Erosion and Water Management Plan

From Strategy to Implementation

Location: Mountains of Ibi, Alicante, Spain

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Content

Executive Summary

This Erosion and Water Management Plan presents a comprehensive strategy to transform a severely degraded 31.3-hectare landscape in the mountainous region of Ibi, Alicante (800–950 m elevation), into a climate-resilient, biodiverse, and water-retentive system. The site currently suffers from a disrupted water flow and cycle, soil degradation, wildfire vulnerability and a lack of vegetative diversity; challenges that are both urgent and systemic. Yet, this report demonstrates that these issues are reversible through targeted, nature-based interventions.

At the heart of this plan lies a watershed-based, top-down zoning strategy designed to restore the local water cycle and regenerate vegetation. By combining passive water harvesting structures, native and fire-adapted planting, and strategic erosion control measures, the plan aims to rebuild the site's ecological and hydrological functions from the ground up.

Landscape Diagnosis

Hydrological analyses show that the site experiences highly uneven rainfall, with intense downpours followed by prolonged dry periods. Combined with historic land degradation, this pattern results in severe runoff, deep gully erosion, poor water infiltration, and widespread loss of topsoil and vegetation. Rainwater fails to infiltrate and is instead rapidly discharged, leading to::

- Uncontrolled runoff and erosion along slopes, roads, and terraces.
- Water scarcity during dry periods.
- Increased wildfire risk due to the dominance of highly flammable Pinus halepensis.
- Blocked ecological succession toward more diverse, resilient, mature ecosystem.

This vicious cycle has undermined biodiversity, increased vulnerability for floods, and rendered the landscape ecologically fragile.

Strategic Objectives

The plan aims to reduce runoff and erosion, restore native vegetation and biodiversity, and increase the site's resilience to drought, wildfire, and climate extremes.

System Design and Measures

The site has been subdivided into hydrologically distinct subwatersheds. Each subwatershed received a tailored intervention strategy based on the characteristics, such as slope, runoff volume, soil conditions, and ecological potential. A phased implementation from high to low elevation zones ensures that upstream interventions support downstream resilience. Key components include:

Earthworks: Swales, one-rock dams, Zuni bowls, ponds and depressions designed to slow, spread, and sink water into the soil.

Vegetative Interventions: Use of native, drought-tolerant and fire-resilient species, combined with nurse-planting strategies to boost biodiversity, and erosion control species for earthwork and soil stabilisation.

Fire and Erosion Control: Integrated approach combining firebreaks, removal of combustible biomass, erosion-resistant vegetation, and strategic planting layouts to reduce erosion and slow fire spread.

Runoff simulations show that full ecological upgrades, earthworks reinforced with a more dense and biodiverse vegetation, can reduce surface flow by over 90% in critical zones. These interventions also help recharge groundwater, increase infiltration rates, and rebuild topsoil.

Implementation Framework

Implementation follows a three-tiered approach:

- Top-down phasing: Interventions begin at higher elevations where infiltration has the greatest downstream impact.
- Start small, scale smart: Initial pilots at key points allow adaptive learning before scaling sitewide.
- Community Involvement: Local involvement in implementation and agroforestry increases long-term viability and strengthens social, ecological and economic relevance.

Monitoring is integral to the plan, with key indicators for infiltration, vegetation recovery, erosion control and biodiversity. Feedback loops enable adjustment of techniques to ensure long-term success.

Key Findings

- Disruption of water flow and cycle is severe: Without intervention, water loss will persist, halting ecological succession and increasing climate vulnerability.
- Water retention potential is high: Targeted structures and planting can dramatically reduce runoff and improve infiltration, even under extreme rainfall scenarios.
- Ecological Regeneration is achievable: With strategic implementation, the site can transition from erosion-prone and fire-sensitive terrain to a resilient, self-sustaining landscape that buffers climate impacts.
- Fire and water are interconnected: Vegetation structure, fuel load management, and firebreaks are essential to protecting and enhancing both soil and biodiversity.
- Integration is critical: Earthworks must be coupled with revegetation to stabilize soils and maintain hydrological function.

Recommendations

- Prioritize upper subwatersheds for initial implementation.
- Reinforce all earthworks with appropriate vegetation.
- Monitor runoff, infiltration, and vegetation growth continuously.
- Engage local communities in implementation and agroforestry.
- Use adaptive management to fine-tune interventions based on actual outcomes.

Outlook

If fully implemented, this plan will create a landscape that not only survives climate stress but thrives under it. Water retention will increase, soil fertility will improve, and biodiversity will return. Importantly, this system will require less external input over time, less irrigation, less maintenance, and will serve as a scalable model for similar Mediterranean environments facing degradation.

In sum, this plan lays out a technically robust, ecologically grounded, and socially inclusive path to regenerate a degraded landscape into a climate-resilient and biodiverse system with a restored and functional water cycle.

Introduction

Project Background and Coherence

This Erosion and Water Management Plan focuses on the ecological restoration of a mountainous site in the province of Alicante, located north of the village of Ibi, at an elevation of 800 to 950 meters (see colophon for project details). The plan outlines a comprehensive strategy to reduce runoff and erosion, enhance infiltration, and reestablish vegetation, thereby supporting long-term landscape recovery.

At the heart of this plan lies a watershed-based, top-down strategy aimed at restoring the local water cycle. By treating the site as a series of interconnected hydrological units, each defined by slope, flow dynamics, and landscape function, interventions are positioned to slow, retain, and infiltrate water at every stage of the watershed.
Zones at higher elevation are addressed first, as interventions in these areas influence hydrological processes further downslope. Improving water retention and infiltration upstream reduces both the volume and velocity of surface runoff during storm events, enhancing the effectiveness and reliability of downstream interventions.

This approach enhances both water availability and flood control, by buffering water in the landscape and minimizing erosive surface flows. By smoothing out the effects of seasonal rainfall patterns and managing extremes, it contributes to a more stable and resilient hydrological system. The strategy integrates structural water-harvesting structures, erosion control measures, and vegetative interventions—each tailored to local conditions and collectively designed to rebuild infiltration capacity and soil moisture, strengthen landscape function, and reduce downstream risk.

Context of the Methodology

This Erosion and Water Management Plan is a practical application of the integrated methodology for climate adaptation developed by Ecology Academy. While presented as a standalone document, it is designed to function in synergy with broader restoration strategies, including an Ecological Restoration Strategy and a specialized Vegetation Plan. By addressing these disciplines as interconnected system layers, the plan contributes to a coherent, interdisciplinary strategy for landscape recovery.

Objectives of the Erosion and Water Management Plan

The objectives of this plan are outlined in detail in Chapter 1. These objectives are central to the ecological restoration of the site and serve as the foundation for the analyses, strategies, and interventions proposed. They also provide the basis for evaluating the coherence and effectiveness of the implementation.

Guiding Principles

This water and erosion management plan is grounded in the understanding that ecological restoration is inseparable from water resilience. The current challenges, erosion, vegetation loss, and fire risk, are symptoms of a disrupted water cycle.

The interventions aim to slow, spread, and sink water across the landscape to reverse degradation and restore ecological function. The plan builds on natural hydrology, existing landforms, and local plant ecology, while applying proven land-based strategies such as passive water harvesting, vegetative recovery, and landscape contouring.

The result is a practical, zone-based strategy that supports the regeneration of native vegetation, improves water retention, and reduces fire and erosion risks, paving the way toward a long-term resilience against erosion and climate extremes, and toward a biodiverse landscape.

1. Objectives and Project Context

1.1 Objectives of the Erosion and Water Management Plan

This plan aims to improve water and erosion dynamics across the 31.3-hectare site by capturing, retaining, and safely guiding runoff through ecologically integrated measures. Objectives are grouped as follows:

1 Water and Soil:

- Reduce peak runoff Reduce peak runoff and prevent erosion.
- Increase infiltration and soil water retention.
- Enhance soil health through vegetation cover.

2 Vegetation and Biodiversity:

- Restore native cover and enhance habitat biodiversity.
- Maximise the functional use of runoff for ecological regeneration.
- Strenghten habitat connectivity and migration corridors for regional wildlife.

3 Resilience and Land Use:

- Reduce wildfire risk via fire-resistant/adapted species, structural diversity, firebreaks and fuel load reduction.
- Protect infrastructure from water damage
- Integrate and support climate-resilient and regenerative land use, a.o. via agroforestry

1.2 Project Context

1.2.1 Landscape Setting and Challenges

The site is located in a mountainous area of southeast Spain, within a dry Mediterranean climate. Steep slopes, shallow soils, and historic land use have caused erosion, degraded vegetation, and water scarcity. Flammable species such as Pinus halepensis dominate, increasing fire risk.

Despite this degradation, the site offers strategic opportunities: shallow soils still retain moisture in pockets, terraced land is available for planting, and elevation differences support gravity-fed water design.

1.2.2 Integrated Strategy

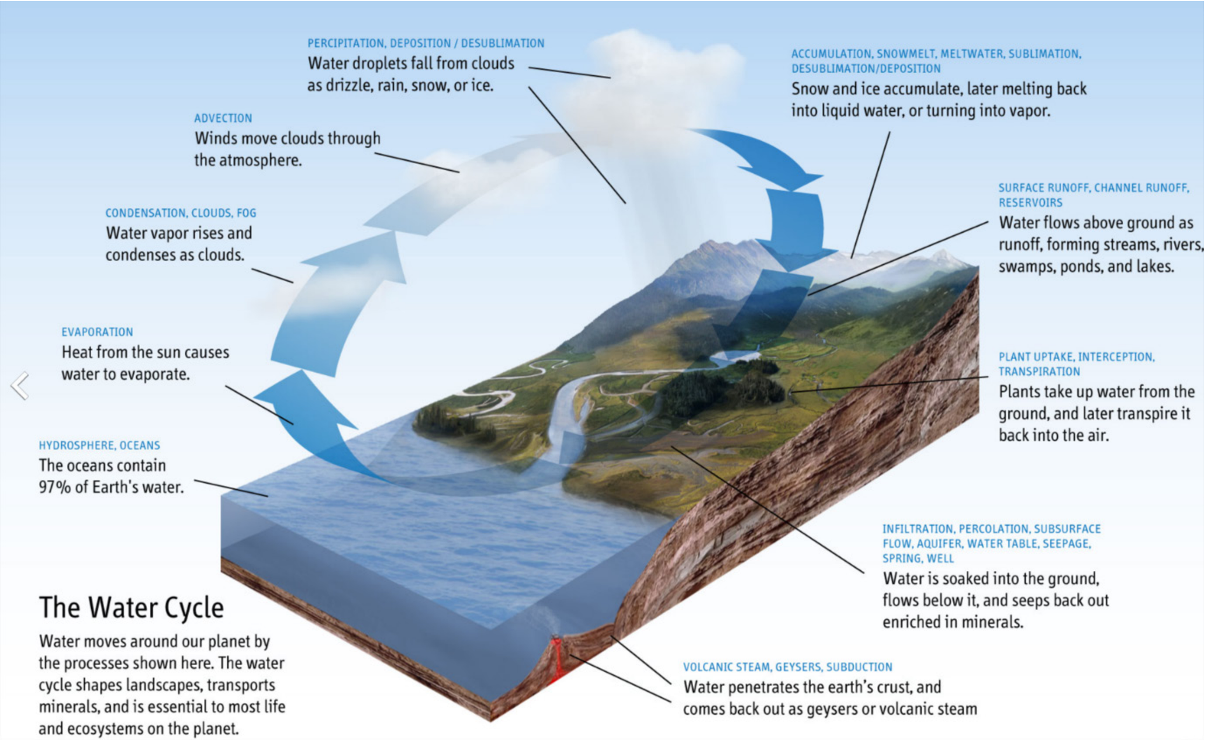
This Erosion and Water Management Plan is part of a comprehensive ecological restoration framework. It follows the integrated methodology for climate adaptation of Ecology Academy, which is structured to address the hydrological system layer as the primary foundation for subsequent vegetation and structural recovery. These distinct layers—water, vegetation, and ecosystem structure—are treated as complementary components to ensure a holistic and resilient approach to landscape restoration.

2. Hydrological Analysis

2.1 Rainfall Deficit and Site Water Balance

The water cycle is fundamental to understanding the hydrological dynamics in the mountainous region just north of Ibi. (see Figure 2.1-1 for a visual overview of the water cycle). By smoothing out the effects of seasonal rainfall patterns and managing extremes, we can support a resilient, climate-adaptive landscape.

Fig 2.1-1 Water Cycle



Source: Wikipedia, *Water Cycle*, edited by Ehud Tal

2.1.1 Regional Precipitation and Climatic Extremes

Annual precipitation in Ibi and its surroundings fluctuates between 330 mm and 460 mm, depending on topography and elevation (AEMET; climate-data.org). This is significantly lower than the Spanish national average of approximately 600 mm (Ministerio para la Transición Ecológica y el Reto Demográfico, 2023).

Rainfall rarely comes in perfectly timed doses though. Precipitation is concentrated in autumn and spring, with 25–30% occurring in September and October, and 20–25% in March and April. Summer remains virtually arid. Combined with high temperatures, this seasonality exacerbates desiccation and wildfire risk.

Cloudbursts (exceeding 20 mm/h) occur on average every two to three years, primarily in autumn. Heavy rainfall events (exceeding 60 mm/day) are less frequent—typically occurring once every five years—and often trigger flash floods (World Weather & Climate Information; Weather Atlas).

Global warming is driving an increase in weather extremes, including high-intensity precipitation. A critical phenomenon in this context is the Depresión Aislada en Niveles Altos (DANA)—an isolated upper-level low. These systems can cause catastrophic rainfall, as seen in late 2024, when parts of the Valencia region received between 150 mm and 400 mm in a single day.

The increasingly warm Mediterranean Sea provides a massive energy source for atmospheric instability, amplifying the intensity and frequency of torrential rain and flash floods. Furthermore, climate models frequently underestimate the impact of global warming on extreme precipitation (Otto et al., 2024), suggesting that actual risks may exceed current projections.

This combination of erratic rainfall—alternating between prolonged drought and sudden extremes—underscores the necessity for robust water management and erosion control. Summer droughts require efficient water capture and storage, while torrential events necessitate rapid flood mitigation and soil protection.

Box 2.1.1-1 Extreme Rainfall in Valencia (late 2024)

During the late 2024 Valencia floods, a pocket of cold air (below -20°C) was trapped within a low-pressure system at an altitude of approximately 5 km. The collision of this "cold pool" with exceptionally warm Mediterranean waters (above 20°C) triggered violent vertical air currents and rapid convective cloud formation.

This low-pressure system was blocked by surrounding high-pressure areas, causing the depression to stall. The resulting persistent rainfall delivered record-breaking volumes in a very short period, intensified by orographic lift in mountainous terrain.

2.1.2 Evaporation and Vegetation

Opposing rainfall is evapotranspiration, which includes both evaporation from the soil surface and transpiration through plant leaves. The ***precipitation deficit*** (the amount of water lost through evapotranspiration minus rainfall) often serves as an indicator of drought (box 2.1.2-1). Additionally, the amount of water that runs off directly without infiltrating the soil plays a crucial role in drought conditions, but this runoff will be discussed in the following section.

Box 2.1.2-1 Relationship Between Precipitation Deficit and Drought

Factors Contributing to Drought:

- the amount of rainfall
- the amount of water lost through evaporation
- the volume of water that runs off directly

(the amount of rainfall and the amount of water lost through evaporation) = Precipitation deficit

Source: Ecology Academy

The summers in this area are not only dry but also sunny and warm, leading to high evaporation rates. Evaporation varies significantly depending on land use though. On bare soil, evaporation is higher than on soil with plant cover. This difference is mainly due to two factors. First, the bare ground heats up quickly, causing water to evaporate before it can infiltrate the soil. Without plants to provide shade and cooling, the soil becomes even hotter, and the evaporation rate accelerates. Second, rainwater has difficulty infiltrating bare soil because of an inverse temperature gradient; the cool rain meets the hot surface, keeping water on the surface where it evaporates more easily. As the soil dries, it becomes more compact, further inhibiting water infiltration.

Restoring tree cover can reduce overall evapotranspiration, even though transpiration (water loss through leaves) may increase. This is because vegetation significantly reduces soil evaporation by shading and protecting the soil structure (Baldocchi & Ma, 2013; Valentini & Miglietta, 1998). At the site, evapotranspiration on the northern slope of the Sierra d'Ibi has already improved significantly due to early-stage forest regeneration, as indicated by the forming humus layer and the presence of feather moss (Brachythecium spp.)

Satellite estimates suggest that annual evapotranspiration of the site is approximately 380 kg H_2O per m² (Restor.eco). In comparable areas with high tree density and substantial ground cover, annual evapotranspiration is generally lower, ranging from 300 to 350 kg H_2O per m² (Baldocchi, 2020).
Currently, tree cover is about 18%, while potential tree cover for this area is estimated at 52% (derived from site data at Restor.eco). ***Increasing tree cover*** could thus help ***reduce evapotranspiration***.

In this way, ***increasing tree cover*** could improve the water balance by ***reducing water loss through soil evaporation***.

2.2 Water balance

The water balance is determined by inflow (precipitation, runon from surrounding areas), storage (water retention), and outflow (evapotranspiration and natural runoff), see box 2.2-1.

Box 2.2-1 Components of the Water balance

The water balance is determined by:

- Inflow: Precipitation and runon from surrounding areas
- Storage: Water retention within the site
- Outflow: Evapotranspiration and natural runoff

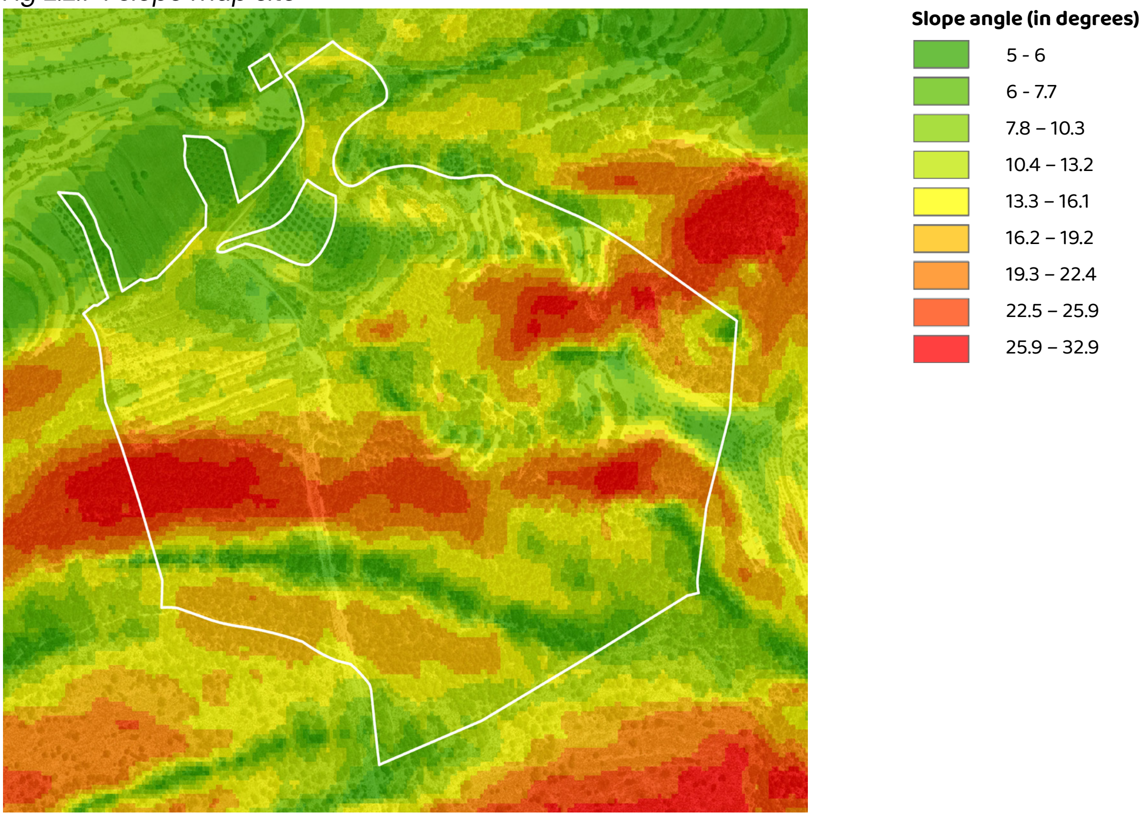
Source: Ecology Academy

The previous paragraph discussed precipitation and evapotranspiration. Before addressing the other factors in the water balance, it is essential to first consider the topography of the site, as it plays a crucial role in determining whether water runs off or infiltrates. The shape and slope of the landscape influence not only the speed of runoff but also where and how effectively water is retained. The following paragraph will explore this in more detail.

2.2.1 Topography and catchment area

The terrain varies, with slope angles for most of the road network ranging between 5° and 12°, while the terraces have slopes between 0° and 9°. Outside these accessible areas, slope angles can increase sharply (see Figure 2.2.1-1). These slope gradients play a key role in determining the appropriate water management structures, which will be discussed later.

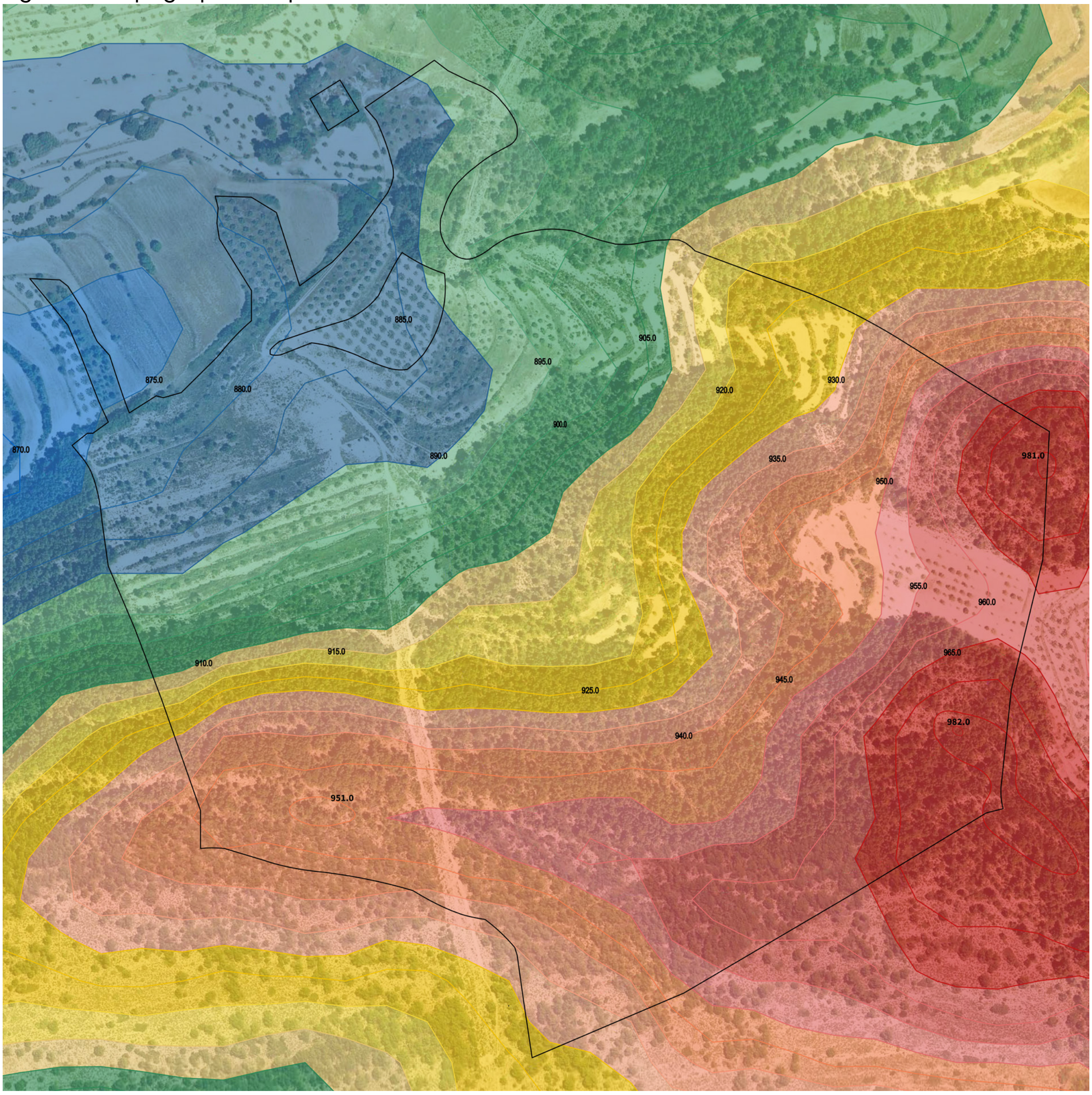
Fig 2.2.1-1 Slope map site



Source: ArcGis

The steepest slopes are found along the edges of the ridge on the southern side of the site (above and below the dark green, west-to-east running mountain ridge in the lower half of the image) and around the peak on the eastern side (see Figure 2.2.1-1 'Slope Map'). Except for a narrow strip along the southern edge of the ridge, the terrain generally slopes down towards the northwest. The northwestern area lies at a lower elevation, directing the flow of water in that direction (see Figure 2.2.1-2 'Topographic map').

Fig 2.2.1-2 Topographic map



Source: Topo Export

The site has an area of 313,374 m² (31.3 hectares). Annually, it receives an estimated 101 to 141 million liters of rainfall, most of which runs off toward the west to northwest. As part of a larger drainage basin, some rainfall from outside the site flows onto the northern edge as runon before flowing off again, creating a wetter zone in that area. While this increases the total available water beyond direct rainfall on-site, it is primarily limited to the northwestern section.

The two elongated terraces on the northwest side of the property lie along the drainage route of this water though, channeling both on-site and surrounding runoff southwest (see Figure 2.2.1-3 'Catchment analysis, runon'). The rest of the site receives minimal additional water from outside the site.

Fig 2.2.1-3 Catchment area analysis, runon

Source: ArcGis

The previous analysis shows the volume of water flowing through the system and the potential for capturing it. Effective water management on-site requires ***capturing*** both ***local rainfall*** and ***runoff from the surrounding*** watershed. The site receives minimal additional water from outside the site (runon for the site itself) though, except for the northern section and two elongated terraces on the northwest side of the property. Given the extent of the upstream catchment area, the hydrological regime in this northwestern sector can be drastically improved. The creation of diverse habitats—including wetlands and seasonal pools featuring more moisture-tolerant vegetation—is highly achievable here.

2.3 Runoff Dynamics and Water Retention

The watershed analysis in the previous paragraph made clear that or the majority of the site, the first component of the water balance—the inflow—does not significantly exceed local precipitation (see box 2.3-1).

Box 2.3-1 Components of the Water balance

The water balance is determined by:

- Inflow: Precipitation and runon from surrounding areas
- Storage: Water retention within the site
- Outflow: Evapotranspiration and natural runoff

Source: Ecology Academy

This precipitation occurs in limited quantities and is erratically distributed, often manifesting as intense cloudbursts. The combination of torrential rain and steep topography ensures that water runs off immediately, leaving insufficient time for infiltration. This results in high-velocity inflow and outflow dynamics, rendering the residence time of water on-site minimal (see box 2.3-2).

Box 2.3-2 Key factors Water System Dynamics

System Response:

- **Inflow dynamics** Erratic and high-intensity rainfall
- Storage dynamics
- **Outflow dynamics** Rapid runoff due to steep topography
- Residence Time

Source: Ecology Academy

The existing road network and degraded terraces currently function as primary drainage routes, which has led to severe erosion damage. The presence of deep erosion gullies confirms that a significant volume of rainwater runs off without being utilised by the ecosystem.

Visual evidence of the roads (see Figure 2.3-3) illustrates the scale of the structural damage. Significant portions of the site, particularly in the eastern sector, are virtually inaccessible. This poses a risk during emergencies and makes the transition to the upper terraces—essential for sustainable agriculture and ecological restoration—nearly impossible.

Figure 2.3-3 Current state of road infrastructure and erosion gullies

Restoring the road network without first mitigating the erosive power of these water flows is futile. The erosion cycle must be broken at its source before infrastructure can be stabilised. Chapter 3 'Water Management Strategies', provides a detailed analysis of the interventions required to achieve this.

2.4 Water Storage Potential

The high-velocity inflow and outflow dynamics, along with the associated soil loss, can be mitigated by attenuating water flow and reducing peak volumes. Expanding the site's water storage capacity is crucial to this objective (see Box 2.4-1). As storage capacity increases, the overall system load decreases, thereby reducing erosive pressure.

Box 2.4-1 Key factors Water System Capacity

System Capacity:	
• Inflow capacity	
• **Storage capacity**	Soil retention capacity, infiltration rate
• Outflow capacity	
• System load (belasting)	

Source: Ecology Academy

This underscores the vital role of on-site water retention—the second component of the water balance. By enhancing infiltration and sub-surface storage, the volume of water discharged during extreme precipitation events is significantly reduced, causing the runoff to lose its erosive power. This increased residence time directly supports vegetation health and ecosystem resilience. For a comprehensive overview of these interactions, refer to Box 2.4-2: 'Key Factors in Water Management'.

Box 2.4-2 Key factors Water Management

Water Balance:	System Capacity:	System Response:
• Inflow	• Inflow capacity	• Inflow dynamics
• **Storage**	• **Storage capacity**	• Storage dynamics
• Outflow	• Outflow capacity	• Outflow dynamics
	• System load (belasting)	• **Residence Time**

Source: Ecology Academy

Increasing vegetation in general, and tree cover in particular, could significantly enhance the site's water retention capacity. Plant roots improve soil structure, facilitating water infiltration. Research shows that vegetation cover can improve water infiltration by 50-75% (Gharakhani & Naderi, 2020) and that healthy vegetation in Mediterranean ecosystems can retain 30-60% more water than bare areas (Wang & Li, 2015).

Currently, 90% of the existing trees consists of Pinus halepensis which limits the site's water retention potential, as detailed in the companion Vegetation Plan (De Waard, 2026) which addresses the second system layer of the Ecology Academy's integrated methodology. The calcareous, stony soil further reduces its capacity to retain water, as highlighted in the Ecological Restoration Strategy (De Waard, 2026).

Holm oak (Quercus ilex) improves the water balance demonstrably more than Aleppo pine (Pinus halepensis): in eastern Spain, runoff was more than six times lower and soil erosion ten times lower under holm oak than under Aleppo pine, indicating better infiltration and water retention (Cerdà et al., 2017; EGU abstract Cerdà et al., 2015). Broadleaf trees, such as holm oak, supply organic material that retains moisture and helps prevent erosion (Sancho & Pinzón, 2017). Moreover, soils under Aleppo pine are generally more water-repellent than under holm oak, which further hinders infiltration (Cerdà et al., 2017; EGU abstract Cerdà et al., 2015).

A more diverse deep-rooted vegetation could thus help minimize direct runoff by encouraging greater infiltration. Replacing monocultures like Aleppo pine trees with native mixed species can increase infiltration by 20–40% (Zeller & Ley, 2013) and improve water retention (Zhang et al., 2018; Leith et al., 2016; Kauffman et al., 2015).

Moreover, the site lacks sufficient infiltration basins and shallow depressions for water retention at strategic locations along and near the watercourses. Some rainfall does accumulate in certain areas, as indicated by moisture-loving vegetation such as autumn crocus, giant reed (Arundo donax), and patches of holm oak. However, a large portion of the rainwater flows off the site without the chance to soak into the soil (see figure 2.4-3 'Water flow direction map site').

Fig 2.4-3 Water flow direction map site

Source: Based on topographic data, field measurements, and mapping of erosion gullies and water flows.

Water harvesting techniques should be a top priority at the site. The lack of shallow depressions to trap rainwater and suitable catchment structures, such as swales and bunds, combined with het erosion degraded terraces clearly underscores the ***need to capture runoff*** by creating ***water catchment areas*** and ***improving water infiltration***.

Highlights

- Increase vegetation cover to reduce evapotranspiration.
- Introducing a diverse deep-rooted vegetation to minimize direct runoff by promoting greater infiltration.
- Reduce the erosive power of water by reducing its volume, spreading it, slowing its flow, and encouraging infiltration;
- Expand both the number and size of water catchment areas and apply water harvesting techniques to capture runoff and and enhance the site's water retention capacity.

Ultimately, the findings confirm that without active ecological restoration—specifically the strategic introduction of deep-rooted trees, diverse vegetation structures, and improved soil organic matter—the landscape's capacity for infiltration and structural stability will not recover. Consequently, erosion cannot be significantly mitigated through passive means alone. To break the current cycle of degradation and restore a functional water balance, proactive ecological intervention is an absolute necessity.

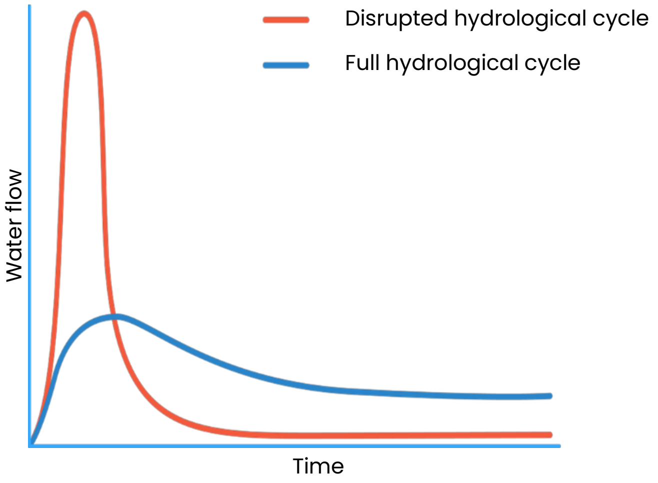
3. Water Management Strategies

3.1 Disrupted Water Cycle and Vicious Circle

The site currently lacks water-harvesting structures such as shallow basins, infiltration pits, swales and bunds. Combined with the site's topography, land degradation, and irregular rainfall, this absence accelerates runoff and water loss. Water drains rapidly off-site rather than infiltrating into the soil, and this symptom reveals a deeper issue: the local water cycle is broken.

Historically, rainfall would slowly infiltrate into the soil, feed vegetation, replenish aquifers, and contribute to streamflow over time. Today, the opposite occurs: rain strikes bare or degraded soil and runs off quickly, transporting sediment and creating gulleys. Vegetation loss, soil compaction, and surface crusting prevent infiltration. This shift is human-induced and self-reinforcing.

Fig 3.1-1 Disruption of the hydrological Cycle



Source: Ecology Academy

Historically, rainfall would slowly infiltrate into the soil, feed vegetation, replenish aquifers, and contribute to streamflow over time. Today, the opposite occurs: rain strikes bare or degraded soil and runs off quickly, transporting sediment and creating gulleys. Vegetation loss, soil compaction, and surface crusting prevent infiltration. This shift is human-induced and self-reinforcing.

Drought and flash floods are symptoms of a disrupted water flow and cycle (figure 3.1-2); land degradation is its consequence. This is not an isolated issue, but part of a self-reinforcing feedback loop in which soil degradation, disrupted water flow and cycle, and climate change interact and intensify each other:

1. Fresh water becomes increasingly scarce.
2. Natural cycles mean that water is not available in the desired quantity at all times.
3. Land degradation, homogenous vegetation, and the absence of retention structures reduce water holding capacity, preventing rainwater from being absorbed or stored.
4. Runoff accelerates and becomes less evenly distributed over time, leading to both droughts and floods.
5. Water's physical properties amplify drought and heat: drier soil heats up faster and absorbs less water.
6. Climate change intensifies extreme events like floods and droughts.
7. These extremes further degrade ecosystems, soil structure, and infiltration capacity, thus reinforcing the vicious cycle.

This feedback loop degrades ecosystems and amplifies climate extremes. According to the FAO (2017), healthy systems produce only 15% runoff (FAO, 2017); in degraded systems, the majority of rainfall is lost as immediate runoff.

To reverse this trend, the water cycle must be restored through landscape-based interventions that retain water where it falls, enhance infiltration, build soil moisture buffers, and reduce the erosive power of water. Failure to restore the hydrological cycle will exacerbate both the consequences of climate change and climate change itself (IPCC, 2022). This chapter outlines the strategy, with a specific focus on ephemeral flow.

3.2 Strategy for Restoring the Water Cycle

This plan adopts a watershed-based, top-down strategy. Interventions start at the highest elevations and proceed downslope. Each part of the landscape is treated as a separate catchment area. The earlier water is intercepted, slowed, spread, and infiltrated, the more effective the system as a whole. This strategy voor waterregulatie volgt wee sporen:

1. Water availability
2. Flood control

3.2.1 Water availability (beheer van waterverdeling en -opslag)

Rainfall in this region is infrequent, often intense, and followed by long dry periods. This means that we must capture, store and distribute what falls from the sky as effectively as possible. Therefore, to catch water on site, both **surface water storage** and **soil moisture storage** are essential.In this climate zone.

The flow should be slowed, spread out, and infiltrated in the soil as much as possible.

A. Surface Water Storage

Constructed elements such as ponds, reservoirs, wadi and swale systems, and wetlands slow down runoff and store water. Placement is critical: Basins should be located where slopes are steeper above and gentler below. Deeper basins help reduce evaporation since a smaller surface area is needed. Overflow must be carefully routed and controlled.

B. Soil as a strategic Water Reservoir

Soil is the largest and most cost-effective water storage medium available on most sites. It absorbs rainfall, slows runoff, and moisture held in soil doesn’t evaporate easily. This makes it a key component in any strategy for sustainable water management (Lancaster, 2010; Zeedyk & Clothier, 2009).
The overall water-holding capacity of soil depends strongly on its texture, structure, and especially its content of organic matter. Organic matter plays a crucial role: it acts like a sponge, capable of retaining up to ten times its own weight in water (Berman, 1994). Research shows that soils containing just 2% organic matter can reduce irrigation needs by up to 75% compared to degraded soils with less than 1% (Hudson, 1994).
However, the benefit of added organic matter varies by soil type. A 1% increase in organic matter improves water retention in sandy soils by 2.3%, but by only 1.3% in calcareous soils, such as in IBI (Khatiwada & Swanson, 2020).

Key practices for improving soil water storage capacity

Strategies (or tasks) to improve and ensure water storage in the soil:

a) Shape the land to slow, sink, spread water (contouring to catch water)
b) Building organically rich soil (mulch, green manure, compost)
c) Keeping the water (maximising living and organic groundcover)

Ad a) Contouring to catch water

Effective water management on sloped terrains can be achieved through contouring techniques that capture and infiltrate runoff. Two primary methods are keyline plowing and swales.

Keyline Plowing: This technique involves subsoiling along keylines to enhance water distribution with minimal soil disturbance. It's particularly suitable for agricultural settings where maintaining accessibility for machinery is crucial. However, in arid or degraded tropical landscapes, its effectiveness diminishes due to limited water retention capabilities.

Swales: These are shallow, level trenches dug along contour lines, designed to harvest water, organic matter, and soil. While more labor-intensive and permanent, swales are highly effective in more arid environments, not only for water storage but also for mitigating the impact of strong water flows.

Given the site-specific conditions at IB, swales are the preferred method. The core principle is to integrate these structures with the natural topography, building upon existing landscape features. For a detailed explanation of contouring, refer to Annex A.1; for a comprehensive justification of why swales are specifically suited for this context, see Annex A.2: Comparative Analysis of Swales and Keyline Plowing.

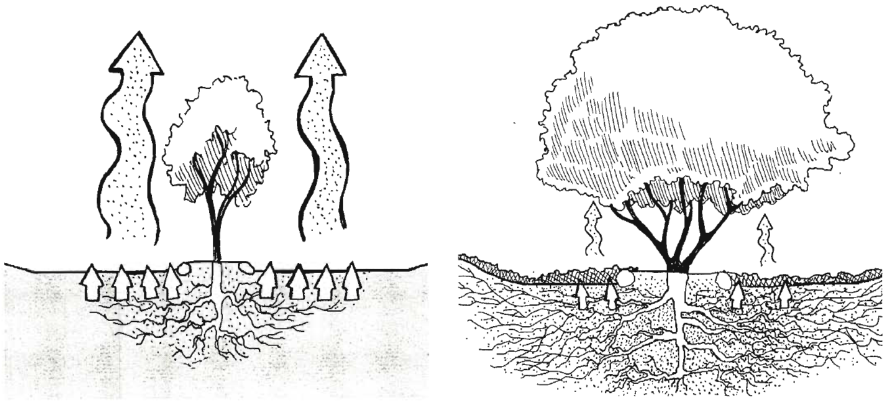
During rainfall, once the soil reaches its saturation point and can no longer infiltrate the rainfall, the surplus water moves downslope as surface runoff. As the surface water and the rain water flows downhill it's intercepted by the swales, it spreads out over his length and slowly (pertilates) into the soil. This underground water then seeps downslope increasing moisture downslope.

In addition to these tools, some other techniques may be useful in improving hydrology, such as slots/gullies filled with wood chips (to prevent runoff) that are both walkways and moisture buffers (sponge ladders).

Ad b Building organically rich soil (mulch, green manure, compost)

A two- to four-inch mulch layer (or more) will squelch moisture loss by slowing evaporation from the soil and by keeping plant roots cool, which will reduce evaporation (figure 3.2.1-1).
Organic mulches also soak up rain rather than letting it run off. And as organic mulches break down, soil fertility improves. It also limits soil erosion and weed growth. The capacity of the land to store water will increase over time as the build up of the soil's organic matter continues.

Figure 3.2.1-1 Mulching for moisture (and healthy plants)



A: a basin without mulch losing the bulk of the soil moisture to capillary action and evaporation
B: The basin mulched for improved infiltration and retention of water into the soil
Source: Lancaster, 2019

The moisture-retaining mulch can also delineate planting basins from paths and all basins could be filled with organic material to make them almost invisible for the eye.

Ad c Keeping the water
Mulch plays a vital role in reducing soil moisture loss and maintaining soil integrity, particularly in areas prone to erosion. By covering the soil with mulch or living plants, water retention improves as evaporation is reduced, helping to stabilize the landscape and minimize erosion risks. Shading soil, either with mulch or vegetation, can reduce evaporation by over 60%, which is crucial in preventing soil degradation and runoff during dry spells (UC Master Gardener Program, 2024). This plan promotes strategies that maximize soil moisture retention to reduce erosion, including techniques like mulching, contouring, and the strategic planting of vegetation suited to the landscape (Lancaster, 2019).

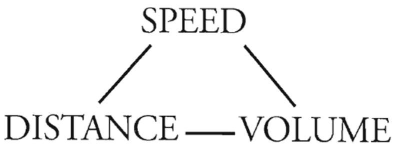
In this context, the focus remains on the broader landscape, using cover crops and organic mulch to help stabilize soil, manage runoff, and improve water infiltration. Dense planting is recommended in erosion-prone areas to help maintain groundcover, thus reducing runoff and enhancing water absorption.

The companion Vegetation Plan provides a more detailed focus on planting (De Waard, 2026).

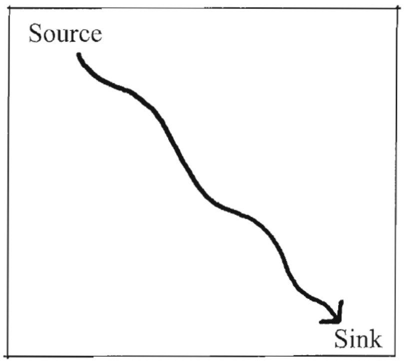
3.2.2 Flood Control

Flood control is a major concern. Preventing erosive surface runoff is crucial, especially after road restorations, to protect the newly repaired infrastructure. It is essential to slow or check the flow of runoff upstream to prevent it from accumulating into more destructive volumes and velocities. see box 3.2.2-1 on the erosion triangle for further insight.

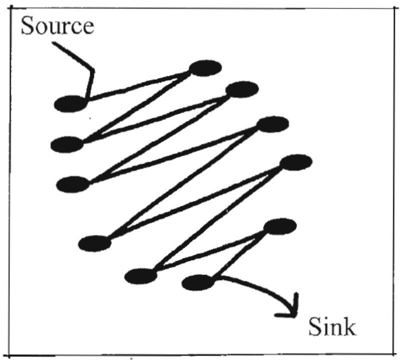
Box 3.2.2-1 Erosion triangle



Speed, distance and volume refer to characteristics of water flowing on the land's surface. Reduce any of the three and you begin to cut the erosion cycle. The more you break the cycle the more you reduce erosion.
If you put in water-harvesting strategy such as berm 'n basin, check dam, or infiltration basin in the path of water flowing over the land, you will reduce erosion by reducing the **SPEED** of water flow.
If you place one or more of these strategies at the top of the watershed rather than beginning at the bottom, you will be reducing erosion by reducing the **DISTANCE** the water travels before being encouraged to infiltrate the soil.
If numerous strategies that hold and infiltrate runoff water into the soil are placed throughout a watershed – from tops of slopes to their bottom, erosion is reduced further by reducing the **VOLUME** of surface water flow.



A: Source and sink. A fairly quick and linear downward flow drains the landscape



B: Source and sink. The zig-zag increases the time of flow, distance travelled, and ground infiltration from source to sink

Source: Lancaster, 2019, adapted by Ecology Academy

Flooding is not an isolated event, but a symptom of a disrupted watercycle and ecological degradation. In this plan, flood control is approached not by fighting floods downstream, but by breaking the erosion cycle upstream; through infiltration, dispersion, and the restoration of flow patterns. The goal is to reduce the erosive power of water before it becomes a destructive force.

The solution lies in reducing three key erosion drivers:

- Speed (steep slopes, bare ground, compacted flow paths)
- Volume (concentrated runoff)
- Distance (length of flow without before encouraged to infiltrate the soil)

Principles of Effective Flood Control

The core principle of flood control is deceptively simple: slow, spread, and sink water as high in the landscape as possible. Surface water should never be abruptly blocked, especially not in high-flow drainage channels. Instead, the design must:

- Work along contour, allowing water to infiltrate gradually.
- Use topography to redirect flows toward gentler slopes and infiltration zones.
- Install overflow routes that safely carry excess water into the next buffer zone.

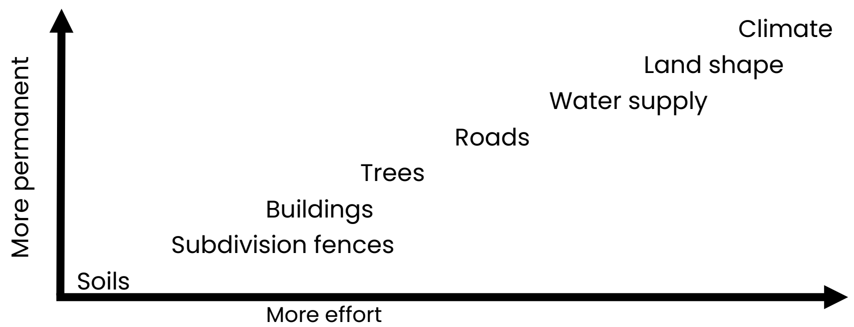
Effective interventions include vegetated slopes, check dams, infiltration basins, and swales. These are not just physical structures; they are part of a broader system that restores the hydrological function of the land.

Strategic Placement and Natural Flow Logic

Placement is critical. Water-retention features must be located where they can intercept runoff before it accumulates velocity—ideally where steep slopes lie above and gentle terrain lies below. Water is guided laterally, never dropped vertically, to avoid erosion. Overflow is designed not as an afterthought, but as a functional resource—each overflow becoming the inflow of the next basin.

This strategy aligns with Yeomans' Scale of Permanence, which ranks landscape design elements by their influence and reversibility. Water design ranks high: it has a strong and lasting effect on landscape health, yet can often be implemented with minimal intervention. Small, well-placed structures upstream often outperform large-scale interventions downstream.

Fig 3.2.2-2 Yeomans's Scale of Permanence



Note: Soil is easy to destroy, yet remains easy to build.

Flood control is not about resisting the power of water, but about diffusing and harnessing it. Where flash floods may cross the site, we do not attempt to block the natural channel. Instead, dual flow paths are sometimes introduced: one following the original route, the other diverted to a stable secondary path. This reduces pressure and splits flow volumes.

Pattern-based strategies for managing flow:

1. Sheet flow: on-contour planting, swales.
2. Channel flow: check dams, rock step-downs.

These designs reduce the erosive potential by shortening the distance, slowing the speed, and lowering the volume of flow. By addressing each point of the erosion triangle, the system weakens the cycle of degradation and redirects it toward regeneration.

3.3 Strategic guidelines for water harvesting and flood control

This strategy is rooted in practical principles from successful water harvesting projects (Zeedyk, Lancaster, Halsey, and others) and site analysis. These principles structure all decisions in design, phasing, and site execution:

A. Observational and strategic:

- Begin with long and thoughtful observation.
- Observe, map, and understand existing flow patterns
- Create a site plan and map your observations
- Map the catchment and divide it into smaller water basins.
- Start at the top of a drainage basin and work downslope.
- Connect with the landscape and build on what already exists.
- Apply water harvesting techniques to capture runoff and enhance the site's water retention capacity.
- Focus water-harvesting and erosion control efforts on more gentle slopes in the landscape
- Always integrate a feedback loop: monitor, learn, adapt.

B. Technical and sequencing:

- Start with small and simple interventions.
- Build where impact is high and risk is low.
- Prioritise damaged areas before intact ecosystems.
- In drylands, begin with the wetter or low-lying parts.
- Do not overengineer — work with terrain, vegetation, and flow.

C. Hydrological:

- Reduce the erosive power of water by reducing its volume, spreading it, slowing its flow, and encouraging infiltration;
- Slow water, spread it, sink it using topography and structures.
- Diffuse energy of flowing water by meandering flow patterns
- Direct the controlled runoff to reservoirs just below
- Store water in soil and surface basins.
- Infiltrate before diverting.
- Never let water gain speed or flow unbroken over long distances.

D. Vegetation and soil:

- Design for infiltration, not just collection.
- Reduce runoff by increasing vegetation cover and rooting depth upslope.
- Choose deep-rooted, drought-resilient native species to promote greater infiltration.
- Maintain groundcover with mulch or living plants.
- Avoid bare soil: it increases runoff, heat, and erosion.
- Improve soil organic matter continuously.
- Consider biodiversity gains, create klimaat—en droogtebuffers voor fauna and flora

E. Overflow and safety:

- Always design a safe overflow route.
- Build energy-dissipating structures below overflows
- Manage overflow as a resource — guide it to the next buffer.
- Do not build infiltration systems near foundations and terrasranden.
- Avoid construction in steep or unstable zones without professional support.

F. Construction recommendations:

- Design overflow zones first, then build water retention structures.
- Place reservoirs just below key catchment zones.
- Situate reservoirs and ponds where the slope is steep above and gentle below.
- Maak reservoirs dieper en wallen groter dan je denkt
- Voer geen aarde af of aan tot bestaande bronnen gebruikt

- Seed earthworks during construction to speed up vegetation.
- Keep rock structures one rock high where possible — simple, flexible, durable.
- Use gravity-fed systems over piped systems wherever possible.
- Never build directly in water channels or steep slopes without expert design.
- Always plan for maintenance and future adaptation

These principles form the foundation for the next chapter, which translates them into specific design choices and phased implementation.

4. Water Management System Design

4.1 Key Principles and Scenarios

4.1.1 Top-down Watershed-Based Approach

All interventions in this chapter are derived from the strategy and principles in Chapter 3. The guiding approach is a watershed-based, top-down sequence: interventions begin in the highest subwatershed and move downward, working within the natural flow patterns of the site.

The site has been divided into zones, each representing a distinct hydrological unit—often corresponding to an individual subwatershed. These units are defined by their topography, drainage patterns, and landscape function, and each requires a tailored combination of measures for water retention, infiltration, erosion control, and vegetation restoration.

This chapter presents the water management and erosion control strategy for each zone, with a primary focus on water harvesting, storage, and flood mitigation. Zones at higher elevations are addressed first, as interventions in these areas influence hydrological processes downstream. Improving water retention and infiltration in the upper parts of the watershed reduces both the volume and velocity of surface runoff during storm events, thereby enhancing the performance and reliability of downstream interventions and reducing the risk of flood damage.

The strategies described here are selected because they are relatively easy to implement by hand, they typical use readily available on-site materials, and they are effective when placed and built right. The focus is on understanding what is happening with the flow of water and sediment at the site and why it is happening, then determine an appropriate strategy and measures. The principles outlined in Section 3.2: Strategic Guidelines for Water Harvesting and Flood Control serve as the guiding framework.

4.1.2 Rainfall scenarios

In semi-arid Mediterranean regions such as Ibi, rainfall is highly irregular and may include intense convective storms. Based on observed data and hydrological design principles, three key scenarios are defined (Climate Data, Weather Underground, Meteoblue, ResearchGate, WolrldWeatherOnline, Meteostat):

Table 4.1.2-1 Rainfall Scenarios for Design and Risk Assessment

Scenario	Description	Rainfall	Duration	Design application
A	Peak rainfall	40 mm	20 min.	Drainage capacity, emergency overflow, erosion control
B	Heavy rainfall	60 mm	2 hours	Infiltration assessment, swale capacity, basin retention
C	Extreme event	150 mm	6 hours	Dimensioning of total storage volume (ponds, terraces, buffers)

Sources: Climate Data, Weather Underground, Meeoblue, ResearchGate, WolrldWeatherOnline, Meteostat; Scenario development and analysis by Ecology Academy.

Scenario A represents the critical peak intensity that the system must be able to handle over a short period, primarily for drainage, erosion control, and emergency overflow. It simulates a realistic short but intense cloudburst with rapid runoff.

Scenario B reflects a realistic high-rainfall event (60 mm in 2 hours), typically associated with severe but not extreme convective storms. This scenario is used to assess infiltration capacity, the effectiveness of water management structures, and water retention under severe high-stress condition.

Scenario C represents an extreme, rare but plausible event (150 mm in 6 hours), such as a DANA (Depresión Aislada en Niveles Altos). It is used to evaluate the overall system resilience and storage capacity under climate-induced extremes.

These scenarios allow for performance evaluation under frequent, severe, and rare conditions, supporting robust and adaptive hydrological design.

4.1.3 Runoff Assumptions

Infiltration rates depend heavily on both slope gradient and surface characteristics, including vegetation cover, soil structure, and land management. For the hydrological analysis, infiltration rates (in mm/hour) have been estimated for three slope classes.

- 0 - 5º (flat to gently sloping)
- 5 - 9º (moderate slope)
- >9º (steep slope)

These values are derived from published literature (FAO (1998), USDA NRCS (2007), Zeedyk & Clothier (2009) and Lancaster (2019, 2020)) and adapted to local soil conditions: shallow, stony calcareous rendzina with limited water-holding capacity, moderate permeability, and thin or discontinuous top soil, especially on steeper terrain.

Table 4.1.3-1 shows how infiltration capacity increases with ecological improvement, from bare, compacted soil to fully vegetated and organically enriched surfaces. The highest values are reserved for flat areas with combined interventions, such as mulch, humus, and water harvesting structures (e.g., swales, bunds a.o.).

These values form the basis for the runoff calculations in all rainfall scenarios, allowing for accurate differentiation between degraded, current, and improved landscape conditions.

Table 4.1.3-1 Infiltration Rates by Surface Condition and Slope Class

Surface condition and treatment	**Slope** 0–5º	**Slope** 5–9º	**Slope** >9º
Exposed bedrock or severely compacted bare soil	1	1	1
Sparse vegetation cover on degraded soil	3	3	2
Sparse vegetation cover with lightly tilled soil	6	5	3
Partial vegetation cover without soil enhancement	10	8	5
Partial vegetation cover with understory (herbs, green manure, groundcovers)	12	10	7
Partial vegetation cover with understory and small-scale harvesting structures	15	12	8
Dense vegetation cover (no mulch)	16	13	9
Dense vegetation cover and mulch	20	17	12
Dense vegetation, mulch and small-scale water structures	23	18	13
Dense vegetation, mulch, enriched soil and water harvesting & control structures	30	25	15

Sources: Barnes (2023), Lancaster (2019), Zeedyk (2009). Infiltration class definitions and scenario alignment by Ecology Academy

4.1.4 Infiltration Improvement Scenarios

This analysis includes not only the current (baseline) condition of the site, but also a set of improved infiltration levels representing different land management strategies. Each level reflects a distinct combination of ecological and technical interventions, applied to slopes, terraces, or to specific parts of the catchment.

The measures range from revegetation, light tillage and the addition of mulch, to structural solutions such as swales, erosion control features and, in some cases, the diversion of runoff.

Table 4.1.4-1 summarises the baseline and improved levels, describing the scale and nature of each intervention:

Table 4.1.4-1 Progressive Intervention Levels

	Scenario	**Added Measures**	**Scope**	**Intensity**
B	Baseline	Current condition (light vegetation on slopes, limited management on terraces)	Slopes+terraces	Reference
I	Vegetative improvement	Revegetation of slopes + light tillage on terraces	Slopes+terraces	Low
II	Vegetation densification	+ Replanting of missing trees and understory with herbs, green manure, and groundcovers	Terraces	Medium
III	Water structures	+ Small-scale water harvesting structures	Terraces	High
IV	Full ecological upgrade	+ Dense vegetation cover + mulch + swales + erosion control measures	Slopes+terraces	Very high
V	Diversion enhanced	+ Any of the above, combined with diversion of runoff	Zones within sub-catchments	Add-on enhancement

Source: Scenario development and classification by Ecology Academy

These intervention levels serve as the basis for calculating runoff volumes under different rainfall conditions, and for determining both the required capacity and the appropriate combination of water harvesting structures, erosion control, and vegetation or soil improvement measures across the terrain.

4.1.5 Runoff Calculation and Zoning

For hydrological design and analysis, the site is subdivided into zones that typically correspond to sub-catchments or mini-watersheds. These zones are defined based on topography, flow direction, and functional landscape units. Within each zone, the terrain is further classified into types—such as bare slopes, terraces, or vegetated areas—based on surface condition, slope class, and land use.

Runoff is calculated separately for each terrain type within a zone using the following formula:
Runoff (mm) = Rainfall (mm) – (Infiltration rate (mm/h) × infiltration duration (h))

If rainfall exceeds the infiltration capacity of a given surface, the surplus is considered runoff. By calculating runoff per terrain type, the total runoff volume can be estimated for each zone. This forms the basis for evaluating whether planned measures—such as revegetation, soil improvement, or water retention structures—are sufficient to manage runoff effectively within that zone.

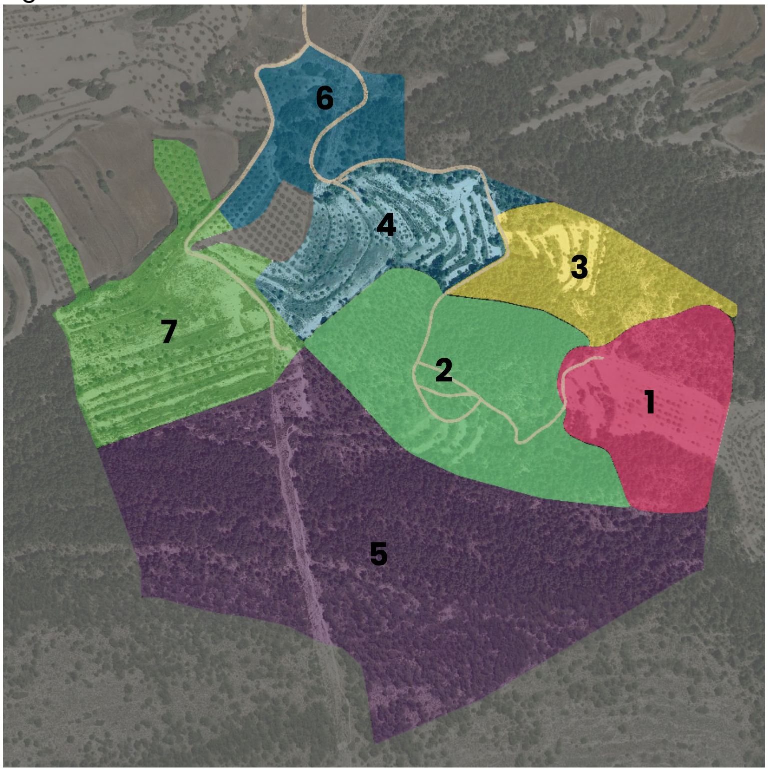
Infiltration duration is not determined solely by rainfall duration. Measures such as revegetation, mulch application, soil improvement, and water harvesting structures allow infiltration to continue after precipitation has ceased.
Infiltration durations are therefore adjusted per intervention level. Under baseline conditions, a conservative duration is applied, while improved conditions progressively increase infiltration time,

up to 8.5 hours in well-vegetated and structurally enhanced systems during prolonged rainfall (Scenario C, 150 mm in 6 hours).

In intervention levels III and IV, an additional infiltration volume is included to account for the storage capacity of small-scale structures such as swales and bunds. This volume is calculated separately per zone based on the number, size, and layout of the structures.

Figure 4.1.5-1 shows the layout and names of all subwatersheds across the sit. It forms the basis for the following sections of this chapter. Each subwatershed is analysed individually, and context-specific measures are proposed to reduce runoff and erosion.
Subwatersheds at a higher elevation are addressed first, as interventions in these areas influence hydrological processes downstream. This approach aligns with a watershed-based, top-down strategy, in which implementation starts upstream and gradually progresses downslope. Improving infiltration and water retention upstream helps reduce runoff volumes during storm events, thereby lowering flood and erosion risks downstream.

Fig 4.1.5-1 Overview of all Watersheds on the site



Legend

1. Upper Terrace Watershed
2. Mid-Terrace Watershed with Access Route
3. Upper East Buffer Terraces
4. Central-West Terraces and Inflow Zones
5. Southern Mountain Ridge
6. Northern Tip Subwatershed
7. NorthWest Terraces and Plain

Source: Ecology Academy

The design takes into account the presence of the gas pipeline. Within a 2 to 4-metre radius from the pipeline axis, no water harvesting structures are installed, and no trees are planted. This buffer ensures access for maintenance and also functions as a firebreak to help mitigate the impact of wildfires.

The following sections provide a detailed overview of the proposed measures for each zone which mostly represent smaller catchment areas.

4.2 Zone-Specific Water and Erosion Control Measures

4.2.1 Measures for the Upper Terrace Watershed

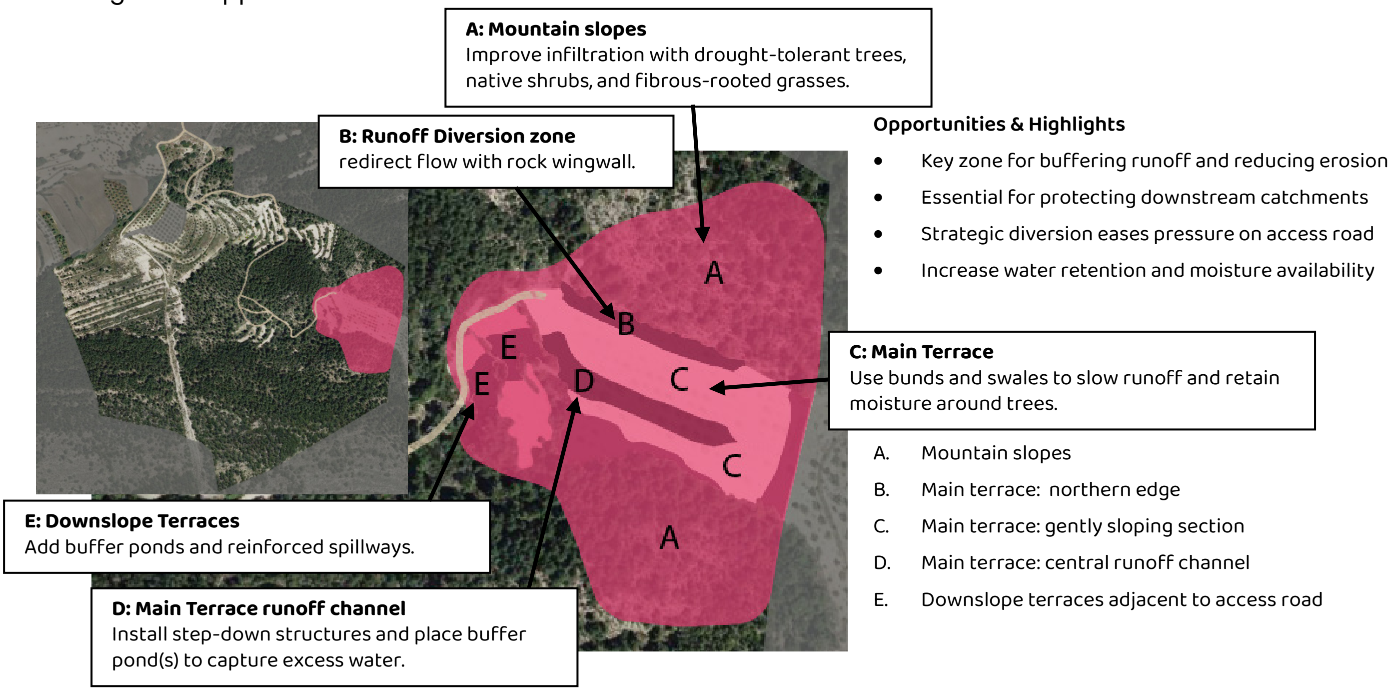
Overview

The highest watershed of the site covers 2.8 hectares and drains westward. It consists of a large central terrace, flanked by mountain slopes to the north and south, and two smaller, lower terraces to the west. These western terraces form the transition toward the access road and the downstream zones.

This watershed plays a critical role in capturing and regulating runoff. Due to its size and position, it generates a substantial volume of runoff that can severely damage the access road and the lower zones—especially since the road lies directly in the natural drainage path and even forms part of the main channel flow route.

Figure 4.2.1-1 provides a spatial breakdown of this subwatershed into zones (A–E) and highlights the key interventions.

Fig 4.2.1-1 Upper Terrace Watershed Zones and Measures



Source: Ecology Academy

Characteristics

The watershed consists of five functional zones (A–E), each with distinct topographic and hydrological characteristics:

- Zone A – Mountain slopes: Steep, rocky slopes with homogenous vegetation (mainly Aleppo pine) dominate the northern and southern flanks. These slopes are prone to rapid runoff due to limited infiltration capacity and lack of vegetation diversity, especially the south-facing slope of Cabaceta de Fabriqueta. In contrast, the north-facing slope (Sierra d'Ibi) shows early ecological recovery, with a forming canopy, humus layer, and feather moss (Brachythecium spp.), indicating improving moisture retention.

- Zone B – Northern edge of the central terrace: This edge receives runoff from the adjacent northern slope (Cabeceta de la Fabriqueta) and channels it westward and diagonally across the terrace, resulting in significant erosion gullies.
- Zone C – Gently sloping central Terrace area: This broad, cultivable section covers the largest surface area. The slope is moderate, with bare ground and widely spaced almond trees.
- Zone D – Central depression: A shallow channel running through the middle of the terrace, where runoff from both sides converges and flows westward with higher velocity. This zone is highly susceptible to erosion.
- Zone E – Downslope Western Terraces: These smaller terraces mark the transition to the access road and serve as the final opportunity for water harvesting and infiltration before runoff reaches the access road and lower catchment areas.

Runoff and Risk

The surface area of this subwatershed is 2.8 hectares, with approximately 1.7 hectares of mountain slopes and 1.1 hectares of terraces. Based on the defined rainfall scenarios, this generates the following rainfall during short-duration storm events:

A. Peak rainfall (20 min event): 1,131 m^3
B. Heavy rainfal (2 hr event): 1,681 m^3
C. Extreme rainfall (6 hr event): 4,202 m^3

Runoff modeling of the baseline (undeveloped) condition shows high surface runoff volumes, between 1.097 m^3 (A. Peak rainfall) to 3.814 m^3 (C. Extreme event). These volumes pose a major risk to the access road and downstream zones. The road lies directly in the natural drainage path, and parts of it coincide with the main channel flow, which amplifies erosion and sediment transport during heavy rains.

Objectives

Primary objective:

- Reduce runoff and erosion to protect the access road and downstream zones.

Secondary objectives:

- Improve infiltration and water retention on both slopes and terraces
- Capture surplus runoff via water reservoirs (ponds)

Intervention Strategy

Based on the watershed characteristics, a distinction is made between the mountain slopes (Zone A) and the terraces (Zones B to E). The mountain slopes cover approximately 1.7 hectares, while the terraces comprise nearly 1.1 hectares.

The interventions are designed according to the principle start at the top and work your way down, targeting each zone based on its topography, characeristics, runoff behavior, and function within the subwatershed.

The following sections outline the proposed interventions, supported by detailed construction guidelines and drawings in Annex A.3.

Table 4.2.1-2 shows the cumulative impact of the listed interventions on total runoff.

Table 4.2.1-2 Upper Terrace Runoff by Intervention Level and Rainfall Intensity

Code	Scenario name	Intensity		Peak	Heavy	Extreme
B	Baseline	Reference scenario		1090	1512	3685
I	Basic vegetative improvement	Low		1030	1226	3019
II	Vegetation densification	Medium		959	942	2354
III	Water harvesting structures	High		847	688	1719
IV	Full ecological upgrade	Very high		613	50	215
V	Diversion enhanced	Add-on enhancement*		360	0	0

Source: Ecology Academy
*: Diversion of runoff from north-facing slope

A. Mountain Slopes (+B)

The primary goal on the mountain slopes is to minimize direct runoff by enhancing vegetative cover and improving infiltration. No engineered water-harvesting structures are proposed on the mountain slopes due to steepness (>13°) and erosion risk. Instead, the focus is on vegetation:

- Introduce drought-tolerant, deep-rooted tree species (e.g. Quercus ilex) to improve infiltration and stabilize soil.
- Seed perennial fibrous-rooted grasses like Brachypodium retusum and Stipa tenacissima, which slow runoff, trap sediment, and support organic matter build-up.
- Increase plant diversity with native shrubs and groundcovers to stabilize bare areas and restore ecosystem function (see Vegetation Plan; De Waard, 2026).

Runoff Diversion from Northern Slope

Although the measures described here, as well as those proposed for the terraced zones, contribute substantially to reducing runoff and improving water retention, they are not sufficient on their own to prevent damage to the access road and lower catchment zones during high-intensity rainfall events.

As an additional measure to reduce runoff, it is recommended to redirect a portion of the runoff from the northern slope (approx. 0.8 ha) toward a different location. This measure alone could reduce runoff volumes by over 300 m³.

However, the redirected water would discharge into the highest terrace of the lower terrace series, near the site entrance. This terrace must therefore be adapted to accommodate the additional volume (see 4.2.3 Measures for the Upper East Buffer Terraces).

To enable this redirection, a set of targeted measures is required at the base of the northern slope, specifically zone B, the northern edge of the central terrace.
This strip gently slopes westward at an angle of around 6°, and serves as the key zone where redirected flow must be stabilized, dispersed, and partially infiltrated before continuing downslope.
The following interventions are proposed:

- Stabilization of the existing gully
  A series of one-rock dams will be installed to slow the water flow, reduce erosive energy, prevent further incision, trap sediment, and allow infiltration.
  Given the slope of approximately 6°, structures should be spaced every 2.5 to 3 m.
- Restoration of vegetative cover
  Reestablishing sponge-like ground cover by planting drought-tolerant deep-rooting shrubs and trees and/or seeding fast-rooting, fibrous species such as Stipa tenacissima (esparto grass), which anchor the soil and reduce runoff.

- Flow redirection using a rock wingwall
  At the outlet of the gully, a rock wingwall will be constructed to deflect runoff safely toward the planned distribution area.
  Specifications: minimum wall height of 0.70 m, a bend radius of 6.1 m, and a total length of 7.6 m including the tail.
  The structure must be built from angular, erosion-resistant rock (30–60 cm in size), embedded into the subsoil, with toe protection and an emergency spillway on the inner curve to handle overflow safely.
- Sheet flow dispersal
  Immediately downstream of the wingwall, a low, wide spreader fan with a level sill spillway will be constructed to evenly disperse the redirected flow across the terrace surface, minimizing erosive force and supporting infiltration.

All technical details and design specifications for the above interventions are provided in Annex A.3: Specific Water Management Structures.

C t/m E. Terraces

This section builds upon the preceding interventions on the mountain slopes of the upper terrace and outlines specific measures to manage runoff, enhance infiltration, and prevent erosion on the terraced areas. All measures are aligned with the watershed-based, top-down strategy introduced earlier in this chapter and follow the natural flow dynamics of the landscape.

The terraced zones span a total area of approximately 1 hectare. The main terrace, situated between two mountain slopes, covers about 0.8 hectare. Two smaller terraces lie downslope, together adding around 0.2 hectare. The general gradient of the main terrace is approximately 5.5°, but runoff converges in the central section of the main terrace and to the west, where the slope steepens to nearly 9°. This concentrated flow generates erosive sheet runoff and increases the risk of gully formation and terrace degradation. Without intervention, this runoff would compromise both the terraces and the access road below.

To address these challenges, an integrated system of bunds, swales and step-down structures, and infiltration basins is proposed. These features are designed to slow down, spread, and sink surface water, improving infiltration capacity before the runoff reaches the lower terraces and ultimately the access road. Where no bunds or swales are placed, infiltration can be enhanced using keyline plowing or subsoiling. For this, ensure sufficient spacing for machinery access.

The combined measures also contribute to soil regeneration, vegetation recovery, and local water storage.

Recommended water retention measures terrace (area C to E (B already mentioned)):

1. Bunds around key trees (area C)
   - Curved half-moon bunds around existing and newly planted trees
   - Function: small-scale water capture and infiltration, supporting individual trees
2. Swales between bund rows (area C)
   - Placed on contour between tree rows or between tree rows
   - Function: intercept sheet flow, infiltrate moderate volumes, direct overflow downslope
3. Step-down structures in centre main terrace (area D)
   - Applied where slope steepens and runoff converges.
   - Use one-rock dams for shallow concentrated flow or log-and-rock step-downs for deeper flow sections.
   - Function: slow and sink runoff, reduce erosive force before entering pond zone

4. Sheet flow spreader between step-down structures and pond
    - Wide, level rock apron located at pont entry
    - Function: Evenly spread inflow before it reaches the pond
5. Emergency overflow from pond to lower terrace
    - Gently sloped rock-lined spillway starting at the pond's lowest edge at the norteast side, optionally reinforced with a series of Zuni bowls to to safely convey excess water to the terrace below (2.5m lower) and break the vertical drop, reduce velocity and prevent erosion.
    - Function: direct excess water safely to the lower terrace without causing gully erosion
6. Additional buffer capacity on lower terraces (area E)
    - On both smaller terraces, create ponds shaped like shallow basins or wadi-like depressions.
    - Function: Increase buffering capacity during extreme events

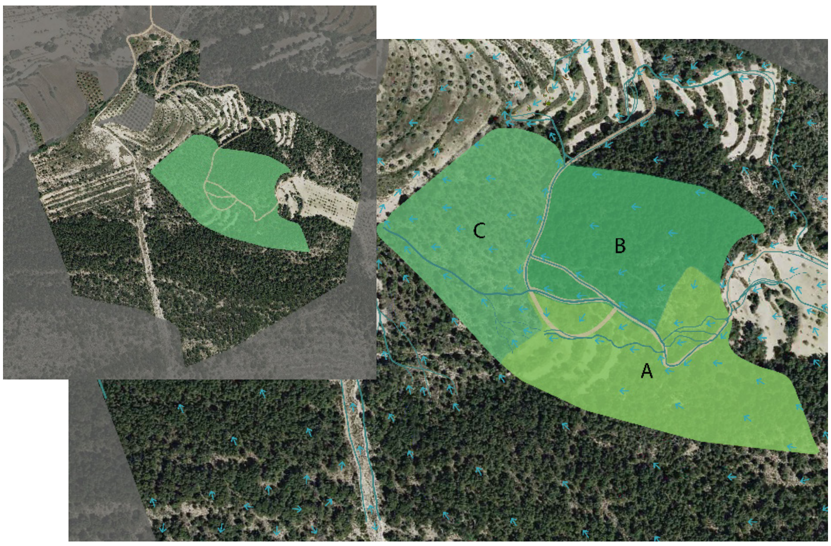
For construction details of bunds, swales, ponds and spillways, see Annex A.3.2. *"Structure-Specfic Guidelines and Specifications"*. The combined design capactity of the ponds should be 600 m^3, decreasing to 450 m^3 as vegetation density improves.

4.2.2 Measures for the Mid-Terrace Watershed with Access Route

Overview
This 4.6-hectare zone lies directly downslope (west) of the upper terrace and drains westward (see Section 4.2.1 for upstream measures). It consists primarily of sloped terrain, and also includes 0.5 hectares of degraded secondary terraces. A severely eroded access road to the upper terrace cuts through this watershed. At the lower end, a forested drainage corridor channels runoff toward the downstream area.
Erosion is severe on both the road and terraces due to significant runoff from the upper terrace. The road is especially vulnerable, as it lies directly in the natural drainage path and partly follows the main channel.

Figure 4.2.2-1 divides the watershed into zones (A–C) and shows key interventions.

Fig 4.2.2-1 Mid-Terrace Watershed Zones and Measures



Source: Ecology Academy

Highlights

- Hillside vegetation enriched for infiltration
- Road protection and lateral runoff control
- Flow slowed and dispersed at road bend
- Cross-drains redirect hillside runoff
- Redundant road returned to nature
- Runoff along terraces slowed to reduce erosion
- Pond on lowest terrace to buffer runoff and create a less dry habitat
- Moist runoff corridor downstream enriched with diversity of trees

Legend

A. Upper access road and adjacent slopes
B. West-draining forested hillside
C. Vegetated downstream drainage corridor

Characteristics

The watershed consists of three distinctive zones (A–C), each with distinct topographic and hydrological challenges:

- Zone A – Located directly below the upper terrace watershed (see 4.2.1), this area is most affected by erosion due to direct runoff from the upper terrace. It includes the upper section of the access road and the degraded secondary terraces. The adjacent slopes that drain onto these road and terraces are also part of this zone and are mostly covered with homogeneous Aleppo pine.
- Zone B – This forested hillside drains west and southwest into the lower section of the access road and then into Zone C. Several road segments in this area show severe erosion damage.
- Zone C – A downstream drainage corridor collecting runoff from Zones A and B. It is moderately forested, mainly with Aleppo pine and understory vegetation. Several erosion gullies channel water westward toward the lower catchment.

Runoff and Risk

Under the defined rainfall scenarios, total rain that falls on this watershed during storm events ranges from 1,842 m^3 (peak event, 20 min) to 6,909 m^3 (extreme event, 6 hrs). While runoff from the upper terrace is assumed to be largely mitigated by upstream interventions, substantial overland flow still originates within this watershed.

Given the existing vegetation cover on the slopes, estimated surface runoff from this subwatershed ranges from approximately 1,665 m^3 (peak event) to 4,607 m^3 (extreme event). This figure represents the cumulative runoff from this entire subwatershed, which would, without intervention, continue flowing toward the downstream catchment area.

Due to the site's topography, this runoff does not spread evenly but accumulates in specific areas, creating critical erosion hotspots, particularly on the access road and along the degraded terraces. The road lies directly in the natural drainage path, with parts of it overlapping the main channel flow, which greatly amplifies its vulnerability. Although the runoff at these locations stems from only a portion of the total watershed, the concentrated flow—combined with steep slopes and converging drainage lines—is sufficient to cause significant and recurrent damage.

Key pressure zones include:

- Upper and mid sections of the access road: Receive between 250–600 m^3 of runoff during heavy rainfall, originating from directly adjacent slopes with gradients ranging from 6° to 11°. This results in local peak discharges of up to 100 L/s.
- Mid-terraces: Subject to 300–800 m^3 of overland flow depending on upslope infiltration performance. Flow occurs on slopes ranging from 5° to 10°, with local discharge rates reaching up to 120 L/s.
- Lower road section at the transition between Zones B and C: Receives between 450–1,100 m^3 of dispersed runoff from the forested slopes of Zone B. A significant portion of this runoff converges at the crossing between the midsection and lower section of the access road, where the slope reaches 10°. Local discharge at this crossing can peak at approximately 120 L/s, also because of the channel flow on the road upstream.

These values highlight the need for site-specific interventions designed to reduce flow velocity, enhance infiltration, and redirect excess runoff safely downslope.

Objectives

- Reduce runoff concentration and erosion on acces road, terraces and and downstream zones;
- Improve infiltration and water retention on both slopes and terraces;
- Safely redirect excess flow to protect downstream areas.

Intervention Strategy

The following sections outline the proposed interventions. Since a vegetative improvement already occurs, this is taken as the reference. Table 4.2.2-2 shows the cumulative impact of the listed interventions on total runoff.

Table 4.2.2-2 Upper Terrace Runoff by Intervention Level and Rainfall Intensity

Code	Scenario name	Intensity		Peak	Heavy	Extreme
I	Vegetative improvement (baseline)	Reference scenario		1665	1878	4607
II	Vegetation densification	Medium		1560	1472	3679
III	Water harvesting structures	High		1166	701	1978
IV	Full ecological upgrade	Very high		959	255	993

Source: Ecology Academy

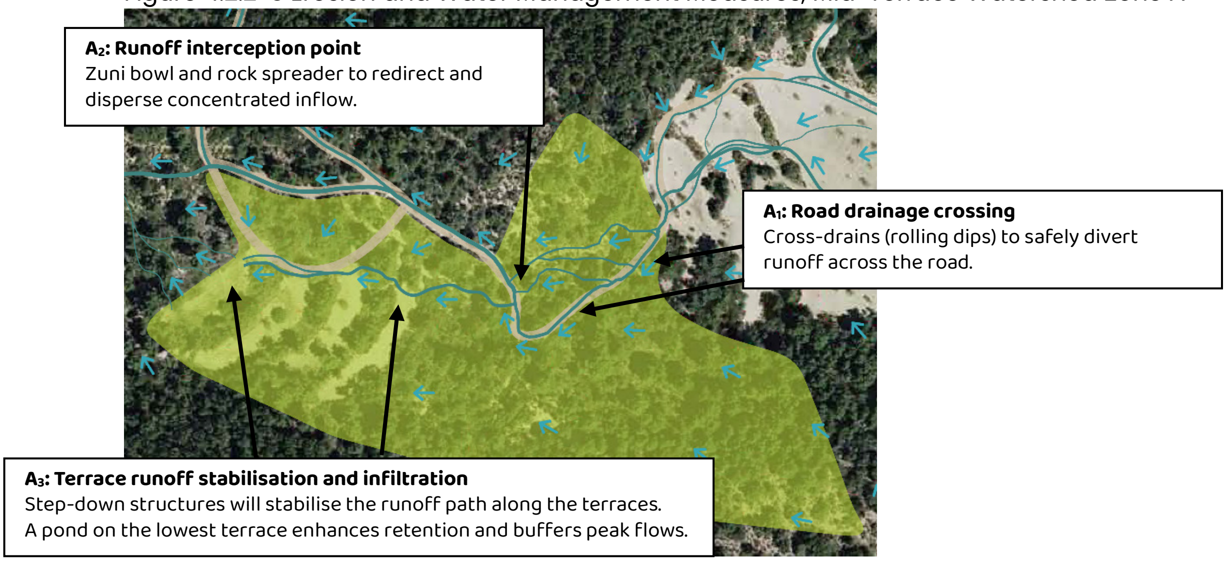
The resulting runoff under a full ecological upgrade flows downslope through multiple dispersed pathways, significantly reducing its erosive impact. Based on the watershed characteristics, zijn de maatregelen uitgewerkt per functional zone (zone A - C).

For construction details of earthworks mentioned below, see Annex A.3.2. “Structure-Specfic Guidelines and Specifications”. Voor geschikte native trees, shrubs and groundcovers to stabilise areas, het verbeteren van de vegetative cover and increase plant diversity (see Vegetation Plan; De Waard, 2026).

A. Upper Access Road and Adjacent Slopes

The interventions are illustrated in figure 4.2.2-3.

Figure 4.2.2-3 Erosion and Water Management Measures, Mid-Terrace Watershed Zone A



Source: Ecology Academy

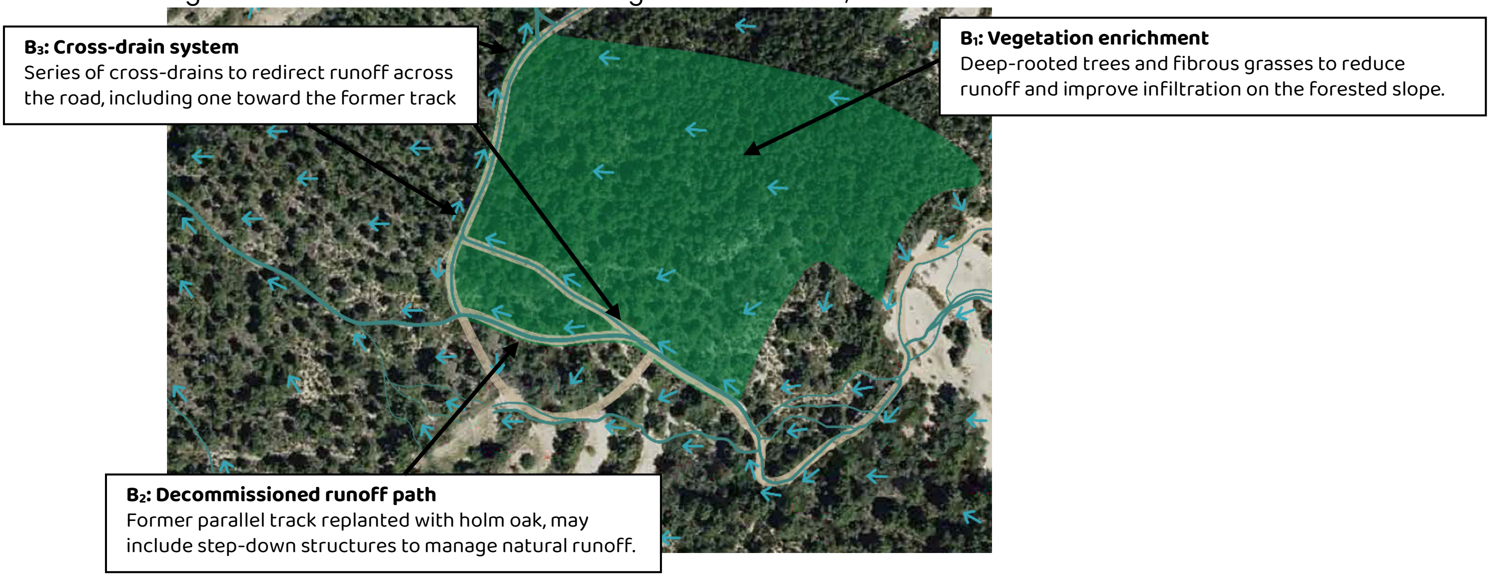
Measures:

- A_1: Protection of road surface and lateral drainage
  To minimize direct runoff to the road and prevent channelisation on the road the vegetative cover of the hills adjacent slopes that drain onto the road will be enhanced, by planting drought-tolerant, deep-rooted tree species seed perennial fibrous-rooted grasses.
  To protect the road, rolling dips or cross-drains will be installed at regular intervals to divert runoff laterally, with spacing depending on slope and designated discharge points. Given the road length (approx. 115 m) and slope gradients (ranging from 5° to 11°), around seven cross drains will be required.
  Discharge spots from the hill must be protected with vegetation or rock energy dissipaters to prevent erosion.
- A_2: Runoff interception and redirection at inner road bend
  At the inner bend where runoff concentrates, a Zuni bowl will be constructed to dissipate energy and and slow the flow before it reaches the road.
  Along the road'ss edge, a curved rock spreader will be placed or a broken spreader if space is limited. This structure transforms the current channel flow into sheet flow.
  To safely redirect the dispersed water across the road, rolling dips will be placed slightly downslope. At the downhill edge of each rolling dip, a stone-lined dip will be added to prevent scour and erosion at the discharge point.
- The runoff path that currently flows alongside and over the terraces will be stabilised with a series of step-down structures (e.g. one-rock dams, log-and-rock stepdowns) to reduce erosive force. Where feasible, runoff will be intercepted and diverted into swales across the terraces using grade control structures such as Zuni bowls. On the lowest terrace, a small pond will be constructed to buffer peak flows and improve moisture retention. An emergency overflow will direct excess water to a sheet flow spreader before it continues downslope.

B. West-Draining Forested Hillside

The interventions are illustrated in figure 4.2.2-4.

Figure 4.2.2-4 Erosion and Water Management Measures, Mid-Terrace Watershed Zone B



Source: Ecology Academy

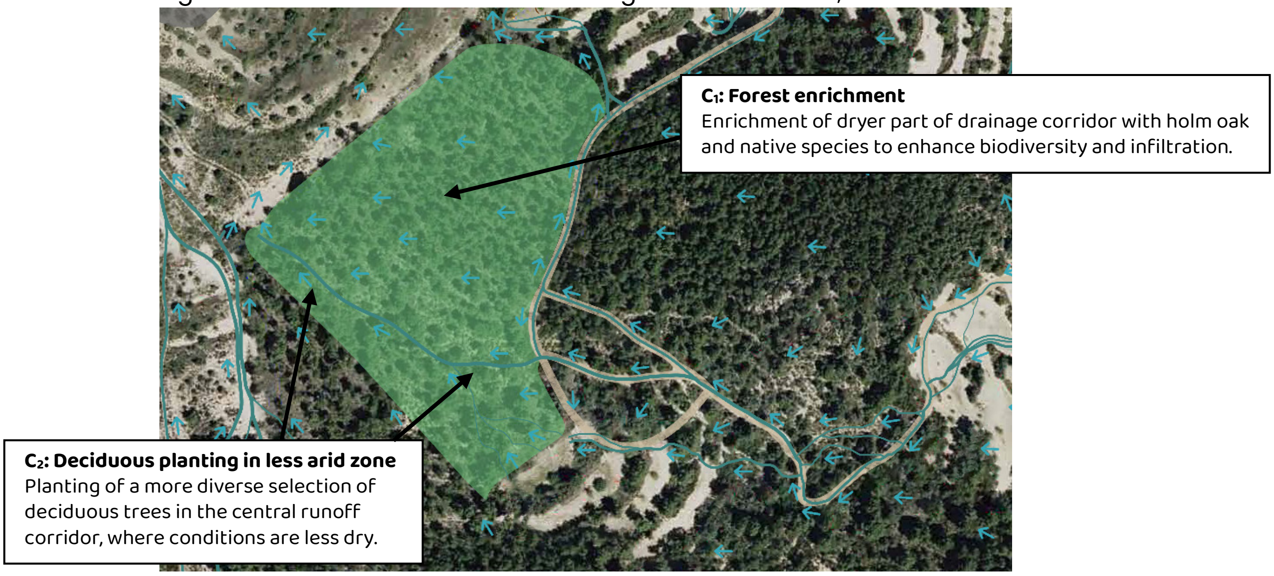
Measures:

- B_1: As this zone mainly consist of forested hillside, it will be enriched with a more diverse vegetation, with a focus on species that reduce surface runoff and enhance infiltration. Priority will be given to deep-rooted trees and fibrous-rooted grasses that stabilize the soil and support hydrological recovery;
- B_2: A redundant parallel track of the access route to the upper terrace will be returned to nature. This path will be replanted, primarily with holm oak (Quercus ilex). As this track also serves as a natural runoff path, additional step-down structures (e.g. one-rock dams) may be required, depending on the effectiveness of upstream measures.
- B_3: Since the zone drains west and southwest into the lower section of the access road, around ten cross-drains will be installed to safely redirect runoff—one of which will divert water toward the former parallel track to reduce pressure on the main road. Discharge points will be reinforced where necessary.

C. Vegetated Downstream Drainage Corridor

The interventions are illustrated in the figure 4.2.2-5.

Figure 4.2.2-5 Erosion and Water Management Measures, Mid-Terrace Watershed Zone C



Source: Ecology Academy

Measures:

- C_1: Enrichment of the forested drainage corridor with holm oak and additional native species to increase biodiversity and enhance infiltration.
- C_2: Planting of moisture-loving tree species in the central runoff corridor to strengthen ecological function and support water retention (see Vegetation Plan; De Waard, 2026).

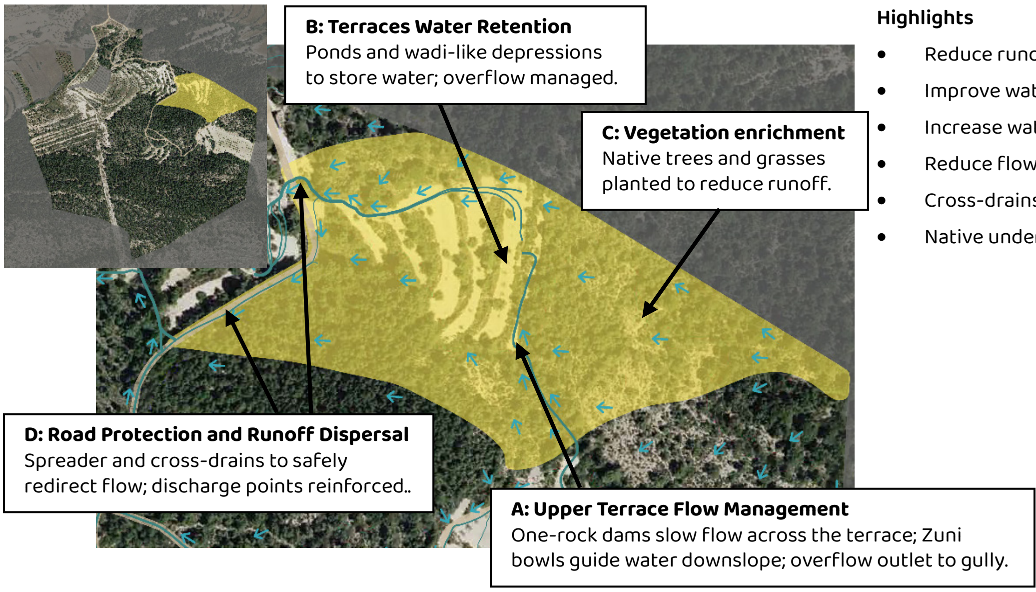
4.2.3 Measures for the Upper East Buffer Terraces

Overview

Located northwest of the upper terrace, this 2.1-hectare subwatershed receives runoff from the steep, Aleppo pine–covered slopes of the northern mountain (Cabaceta de Fabriqueta). Water flows downslope toward a set of terraces (0.4 ha) situated on terrain with an average slope of 9°, though gradients vary locally. A concentrated flow path has developed along the adjacent access path to these terraces/ This runoff crosses the the main access road near the cabin at the entrance, and drains into the terraces downstream, with a small portion diverting southward along the access road to a additional discharge point south of the road.
As part of the upstream intervention strategy, approximately 300 m³ of runoff from the northern slope of the upper terrace subwatershed will be redirected toward this area to reduce pressure and erosion upstream. This redirected flow enters the highest terrace in this subwatershed from the southeast and must be safely managed.

Figure 4.2.3-1 highlights the key interventions of this subwatershed.

Fig 4.2.3-1 Measures Upper East Buffer Terraces and hillside



Highlights

- Reduce runoff and erosion
- Improve water retention on slopes
- Increase water storage on terraces
- Reduce flow velocity in main drainage path
- Cross-drains and spreader protect the road
- Native underplanting on slopes to enhance infiltration

Source: Ecology Academy

Runoff and objectives

This subwatershed covers a surface area of 2.1 hectares, consisting of approximately 1.7 hectares of mountain slopes and 0.4 hectares of terraced land. Based on the defined rainfall scenarios, total rainfall during short-duration storm events is estimated as follows:

- Peak rainfall (20 min event): 856 m³
- Heavy rainfall (2 hr event): 1,284 m³
- Extreme rainfall (6 hr event): 3,211 m³

In addition, this area receives redirected runoff from the northern slope of the upper terrace subwatershed. This contribution is estimated at 220 to 450 m³, depending on rainfall intensity.

As a result, total runoff under current conditions (baseline) ranges from over 1,000 m³ during peak events to more than 3,600 m³ under extreme rainfall. The main access road to the upper terraces crosses the natural drainage path of a large part of this runoff, posing a significant risk to the road's stability and long-term functionality.

This results in the following objectives:

- Slow and spread runoff across terraces
- Increase infiltration and buffer capacity
- Prevent erosion along current concentrated flow paths

Intervention Strategy

This section outlines the proposed interventions. Table 4.2.3-2 summarizes the cumulative impact of all measures on total runoff.

Table 4.2.3-2 Upper Terrace Runoff by Intervention Level and Rainfall Intensity

Code	Scenario name	Intensity		Peak	Heavy	Extreme
B	Baseline	Reference scenario		1080	1312	3211
I	Basic vegetative improvement	Low		1031	1077	2672
II	Vegetation densification	Medium		993	939	2367
III	Water harvesting structures	High		442	98	865
IV	Full ecological upgrade	Very high		321	0	245

Source: Ecology Academy

Under the full ecological upgrade, runoff is significantly reduced and dispersed downslope via multiple controlled pathways, greatly lowering erosive force. To achieve this, the subwatershed requires a set of integrated earthworks to slow surface runoff, enhance infiltration at terrace level, and safely convey excess water downslope.

The following measures are proposed:

- **A: Upper Terrace Flow Management**
  On the upper terrace, water enters at the southeastern edge and drains halfway through an eroded guly toward the terrace below. This gully will be stabilised using Zuni bowls, which safely bridge the 2 m elevation drop and dissipate erosive energy (upstream, one-rock dams may be installed to slow inflow.). Near the outflow point to the lower terrace, a reinforced overflow channel will divert excess water into the main drainage channel next to the terraces. This channel will include one-rock dams and Zuni bowls at steeper sections to control flow speed between terraces and minimize erosion.
- **B: Terrace Adaptation for Water Retention**
  The lower terraces will be reshaped into shallow basins or wadi-like depressions, each with swale-like edges along their downslope borders. These structures temporarily store runoff and promote infiltration, creating a total buffer capacity of approximately 500 m³. Each terrace will receive inflow via controlled inlets from the adjacent channel. When terraces reach capacity, overflow is directed back to the main channel, which also functions as a shared outflow path.
- **C: Vegetation enrichment**
  Slopes surrounding the terraces and along the main access road will be planted with holm oak and other native species to improve infiltration. All terraces will be revegetated with a diversity of deep-rooted native trees and fibrous-rooted grasses to stabilize soil, intercept rainfall, and improve biodiversity and create more diverse habitats.
- **D: Runoff Dispersal and Road Protection**
  A rock spreader will be placed just upslope of the road to disperse concentrated inflow. At this location, some cross-drains will redirect the dispersed flow toward the terraces below. Additional cross-drains will be spaced further along the 130-meter road section to manage

general surface runoff. In total, six stone-lined cross-drains will be installed, with the final one discharging at the southern end of road in this subwatershed, at the lowest point of the road. Discharge points will be reinforced with vegetation or rock armouring to prevent erosion.

For construction specifications, see Annex A.3.2. For plant species and strategy, see Vegetation Plan (De Waard, 2026).

4.2.4 Measures for the Central-West Terraces and Inflow Zones

Overview

This 2.7-hectare subwatershed lies west of the site entrance, at a lower elevation. It consists of wide terraces with sparse vegetation, mainly scattered olive and fruit trees surrounded by bare soil, and some drought-tolerant plants along the edges. Although slopes are moderate, the area is hydrologically sensitive because it receives runoff from multiple upstream sources.

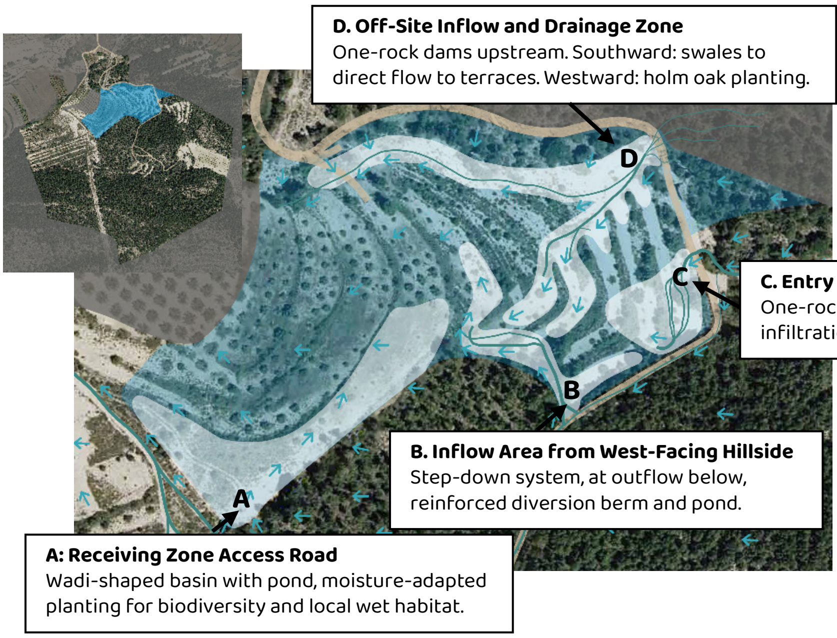
The terrace system receives:

- runon from upstream subwatersheds, concentrated at inflow points A, B and C (up to 1300 m³ after full ecological upgrade there).
- Off-site runoff from surrounding slopes, entering at point D.

The terrain offers multiple microclimatic opportunities for water harvesting and ecological enrichment, including pond construction and local wet zones.

Figure 4.2.4-1 shows the subwatershed layout, main inflow points (A–D), associated inflow areas (semi-transparent white), and key intervention zones.

Fig 4.2.4-1 Overview, Inflow Points and measures, Lower Central-West Terraces



Opportunities and highlights

- Area collects runoff from higher watersheds
- Key site to retain and infiltrate water
- Opportunities to create wet microhabitats
- Prevent unproductive outflow downslope
- Extend the local water cycle

Entrypoints run-on with catchment zones

A. Receiving zone access road upper terraces
B. Inflow Area West-facing Forested hillside
C. Entry zone from upper east terraces
D. Off-site inflow (primarily) with drainage zone

Source: Ecology Academy

Runoff and Risk
Based on the defined rainfall scenarios, total rainfall input on this subwatershed during storm events is estimated between 1,096 m3 (peak rainfall, 20 min event)) and 3,211 m3 (extreme rainfall (6 hr event).

In addition, this subwatershed collects runoff from upstream on-site zones and nearby off-site terrain. The main inflow points are:

A. Point A: inflow from the upper access road, mid terraces, and adjacent slopes
B. Point B: inflow from the west-facing forested hillside directly upslope
C. Point C: inflow from buffer terraces and hillside in the previous subwatershed
D. Point D: runoff from external terrain and the hill behind the cabin at the entrance

Even with a full ecological upgrade upstream, extreme rainfall could generate over 1,300 m³ of cumulative run-on from the site alone. Most of this would enter via Points A to C.

As a result, total runoff to downstream areas could range under current conditions (baseline) from over 2,000 m³ during peak events to around 5,000 m³ under extreme rainfall.

Without intervention, such inflows, together with the rainfall ter plekke, could cause severe erosion, and lead to uncontrolled runoff.

Objectives
Primary objective:

- Harvest, store, and infiltrate upstream and off-site runoff to enhance local moisture availability and prevent erosion.

Secondary objectives:

- Establish local wet zones for biodiversity enhancement;
- Reduce peak flows and increase infiltration across terraces;
- Stabilize and utilise inflow points through passive earthworks.

Intervention Strategy
A targeted set of earthworks is proposed per inflow zone, based on slope, flow intensity, and ecological opportunity. Measures include swales, bunds, ponds, Zuni bowls, and rock spreaders.

Table 4.2.4-2 shows the estimated runoff mitigation potential across rainfall intensities.

Table 4.2.4-2 Estimated Runoff by Intervention Level and Rainfall Intensity, Central-West Terraces

Code	Scenario name	Intensity		Peak	Heavy	Extreme
B	Baseline	Reference scenario		2350	2023	4926
I	Basic vegetative improvement	Low		2252	1545	3745
II	Vegetation densification	Medium		2149	1126	2762
III	Water harvesting structures	High		1384	279	1186
IV	Full ecological upgrade	Very high		1054	0	0

Source: Ecology Academy
N.B. Estimates based on full ecological upgrade watersheds upstream

The following measures are proposed, structured per inflow zone:

A. Western Inflow and Wet Zone (Entry Point A)

A. Create a broad wadi-shaped basin at the receiving terrace, with a deepened core for a seasonal pond near the forest edge to benefit from shade and reduced evaporation.
B. Use excavated soil to build a crescent of swales and bunds downslope (NW and NE) to capture overflow and additional runon from other places, and to improve soil moisture around planted vegetation.
C. Establish a locally wetter microhabitat by planting a more diverse mix of deep-rooted trees and moisture-adapted species, to support higher biodiversity. Where possible, reintroduce traditional rainfed grain plots with native arable flora around the wadi-shaped basin to restore habitat for birds of prey (see Vegetation Plan, De Waard, 2026).

B. Inflow Area from West-Facing Forested Hillside (Entry Point B)

- Install a series of step-down structures (e.g. Zuni bowls, one-rock dams) along the steep inflow path (around 10° slope) to slow runoff and reduce its erosive force. Include a swale diversion on the upper terrace with a bypass to return excess water to the step-down line.
- At the base below, build a final Zuni bowl and Integrate a reinforced curved diversion berm to direct inflow to the pond under normal conditions, while allowing excess water to overflow straight ahead during peak events. Add a rock spreader beyond this point to evenly distribute flow to the pond.
- At this outflow point, establish a pond with associated vegetation to create a moister microhabitat. Include a spillover outlet at the pond's lowest edge, lined with stone or vegetation, to safely release water when full.

C. Entry zone from Upper East Terraces

- Install one-rock dams and swales to slow runoff and enhance infiltration.
- Place bunds near existing and planned trees to improve soil moisture and support revegetation.
- Stabilize key inflow points to reduce erosion.

D. Off-site inflow (primarily) and drainage zone (Entry Point D)

- Stabilize the upper slope with one-rock dams to reduce flow speed (slope around 10°).
- The existing flow path splits into two branches, reinforce the split and:
    - Southward branch: apply one-rock dams in the channel, use swales to redirect water toward adjacent terraces, and place bunds near existing and planned trees to support infiltration.
    - Westward branch: slow runoff as much as possible using bunds and native vegetation, including holm oak (Quercus ilex subsp. ballota), to establish a tree-dominated zone.
- Along both branches, enhance infiltration by adding pitting (small shallow water-holding depressions) and plant native species to reduce surface flow and improve shading.

4.2.5 Measures for the Southern Mountain Ridge

Overview

This 12.3-hectare subwatershed covers the southern mountain ridge of the site and ranks among its highest zones, along with the upper terrace area. The terrain consists of a broad ridge and upper flank, from which the mountain slopes bend northwestward on one side and southward on the other.

A 10-meter-wide corridor runs north–south through the area, marking a gas pipeline route. This unvegetated gas utility strip acts as a drainage line during rainfall, with visible erosion and concentrated runoff.

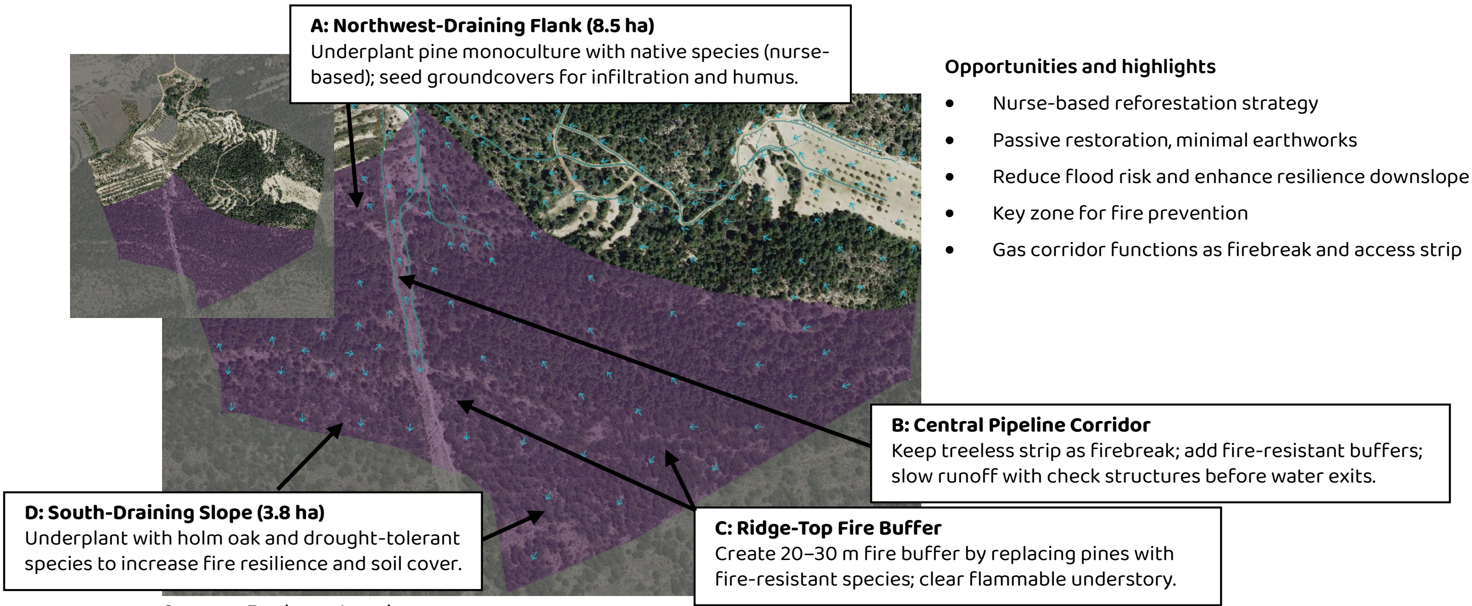
Drainage divides as follows:

- 8.5 hectares flow northwestward into lower areas of the site.
- 3.8 hectares discharge southward beyond the site boundary.

The zone is dominated by Pinus halepensis in a degraded monoculture, with low biodiversity and high vulnerability to wildfire, erosion, and drought. The shallow, rocky substrate shows minimal soil development, further limiting water retention and reducing ecological resilience.

Figure 4.2.5-1 highlights the key interventions of this subwatershed.

Fig 4.2.5-1 Measures Southern Mountain Ridge



Source: Ecology Academy

Runoff and Risk

Depending on storm intensity, rainfall input on this 12.3-hectare subwatershed ranges from approximately 4,920 m³ during a peak 20-minute event to 18,449 m³ during an extreme 6-hour event. Of this, only the northwest-draining section (8.5 ha) contributes to on-site runoff; the south-draining section (3.8 ha) drains off-site, but is also targeted for ecological improvement.

Within the northwest-draining section, surface runoff ranges from 3,153 m³ to 8,752 m³ under current vegetation and soil conditions. Due to steep slopes and shallow, rocky soils, runoff rapidly concentrates, with around 60% funneled through the central gas pipeline corridor, which acts as an incised drainage line. The remaining flow disperses northward, west of the pipeline corridor, onto the terraces in the subwatershed downslope.

This concentrated runoff poses significant risks, including:

- Accelerated erosion along the pipeline corridor;
- Uncontrolled inflow into downstream subwatershed;

At the same time, this runoff represents a valuable water source for the dry plains and lower terraces further downslope.

In addition, the Pinus halepensis monoculture and drought-prone conditions create high fire vulnerability, due to dense flammable vegetation, limited species diversity, and low vegetation moisture content.

Objectives

Primary objectives:

- Reduce erosion and concentrated runoff, especially along the central corridor;
- Retain and guide runoff to supply water to downstream zones;
- Increase vegetation diversity, canopy structure, and soil moisture retention;
- Lower fire risk through fire-resistant species, strategic fuel management, and improved soil moisture

Secondary objectives:

- Support long-term transition toward a more climate-resilient mixed forest;
- Use the gas corridor as a dual-purpose fire buffer and access strip;
- Improve connectivity and ecological value of the mountain ecosystem.

Intervention Strategy

Given the steep terrain and sensitive conditions, interventions rely solely on vegetation-based strategies, focusing on gradual forest conversion, passive water retention, and fire-adapted landscape design.

Table 4.2.5-2 shows the estimated runoff from the northwest-draining section and its mitigation potential across rainfall intensities; approximately 60% of this runoff is conveyed downslope via the central gas pipeline corridor.

Table 4.2.5-2 Estimated Runoff from Northwest-Draining Section by Intervention Level and Rainfall Intensity

Code	Scenario name	Intensity		Peak	Heavy	Extreme
B	Baseline	Reference scenario		3153	3789	8752
I	Basic vegetative improvement	Low		3018	3221	7866
II	Vegetation densification	Medium		2821	2482	6205
III	Water harvesting structures	High		2780	2399	6039
IV	Full ecological upgrade	Very high		2103	1443	2759

Source: Ecology Academy

Note: Very few earthworks are implemented in this zone; water management structures are limited to the main drainage channels along the gas pipeline corridor.

Measures are divided into functional zones.

A. Northwest-Draining Mountain Flank (8.5 ha)

- Gradually replace Pinus halepensis by underplanting drought-tolerant native species using a nurse-based approach that supports natural succession (see Vegetation Plan).
- Seed fast-establishing pioneer species in open zones to improve groundcover and water infiltration.
- Build up a humus layer over time through leaf litter, root mass, and improved groundcover diversity.

B. Central Pipeline Corridor

- Keep the corridor free of trees to serve as a fire break (cortafuegos) and preserve access for maintenance.
- Stabilize soil using low-fuel and low-growing groundcovers with shallow roots and install one-rock dams at key erosion points to prevent incision.
- Along both edges of this corridor, establish fire buffer zones of 5 m wide by replacing existing vegetation with fire-resistant, low-fuel native species (Vegetation Plan; De Waard, 2026)
- Install check dams and step-down structures to prevent incision and slow runoff, especially downslope, to ensure water enters the lower subwatershed with minimal erosive force.

C. Ridge-Top Fire Buffer

- Selectively clear flammabe undergrowth and deadwood to reduce fire risk.
- Establish a 20-30 m hybrid fire buffer zone by removing Pinus halepensis and replacing the strip with fire-resistant native species (Vegetation Plan; De Waard, 2026).

D. South-Draining Zone (3.8 ha)

- Transform the sparse pine forest into a more fire-resilient woodland by underplanting with holm oak (Quercus ilex subsp. ballota) and other species suited to hot, dry south-facing slopes.
- Focus on improving vegetation cover and ecological stability through natural succession and gradual canopy diversification.

4.2.6 Measures for the Northern Tip Subwatershed

Overview

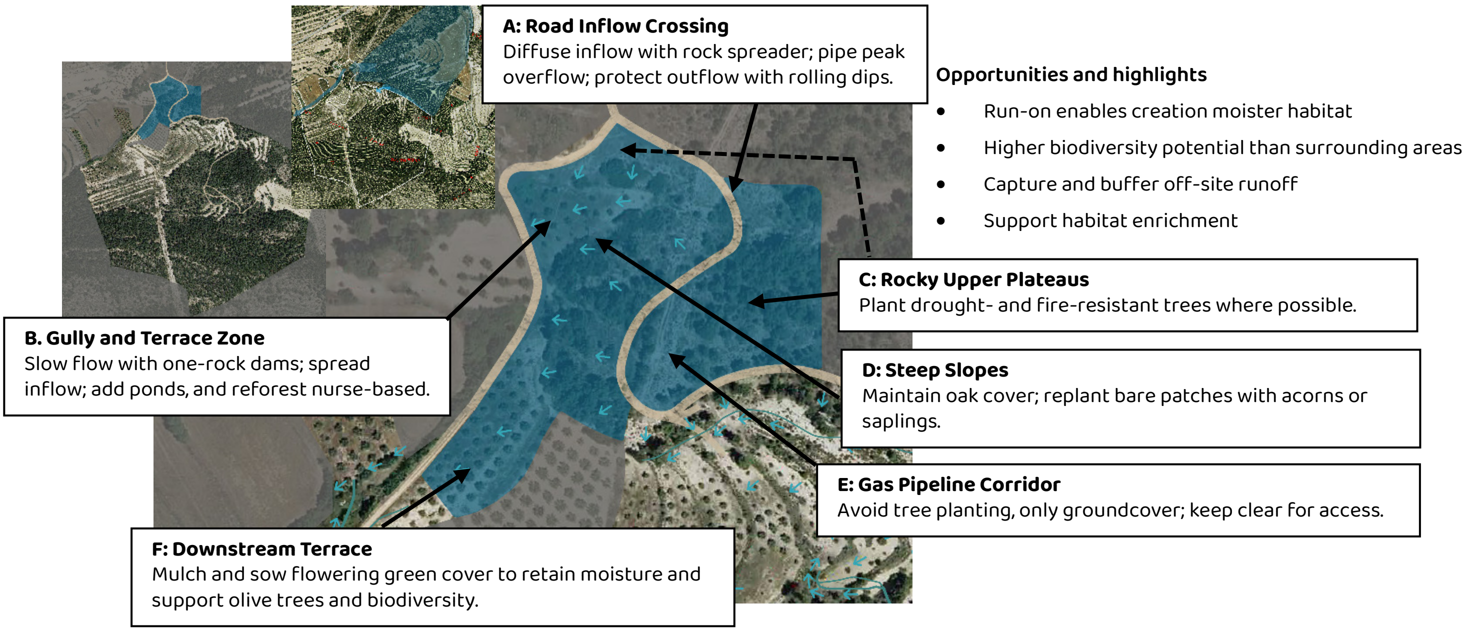
This 1.8-hectare subwatershed lies at the northern tip of the site and is characterised by a gully system draining into two elongated terraces. It receives concentrated off-site runoff from the northeast (Point A), which crosses an access road before entering the gully. The southern edge of the terraces forms a relatively moist microhabitat due to shade from adjacent forested slopes and regular runoff input.

Surrounding this core zone are steep slopes (4–6 m) vegetated with Quercus ilex subsp. ballota, while the dry, rocky upper plateaus are sparsely covered with isolated Aleppo pines. Downstream lies an additional terrace, sparsely planted with olive trees and lacking groundcover.

The increased water availability from off-site runoff creates opportunities to establish a moister habitat and enhance ecological diversity.

Figure 4.2.6-1 shows the runon entry point, gully system, terrace zone, and intervention areas.

Fig 4.2.6-1 Overview, entry point runon off-site and measures, Northern Tip Subwatershed



Source: Ecology Academy

Runoff and Risk

Short-duration rainfall input within this subwatershed ranges from approximately 700 m³ (peak 20-minute event) to 2,700 m³ (extreme 6-hour event), depending on storm intensity.

This subwatershed is unique in receiving substantial runon from off-site terrain, with up to 3,000 m³ of additional inflow entering from the northeast during extreme events (point A). This concentrated runoff crosses the access road and flows into the gully and terrace zone downslope.

Such inflow poses a significant erosion risk, particularly where the flow crosses the road and at terrace edges, especially near flow outflow points.

Objectives and Interventions

- Safely manage off-site runoff to protect road and terraces from erosion.
- Transform the terrace area into a water-retentive, ecologically enriched zone.
- Restore degraded plateaus through targeted reforestation with drought-tolerant native species.

Intervention Strategy

Table 4.2.6-2 presents the estimated runoff from this subwatershed under varying levels of ecological intervention.

Table 4.2.6-2 Estimated Runoff by Intervention Level and Rainfall Intensity – Northern Tip

Code	Scenario name	Intensity		Peak	Heavy	Extreme
B	Baseline	Reference scenario		675	855	2016
I	Basic vegetative improvement	Low		634	670	1634
II	Vegetation densification	Medium		577	442	1106
III	Water harvesting structures	High		570	412	1030
IV	Full ecological upgrade	Very high		311	0	0

Source: Ecology Academy

Figures exclude additional off-site runon, which requires supplementary measures such as ponds, depressions, and controlled overflow structures. These are included in the proposed measures below to maximise water retention and safely manage excess flow.

Proposed Measures by Zone:

A. Road Crossing at Off-site Inflow (Point A)

- Install a rock spreader upstream of the road to diffuse inflow.
- Add a buried pipe with elevated elbow inlet for peak overflow, reinforced with stone.
- Install rolling dips across the road; reinforce outflow with vegetation or rocks.

B. Gully and Terrace Zone (Main Ravine Axis)

- In the gully: place one-rock dams every 5 m to slow flow and support vegetative recovery.
- At gully end: install a rock spreader for even terrace inflow.
- On terraces:
  - Create small ponds or shallow depressions near the inflow point and where space and infiltration allow to increase buffer capacity; Include overflow outlets.
  - Add micro-wadis and bunds near trees; include overflows.
  - Reforest terrace margins with moisture-adapted native species using a nurse-based approach, starting from the southern edge.
  - Reinforce terrace walls and discharge points with rock and vegetative buffers, install Zuni bowls where needed.

C. Dry, Rocky Upper Plateaus (Surrounding the Gully and Terraces)

- Where possible, plant drought- and fire-resistant trees (e.g. ballota oaks) using nurse-based techniques and hydrogel to support initial establishment.

D. Steep Slopes Adjacent to Gully and Terraces

- Maintain existing oak cover; replant bare patches with acorns or saplings.

E. Gas Pipeline Corridor

- Avoid tree planting within the corridor.
- Use low-growing shrubs and groundcovers to stabilize soil while preserving access.

F. Additional Downstream Terrace

- Apply mulch and sow suitable green manures with native arable flora to protect the soil surface, reduce evaporation, and enhance biodiversity.
- Establish a flowering understory to support olive trees and attract pollinators.

4.2.7 Measures for NorthWest Terraces and Plain

Overview

Located in the northwest corner of the site, this 4.2-hectare subwatershed forms the lowest catchment area of the entire site. Despite receiving substantial runoff from surrounding zones, particularly from the southern mountain ridge, it remains arid and ecologically degraded. This is due to a deeply incised drainage line, formed along the gas pipeline corridor and continued by the northbound access road, which rapidly diverts water off-site. As a result, most runoff bypasses the terraces and degraded plain within this zone.

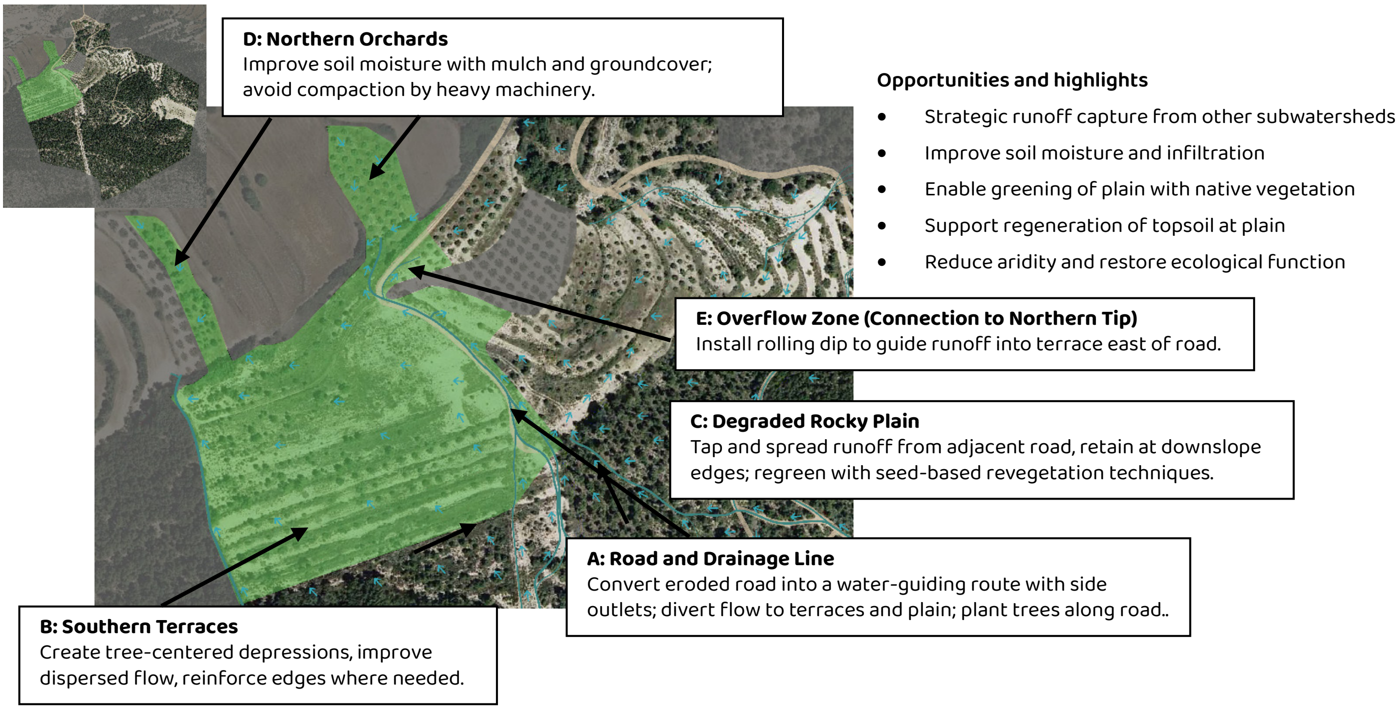
The area comprises:

- A central terrace system (1.2 ha) along the southern forested slope;
- A degraded, rocky plain (1.5 ha) with minimal vegetation;
- Two isolated northern orchards (0.5 ha total), located on lowland extensions at the edge of the site, sparsely planted with olive and almond trees, and partly supported by runoff from off-site terrain.

Runoff exits the site at the far western corner.

Figure 4.2.7-1 shows the subwatershed layout, the primary water flow direction along the lowest section (blue arrow), and the main intervention zones.

Fig 4.2.7-1 Overview and Measures Northwest Terraces and Plain



Source: Ecology Academy

Runoff and Risk

During peak rainfall events, this 4.2-hectare subwatershed receives between 1,700 m³ (peak 20-min event) and over 6,000 m³ (extreme 6-hr event) of direct rainfall input. In addition, it collects substantial off-site and upslope runon, up to 5,000 m³ under current conditions, most of which flows northward and is rapidly discharged via an eroded drainage channel that follows the north–south access road.

While the southern terraces benefit from dispersed inflow (1,000–3,500 m^3 during extreme events), which supports a moister microclimate, the majority of runoff bypasses the zone entirely. This concentrated outflow leads to:

- Accelerated erosion along the road and pipeline corridor;
- Uncontrolled water loss at the site's lower edge.

Yet this runoff presents a key opportunity: it could be redirected and captured to regenerate the degraded plain, and improve ecological function across the subwatershed.

Objectives and Interventions

- Capture and retain runoff from the forested ridge upstream to rehydrate the terraces and degraded plain.
- Restore vegetation and enhance infiltration through water harvesting and passive greening.
- Prevent further erosion and reduce uncontrolled runoff.

Intervention Strategy

Table 4.2.7-2 shows the estimated runoff generated within the 4.2-hectare subwatershed itself under different rainfall intensities and ecological intervention levels.

Table 4.2.7-2 Estimated Runoff by Intervention Level and Rainfall Intensity – Northwest Terraces and Plain

Code	Scenario name	Intensity		Peak	Heavy	Extreme
B	Baseline	Reference scenario		1588	2034	4817
I	Basic vegetative improvement	Low		1469	1475	3584
II	Vegetation densification	Medium		1355	1048	2619
III	Water harvesting structures	High		1001	215	866
IV	Full ecological upgrade	Very high		546	0	0

Source: Ecology Academy

In addition to on-site rainfall, this subwatershed receives additional runoff from upslope areas (not included in figures above). To address this, the proposed measures below include supplementary interventions to make full use of this inflow while avoiding erosion and water loss.

Proposed measures by zone:

A. Road and Central Drainage Line

- Convert the eroded road into a multifunctional water-guiding route by:
    - Filling and reinforcing the former gully on the road with compacted gravel or stabilised material.
    - Raising road edges to channel runoff and prevent uncontrolled overflow.
    - Adding stone-lined side openings (like curb cuts in urban sidewalks) at intervals to gradually divert water into adjacent infiltration areas.
      If more practical, the road can be lowered and levelled, using excess material to raise the edges.
- Guide diverted water from each point toward either:
    - Broad swales feeding the southern terraces, or
    - Rock spreaders dispersing sheet flow across the degraded plain.
- Plant trees (mainly Quercus ilex) along both sides of the road to create a shaded green corridor and enhance infiltration alongside the road..

B. Southern Terraces

- Create shallow tree-centered depressions or pits to retain runoff and enhance infiltration; use excavated soil where useful for bunds or elsewhere on the terrace.
- Preserve or improve dispersed flow across terraces; ensure overflow edges are level or shaped like natural spreaders and allow even water distribution to elsewhere.
- Reinforce erosion-prone terrace edges with fibrous-rooted vegetation and minor rockwork where needed.
- Tap runoff from the drainage channel at the far western edge of the subwatershed wherever possible.

C. Degraded Rocky Plain

- Maximise runoff capture from the southern mountain ridge and divert it toward this zone using broad sheet flow spreaders.
- place small swales or bunds only where needed and at the lower, downslope edges to retain water and slow final outflow.
- Tap runoff from the drainage channel at the far western edge of the subwatershed wherever possible.
- Restore vegetation through green manures, native annuals, via hydroseeding and/or seed balls.

D. Isolated northern orchards and adjacent area

- Enhance infiltration thorugh groundcover and mulch.
- Avoid heavy machinery to prevent soil compaction.

E. Overflow Zone (Connection to Northern Tip Subwatershed)

- Install a rolling dip at the road to direct residual runoff into the eastern olive terrace.
- Enrich the terrace with mulch, understory planting, and native flora to absorb water and enhance biodiversity (see F. Additional Downstream Terrace' in previous subwatershed).

5. Implementation and Monitoring

5.1 Phasing and Prioritisation

Implementation follows a top-down watershed approach, starting in the highest zones and moving downslope. Priority is given to interventions that reduce erosion, safeguard infrastructure, and retain water in the upper landscape.

Each subwatershed has a tailored set of measures, ordered by urgency and impact. Structural works (e.g. swales, ponds, spillways) are implemented first, followed by vegetation restoration.

For the project timeline, please refer to the Ecological Restoration Strategy (De Waard, 2026).

5.2 Monitoring and Evaluation

All structures are checked seasonally and after major rain events, especially for structural integrity (scour underneath and bypass on sides). Minor repairs (e.g. to bunds or one-rock dams) are expected and should be addressed quickly. Vegetation zones are monitored for plant survival, erosion signs, and water infiltration.

Adaptive management allows for adjustments based on field conditions and monitoring feedback.

Monitoring focuses on four key indicators:

- Runoff reduction and erosion control (visual and volumetric observation)
- Water retention (pond levels, infiltration rates)
- Vegetation establishment and survival
- Functionality of earthworks and safe overflows

Field notes, photo documentation, and annual assessments are used to track progress and guide future actions.

6. Conclusion and Recommendations

6.1 Summary of Findings

This Erosion and Water Management Plan lays the foundation for regenerating a 31.3-hectare degraded Mediterranean landscape into a resilient, water-retaining and biodiverse system. Through a rigorous watershed-based analysis and a top-down zoning approach, the plan demonstrates how ecological restoration can be achieved by reactivating the local water cycle.

Key findings include:

- Severe hydrological disruption: Historic land use and lack of infiltration have caused high-velocity runoff, deep erosion gullies, slope degradation, and disconnected vegetative structure. Peak runoff volumes during extreme events pose major risks to roads, terraces and downstream catchments.
- Systemic Water Loss and Soil Depletion: Most rainfall currently escapes as surface runoff, reducing infiltration, degrading soil structure, and hindering the ecological succession toward a more diverse and resilient vegetation cover.
- Strategic Zoning yields major gains: A phased, zone-specific strategy, starting at the highest elevation, maximizes hydrological effect while minimizing implementation risk. Runoff simulations show that full ecological upgrades can reduce surface flow by over 90% in critical zones.
- Multifunctional earthworks: A suite of simple, low-tech structures, such as swales, one-rock dams, and ponds, can slow, spread, and sink water across the landscape. These measures are reinforced by vegetative interventions using native, drought-resistant and fire-resilient species.
- Integrated fire and erosion Strategy: Combine fire-adapted and fire-resistant species with structural firebreaks and removal of dead biomass to reduce wildfire spread, enhance infiltration, and stabilise soils.
- Fire-adapted and fire-resistant planting, combined with structural firebreaks and removal of dead biomass will reduce wildfire spread while enhancing infiltration.
- Ecological Regeneration is achievable: With targeted interventions, the site can transition from an erosion-prone landscape dominated by Aleppo pines to a climate-resilient, ecologically functional system that retains water, supports biodiversity, buffers extremes, and regenerates itself over time.

In sum, this plan demonstrates that the site can be restored into a climate-resilient and biodiverse system with a functional and restored water cycle.

6.2 Recommendations

- Prioritise Top-Down Implementation: Begin with upper subwatersheds to maximise hydrological impact and reduce downslope pressure.
- Start Small, Monitor Closely: Focus initial efforts on key leverage points; use feedback from early interventions to refine strategies site-wide.
- Reinforce Earthworks with Vegetation: Ensure all water harvesting structures are seeded or planted immediately to stabilise soils and accelerate ecological recovery.
- Monitor and Adapt: Install infiltration and erosion measurement points; revise techniques based on performance.
- Engage local Community and share benefits: Involve local communities in implementation, maintenance, and agroforestry to strengthen long-term stewardship, create ownership, and generate ecological and economic returns.

6.3 Exploration of Long-Term Effects

If implemented fully, the proposed system will trigger a self-reinforcing process of ecological regeneration. Increased soil moisture and organic matter will improve plant survival, encourage wildlife return, and accelerate succession toward a semi-natural forest mosaic. Over time, this will:

- Reduce irrigation needs and external inputs.
- Restore natural flow regimes and groundwater recharge.
- Enhance ecosystem services such as pollination, shade, and carbon storage.
- Serve as a replicable model for landscape restoration in semi-arid Mediterranean zones.

Glossary of Terms

Channel flow	Concentrated distribution of runoff within distinct channels or drainages. Look for nick points, rills, gullies, bank cutting, different sediment sizes, vegetation growing within channels, exposed roots, high water marks such as lines of discoloration on rocks and vegetation and deposits of branches, twigs, grass, and other debris that indicate the high water mark from flooding.
Ephemeral flow	Short-lived surface runoff that appears only after rainfall and disappears within days (not more than 30 a year), not supported by groundwater.
Evapotranspiration	The amount of water evaporating and being transferred from plants to the atmosphere.
Keyline plowing	Small water channels (parallel to keyline) that intercept water, slow it and spread it across the landscape.
Mulching	Mulching is the application of porous materials such as compost, aged manure, straw, or wood chips onto the surface of the soil.
Precipitation Deficit	The amount of water lost through evapotranspiration minus the amount of precipitation received. It indicates a net water shortage in the system and is a key parameter in assessing drought stress and hydrological balance.
Sheet flow	The relatively even distribution of runoff water over the land surface, following the slope of the land downward, but not focused in distinct channels. Sheet flow occurs most likely after a large rainfall if you don't see distinct channels in an area of loping bare dirt.
Swale	Shallow trench laid out dead level along the land's contours
Waterbar	A water bar is a shallow, diagonal trench constructed across sloped roads or trails to divert surface runoff into a drainage area, thereby preventing erosion and road degradation. Regular maintenance is required to avoid clogging and ensure proper functioning.
Watershed	The total area of land from which water, sediments, and dissolved materials flow by gravity to a particular end point.

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Annexes

A.1 Contouring Techniques

Contouring the land

Contouring is a landscape design method that follows the natural elevation lines (contour lines) of a slope to manage water, reduce erosion, and improve soil health. All points on a contour line are at the same elevation. By designing planting rows, swales, or bunds along these lines, rainwater slows down, allowing it to infiltrate rather than run off. This helps to build topsoil, recharge groundwater, and support vegetation growth.

Key Concepts

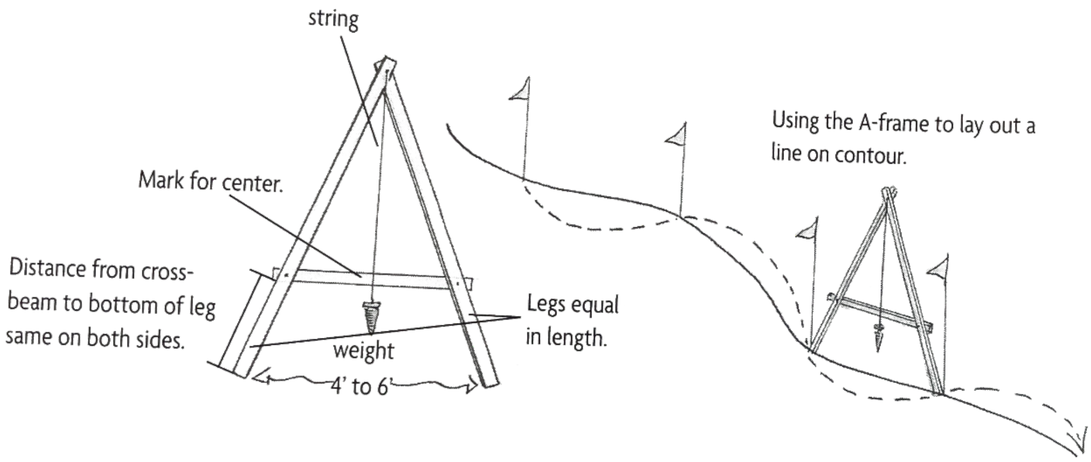
- A crucial reference point is the keypoint, the spot where the land transitions from steep to gentler slope. It marks the ideal location to begin laying out swales, ponds, or terraces because water slows naturally here.
- On steep or uneven terrain, it's critical to lay out multiple contour lines with minimal vertical spacing to prevent water from gaining speed between them. This layered approach reduces the risk of erosion.

Contour lines can be identified using simple tools like an A-frame level, water level (tubing), or a T-stick. After identifying a contour, mark points every few meters (e.g., 5–10 m), ensuring the line curves with the land.

How to lay out contour lines (using an A-frame level)

- Build an A-frame: Two legs of equal length joined at the top, with a string and weight (plumb line) hanging from the apex.
- Calibrate the center mark: Set the A-frame on level ground and mark where the string hangs; this is your level reference.
- Lay out the line: Move the A-frame step by step along the slope, pivoting one leg at a time and marking each level point with a flag or stick.
- Flag each point to create a continuous level contour.

Fig A.1-1 Contour Layout using A-Frame



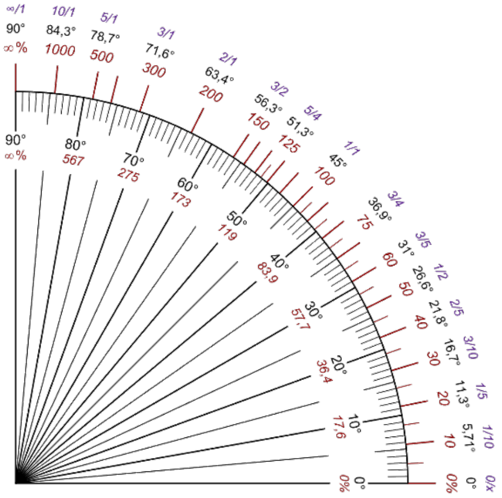
Source: Hemenway, 2009

Good Practice Tips

- Avoid sudden rises or dips in the line—contour lines must follow a consistent elevation.
- For irregular slopes, shorten segment length to improve accuracy.

The slope angle chart below helps translate slope percentages to degrees, aiding in correct contour placement and understanding water behavior on the terrain. Gentle slopes (e.g., <5%) are best for swale-based infiltration, while steeper areas may need terracing or more robust earthworks.

Fig A.1-2 Slope angle Chart



Contouring is a foundational technique in waterwise and regenerative design. When implemented correctly, it transforms erosion-prone slopes into productive, water-retentive, and biodiverse systems. While contour lines are initially passive reference lines, they provide the essential framework for strategic interventions such as planting, swales, or bunds—allowing water to slow down, spread out, and sink in where it's needed most.

A.2 Comparative Analysis of Swales and Keyline Plowing

Swales and keyline plowing are both contour-based techniques that enhance infiltration and manage runoff, but they differ significantly in construction, impact, and suitability.

- Swales are shallow trenches on contour lines that collect water in a concentrated zone for deep infiltration. They reshape the land permanently, making them better suited to degraded, arid, or reforestation areas.
- Keyline plowing spreads water uniformly with minimal disturbance, ideal for farming landscapes where land access and full productivity are priorities.

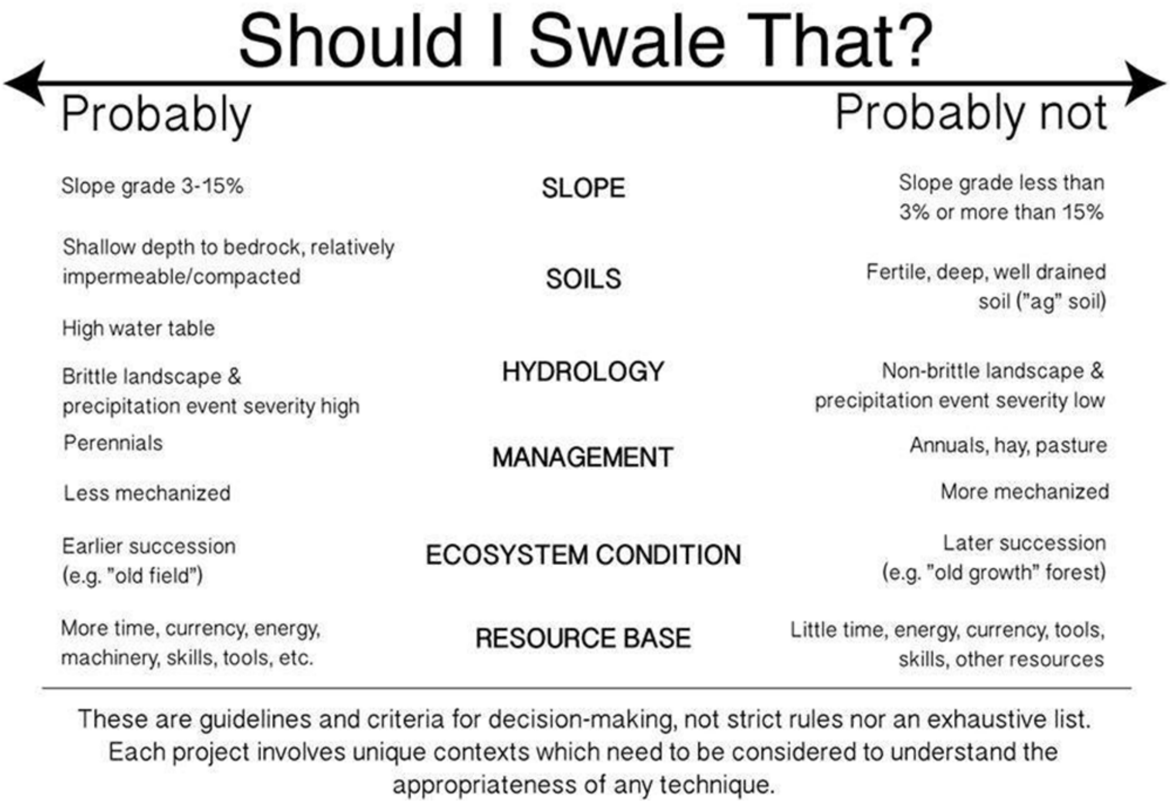
Key differences:

- Swales require excavation and berm building; keyline plowing only requires shallow furrows.
- Swales are better for bare slopes; keyline plowing is preferable in fertile, farmable terrain.
- Swales manage high-volume runoff; keyline systems prevent overland flow by distributing it early.

Where water must be captured and retained, swales are appropriate. Where water should be redirected, dispersed and absorbed broadly, keyline plowing is often preferable—particularly where machinery access is feasible. Keyline Plowing enhances water distribution with minimal soil disturbance; ideal for accessible agricultural lands but less effective in arid or degraded areas.

Flowchart A.2-1 helps determine whether swales are an appropriate solution for a site.

Fig A.2-1 Swale Suitability Decision Flowchart



Source: Ben Falk, Whole Systems Design

A.3 Specific Water Management Structures

A.3.1 General Construction Guidelines for Earthworks

- Seed structures during their construction to jumpstart revegetation
- Use a diverse mix of perennial and annual grasses that are native
- Construct rock structures only one rock high where possible
- Lay rocks tightly together and backfill structure with smaller aggregate if available
- Place progressively smaller aggregate as you move upstream
- Rock is laid on its narrow side (bookended) rather than it's wide bottom
- Rocks are placed length wise, parallel with the water's flow
- Rocks downstreamside are anchored or keyed into bedrock or goulders
- Maximise each rock's surface contact with each adjacent rock allowing no unnecessary gaps
- Set rocks to create a realtively even forma so the structure won't channelize and constrict flow
- Use angular rocks
- Size of rocks used is larger than about 90% of naturally deposited rock in the channel
- Take rock nearby and from more stable gradual slopes or falt areas located upslope.
- Rocks are alternated (no continuous water routes)
- Larger rocks are placed on the downstream side
- Remove topsoil and set aside, use the subsoil as the material for the earthworks. The topsoil can then be reapplied and planted immediately.

This will reduce erosion of the structures. Vegetation is regenerative, helps hold rock in place. With only one vertical course of rock, seed is much more likely to germinate. One rock structures are also more structurally sound. Limiting the height of structures reduces the force of the water flowing off their downstream side, which reduces potential erosion.

A.3.2 Structure-Specific Guidelines and Specifications

Some techniques described in literature—such as plug and spread, stepped pools, sediment trap, cross-vanes, or worm ditches—are context-specific or variations of the listed structures below. Where relevant, they have been integrated into the existing types; others are included separately.

A.3.2.1 Swales

Definition and Function

Swales, also referred to as berm-and-basin systems, level trenches, diversion berms, contour berms or boomerang berms, are shallow level-bottomed trenches dug along contour to capture, slow, and infiltrate surface runoff. The excavated soil is placed downslope to form a berm, which enhances the structure's water-holding capacity.

Swales function as key components in water harvesting systems, reducing erosion, recharging groundwater, and supporting vegetation. Two main functional types exist:

- Infiltration swales (berm and basin systems): laid out level on contour to retain water and maximize infiltration on-site.
- Diversion swales: built slightly off-contour to gradually convey excess water to safe discharge or infiltration points (ponds, etc.), allowing some infiltration along the way.

Although the intended function differs, the construction method is essentially the same,, consisting of a level trench with an adjacent berm.

Swales are best suited for slopes between 3% and 15% (1.7° to 8.5°). Below 3%, water flow may be insufficient, making keyline plowing or subsoiling more effective. Above 15%, swales risk overtopping and erosion; in such cases types of check dams, or even terracing, may be more appropriate. Stone lines are a more simple method which may also prove sufficient in some contexts.

Swales are transport systems, not reservoirs; they store water temporarily while encouraging infiltration along their length.

Construction Guidelines

Dimensions and Placement

- Trench (swale) dimensions:
  - Depth: 30–50 cm (mostly 35 cm), measured vertically from the original soil surface on the upslope side to the bottom of the trench.
  - Width (trench only): typically 60–100 cm, refers only to the excavated basin.
  - Berm width (base): 100–120 cm, typically slightly wider than the trench.
  - Berm height: typically equal to or slightly greater than the trench depth, measured from the downslope base.
  - Berm slope: stable angle of repose (around 33° to 45°) depending on soil
    Note: *Although both trench depth and berm height may be around 35 cm, they are measured from opposite sides of the slope. Therefore, the total vertical height difference between the trench bottom and berm crest is usually closer to 35–45 cm, not 70 cm.*
- Spacing specifications:
  - Spacing depends on slope and runoff volume. Indicative guidance:
    - On 5% slopes with moderate runoff, swales can be spaced 10–15 m apart.
    - On steeper slopes or areas with intense runoff, reduce spacing to 5–10 m.
  - The steeper or more degraded the slope, the closer the spacing
    Note: *Adapt spacing based on field observation and infiltration goals.*
- Soil requirements:
  - Berm material should contain at least 25-30% clay to improve structural integrity.
  - Avoid compacting the trench bottom; compaction reduces infiltration.
  - Berms may be lightly compacted for stability.
  - Mulch or plant the trench and berm to stabilize and encourage water absorption.
- Placement Strategy:
  - Place swales on contour, meaning the bottom of the trench is level across its length
  - Begin swale placement high in the landscape to intercept flow early.
  - Swales can be staggered or continuous; link them where possible so that overflow from one enters the next.
  - Avoid placing swales closer than 3 m to buildings or infrastructure.
  - Use swales in combination with boomerang bunds or tree planting where possible.
- Overflow Management:
  - Connect swales to form a cascading system: overflow from one feeds the next
  - Designate a spillway at the lowest point of eacht swale
  - Reinforce the overflow area with angular rock armor, gravel, or cobble
  - Use fibrous rooted vegetations (e.g. grasses) around outflows to prevent erosion.
  - Direct overflow into another swale, bund, or vegetated spillway.
  - Always stabilize outflow with vegetation or Zuni bowls if steep,

- Connect swales in series to form a cascading system where overflow from one feeds the next,
- Direct final overflow to safe discharge or infiltration point (e.g., pond).
- At high-flow zones, use rock armor or Zuni bowls to reduce erosive force.

Planning for overflows is crucial, especially if water is purposefully being directed to it. To control and utilize overflow water, the diversion swale should overflow to infiltration basins or terminate at a point in the landscape where land slope is gradual to level, vegetation is well established, and soil has not been greatly disturbed.

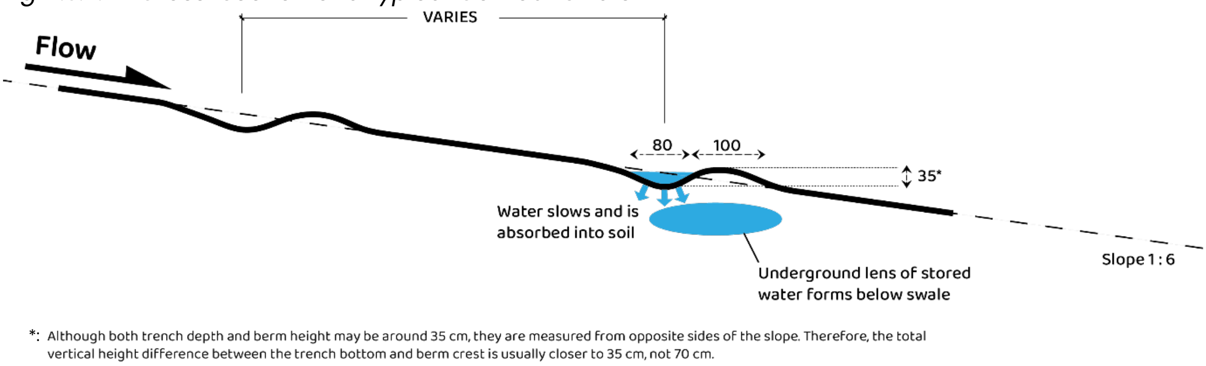
Integration with Landscape

- Place swales in combination with bunds and trees to form a water-harvesting cascade.
- When used in series, swales may fill sequentially.
- In central catchment areas, pair swales with one-rock dams or log-and-rock stepdowns.
- Blend swales into the landscape with mulch and planting.

Technical Drawing

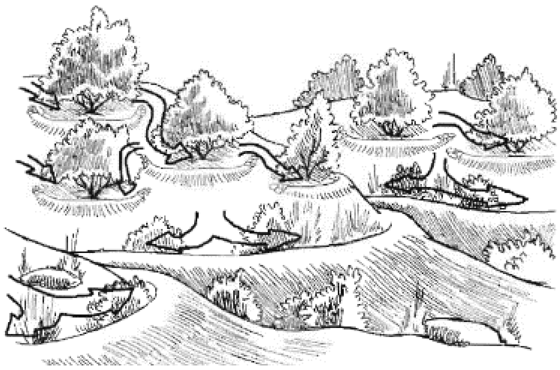
See drawing below for a typical swale cross-section. It shows the swale trench, berm, planted zone, and potential overflow path with reinforcement (rock or mulch).
A cross-sectional technical drawing is included below.

Fig A.3.2.1-1 Cross-Section of a typical Contour Swale



Source: Ecology Academy

Fig *A.3.2.1-2* A series of swales and bunds.



Source: Lancaster, 2019

A.3.2.2 Ground Preparation Techniques (Plowing Methods)

Overview

Soil preparation techniques such as keyline plowing, land imprinting, and subsoiling are designed to improve water infiltration, reduce runoff, and restore soil structure without turning the soil. Each method is suited to different conditions of slope, degradation, and land use intensity.

1. Keyline Plowing
   - Function: Redistributes surface runoff to improve infiltration and subsoil moisture retention, particularly across farming landscapes.
   - Method: Uses a subsoiler (e.g., Yeomans plow) to cut narrow furrows just off-contour, following the keyline pattern, starting from the keypoint. These shallow grooves gradually direct water laterally across the slope.
   - Best suited for: Slopes between 0–15% on moderately compacted soils, particularly in accessible agricultural areas where full tractor coverage is possible and required.
   - Typical Use: Permaculture design, agroforestry, pasture restoration, or dryland agriculture where water distribution is critical.

2. Land Imprinting
   - Function: Capture rainfall, organic matter, and seeds in micro-depressions; promote revegetation in arid or degraded areas without tilling.
   - Method: A land imprinter (heavy steel drum with angled teeth) is rolled across the surface to imprint the soil with microcatchments. No soil is turned; only imprinted. Creates thousands of small V-shaped depressions to catch water, seed, and organic matter; stimulating revegetation in degraded soils.
   - Best suited for: Flat to gently sloping (0–10%) degraded rangelands or bare soils with limited vegetative cover and poor structure.
   - Typical Use: Drylands, desert fringe zones, or barren slopes where conventional tillage is not possible or desirable.

3. Subsoiling (Deep Ripping)
   - Purpose: Break up compacted soil layers (hardpan) without turning the soil, to restore infiltration and improve root penetration.
   - Method: Deep vertical slits (typically 30–60 cm deep) are made in the soil using a subsoiler or ripper tine, deep ripper or chisel plow (e.g., paraplow), without inverting soil horizons.
   - Typical Use: Farmland, degraded soils, or restoration zones with compacted layers or poor drainage.

Each of these methods serves a distinct ecological function. Where water infiltration or distribution is a priority, subsoiling or Keyline plowing may be employed before constructing earthworks such as swales or bunds. Land imprinting is particularly valuable in harsh environments to kickstart natural regeneration processes.

For an overview of the characteristics, differences, and the most suitable conditions for each method, see table *A.3.2.2-1*.

Table A.3.2.2-1 Method Comparison: Swales, Keyline Plowing, Land Imprinting and Subsoiling

	Swales	Keyline Plowing	Land Imprinting	Subsoiling
Function	Capture and infiltrate runoff	Distribute water more evenly and improve infiltration	Create surface indentations to capture rainfall and seeds	Break compacted layers to improve infiltration
Slope Suitability	3–15%	0–15%	0–10%	0–15%
Soil Disturbance	High (earth moved to build berms)	Low (salllow subsoiling)	Low (surface dimpling)	Low to moderate (deep vertical cuts)
Typical Use	Drylands, Mediterranean degraded lands, agroforestry	Temperate climates, farming landscapes requiring machinery access	Arid and degraded lands with low rainfall	Compacted soils in farming or restoration contexts

Sources: Barnes Falk, William Horwath, Perkins,

A.3.2.3 Bunds

Definition and Function

Bunds are shallow, crescent-shaped earth berms built around trees or planting spots to harvest rainwater. They collect overland flow, reduce erosion, enhance infiltration, and create moist microclimates that support vegetation. They are highly effective on degraded slopes with low infiltration.

These structures go by many names, such as boomerang berms, boomerang bunds, fish-scale swales and smiling berms, but all refer to the same basic principle: capturing and infiltrating rainwater in small basins protected by a downslope berm.

In some cases, they are combined into berm-and-basin systems, where each unit is part of a cascade: overflow from one bund is directed into the next, allowing water to step down the slope gradually while reducing erosive force.

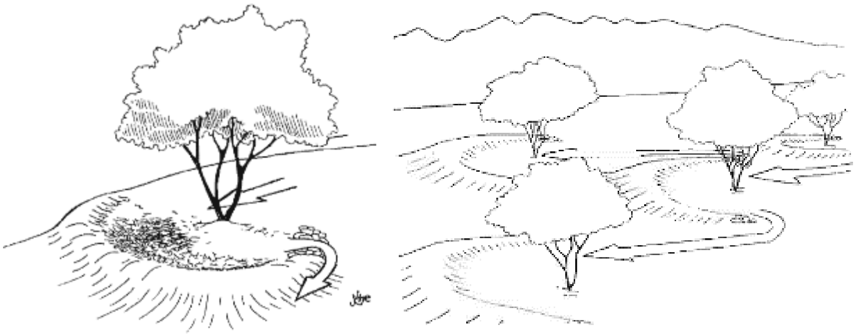
Construction Guidelines

- Shape: Crescent or horseshoe, open upslope (120–150° arc)
- Width (inner span): 2 – 4 meters, depending on tree size and runoff volume
- Height of berm: ~30 – 50 cm, compacted
- Berm thickness at base: 40–70 cm
- Slope suitability: Up to 10° (1:6); reinforce with stone if needed
- Soil: Use excavated inner soil to build berm; compact firmly
- Stabilisation: Apply mulch and plant drought-tolerant grasses on berm and edges
- Overflow: Sidearms slightly lower to allow safe spillover downslope

Placement Strategy

- Place bunds around key trees and seedlings where infiltration is most needed
- Space bunds irregularly to match vegetation layout and slope shape
- Combine with contour swales between rows to harvest sheet flow
- Align bunds perpendicular to slope; where bunds are linked, guide overflow from one to the next downslope

Fig A.3.2.3-1 A bund with an overflow spillway and a series of bunds



Source: Lancaster (2019)

A.3.2.4 Infiltration Basin

Definition and Function

An infiltration basin is a landscaped, shallow, level-bottomed depression dug into the ground to capture and infiltrate rainwater, runoff, and optionally greywater in the planting basin it creates. Its primary function is to retain water in place and allow it to soak into the soil, thereby reducing surface runoff, preventing erosion, recharging groundwater and creating moist microhabitats.

They differ from swales and bunds in both form and function as they are static depressions, typically used in flatter areas, designed to hold and soak water in place rather than direct it. Whereas bunds and swales are often applied on slopes, infiltration basins are best suited to flat or gently sloping terrain, where water would otherwise run off or pool inefficiently.

Infiltration basins are particularly effective in arid and semi-arid climates, where improving infiltration is key to vegetation establishment and long-term landscape restoration.

Construction Guidelines

- Shape: Circular or oval basin, gently concave.
- Depth: Typically 20–50 cm deep (deeper if needed for storage)
- Bottom: Flat, to promote even infiltration
- Edges: no berm if sunken basin, or slightly raised berm to retain water
- Diameter:
  - Small tree: 1.2–2 m
  - Large basin: up to 6–10 m
- Soil: Avoid compacting the basin bottom; loosen subsoil to enhance infiltration. Excavated soil may be used to build small berms around the edges or stabilise downhill slopes.
- Reinforcement (if needed): Use stone or geotextile where basin edges might erode or where runoff concentrates.
- Lining (optional): On highly permeable or sandy soils, infiltration can be slowed by compacting subsoil or lining with clayey material. Use of GCLs (geosynthetic clay liners) or bentonite clay may be considered if water retention is needed.
- Vegetation: Plant drought-tolerant, deep-rooted species inside and around the basin to stabilize soil and maximize water uptake

Placement Strategy

- Topography: Ideal for flat or gently sloping terrain (<3%)

- Tree planting: Use small sunken infiltration basins around newly planted trees. Align on contour and shape them as shallow bowls.
- Spacing: Tailored to planting design and hydrology; basins should not interfere with each other's overflow paths.
- Overflows: It is acceptable, and often beneficial, for overflow from one basin to gently spill into the next. However, basins should be spaced to avoid erosive flow paths and ensure water moves gradually and safely downslope.
- Connectivity: Basins can be placed in series or networks if overflow is guided with care.

In other words, for new trees, the planting area should be lower than the surrounding ground, see figure A.3.2.4-1. This could be done by constructing circular patches that are contoured like a dish (the center of the circle is a few inches lower than the edges, a gentle concavity that you can hardly see).

Figure A.3.2.4-1 Trees planted lower than the surrounding ground

Source: Lancaster, 2019

A.3.2.5 Spreader Drain

Definition and Function

A spreader drain—also called a media luna, sheet flow spreader, or level sill spillway—is a shallow, arc-shaped structure made of rock, designed to intercept concentrated runoff and distribute it laterally across the land. This slows the water, reduces erosion, spreads infiltration, and allows sediment to settle out before the water continues downslope.

The structure functions as a hybrid between a check dam and a diversion swale: it halts narrow, channelized flow and redistributes it laterally across the contour. This helps to settle sediment, recharge soil moisture, and reduce gully formation.

If the terrain is irregular or not ideal, a broken spreader could be constructed to diffuse and distribute flow evenly. These mini-spreader consists of a series of short, offset rock segments (also called dispersal fans) and mimic the function of a full spreader drain.

Sheet flow spreaders are particularly effective in drylands and semi-arid environments, where intense rainfall events generate sudden surges of runoff that would otherwise degrade the land. They are best suited for flatter terrain, gentle slopes, or below culverts and swales, where flow can be safely dispersed.

Note: These structures go by different names depending on the context. While the form may vary slightly, the core function—transforming erosive flow into non-destructive sheet flow—remains the same. They should always be sized and placed according to expected runoff volume.

Construction Guidelines

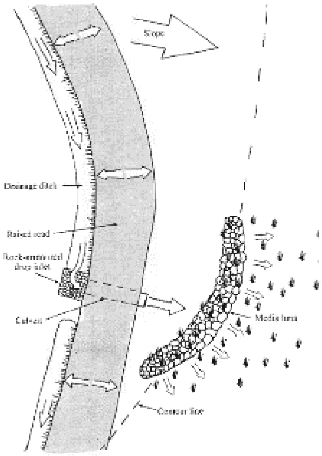
- Shape: Crescent or arc-shaped (120–150°), with ends angled slightly upslope to capture water and prevent bypass
- Height: Single course of rock, typically 20–40 cm high
- Length: Varies by site; the arc should be wide enough to span the drainage width
  Recommended length formula:
  Length (m) ≈ 0.5 × Q
  where Q = peak inflow in liters per second (L/s)
  This ensures the spreader can safely dissipate the volume into sheet flow without overflow or bypassing.
- Rock placement: Overlap rocks like shingles; at least half to three-quarters of each rock should be embedded in the soil. For flow paths with higher velocities, increase rock size and spreader width.
- Base preparation: Compact the ground; avoid building on on loose or unstable ground
- Vegetation: eed surrounding area with native grasses to enhance long-term infiltration and stability

Placement Strategy

- Place at locations where flow is concentrated but can be redirected safely
- Use where concentrated runoff exits a swale, culvert, or rundown and enters flatter terrain
- Ensure a level contour line across the full arc to allow even distribution
- May be used as a transition into infiltration zones, tree basins, or lowland terraces
- Avoid locating where incoming flow exceeds spreader capacity

Sheet flow spreaders require regular inspection after storms to check for undercutting or bypass flow.

Fig A.3.2.5-1 Spreader drain



Source: Lancaster, 2019

A.3.2.6 One-Rock Dam

Definition and Function

A one-rock dam is type of check dam, see box below for algemene uitleg check dams.

Box A.3.2.6-1 Check dams

Check dams are relatively small structures constructed within concentrated-flow areas to slow down concentrated water flow, reduce erosion, and encourage sediment deposition. They are the most effective when installed in series and when combined with other erosion and sediment control practices.
Siting and Design Considerations:

- The check dam should extend fully from bank to bank and be embedded at least 15 cm into the channel bed and sides for stability.
- Constructed from angular rock or sand/gravel bags.
- Dams should be spaced so the toe of the upstream dam equals the crest height of the downstream dam, flattening the channel slope.
- The center should be lower than the sides (weir shape); max height at center ≈ 60 cm, and at least 15 cm lower than edges.
- Most effective on slopes where velocity > 1.2 m/s (4 ft/s) during peak events.

A check dam does not stop, but rather slows the flow of water. As it does so, running water temporarily backs up behind the dam and spreads out over more of the drainage's surface before flowing through and over the dam. By slowing and spreading the flow of water, check dams help moisture infiltrate into the soil, reduce downstream flooding by moderating the peak flow of water, retain soil and organic matter on the upslope side of the dam, reduce erosion, and stabilize a section of the landscape.

There are several variations or types of check dams, including:

- One-Rock Dam
- Zuni Bowl (Rock lined plunge pool)
- Log and Rock Stepdowns
- Gabion (check dam in which rocks are held by a wire basket (niet behandeld))

Each serves the same basic function - slowing runoff and reducing erosion, while varying in form,

A one-rock dam is a low, permeable structure built with a single layer of rocks across a drainage or gully. Its main purpose is to slow down concentrated runoff, spread the flow, and encourage infiltration while trapping sediment and rebuilding soil. Running water and sediment slow down and back up behind the dam, spreading out over the channel bed before flowing through and over the dam.
One-rock dams are effective structures for slowing down concentrated flow in small channels and promoting infiltration and sediment deposition.

Construction guidelines

- Install dams perpendicular to flow direction, in areas with concentrated flow.
- Each dam consists of a single rock layer, typically 25-30 cm high.
- Build five or more parallel rows, tightly packed and staggered for strength.
- The first downslope rows should extend into the banks and be partially embedded for anchoring.
- Place the largest rocks on the downstream side to reinforce the dam.
- Ensure a flat top, with a slight dip in the center to guide controlled overflow.
- Upstream of the dam, water temporarily pools, spreads, and infiltrates.
- Seed during construction to accelerate up vegetation recovery.

Spacing guidelines

Spacing is based on the slope gradient and intended height of each dam. Rule of thumb:
Install the next dam upstream where the bottom of the previous pool touches the channel bed, or place a one-rock dam downstream every time the channel drops by approximately one stone height. In other words, maintain a vertical drops of roughly 25-30 cm between dams. Formula for spacing:

$$\Delta x = \frac{0,25}{\tan(\theta)}$$

Where:
θ is the slope angle in degrees
0.25 m is the height of one rock dam (vertical drop between dams)

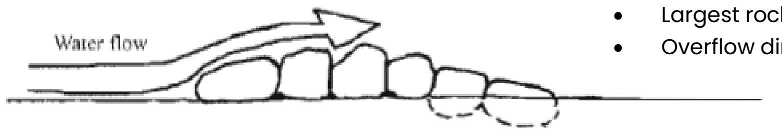
Example:
On a 6° slope, horizontal spacing is about 2,5-3 meters.

Technical drawing

Under development, for impression see figure 4.2.6-2: Cross-section of a one-rock dam

Fig 2.2.6-2 One-rock dam – cross-section and water flow

- Single layer, one rock high
- Tightly packed in five or more parallel rows.
- Anchored into banks
- Largest rocks downstream
- Overflow directed centrally



Key is to avoid a sudden elevation drop on the downstream side and to anchor the structure.

A.3.2.7 Zuni bowl (Rock lined plunge pool)

Definition and Function

A Zuni bowl, also known as a rock-lined plunge pool, is a water-harvesting and erosion-control structure designed to reduce the erosive force of water flowing over a headcut or down a steep section of a channel. It consists of a circular or oval basin lined with rock, placed at the base of a drop (headcut), often combined with a one-rock dam upstream to guide and slow the flow, as well downstream.

Its primary function is to capture fast-moving water, slow it down, and allow it to pool temporarily before continuing downstream in a non-erosive way. The rock lining dissipates the kinetic energy of falling water and protects the soil from scouring. Over time, Zuni bowls also promote sediment deposition and revegetation.

Zuni bowls differ from simpler check dams in that they combine vertical flow interruption (from headcuts or falls) with lateral spreading and energy dissipation in a plunge pool.

Placement Strategy

- Install at the base of headcuts or steep channel drops where water cascades.
- Use in combination with a one-rock dam upstream to gently direct flow over the structure.
- Avoid placing directly under extremely high or unstable falls; stabilise the slope above first.

- Ideal spacing between bowls: place the next bowl 3 or 4 times the height of the headcut downstream.
- Align so that overflow is central, while side arms curve gently up the channel banks (like an arch).

Construction Guidelines

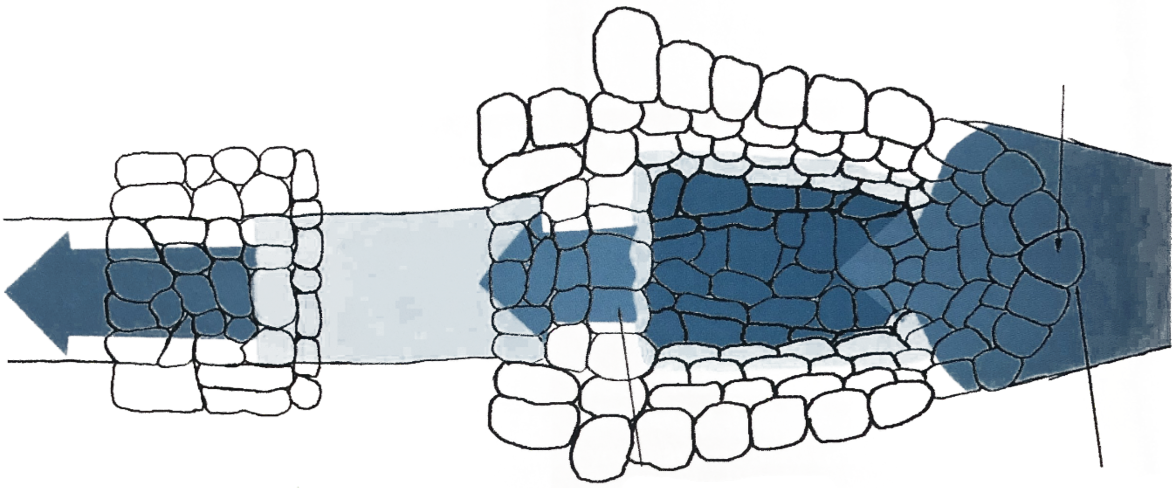
Excavation and shaping:
- Excavate a basin downstream of the headcut to a depth of half the vertical drop (headcut height).
- Shape the sides to taper back gradually toward the top (see dotted lines in Fig. 10.23A).

Rock lining:
- Place the largest rocks at the base of the bowl and along the lower pour-over edge.
- Construct side arms that arch upward and outward toward the channel banks (Fig. 10.24).
- Rock should be embedded in soil so that at least ¾ of each rock is buried, forming a compact and interlocking matrix.
- No vertical gaps: avoid stacking rocks directly on top of each other; overlap for stability.

Overflow and stability:
- The uppermost rock course (pour-over lip) must be the lowest point of the wall, to control overflow location.
- Install a splash apron—two rows of flat rock downstream—to further dissipate energy.
- Optional: seed surrounding area with native grasses and wildflowers to speed up soil recovery.

For impression see figure below: Topview of a zuni bowl

Fig A.3.2.7-1 Topview of a zuni bowl



Source: Modified by Ecology Academy, based on Lancaster, 2019

A.3.2.8 Redirective Rock Wingwall

Definition and Function

A redirective rock wingwall is a hydraulic structure built from stone to divert concentrated surface runoff away from vulnerable features such as roads, terraces, or erosion-prone zones. Installed where the flow must be redirected, it redirects the flow (typically 45–90°) and dissipates energy to reduce erosion risk and structural damage. Primary Functions:

- Channel flow redirection at predetermined angles
- Energy dissipation during high-flow events
- Prevention of headcut migration and channel incision
- Integration with natural drainage patterns

Height and Length Calculation

The wall must be high enough to resist overtopping. Use the following formulas:

Manning's Equation for Flow rate:

Q = (1/n) × A × R^(2/3) × S^(1/2)

Where:

Q = discharge (m^3/s) - how much water moves through the channel each second.

n = Manning's roughness coefficient - surface resistance factor

A = cross-sectional area of the flowing water (m^2) – the shape and size of the flow area

R = hydraulic radius (A/P) – where P is the length of the boundary in contact with water (bottom and sides). It describes the efficiency of the channel's shape

S = channel slope – the steepness of the channel

This formula calculates how much water flows through a channel per second. This is called the discharge, or flow rate, and is expressed in cubic meters per second (m^3/s). It shows how channel shape, slope, and roughness affect the amount of water the channel can carry.

Velocity Calculation:

V = Q/A - Used to determine flow energy and superelevation effects.

Where:

V = velocity (m/s) – how fast the water is flowing.

Q = flow rate (m^3/s) – how much water is flowing.

A = cross-sectional area of flow (m^2) – the "shape" through which the water is moving.

This calculates the average velocity of the water flowing through the channel, in other words, how fast it's moving.

Superelevation at Bends:

$\Delta h = V^2/(g \times R) \times \sin(\theta)$

Where:

Δh = additional water height at outside bend (m)

V = flow velocity (m/s)

g = gravitational acceleration (9,81 m/s^2)

R = bend radius (m) – how sharp the bend is: tighter curves (small R) create more superelevation

θ = deflection angle in radians (not degrees) – how much the flow turns: a 90° turn causes more elevation than a 45° turn

When water flows through a bend, it lifts slightly on the outer edge of the curve. This is called superelevation: the rise in water height at the outside of a bend due to centrifugal force.

When designing a redirective rock wingwall, it's not only the angle of deflection that matters, but also how gradually the flow is redirected. This is captured in the **bend radius**, which defines how sharp or gentle the turn is.

Rule of Thumb for Bend Radius
To reduce erosion and minimize superelevation, a gentler curve (larger radius) is preferred. Typical guidance minimum bend radius (R) for flow velocities > 1.2 m/s and peak discharges > 0.2 m^3/s is Minimum bend radius = 6 × channel width (for lower velocities 3 – 5 x channel width)

Total Wingwall Height:
$H_{total} = h_{normal} + \Delta h +$ freeboard
Where:
H_{normal} = depth of the water under uniform, straight, non-curved flow conditions (depth corresponding to a specific Q)
freeboard = 0,25 m

Total Wingwall length:
The total length of the wingwall includes:
1. Curved Deflection Section
Length depends on radius and angle:
$L_{curve} = R_{bend} \times \theta$
2. Downstream Extension (Tail Section)
To stabilize the redirected flow, the wingwall should extend downstream beyond the bend:
L_{tail} = 1,5–2,0 ×channel width

Example
Scenario:
is designing a redirective rock wingwall to divert peak runoff in a steep erosion-prone channel:

- Peak inflow: 300 m^3 over 20 minutes = 0.25 m^3/s
- Slope: 6° (≈ 10.5%)
- Channel width: 0,5 meter
- Soil type: Loam (Manning's n = 0.030)
- Deflection angle: 80°
- Required freeboard: 25 cm

Calculation
1. Normal Flow Depth (via Manning's Equation):
Calculated depth required to pass 0.25 m^3/s in a 0.5 m-wide trapezoidal channel:
$h_{normal} \approx 0.39$ m

2. Velocity:
V=Q/A ≈ 1.29 m/s

3. Superelevation at Bend:
With bend radius $R_{bend} \approx 5$ m: Superelevation $\Delta h \approx 0.038$ m
Beware: a shorter bend radius means higher superelevation.

4. Total Wall Height:
$H = h_{normal} + \Delta h$ + freeboard = $H \approx 0.39 + 0.038 + 0.25 = 0.68$ m
Recommended wall height: 0.70 m

5. Wingwall Length – Curved Section (Bend):
Based on hydraulic design, not just geometric width:
$L_{curve} = R_{bend} \times \theta$ rad $\approx 5 \times 1.22 = 6.1$ m

6. Straight Tail Section:
To stabilize exit flow: ≥ 2 × channel width, but better 1.5-2 m
Total Wingwall Length ≈ 6.1 m + 1.5 m = 7.6 m

Summary:
- Wall height: 0.70 m
- Bend length: 6.1 m
- Total wall length (incl. tail): 7.6 m

This design ensures safe redirection of high-energy runoff, allows for superelevation at the bend, and provides adequate freeboard and energy dissipation after the curve.

Construction Guidelines

Material Selection:
- Use angular, erosion-resistant rock (e.g. basalt or dense limestone)
- Base/key rocks: minimum size 30–60 cm diameter, depending on flow velocity and energy
- Filler/chinking stones: smaller rocks (10–30 cm) to stabilize voids and prevent erosion through the wall
- Avoid rounded, loose, or friable materials

Foundation Requirements:
- Depth: ≥ 0.5 × wall height, anchored below anticipated scour level
- Base width: ≥ 1.5 × wall height
- Base of the wall should consist of well-packed angular rock

Structural Design
- Wall thickness: ≥ 1.5 × wall height
- Add toes of 1 m on both sides for protection structure
- Extend 1.5–2 m downstream beyond deflection to stabilize redirected flow
- Locate on the outer curve, just before the intended redirection point

Vegetation guidelines:
- Place fast-rooting native grasses and drought-tolerant shrubs:
    - above the wall to slow runoff
    - at the toe and flanks of the wall to buffer splash and protect against scour
    - on adjacent bare soils disturbed by construction

Provide a controlled overtopping point, see next structure specific guidelines

A.3.2.9 Emergency Spillway

Construction Guidelines

Emergency spillways are critical safety features that allow controlled overflow during peak rainfall events, protecting water-harvesting structures from structural failure.

All spillways, regardless of their type or location, should:

- Be included in the design phase.
- Be positioned where overflow water can safely exit without causing erosion (location with low flow)
- Remain inactive during regular flow (only for overflow events).
- Be lined with erosion-resistant material (rock, gravel, turf reinforcement).
- Be connected to a safe, stabilised outlet path, e.g., a lower swale, basin, or energy-dissipating surface.
- Be kept clear of sediment, vegetation, and debris buildup.

Specific spillway requirements vary by structure type and flow energy, as described below.

1. Redirective Wingwalls
   - Location: On the inner curve, just before peak flow reaches the highest wall section.
   - Function: Relieves hydraulic pressure during peak flow and reduces risk of wall overtopping.
   - Design: A lowered outlet section (10–15 cm below wall crest), reinforced with large rocks.
2. Swales
   - Location: On the downslope side, at the lowest berm point.
   - Function: Prevents berm breach when swale fills beyond capacity.
   - Design: Gently sloped outlet notch (10–20 cm deep), lined with grass or gravel, sloped at 1–2%.
3. Retention Basins
   - Location: At the lowest rim of the bund, away from sensitive infrastructure.
   - Function: Ensures controlled overflow during storm events.
   - Design: Wide spillway (15–30 cm below bund crest), lined with rock, concrete, or turf reinforcement.

A.3.2.10 Cross Drains

Definition and Function

Cross drains are structures that redirect surface runoff across or off unpaved roads to prevent rill and gully erosion. They redirect water into safe discharge zones.
There are two main types used in combination:

- Rolling dips: Broad, shallow depressions graded into the road, with a low berm on the downslope side. They allow vehicles to pass while diverting runoff safely across the road.
- Stone-lined dips: Reinforced outflow zones at the downslope end of a rolling dip. They slow water and prevent erosion where runoff exits the road surface.
- Stone-lined dips are used to reinforce these structures, especially where flow volumes are high or road surfaces are erodible.

Together, they manage road runoff while minimizing maintenance and structural damage.

Construction Guidelines

- Placement: Every 10–30 m on unpaved roads, depending on slope (closer together on steep slopes, every 10–15 m on slopes > 8°).

- Rolling dip
    - shape: Broad, shallow, ~20 cm deep, angled slightly downhill (2–5%) toward discharge side and aligned with natural drainage.
    - Width: Should extend across the entire road width, preserving vehicle access.
- Stone-lined dip:
    - Width: equal to dip outlet
    - Depth: 10–20 cm below road edge
    - Material: angular stone (10–30 cm), embedded in compacted subsoil
- Outflow path: Must discharge onto a stable surface (vegetated, armored, or into a swale or Zuni bowl).
- Material: Compacted subsoil; optionally armoured with stone for erosion resistance.

Avoid pipe-based cross drains wherever possible—these often clog and become failure points.

A.3.2.11 Ponds

Definition and Function

A pond (or infiltration basin) is a strategically excavated or bermed water body that captures and temporarily stores runoff for infiltration, flood control, and ecosystem restoration. Ponds can be stand-alone features or part of a cascading system. Use upslope of ponds a sheetflow spreader for evenly spread inflow, reduce erosion and sediment reduction.

Siting Considerations

Ponds should be placed with sufficient buffer from terrace edges and other landscape features. A minimum distance of 5–7 meters is recommended from the terrace drop-off to allow space for:

- Safe spillway routes toward lower zones (e.g. Zuni bowls)
- Spreaders or infiltration paths upstream
- Maintenance and structural stability

Avoid placing ponds directly on terrace edges or near unstable soils.

Depth and Height Calculation

Unlike geometrically regular basins, natural ponds have sloped banks that influence their effective volume. The water volume of a circular pond can be estimated using the formula for a truncated cone (frustum), suitable for basins with gently sloping sides:

Volume (m^3) = $(1/3) \times \pi \times h \times (r_1^2 + r_1 \cdot r_2 + r_2^2)$

Where:

h = vertical depth of the pond

r_1 = radius of water surface

r_2 = radius of pond bottom

For estimating the volume of an **oval** (elliptical) pond, use the following formula:

$V = \pi \cdot \times a \cdot \times b \cdot \times d \cdot \times 0.7$

Where:

a = half of the pond's length (semi-major axis)

b = half of the pond's width (semi-minor axis)

d = average pond depth

0.7 = shape correction factor for sloped sides and irregular bottom contours

$\pi = 3.1416$

This approximation accounts for gently sloping side walls and an uneven base, making it more realistic for natural earth ponds than the simple box or cylinder model.

For ***irregular shapes***, or when ponds follow terrain contours, use GIS tools or average depth x average surface area x 0.6 - 0.8 as a rule of thumb (depending on side slope).

Recommended pond bank slope:
- 1:3 (18–20°) for cut-and-fill ponds
- 1:4 (14–15°) for highly erosive soils or where vegetation must establish rapidly

Avoid vertical sides; these increase collapse and erosion risk.

Adjust area or depth as needed to meet buffer needs. Maintain at least 1.2–1.5 m depth in central parts for prolonged water retention and biodiversity.

Dam Wall Construction

Dimensions:
- The minimum crest width of the dam should be:
- 3 m for machine access
- Or at least 0.3 × dam height, whichever is greater

Side slopes:
- Upstream face (inner side of the dam, water-retaining face): 3:1
- Downstream face (outer side of the dam, dry side): 2.5:1 or flatter
  Standard earth dam slopes are typically 2.5:1 to 3:1 (horizontal : vertical) for stability and erosion resistance. Steeper slopes of 2:1 or even 1.5:1 are possible if high-quality clay is available, and if additional reinforcement is provided, such as retaining walls, geotextile fabrics, or well-anchored vegetation. In such cases, regular inspection and maintenance become essential.

Soil Requirements:
- Use high-quality cohesive clay with at least 40% clay content. Soil must be moist but not wet or dry during compaction. Stones >5 cm (lemon-sized) must be excluded.

Construction sequence:
1. Remove and store topsoil
2. Build up dam with best clay core material in thin layers (max. 15–20 cm)
3. Ensure adequate soil compactionfor each layer
4. Restore topsoil on outer surface
5. Seed dam with fibrous-rooted species (e.g. grasses, bamboo)

Avoid any plants with taproots on dam walls, as they can compromise integrity and to prevent root leakage.

Lining (If Required)

If local subsoil is unsuitable for sealing (e.g. sandy or rocky), consider lining options:
- Option A: Natural clay lining (minimum 30–40 cm thick)
- Option B: Bentonite clay (e.g. powdered or granulated bentonite mixed into native soil at 5–10%)
- Option C: Geosynthetic Clay Liners (GCLs) like Bentomat – used where impermeability is essential.
  Cover GCLs with 30 cm topsoil and moisten well to activate swelling.

Note: Avoid installing pipes through dam walls. If unavoidable, this becomes the weakest point of the structure. Install only with adequate sealing, collars, and compacted surrounds using bentonite. Prefer surface spillways.

Overflow and Spillway

Every pond must include a robust overflow spillway to prevent overtopping during heavy rainfall. Pipes should be avoided unless unavoidable.

Preferred options:

- Vegetated overflow channel (shallow broad spillway lined with erosion-resistant vegetation)
- Rock-armored weir or spread basin
- Position on undisturbed ground and direct toward stable lower catchments or infiltration structures.

Design tip: The spillway crest should sit at least 30–50 cm below the dam crest and be able to handle the expected peak inflow (based on rainfall, runoff coefficient, and catchment size).

- Install rock-lined or grassed spillways at the lowest pond edge.
- Design for extreme rainfall events: overflow pipe at least 30 cm diameter, or open spillway with gentle slope (3–5%).
- Position spillways to direct water away from slopes and roads toward stable ground or infiltration features.

Colophon

Erosion and Water Management Plan

From Strategy to Implementation

Location

Region: Mountains of Ibi, Alicante, Spain. Altitude: 800 – 950 meters above sea level.
Coordinates: 38.642780, -0.590470 (generalized centroid).
Site Characteristics: A 31.3-hectare project area located in the Mediterranean mountain landscape of the Sierra de Ibi. The terrain consists of steep limestone slopes and degraded terraces, typical of the mountain ranges in the Alicante region.

Privacy & Data Access

To protect landowner privacy, specific parcel identifiers and exact boundary data have been omitted from this public report. The coordinates provided represent the general project vicinity. Detailed location data for research or verification purposes can be requested via https://ecology.academy.

Commissioned by

Prepared for a private client (anonymous for privacy reasons)

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For more information about our projects, research, and educational programmes, please visit our website.

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Commissioning & Execution

This Erosion and Water Management plan is commissioned by a private client (anonymous for privacy reasons) and outlines the strategy and measures for ecological restoration in the project area.