo de los Churros can be seen on the location of the present vineyard (Right).*

To protect the vineyard from future flooding, the farmer built an improvised dam around his parcel, bisecting the Ramabujas streambed (Figure 49). However, the dam will not be strong enough to withstand the force of the next DANA event.

Figure 49: *Sand deposits in the vineyard from the Arroyo del Quintillo de los Churros after DANA (left). An improvised dam bisecting the Ramabujas streambed to 'protect' the vineyard from flooding (right).*

Severe erosion in the area with conglomerates of stone and sand layers

The soil structure of the Miocene stone conglomerates and sand layers is not very solid, making it vulnerable for severe erosion during a DANA event (Figure 50). High discharges from the small sub-catchment caused backward erosion, resulting in the transport of large stones over several hundreds of meters.

Figure 50: *Severe erosion caused by high discharges and the vulnerable geological structure in this sub-catchment during DANA.*

4.7 Flood risk in the industrial site Santa Maria de Benquerencia

The Suntory factory is located in the industrial site of Santa María de Benquerencia, an area developed in the second half of the 20th century where the Ramabujas approaches the Tagus Stream (Figure 51). The Ramabujas was redirected into a channel, and culverts were constructed to allow water to pass under the highway and railway. After DANA 2023, the culvert under the highway was enlarged to increase its discharge capacity and prevent future flooding of the highway (Figure 52 left). However, the capacity of the canal remained unchanged, leaving the industrial site still vulnerable to flooding (Figure 52 right).

***Figure 51:** Location of the Suntory factory in the industrial site, with the Ramabujas canalised (left). The same location on the aerial photo of 1956, the Ramabujas at that time followed a natural course and had more space to handle high water discharges (right)*

***Figure 52:** The new culvert construction under the TO-23 highway, with three passages, each having a flow area of 10 m². Downstream of the culvert, the canal has a flow area approximately half of the culvert's capacity.*

And the end of the canal, close to the stream Tagus, two large culvert constructions transport the Ramabujas water under the railway (Figure 53). Both were discharging water during DANA.

Figure 53: *Two large culvert constructions under the railroad, each has five passages with a flow area of 5m2.*

Flooding of the industrial area

During DANA, the industrial area was flooded, and water accumulated in the lowest corner near the Suntory factory site, at more than 1 kilometre distance from the Ramabujas (Figure 54 and 55). Water levels exceeded 50 centimetres in both the factory and the Suntory water treatment plant. Thick layers of mud were deposited in the factory, leading to its closure for two weeks. The small culvert construction under the railway near Suntory was unable to discharge the large volume of water, resulting in high water levels.

Figure 54*: During DANA the water flooded the industrial site and accumulated in the lowest corner at the Suntory factory. Water levels exceeded 50 centimetres in both the factory and the Suntory water treatment plant.*

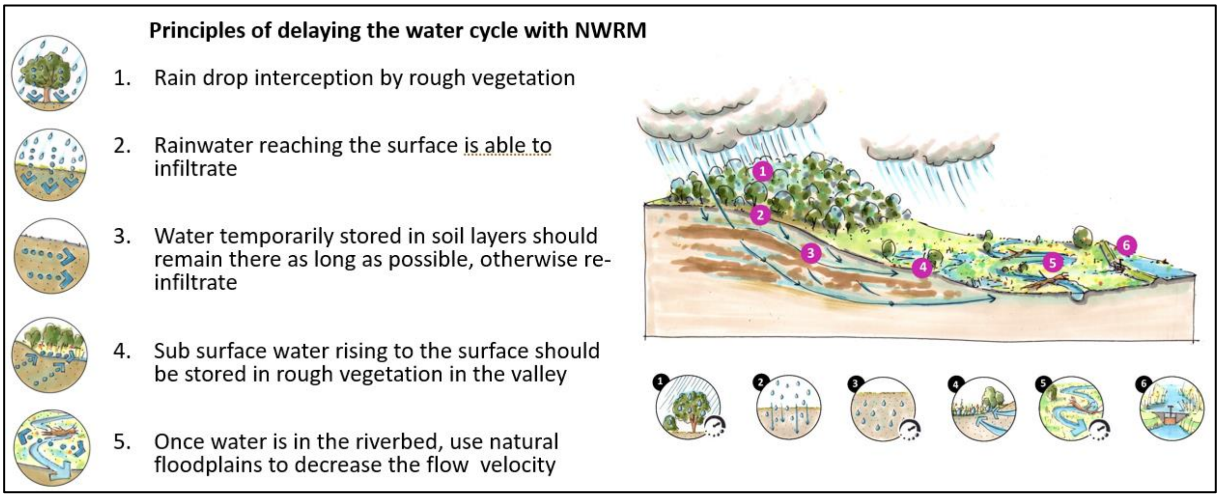
Figure 55*: During DANA the Toledo bus terminal close to the Ramabujas was flooded (Left). Suntory, at more than 1 kilometre distance from the Ramabujas, was flooded as well. The culvert construction under the railway near Suntory was unable to process the flood water. The branch of a tree hanging in the fence indicate the water level during the flood (Right).*

5. Natural water retention measures

In this chapter potential effective measures will be discussed to retain water in the Ramabujas stream catchment and increase infiltration to be adaptive in case of a DANA event or a long period of drought.

To determine effective measures, it helps to think like a raindrop, with the aim of delaying it’s flow to the Ramabujas stream (Figure 56). The time between the DANA event and the flooding in Nambroca and the industrial site is only a few hours, making it crucial to delay the flow of water for at least that long.

The most powerful ally in delaying the water cycle is the soil itself. When a raindrop infiltrates, it does not contribute to downstream flooding and is retained longer to help bridge dry periods. Therefore, measures that increase the soil's infiltration capacity will be highly effective.



Principles of delaying the water cycle with NWRM

1. Rain drop interception by rough vegetation
2. Rainwater reaching the surface is able to infiltrate
3. Water temporarily stored in soil layers should remain there as long as possible, otherwise re-infiltrate
4. Sub surface water rising to the surface should be stored in rough vegetation in the valley
5. Once water is in the riverbed, use natural floodplains to decrease the flow velocity

Figure 56: *Delaying the water cycle by means of natural water retention measures (NWRM) contributes to a lower flood and drought risk.*

The storyline (based on maps, field visit and analyses) indicate the most effective areas to implement water retention measures in the Ramabujas catchment.

The areas where measures are recommended (15.3 km2) accounts for 22.6% of the total Ramabujas catchment (figure 57). The measures will be discussed in more detail in the following paragraphs.

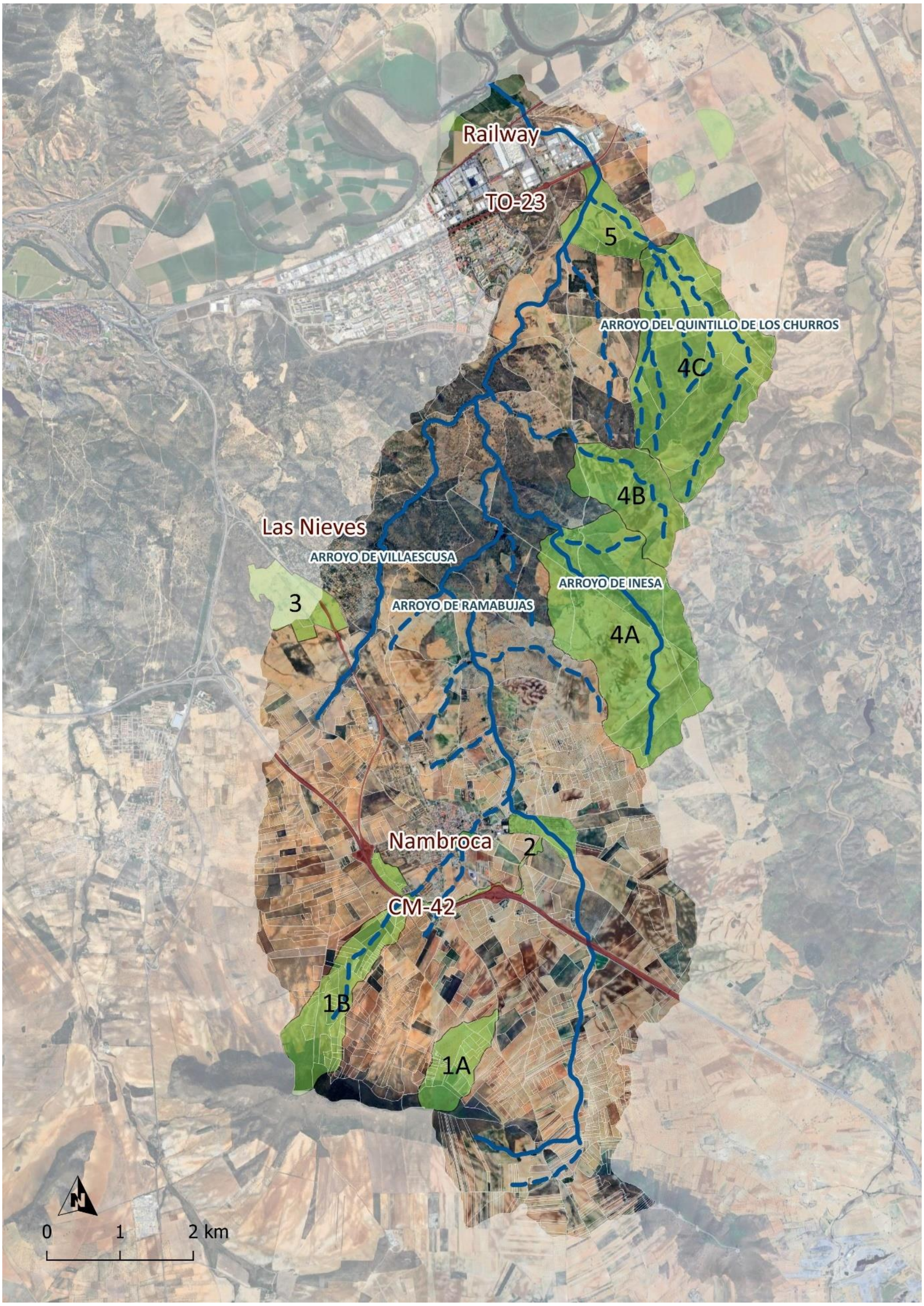


Figure 57: *Catchment-scale map with overview of proposed water retention areas.*

5.1 Prevent land degradation and surface runoff in the upstream catchment

Downstream coordinate 1a: 39°46'35.5"N 3°56'06.8"W
Downstream coordinate 1b: 39°47'22.2"N 3°57'03.9"W

Area 1a (82 ha) and 1b (151 ha) consist mainly of olive and almond fields. The fields lack soil cover and can therefore be categorized as bare soil (figure 58). Surface runoff in both areas originates in the Nambroca mountains at an altitude of ~900 metres, then gradually decreases to ~700 metres. Close to the Nambroca mountains the olive fields are situated on steep slopes with percentages larger than 12%. The total area is vulnerable for continuous land degradation and surface runoff. Area 1b is situated directly upstream of Nambroca village and is therefore one of the source areas of flood water in Nambroca.

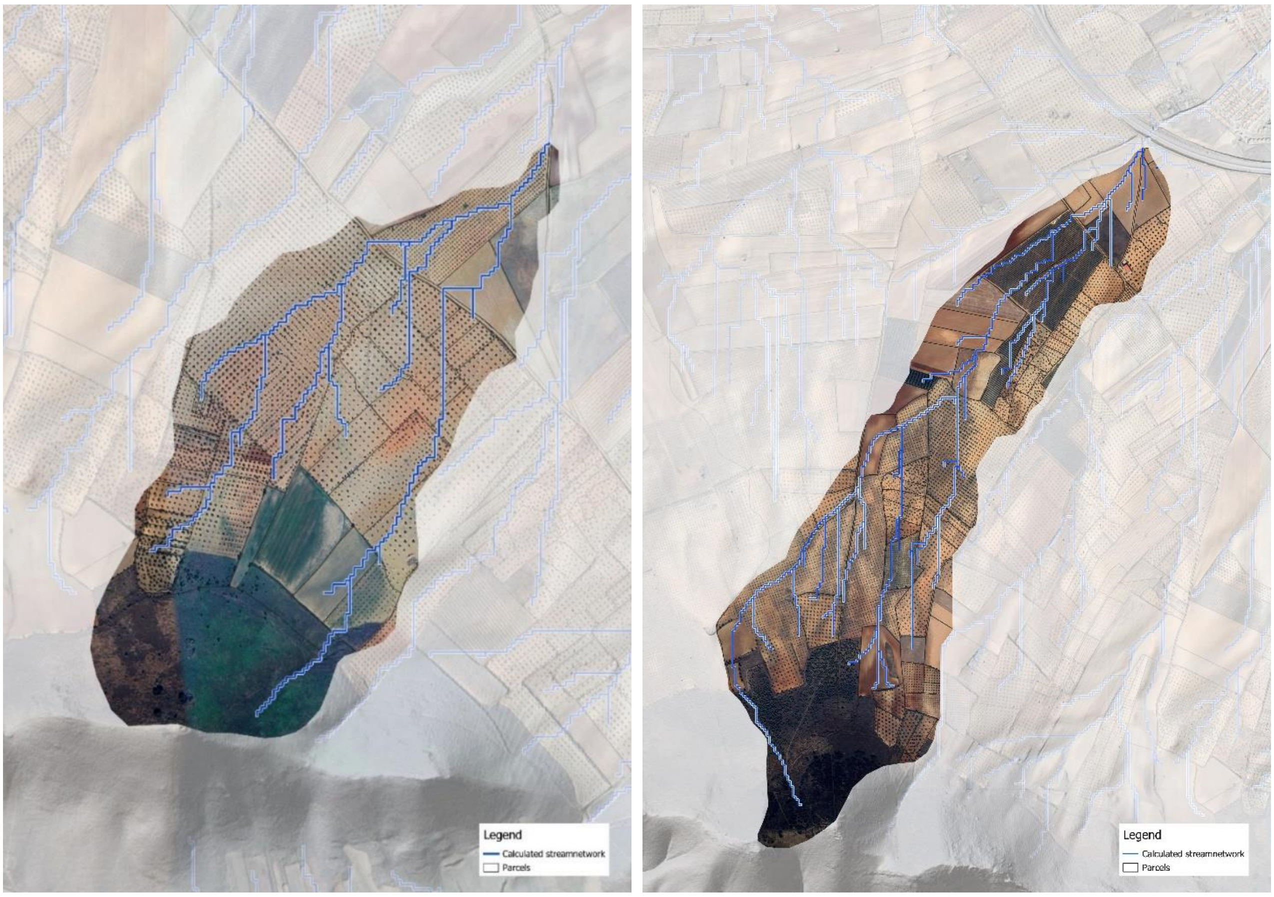


Figure 58*: Area 1a (left) and 1b (right) in with olive fields as the dominant land use.*

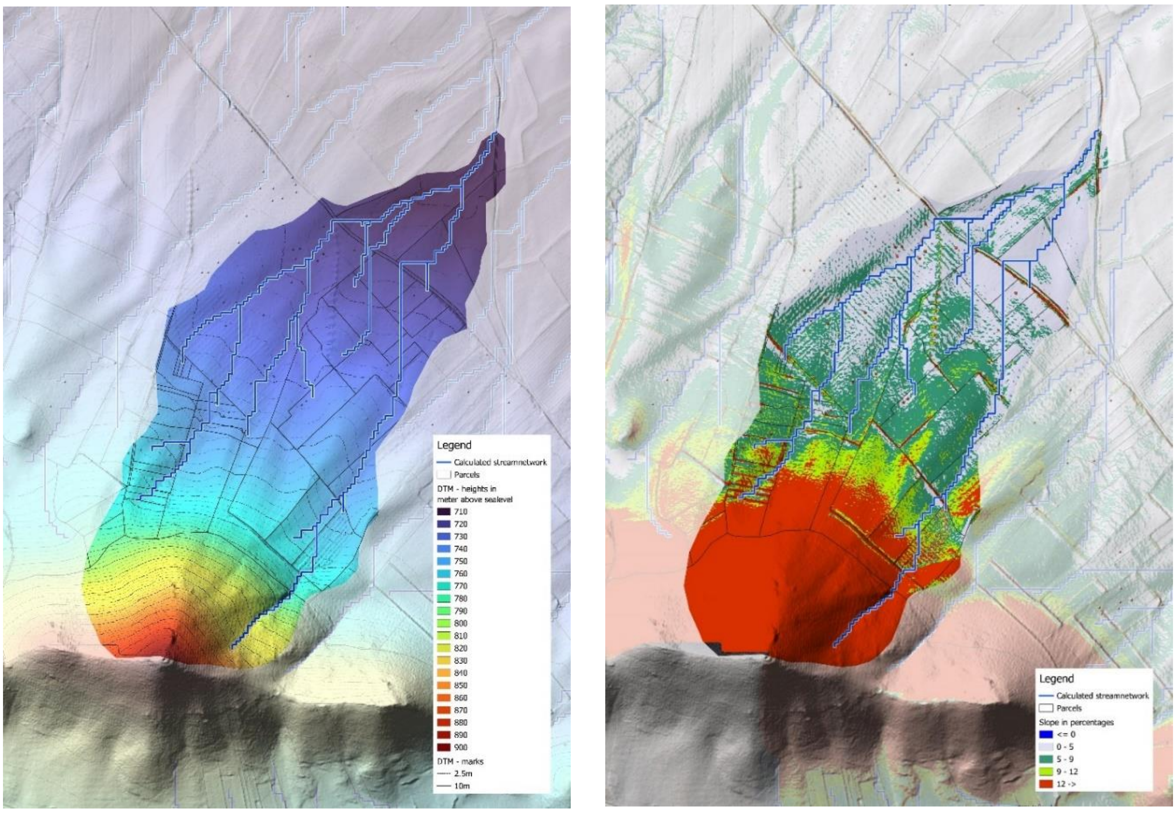


Figure 59*: Digital Elevation Map of area 1a (left) with 200 metres decline from upstream to downstream and slope map of area 1a (right) in which the areas above 12% steepness can be distinguished by its red colour.*

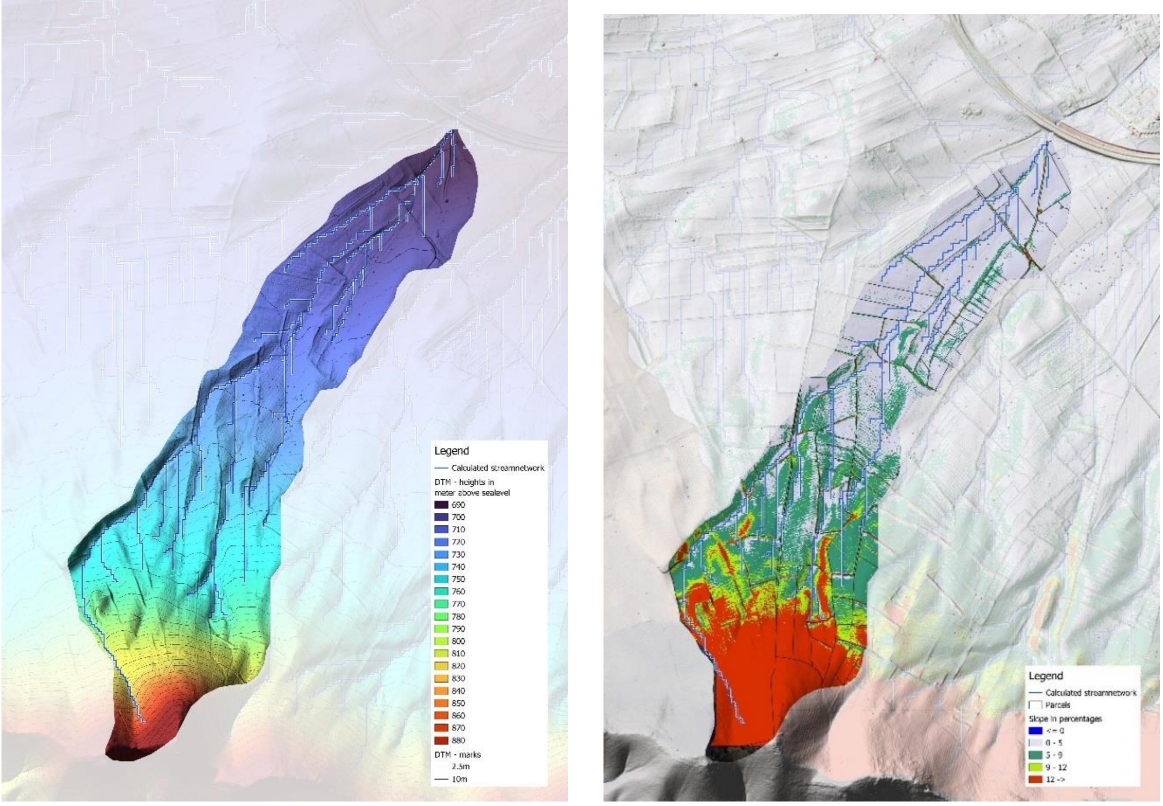


Figure 60*: Digital Elevation Map of area 1b (left) with 200 metres decline from upstream to downstream and slope map of area 1b (right) in which the areas above 12% steepness can be distinguished by its red colour.*

In both areas the main objective of the restoration measures will be to decrease surface runoff by increasing the infiltration capacity of the soil. Surface runoff velocity will be decreased with additional measures.

The following measures are proposed:

- The fields with slopes steeper then 12% will be revegetated and transformed into natural land
- Permanent natural undergrowth in woody crops (olive/almonds/pistachio)
- Implementation of erosion control barriers in existing gullies (albarradas or biorrollos)
- Implementation of natural parcel borders (Lindes)
- Revegetation of streambed with woody vegetation (olive trees, almond trees, pistachio trees, retamas, wild olive trees, etc.) (downstream area 1b)

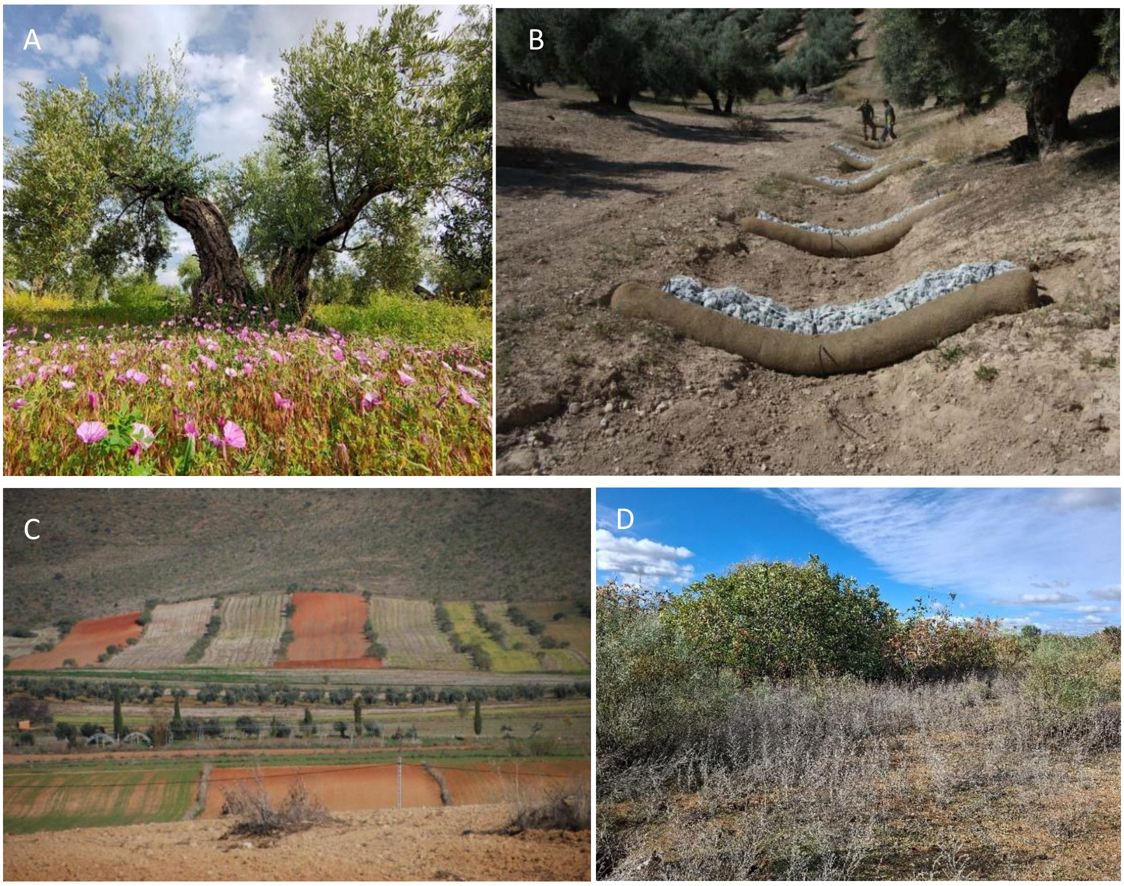


***Figure 61**: Permanent undergrowth in woody crops (A): https://www.olivaresvivos.com/en/improve-the-biodiversity-of-your-plantation/*
Erosion control barriers (B):
http://eutromed.org/images/Guia_del_metodo_instal._filtros_vegetales_TRAMCE.pdf
Lindes with Ratama close to Toledo (C)
Natural vegetation in Arroyo de Villaescusa (D),

***Figure 62**: Water retention map of upstream area 1a.*

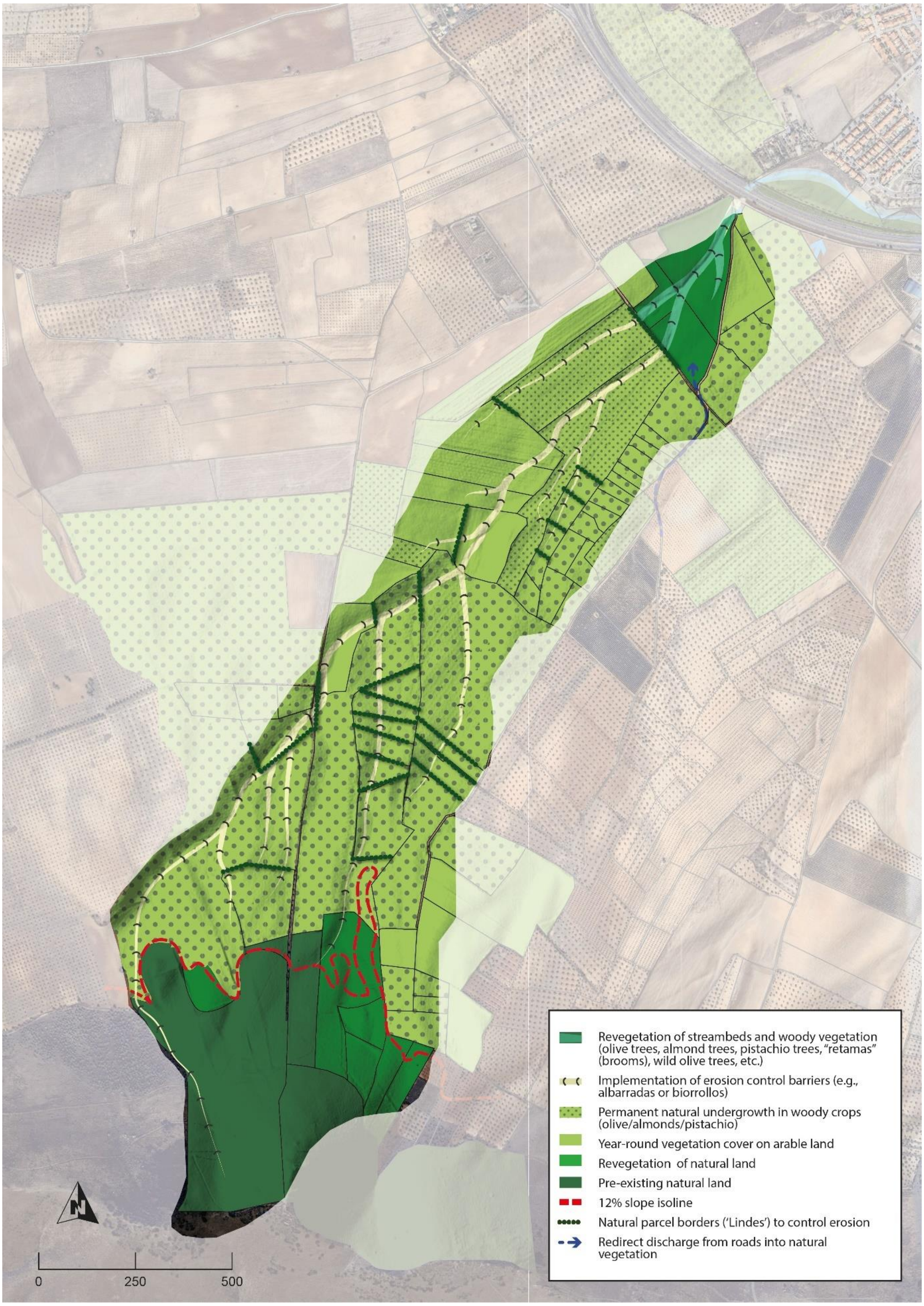


Figure 63: *Water retention map of upstream area 1b.*

5.2 Reduce flood risk in Nambroca

Coordinate: 39°47'54.2"N 3°56'20.2"W

Nambroca is situated on a junction of streams connecting the upstream Ramabujas catchment with the downstream areas.

This results in two main objectives for water retention in the Nambroca area:

1. Reduce flood risk in Nambroca village in case of a DANA event.
2. Retain water from upstream areas to relieve downstream areas

In the water retention map of Nambroca the proposed measures are visualised (Figure 64). They will be explained in more detail in the text below.

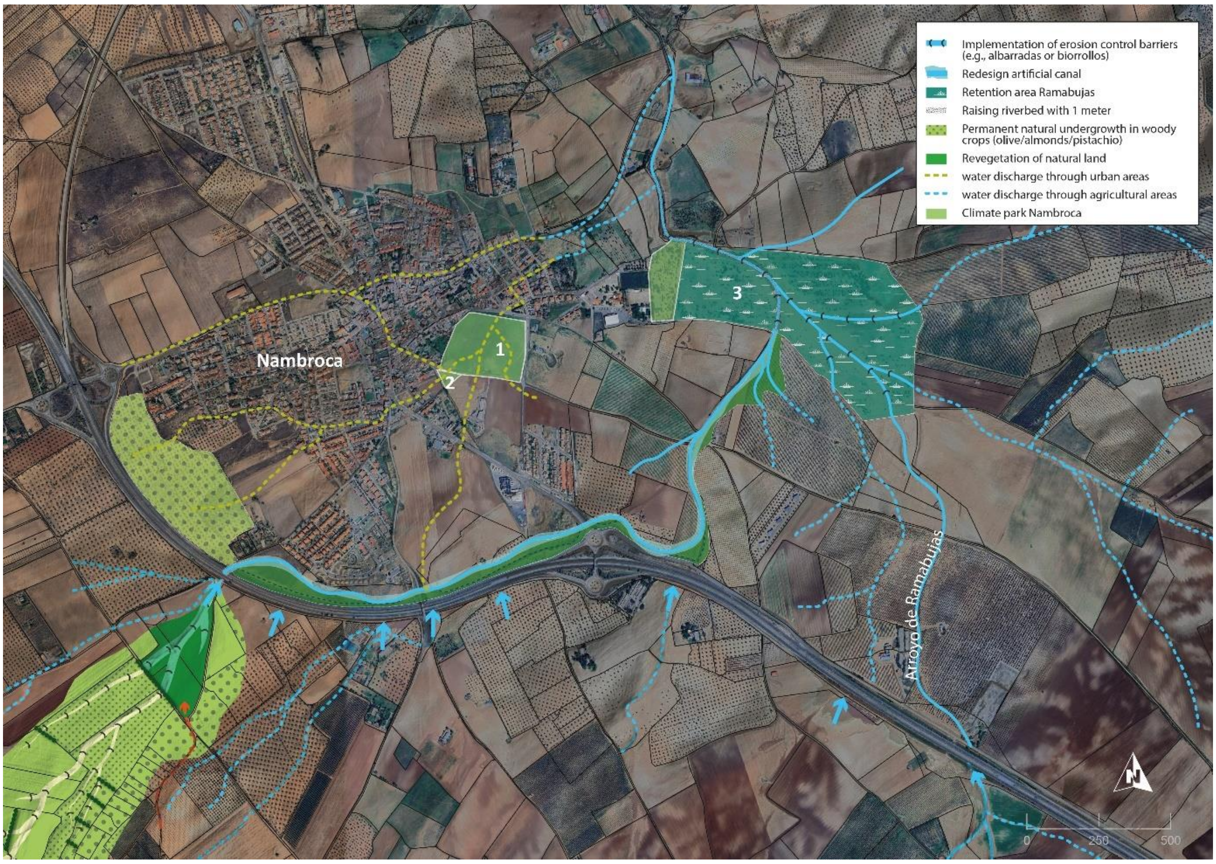


***Figure 64**: Water retention map of Nambroca (area 2).*

Retain water in upstream areas

To retain water in the area upstream of Nambroca is an important source measure. The measures in area 1b (see previous paragraph) are proposed with the aim of decreasing the runoff to Nambroca. In the bottom left corner of the Nambroca water retention map the connection with area 1b is visible.

Improve the Nambroca canal

In the current situation the artificial canal, who diverts the water around the village, is not up to the task of processing the water discharge during a DANA event.
Probably this is caused by the narrow seize of the canal and due to of its sharp bends of sometimes 90 degrees which make the water flow not fluent (figure 65).

Figure 65*: The start of the canal with a 90 degrees angle between the incoming water (through the tunnel) and the canal. In case of DANA much of the water will flow straight into the village instead of flowing into the canal.*

One of the measures proposed is to redesign the canal with gentle banks and a more fluent design. Especially at places where upstream water enters the canal its important to improve the design to capture most of the incoming water. The area surrounding the canal can be revegetated and transformed to natural land which will delay the flow of water when the canal is flooded in case of extreme events.

Retention area Ramabujas

The canal and the Ramabujas streams collide east of Nambroca (3), making it a perfect area for water retention to relieve downstream areas. In this area water discharge velocity is going to be slowed down to increase infiltration and increase the storage capacity. For the normal rain events erosion control barriers will slow down the runoff velocity and increase infiltration. Raising the streambed with 1 meter at a length of ca. 1 km will cause earlier flooding in case of a DANA event. When the area is flooded more easily, runoff water will temporarily be stored, and flow velocity will be decreased. The natural vegetation of herbs, plants and trees in the retention will decrease the flow velocity even further.

Figure 66*: Raising the streambed with ca. 1 metre with stones or sediment in the retention area (3) will increase retention in that area and decrease flow velocity (Source picture: Ophogen beekbodems OBN)*

Climate parc Nambroca

During a DANA event local surface runoff and water that is not captured by the canal will flow through the streets to the fields 1 and 2 before continuing its way through the village.

To retain as much water as possible in fields 1 and 2 contributes to a decrease in flood risk in the streets downstream. At the same time developing these fields provide an excellent opportunity to take measures against heat stress as well and to create an area for the local community to walk, picnic etc. The fields are ideally situated close to the village and could become an improvement for the Nambroca ecosystem for humans and nature. The design of the parc can be done together with the community to include their wishes and ideas.

For water retention it’s important though that at the lowest parts of the field natural vegetation can slow down runoff.

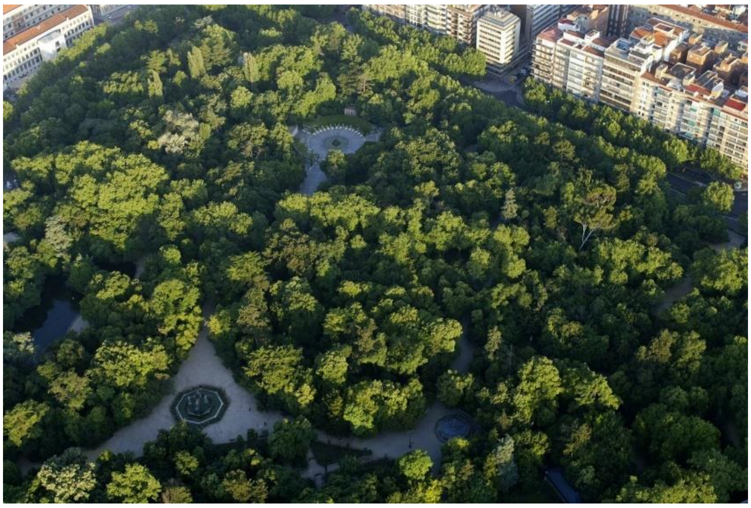


Figure 67: *Parque del Campo Grande – Valladolid as an inspiration. Capturing (sparce) rain water in the park and the presence of trees will have a cooling effect as well as a water retention effect. Source picture:* *https://www.eyeonspain.com/blogs/spains-top-ten/21300/best-city-parks-for-an-early-morning-run.aspx*

5.3 Reduce flood risk in Las Nieves

Coordinate: 39°49'44.5"N 3°58'00.1"W

Las Nieves suffers from mud flows during high rainfall events. The higher situated bare fields southwest of the village, belonging to the municipality of Toledo, are the source areas of those mudflows (figure 68).

The measures proposed to decrease flood risk in Las Nieves are focusing on the western source areas (figure 69). The soil in the olive fields should be covered with natural vegetation such as herbs or grasses. This measure will increase infiltration rates and decrease the loss of sediments (which turns into mud in case of DANA). The arable land in between the olive fields and Las Nieves should be transformed in a natural area in which no erosion takes place and surface runoff water is more able to infiltrate. To decrease the discharge velocity and erosive powers of surface runoff erosion control barriers should be implemented in the existing gullies.

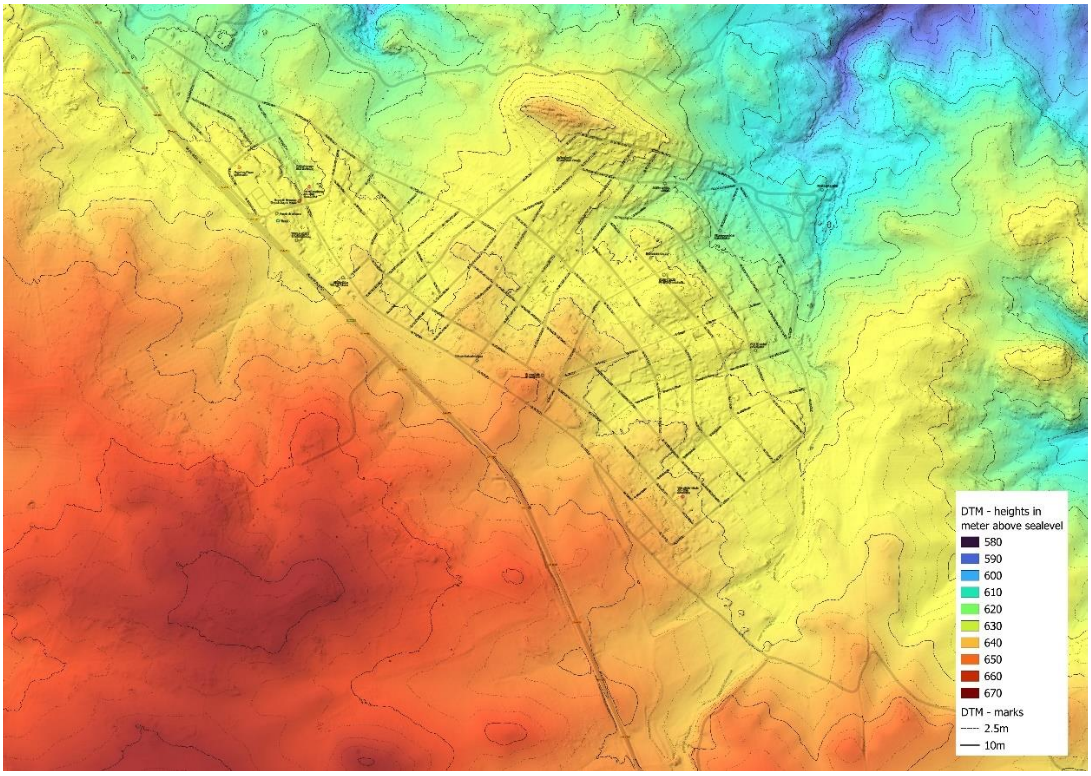


Figure 68: *Digital Elevation Map of Las Nieves showing the higher situated fields southwest of the village.*

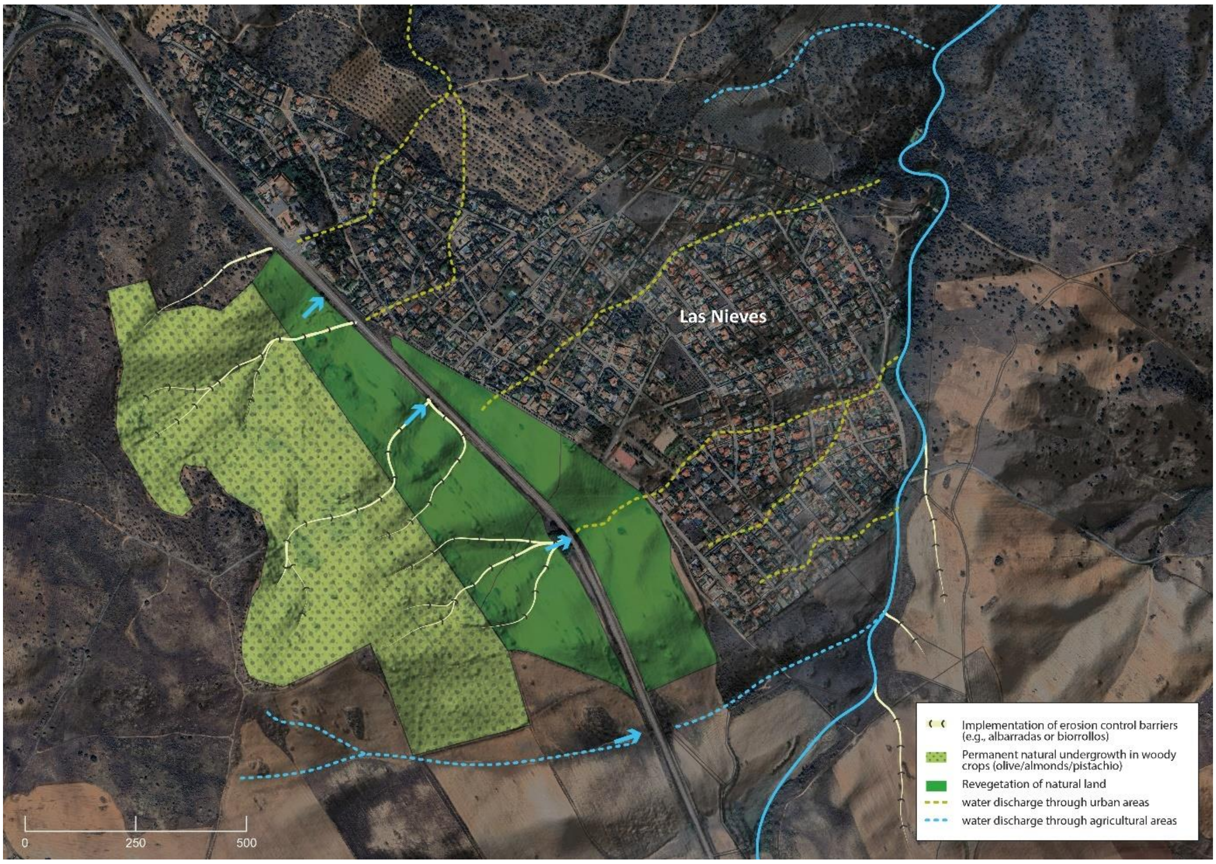


Figure 69: *Water retention map of Las Nieves (Natural water retention area 3).*

5.4 Decrease high discharges and severe erosion in northern sub-catchments

Downstream coordinates:
4a. 39°50'02.0"N 3°55'38.7"W
4b. 39°50'45.0"N 3°55'24.6"W
4c. 39°52'14.8"N 3°54'44.9"W

The northern subcatchments (4a, 4b and 4c) are characterized by shallow soils, steeps slopes and poor soil fertility (Figure 70). The remote sensing analyses indicate a high percentage of fields within these areas that remain fallow for multiple years. These areas contributed significantly to the flooding of the industrial site.

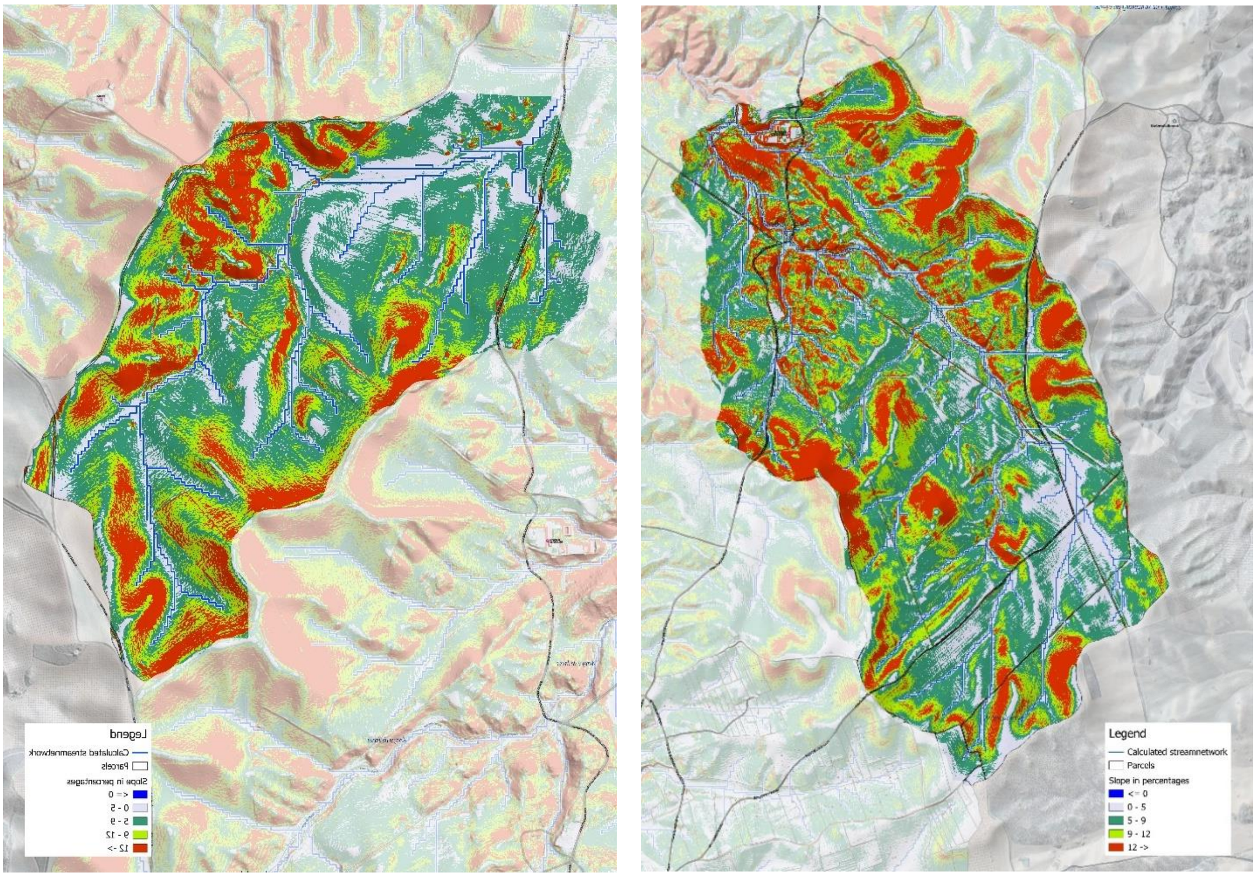


Figure 70: *Slope map of area 4a (left) and 4b (right). Large parts of both areas have slope percentages > 12% (red colour) which make them vulnerable for erosion.*

The measures proposed in areas 4a and 4b are about covering the soil permanently with vegetation and the implementation of erosion control barriers in the gullies and small streams (figure 71 en 72). In area 4c measures are added to implement natural undergrowth in olive fields and the revegetation of the Arroyo del Quintillo de los Churros streambed (Figure 73).

Figure 71: *Water retention map of area 4a*

Figure 72: *Water retention map of area 4b*

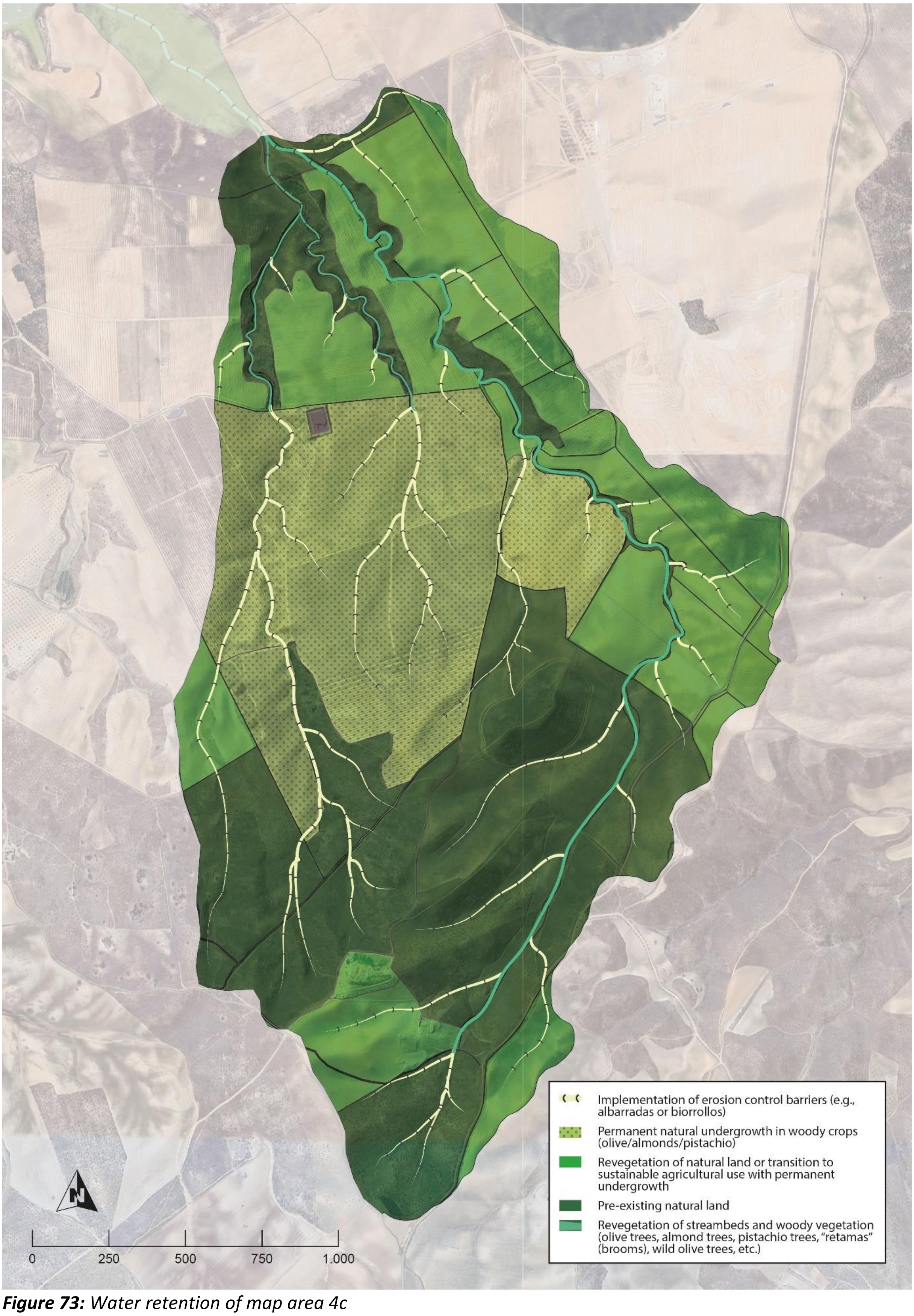


Figure 73: *Water retention of map area 4c*

The large arable fields (light green) should ideally be permanently covered with vegetation. This can be done in several ways: It can be turned into natural land just as the existing natural or forested land (dark green).

The challenge however could be to transform the fields into a sustainable agricultural practice together with the farmers. There are, for instance, inspiring examples in semi-arid areas with syntropic agroforestry. Key factor is developing a topsoil rich in organic matter in combination with water retention measures. This provides the base for a sustainable agricultural practice.

Figure 74: *Example of syntropic agroforestry in semi-arid Australia. Source:* [*https://thehungryspirit.com/greeningtheoutback/*](https://thehungryspirit.com/greeningtheoutback/)

5.5 Increase aquifer characteristics of downstream Ramabujas

Downstream coordinate:
39°52'38.5"N 3°55'15.7"W

In this area the Arroyo del Quintillo de los Churros merges with the Ramabujas stream. It is the last opportunity to retain water before it flows via the canal into the industrial site on the opposite side of the highway TO-23. The digital elevation map shows that the area is much lower than the surrounding areas and the Ramabujas has reached its lowest point so far (Figure 74). During DANA 2023 the area was transformed into a lake before flooding the highway. The vineyard, which is situated at the junction of de Ramabujas and the Arroyo del Quintillo de los Churros, was flooded from both sites.

The aquifer characteristics that were observed during the field visit, could be improved by implementing some restoration measures (Figure 75). The restoration measures can be included in the broader development of the nearby residential area.

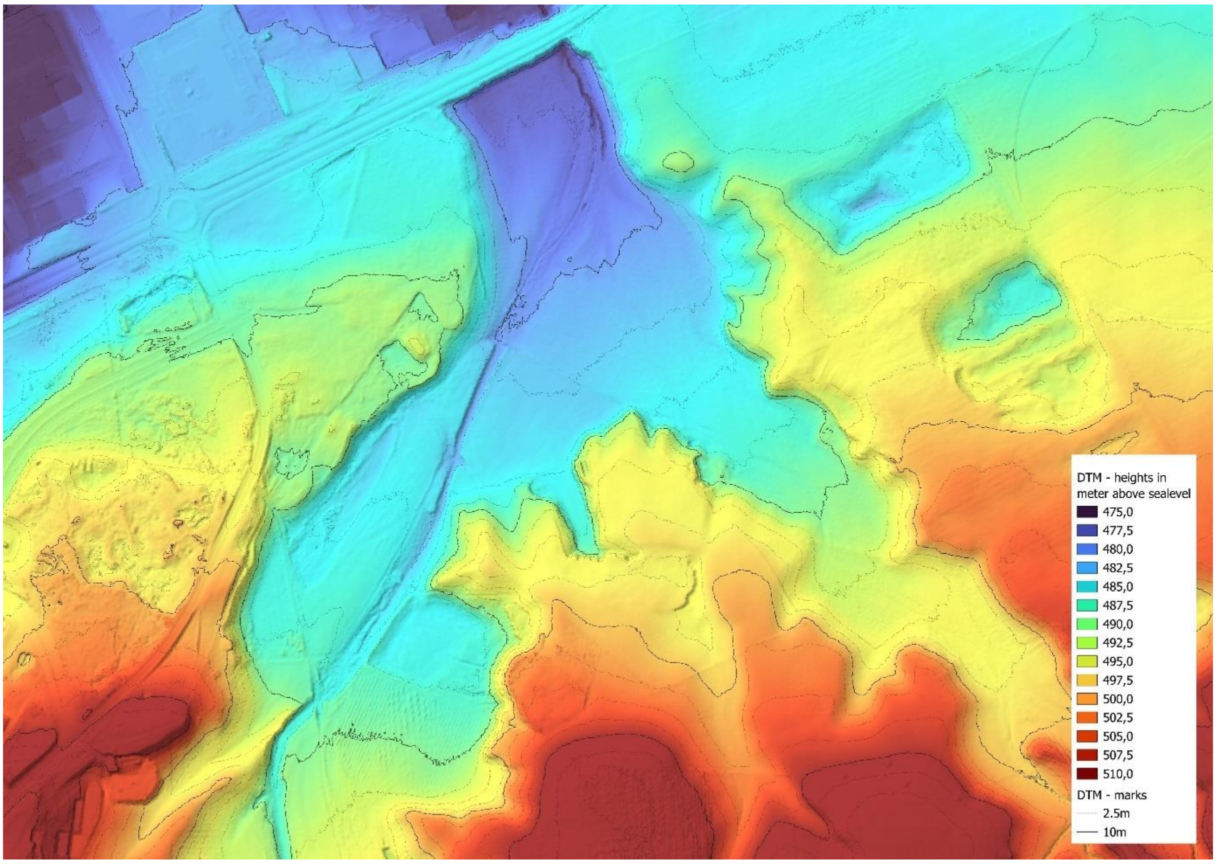


Figure 75: *Digital Elevation Map of downstream Ramabujas*

Figure 76: *Water retention map of area 5*

The aquifer characteristics can be improved by implementing the following measures:

- Raising the streambed of the Ramabujas stream with ca. 1 meter
- Implementation of erosion control measures in the Arroyo del Quintillo de los Churros
- Transition of the vineyard into natural land

By raising the streambed, the Ramabujas will sooner flood its banks which decreases flow velocity and increases infiltration. The Arroyo del Quintillo de los Churros will be able to flow in a natural vegetated area with erosion control measures decreasing its discharge velocity.

The aquifer potential of this area will be optimally utilized.

6 Volumetric Water Benefit Accounting (VWBA)

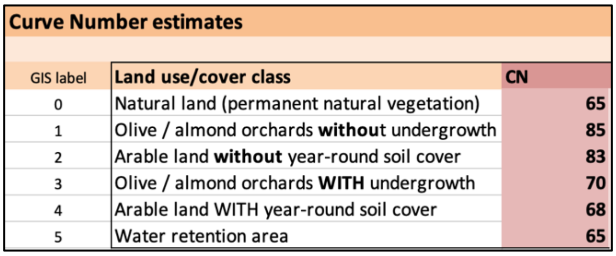
Volumetric water benefits (VWBs) refer to the volume of water resulting from so-called ‘water stewardship’ activities that improve hydrology and help address water challenges, contributing to Sustainable Development Goal 6 (United Nations 2030 Agenda for Sustainable Development). Volumetric water benefit accounting (VWBA) offers a standardised approach to quantify and communicate these benefits (Reigh *et al.,* 2019). Here, VWBA is applied to the Ramabujas catchment, for estimating the effect of the nature-based solution measures recommended for the different water retention areas in Chapter 5.

Suntory has set a goal to replenish 100 percent of the water it consumes at its factory in the Ramabujas catchment (~800,000 m^3 of water per year). A key aspect of the measures proposed in Chapter 5 is vegetation cover, which stimulates rainwater infiltration, promotes the development of organic-rich soils that retain water, and slows down runoff and streamflow. To estimate the additional infiltration resulting from the introduction of year-round vegetation cover in arable fields and olive/mandle groves, or the restoration of natural habitats, two calculation methods from Reigh et al. (2019) were used:

- Runoff reduction via the Curve Number method (Section 6.1)
- Infiltration enhancement via the Recharge method (Section 6.2)

6.1 Runoff reduction

The Curve Number (CN) method (Neitsch *et al.,* 2011) is commonly used to estimate how much rain turns into runoff based on different land use/cover conditions. The most important step is to estimate the CN value for the different land use types in the area, both for the current land use and for the scenario after the implementation of the proposed measures. To do this, we relied on soil type data for the area, field observations, international CN tables (https://www.hec.usace.army.mil/confluence/hmsdocs/hmstrm/cn-tables), and a study on CN values for olive groves in southern Spain (Taguas *et al.*, 2015). The CN values used in our calculations are shown in the table below. It's important to note that we tested a range of possible CN values, and the total volume of runoff reduction did not change significantly as a result.



Curve Number estimates

GIS label	**Land use/cover class**	**CN**
0	Natural land (permanent natural vegetation)	**65**
1	Olive / almond orchards **without** undergrowth	**85**
2	Arable land **without** year-round soil cover	**83**
3	Olive / almond orchards **WITH** undergrowth	**70**
4	Arable land WITH year-round soil cover	**68**
5	Water retention area	**65**

For each of the water retention areas described in Chapter 5, the so-called weighted-CN was calculated for both the current land use and the situation after the implementation of the proposed measures. The weighted-CN is determined by considering the areal percentage of each land use class (as shown in the table with CN values above) and applying the corresponding CN values for those classes.

The CN method recommends using at least three years of precipitation data to calculate daily runoff totals (see Annex for the calculation formulas). In this study, we initially used 10 years of ERA5 rainfall data (2014-2023) as shown in Figure 77. However, given the significance of extreme rainfall events (daily sums > 9 or 10 mm), we also conducted calculations using three years of local weather station data (AEMET; 2021-2023). Both approaches resulted in comparable runoff reductions.

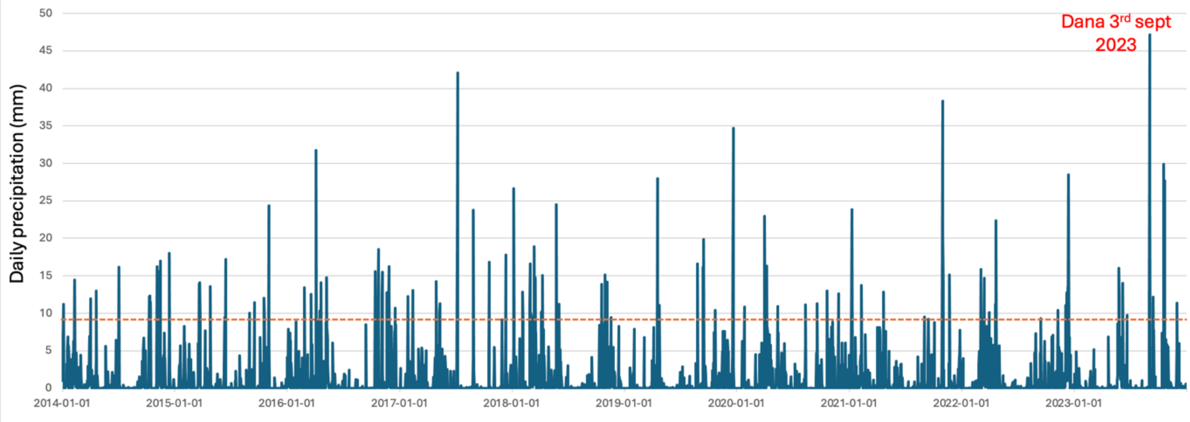


Figure 77: *ERA5 daily rainfall sums. Daily rainfall totals exceeding 9 or 10 mm have the potential to generate runoff in the Ramabujas catchment.*

The Curve Number (CN) method was applied to both the present (baseline) and future (post-project) conditions to calculate the average annual runoff for each of the water retention areas (in m³/year). The table below shows the weighted-CN values for each area, along with their corresponding storage capacity (S) and initial abstraction (Ia) values (both in mm). A comparison between the 'present' and 'future' columns reveals that the reduction in CN values leads to an increase in both storage capacity (from approximately 48-80 mm to 119-137 mm) and initial abstraction (from approximately 10-16 mm to 23-27 mm). For the different water retention areas, runoff reductions ranging from ~5,700 to 22,000 m³/year are estimated, resulting in a total reduction of approximately 93,500 m³/year.

As previously mentioned, a range of CN values and two different rainfall datasets were tested. This resulted in a total runoff reduction consistently within the range of ~**85,000-115,000 m³/year**.

Area	**PRESENT**			**FUTURE**			**Annual Q (m3)**		
	CN	S	Ia	CN	S	Ia	present	future	reduction
1B	79,3	66	13	68,0	119	24	11240	1680	9560
1A	79,9	64	13	67,9	120	24	12347	1624	10723
4B	75,9	81	16	65,0	137	27	6613	896	5717
4A	76,0	80	16	65,0	137	27	6689	896	5794
2	82,9	52	10	66,0	131	26	19846	1119	18727
3	84,1	48	10	69,1	113	23	24219	2065	22153
5	79,5	66	13	65,0	137	27	11575	896	10679
4C	79,3	66	13	66,6	127	25	11352	1181	10171
						Total (m3):	**103880**	**10357**	**93523**

6.2 Recharge enhancement

For the retention areas near Nambroca and in the downstream Ramabujas directly upstream of the industrial site, the goal is to increase groundwater recharge by slowing down and widening the flow of water during storm events. This allows for a larger volume of water to be retained and infiltrated into the groundwater table, contributing to long-term water availability. The additional recharge resulting from these measures can be estimated by comparing the present-day (pre-project) situation with the projected future (post-project) conditions. The formula used to estimate recharge is as follows:

Volume recharged (m^3) = *A* (m^2) × *f* (*m/day*) × *D* (*days*)

Where: A = Inundation surface area, f = Infiltration rate, and D = Duration of inundation.

Based on field observations during rain events in October 2024, the inundation surface area under current conditions was estimated to be limited to the narrow 2–3 m wide stream bed. This restricted flow area reduces the potential for significant infiltration, as water moves quickly through the channel and does not have time to infiltrate into the surrounding soil. However, in Chapter 5 it is proposed to raise the stream bed and restore the natural vegetation across the water retention fields. These changes will increase the zone of inundation, as depicted in Figure 78**.** The widened area will allow for a greater volume of water to be retained, slowing the flow and increasing the duration of inundation. As a result, water will have more time to infiltrate into the soil, significantly enhancing the recharge potential compared to the present-day scenario. Infiltration rates are estimated to increase from circa 5 mm/hour to 25 mm/hour due to improvement of soil conditions. For both current and future conditions, we calculate the effect using 2 days of inundation per year (only 2 or 3 major storm events each year are expected to cause wide inundation of the retention areas as suggested by the ERA5 precipitation data).

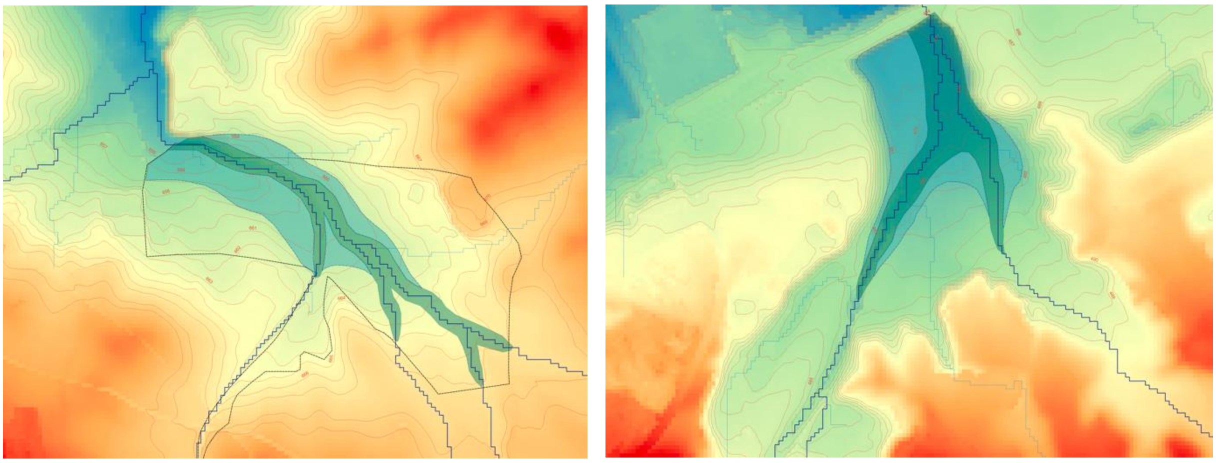
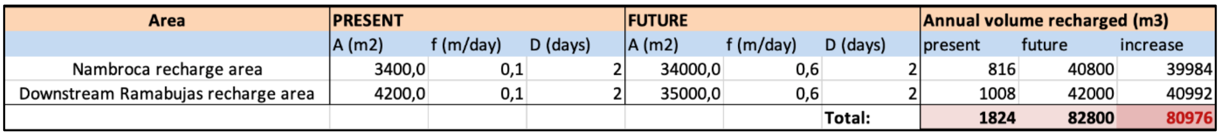


Figure 78: *Estimating the surface area of wetland areas that are expected to become inundated during storm events, which typically occur 1-3 times per year. Under current conditions, only the narrow 2-3 m wide stream bed is inundated. However, by raising the stream bed and restoring natural vegetation, the zone of inundation is projected to expand to 20-25 m wide in the future scenario, as indicated by the innermost polygon directly bordering the streams. A much wider inundation area would occur during Dana events; however, this is not included in these calculations as these do not occur annually. The total length of stream channels is approximately 1,700 m in the Nambroca area and 1,400 m in the downstream Ramabujas area.*



Area	PRESENT			FUTURE			Annual volume recharged (m3)		
	A (m2)	f (m/day)	D (days)	A (m2)	f (m/day)	D (days)	present	future	increase
Nambroca recharge area	3400,0	0,1	2	34000,0	0,6	2	816	40800	39984
Downstream Ramabujas recharge area	4200,0	0,1	2	35000,0	0,6	2	1008	42000	40992
						Total:	**1824**	**82800**	**80976**

The table above presents the parameters used for one of the recharge calculations. By varying these parameters, we estimate that the additional groundwater recharge resulting from the proposed measures will range between **60,000 and 100,000 m³/year**.

In practice, the increased surface area and enhanced infiltration rates will depend on a complexity of factors, including the type of vegetation restored, the soil's capacity to absorb water, and how much the flow regime changes due to the proposed measures. Detailed monitoring and modeling of these parameters will be necessary to refine these estimates further.

6.3 Combined VWBA results

The combined effect of both runoff reductions and recharge enhancement is estimated at **180,000 ± 35,000 m³/year**. It is important to note that this estimate comes with significant uncertainties. This arises because both methods attempt to capture complex natural processes using a limited number of parameter values.

7. Conclusions

The Ramabujas catchment has been analysed for its hydrological and morphological characteristics during (DANA-type) rain events. The catchment's geological features, including rock and soil layers, elevation variations, and slope steepness, play a crucial role in shaping its response to rain events. Along with the current climate conditions, these factors provide the starting point for understanding the hydrological behavior and morphology of the Ramabujas catchment.

Land use also plays a decisive role in the catchment's hydrologic and morphological response to rainfall. Field observations and satellite images reveal that differences in erosion and discharge can largely be explained by variations in land use practices. Ground cover emerges as a key factor in this analysis, as it directly influences water infiltration capacity. Adequate ground cover maximizes infiltration, while bare soils increase surface runoff, leading to land degradation. Ultimately, the level of ground cover is a key factor in controlling peak runoff levels and the risk of downstream flooding, particularly during DANA-type rain events.

Key to the proposed measures is to revive the most vulnerable soils by reintroducing an organic-rich layer. The first step in this process is to stop ploughing and introducing year-round soil cover. Transforming current agricultural practices into more sustainable ones, ideally with increased yields, presents a challenge, but offers long-term hydrological benefits. An alternative strategy involves converting the most vulnerable fields into natural habitats, which would further enhance soil stability and water retention.

Another key measure is the restoration and expansion of natural stream valleys. These valleys, filled with herbs, shrubs, and trees, would allow water to flow more slowly, reducing runoff velocity and increasing infiltration rates. In highly eroded streams and gullies, erosion control barriers could be implemented to prevent further degradation and slow down surface runoff.

Nambroca, located at a junction of streams connecting upstream and downstream areas, is particularly vulnerable to flooding. Retaining runoff in source areas upstream and improvements to the existing artificial canal could help mitigate this risk. Additionally, retention areas can be developed in the designated fields to capture and temporarily store runoff. These measures offer an opportunity to address not only water retention goals but also broader climate challenges, such as reducing the impacts of heatwaves, thereby enhancing the quality of life for the local community.

The mudflows in Las Nieves, originating from fields upstream in the Toledo municipality, also require attention. Proposed measures aim to reduce surface runoff and erosion at the source, addressing the problem before it reaches vulnerable downstream areas of the village.

The Volumetric Water Benefit Accounting (VWBA) analysis shows that the target of replenishing 800,000 m^3/year of water for Suntory in the Ramabujas catchment is not feasible under the current conditions. This is primarily because there are only a few days each year in which rainfall exceeds the threshold of ca. 9 mm/day (i.e., the minimum estimate of initial abstraction in the Ramabujas catchment). Above this threshold surface runoff becomes a dominant hydrologic factor, which can be retained by the restoration measures proposed. The calculations indicate that, with the current set of proposed measures, approximately 180,000 ± 35,000 m^3 of water per year can be retained in the landscape (and preserved to help bridge the dry season).

The most valuable water retention measures in the Ramabujas catchment are the ones that are multi beneficial. They will reduce flood risk by retaining water during the next DANA event and they will contribute to water preservation by retaining water during normal rain events. Ideally measures contribute to a more sustainable ecosystem for nature, farmers and local communities alike.

https://media.stroming.nl/ramabujas/#

8. Recommendations

The following recommendations could help substantiate and implement the natural water retention measures.

- Modelling the hydrological effects of the proposed restoration measures during a DANA event would help to estimate the future flood risk during DANA for Nambroca, Las Nieves and the industrial site. This includes the effects of the renovated culvert under the highway TO-23.

- Designing the proposed natural water retention measures is a customized approach. In the next phase of the project the retention measures can be designed in more detail, to a level that it can be used by contractors.

- Impressions drawings and sketches that show the hydrological principles behind the measures proposed can be beneficial for the communication strategy with farmers and communities. An example can be found at this link: https://media.stroming.nl/stroomgebied/

- The stakeholder process could benefit from a co-creating approach with the farmers and communities.

- Monitoring could show and compare the effects before and after implementation. Writing a monitoring plan would be a logical first step.

- Last but not least: This landscape approach for water retention has its value well beyond the borders of the Ramabujas catchment. The Valencia disaster in October 2024 showed that the next DANA can be severe and can strike anywhere. The call to action should be to adapt the landscape to be more resilient to severe rain events and droughts. It is worth thinking of a strategy to upscale this call to action to other catchments and regions.

9. Acknowledgments

Stroming would like to thank everyone for their inspiring contribution to the project!

Beatriz and Raúl from Cátedra del Tago thank you for travelling with us for days in the Ramabujas catchment. We enjoyed your company and hospitality so much!

Aniela and Camila from CIREF thank you for all your inspiring contributions to the project and travelling with us in the Ramabujas. We are happy to work with you in Spongeboost as well!

Ricardo and David from Suntory thank you for showing us around with pride in the Suntory factory and thank you for making this project possible! We are hopeful that it will lead to a more sustainable Ramabujas catchment.

10. References

Neitsch, S.L., J.G. Arnold, J.R. Kiniry, and J.R. Williams. 2011. “Soil and Water Assessment Tool Theoretical Documentation Version 2009.” Texas Water Resources Institute. http://hdl.handle.net /1969.1/128050

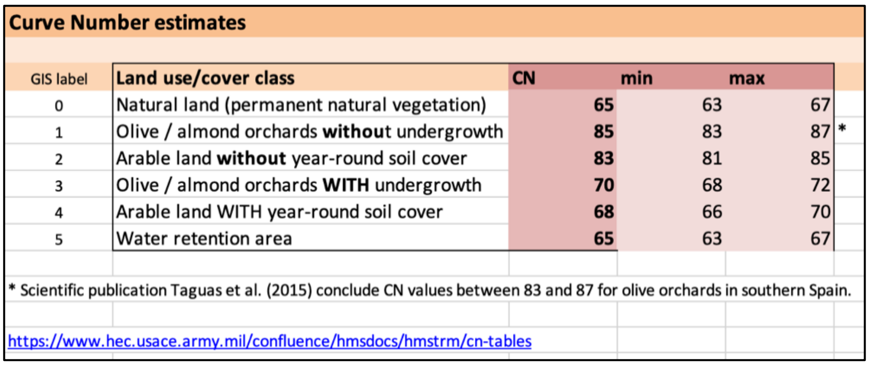
Reig, P., W. Larson, S. Vionnet, and J.B. Bayart. 2019. “Volumetric Water Benefit Accounting (VWBA): A Method for Implementing and Valuing Water Stewardship Activities.” Working Paper. Washington, DC: World Resources Institute. Available online at www.wri.org/publication/volumetric-water-benefit-accounting.

Taguas, Encarnación & Yuan, Yongping & Licciardello, Feliciana & Gómez, J. 2015. Curve Numbers for Olive Orchard Catchments: Case Study in Southern Spain. Journal of Irrigation and Drainage Engineering. 141. 05015003. 10.1061/(ASCE)IR.1943-4774.0000892.

11. Annex

Screenshots of the Excel file used for Volumetric Water Benefit Accounting calculations, together with a short explanation and relevant equations (all according to Reig et al., 2019).

Runoff calculations were performed using a range of Curve Number (CN) values. However, the list below presents our best estimates based on literature and international CN tables. The number of land use/cover classes was kept limited to six, as increasing the number of classes would only introduce greater uncertainty into the calculations.



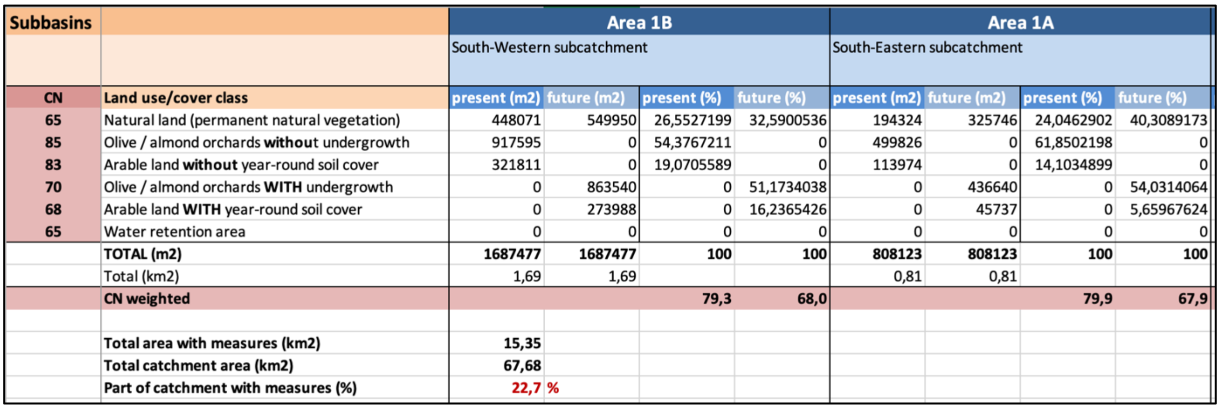
Curve Number estimates

GIS label	**Land use/cover class**	**CN**	**min**	**max**	
0	Natural land (permanent natural vegetation)	**65**	63	67	
1	Olive / almond orchards **without** undergrowth	**85**	83	87	*
2	Arable land **without** year-round soil cover	**83**	81	85	
3	Olive / almond orchards **WITH** undergrowth	**70**	68	72	
4	Arable land WITH year-round soil cover	**68**	66	70	
5	Water retention area	**65**	63	67	

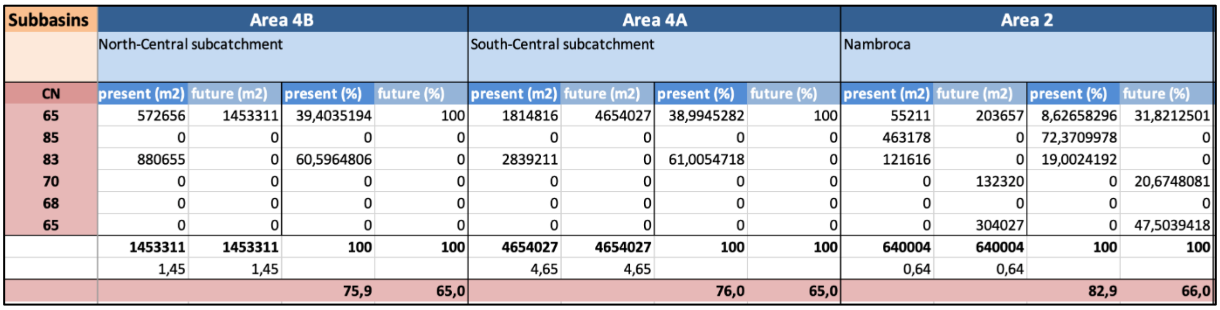
* Scientific publication Taguas et al. (2015) conclude CN values between 83 and 87 for olive orchards in southern Spain.

https://www.hec.usace.army.mil/confluence/hmsdocs/hmstrm/cn-tables

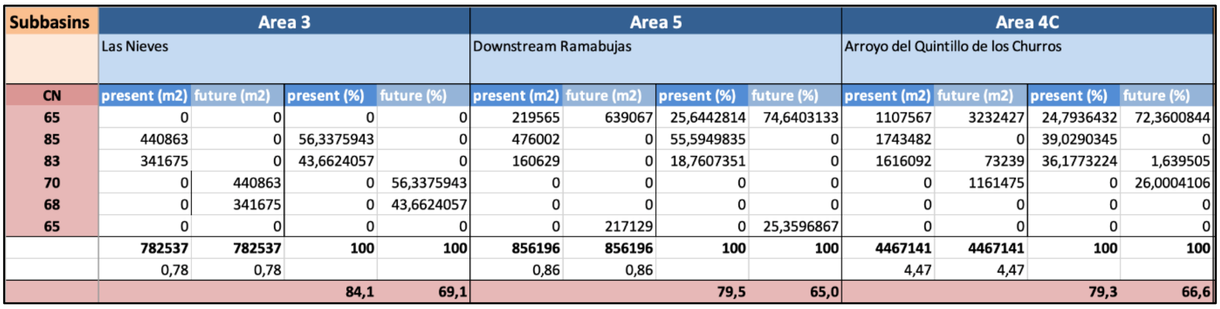
For each of the water retention areas (1A,1B,2,3,4A,4B,4C, and 5), the so-called weighted-CN was calculated for both the current land use and the situation after the implementation of the proposed measures. The weighted-CN is determined by considering the areal percentage of each land use class (as shown in the table with CN values above) and applying the corresponding CN values for those classes.



Subbasins		**Area 1B**				**Area 1A**			
		South-Western subcatchment				South-Eastern subcatchment			
CN	**Land use/cover class**	**present (m2)**	**future (m2)**	**present (%)**	**future (%)**	**present (m2)**	**future (m2)**	**present (%)**	**future (%)**
65	Natural land (permanent natural vegetation)	448071	549950	26,5527199	32,5900536	194324	325746	24,0462902	40,3089173
85	Olive / almond orchards **without** undergrowth	917595	0	54,3767211	0	499826	0	61,8502198	0
83	Arable land **without** year-round soil cover	321811	0	19,0705589	0	113974	0	14,1034899	0
70	Olive / almond orchards **WITH** undergrowth	0	863540	0	51,1734038	0	436640	0	54,0314064
68	Arable land **WITH** year-round soil cover	0	273988	0	16,2365426	0	45737	0	5,65967624
65	Water retention area	0	0	0	0	0	0	0	0
	TOTAL (m2)	**1687477**	**1687477**	**100**	**100**	**808123**	**808123**	**100**	**100**
	Total (km2)	1,69	1,69			0,81	0,81		
	CN weighted			**79,3**	**68,0**			**79,9**	**67,9**
	Total area with measures (km2)	**15,35**							
	Total catchment area (km2)	**67,68**							
	Part of catchment with measures (%)	**22,7**	**%**						



Subbasins	**Area 4B**				**Area 4A**				**Area 2**			
	North-Central subcatchment				South-Central subcatchment				Nambroca			
CN	**present (m2)**	**future (m2)**	**present (%)**	**future (%)**	**present (m2)**	**future (m2)**	**present (%)**	**future (%)**	**present (m2)**	**future (m2)**	**present (%)**	**future (%)**
65	572656	1453311	39,4035194	100	1814816	4654027	38,9945282	100	55211	203657	8,62658296	31,8212501
85	0	0	0	0	0	0	0	0	463178	0	72,3709978	0
83	880655	0	60,5964806	0	2839211	0	61,0054718	0	121616	0	19,0024192	0
70	0	0	0	0	0	0	0	0	0	132320	0	20,6748081
68	0	0	0	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	304027	0	47,5039418
	1453311	**1453311**	**100**	**100**	**4654027**	**4654027**	**100**	**100**	**640004**	**640004**	**100**	**100**
	1,45	1,45			4,65	4,65			0,64	0,64		
			75,9	**65,0**			**76,0**	**65,0**			**82,9**	**66,0**



Subbasins	Area 3				Area 5				Area 4C			
	Las Nieves				Downstream Ramabujas				Arroyo del Quintillo de los Churros			
CN	present (m2)	future (m2)	present (%)	future (%)	present (m2)	future (m2)	present (%)	future (%)	present (m2)	future (m2)	present (%)	future (%)
65	0	0	0	0	219565	639067	25,6442814	74,6403133	1107567	3232427	24,7936432	72,3600844
85	440863	0	56,3375943	0	476002	0	55,5949835	0	1743482	0	39,0290345	0
83	341675	0	43,6624057	0	160629	0	18,7607351	0	1616092	73239	36,1773224	1,639505
70	0	440863	0	56,3375943	0	0	0	0	0	1161475	0	26,0004106
68	0	341675	0	43,6624057	0	0	0	0	0	0	0	0
65	0	0	0	0	0	217129	0	25,3596867	0	0	0	0
	782537	**782537**	**100**	**100**	**856196**	**856196**	**100**	**100**	**4467141**	**4467141**	**100**	**100**
	0,78	0,78			0,86	0,86			4,47	4,47		
			84,1	**69,1**			**79,5**	**65,0**			**79,3**	**66,6**

The Curve Number (CN) method was applied to both the present (baseline) and future (post-project) conditions to calculate the average annual runoff for each of the water retention areas (in m³/year). The table below shows the weighted-CN values for each area, along with their corresponding storage capacity (*S*) and initial abstraction (*Ia*) values (both in mm).

The equations used for calculating *S* and *Ia*:

Potential maximum storage after runoff begins (mm):

$$S = \frac{25{,}400}{CN} - 254$$

Initial abstraction: ***Ia* = 0,2****S***

Daily precipitation sums were used for calculating daily runoff by means of the formula:

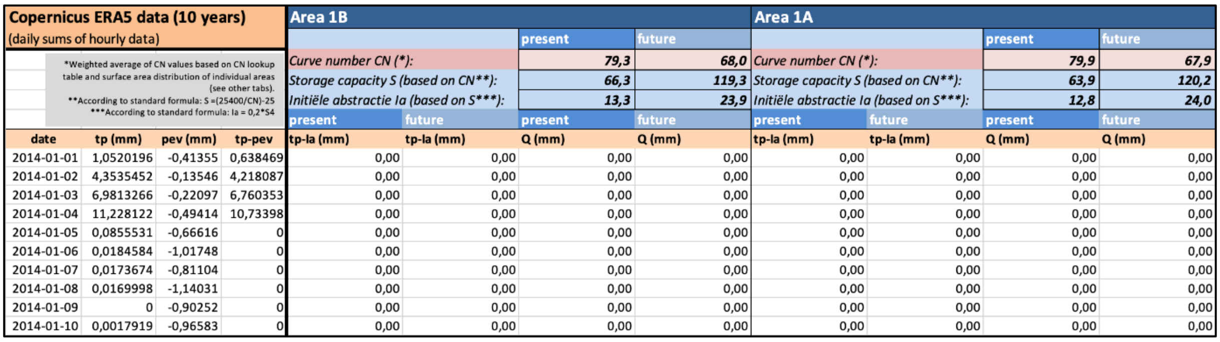
$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \quad (1)$$

Q = Runoff (millimeters)

P = Precipitation (millimeters)

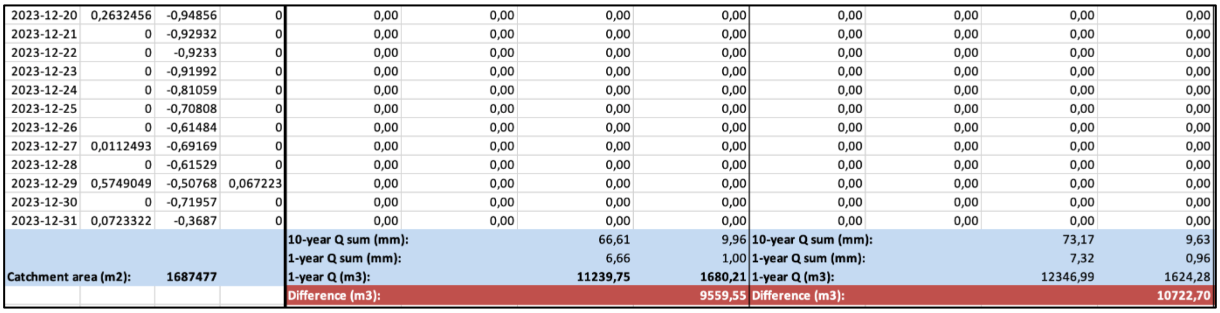
S = Potential maximum retention after runoff begins (millimeters)

Because the initial abstraction value is first substracted from the daily rainfall sums, for most days there is not enough rain for producing positive runoff values (explaining all the zero values in the screenshot below).



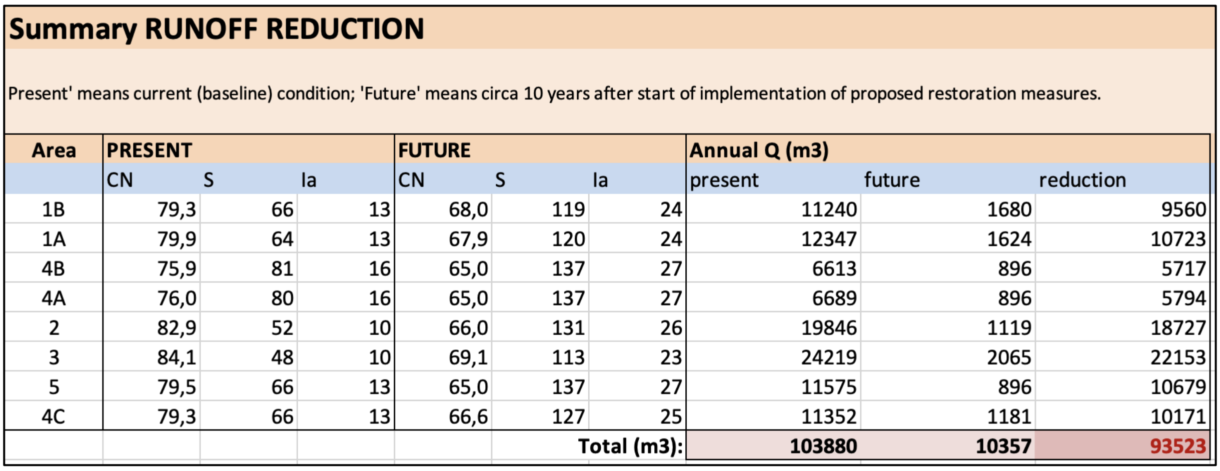
Copernicus ERA5 data (10 years)				**Area 1B**				**Area 1A**			
(daily sums of hourly data)						present	future			present	future
*Weighted average of CN values based on CN lookup table and surface area distribution of individual areas (see other tabs). **According to standard formula: S =(25400/CN)-25 ***According to standard formula: Ia = 0,2*S4				*Curve number CN (*):*		***79,3***	***68,0***	*Curve number CN (*):*		***79,9***	***67,9***
				*Storage capacity S (based on CN**):*		***66,3***	***119,3***	*Storage capacity S (based on CN**):*		***63,9***	***120,2***
				*Initiële abstractie Ia (based on S***):*		***13,3***	***23,9***	*Initiële abstractie Ia (based on S***):*		***12,8***	***24,0***
				present	future	present	future	present	future	present	future
date	**tp (mm)**	**pev (mm)**	**tp-pev**	**tp-Ia (mm)**	**tp-Ia (mm)**	**Q (mm)**	**Q (mm)**	**tp-Ia (mm)**	**tp-Ia (mm)**	**Q (mm)**	**Q (mm)**
2014-01-01	1,0520196	-0,41355	0,638469	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2014-01-02	4,3535452	-0,13546	4,218087	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2014-01-03	6,9813266	-0,22097	6,760353	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2014-01-04	11,228122	-0,49414	10,73398	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2014-01-05	0,0855531	-0,66616	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2014-01-06	0,0184584	-1,01748	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2014-01-07	0,0173674	-0,81104	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2014-01-08	0,0169998	-1,14031	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2014-01-09	0	-0,90252	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2014-01-10	0,0017919	-0,96583	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

However, rain sums exceeding at least ~9-10 mm/day (but more often exceeding ~13 mm/day or more) generate runoff, giving positive total annual runoff sums at the very bottom of this runoff calculation tab in the Excel file:



2023-12-20	0,2632456	-0,94856	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2023-12-21	0	-0,92932	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2023-12-22	0	-0,9233	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2023-12-23	0	-0,91992	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2023-12-24	0	-0,81059	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2023-12-25	0	-0,70808	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2023-12-26	0	-0,61484	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2023-12-27	0,0112493	-0,69169	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2023-12-28	0	-0,61529	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2023-12-29	0,5749049	-0,50768	0,067223	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2023-12-30	0	-0,71957	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2023-12-31	0,0723322	-0,3687	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
				10-year Q sum (mm):		66,61	9,96	**10-year Q sum (mm):**		73,17	9,63
				1-year Q sum (mm):		6,66	1,00	**1-year Q sum (mm):**		7,32	0,96
Catchment area (m2):		**1687477**		**1-year Q (m3):**		**11239,75**	**1680,21**	**1-year Q (m3):**		12346,99	1624,28
				Difference (m3):			**9559,55**	**Difference (m3):**			**10722,70**

For each of the retention areas, the results are summarised in the following table:



Summary RUNOFF REDUCTION

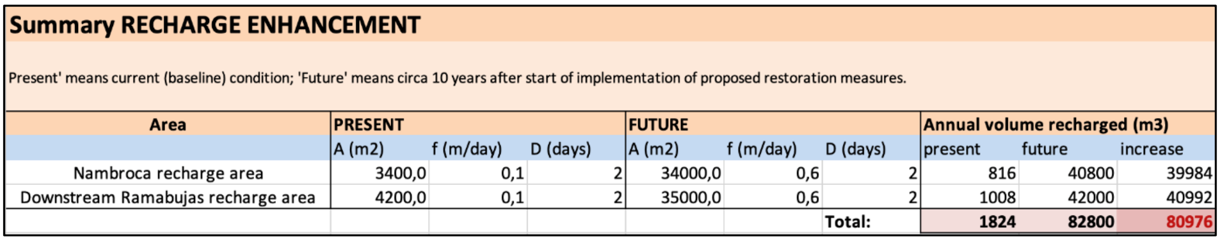
Present' means current (baseline) condition; 'Future' means circa 10 years after start of implementation of proposed restoration measures.

Area	PRESENT			FUTURE			Annual Q (m3)		
	CN	S	Ia	CN	S	Ia	present	future	reduction
1B	79,3	66	13	68,0	119	24	11240	1680	9560
1A	79,9	64	13	67,9	120	24	12347	1624	10723
4B	75,9	81	16	65,0	137	27	6613	896	5717
4A	76,0	80	16	65,0	137	27	6689	896	5794
2	82,9	52	10	66,0	131	26	19846	1119	18727
3	84,1	48	10	69,1	113	23	24219	2065	22153
5	79,5	66	13	65,0	137	27	11575	896	10679
4C	79,3	66	13	66,6	127	25	11352	1181	10171
						Total (m3):	**103880**	**10357**	**93523**

For the two retention areas near Nambroca and in the downstream Ramabujas directly upstream of the industrial site, the additional ‘wetland recharge’ resulting from these measures can be estimated by comparing the present-day (pre-project) situation with the projected future (post-project) conditions. The formula used to estimate recharge is as follows:

Volume recharged (m^3) = *A* (m^2) × *f (m/day)* × *D (days)*

Where: A = Inundation surface area, f = Infiltration rate, and D = Duration of inundation.



Summary RECHARGE ENHANCEMENT

Present' means current (baseline) condition; 'Future' means circa 10 years after start of implementation of proposed restoration measures.

Area	PRESENT			FUTURE			Annual volume recharged (m3)		
	A (m2)	f (m/day)	D (days)	A (m2)	f (m/day)	D (days)	present	future	increase
Nambroca recharge area	3400,0	0,1	2	34000,0	0,6	2	816	40800	39984
Downstream Ramabujas recharge area	4200,0	0,1	2	35000,0	0,6	2	1008	42000	40992
						Total:	**1824**	**82800**	**80976**