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European BECCA project: Solutions for safe reservoirs, integrated into their environment and respectful of biodiversity, as part of climate change adaptation in mountain areas

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Key words

reservoirs, climate change, BECCA, biodiversity, France, Italy

Abstract

The European BECCA project - Sustainable and Safe Basins for Ecology, designed for adaptation to Climate Change -, funded by Europe in Alcotra Program France-Italia, aims to address the design of safe reservoirs and the rehabilitation of existing reservoirs, adopting nature-based techniques. In particular, the BECCA project plans to defining technical recommendations for the design, construction, rehabilitation, and management of small and medium-sized, simple, low-cost dams that guarantee an adequate level of safety for downstream populations, protect against natural hazards, and pay close attention to environmental aspects. The article presents the BECCA project's proposals and operational

techniques for the naturalisation and revitalisation of reservoirs using nature-based solutions.

1. Introduction

In 2022, all climate indicators point to drier-than-average conditions across much of Europe. The combined effects of low rainfall and high temperatures have led to widespread and prolonged drought, affecting many sectors of society. The greatest rainfall deficits were recorded in the Alpine arc (Source: Copernicus), with significant consequences for the population and economy of mountain areas. The critical conditions observed in 2022 merely confirm the trend of climate change over recent decades, with serious impacts on Alpine regions: severe summer droughts detrimental to agriculture in rural mountain areas, to drinking water supplies, to fire risk and to hydroelectric power generation; and, with rising temperatures, a lack of snow in winter detrimental to winter sports resorts.

Local stakeholders are working to identify effective and sustainable solutions for adapting to climate change. One of the preferred solutions involves the creation of small and medium-sized reservoirs to store water, thereby helping mountain regions adapt to climate change by ensuring the continuation of economic activities and an adequate level of safety for the communities living there. However, regulatory authorities in France and Italy have noted that these small and medium-sized reservoirs in the cross-border region can pose risks to the population in the event of failure, as well as having significant impacts on the environment and natural habitats. The European BECCA project – Sustainable and Safe Basins for Ecology, designed for Adaptation to Climate Change – funded by the European Interreg ALCOTRA France-Italy programme, aims to provide the tools to design safe reservoirs and rehabilitate existing ones using nature-based techniques. This project focuses specifically on the France–Italy cross-border area corresponding to the Alpine arc, but the results are widely applicable beyond this to other mountainous or foothill regions. In particular, the BECCA project aims to establish technical recommendations for the design, construction, rehabilitation and management of small and medium-sized, simple, low-cost reservoirs that guarantee an adequate level of safety for downstream populations, protect against natural hazards, and place a strong emphasis on environmental considerations by taking the environment into account from the design stage to minimise ecological impacts. Through a guidance

document [1], the BECCA project proposes operational techniques for the naturalisation and revitalisation of reservoirs using nature-based solutions.

2. Mountain and high-altitude water retention in the face of climate challenges

The mountainous regions of the French and Italian Alps are undergoing significant climate change, with increasingly dry summers and winters with less snowfall. These changes have a direct impact on water resources, agriculture, and hydroelectric power generation and artificial snow production. Against this backdrop, hillside and high-altitude reservoirs, which enable water to be stored during periods of high flow, regulate floods and safeguard local areas, have been developed.

The BECCA project proposes, in a guidance document [1], a technical framework for the design, construction and rehabilitation of these structures, incorporating nature-based solutions (NBS), whilst balancing safety, hydraulic performance, protection against natural hazards, sustainability and respect for the environment, using local materials and ensuring careful integration into the landscape.

This new set of recommendations [1] updates the current technical reference that established best practice [4], and also incorporates recommendations on the risks and impacts of high-altitude reservoirs [5].

3. Site selection – Design principles

The first step in designing a hillside or high-altitude reservoir is to select a site that minimises environmental impacts. The **Avoid > Reduce > Offset** principle guides this approach: the aim is to avoid outstanding environments, wetlands or protected natural habitats, to reduce the ecological footprint by prioritising sites that have already been developed, and to offset any remaining impacts through ecological measures.

The chosen sites must allow for harmonious integration into the landscape. The cut-and-fill technique enables the re-use of excavated materials to construct the embankment, thereby reducing costs and the carbon footprint. This approach is particularly suited to mountainous areas, where access is often difficult and where material volumes must be optimised. The slopes of the embankments are designed to promote vegetation growth and stability, with gradients generally ranging from 1:3 to 1:2.5.

Particular attention is paid to creating ecological refuge zones covering at least 30% of the perimeter of the upstream embankments. These areas, maintained at a constant water level of 20 to 30 cm, allow the development of hydrophytic and helophytic plants, thus providing a permanent habitat for local wildlife, such as amphibians, insects, small mammals and birds. These features also help to stabilise the embankments and limit erosion.

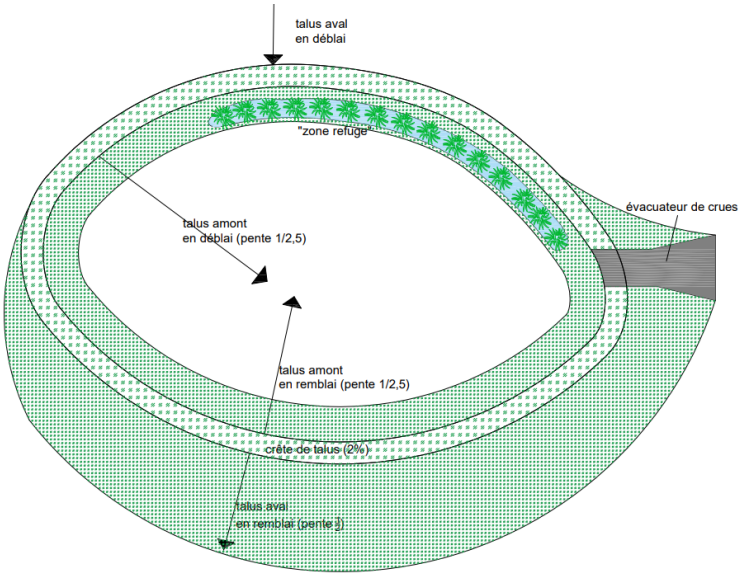


Fig. 1. *General development of a reservoir with a refuge area*

4. integration into the landscape

To ensure optimal integration into the landscape, and where the reservoir is situated within an existing vegetated environment, the BECCA guide recommends that the downstream slopes and the crest of the reservoir be vegetated with local herbaceous species that are resistant to the site's climatic conditions. This vegetation provides protection against surface erosion whilst improving the visual and environmental integration of the structure.
However, planting shrubs or trees on the embankments is prohibited, as their root systems could compromise the stability of the slopes, degrade the DEG by penetrating deeply into the embankment, and make it more difficult to inspect the dams. On the cuttings overlooking the reservoir or in its vicinity, vegetation may include woody plants or small trees as it is not in direct contact with the waterproofing or structural elements.
The guide recommends the use of local materials to minimise visual and ecological impact: rock and soil excavated on site are reused for riprap and embankments, thereby reducing costs and the carbon footprint. Concrete is avoided as far as possible, except for critical hydraulic structures such as spillways.



Fig. 2. *An example of successful integration into the landscape – Manigod Resort (74 – France)*

5. Ecological integration : creating functional ecosystems for biodiversity

The environmental integration of retention basins is a key objective of the BECCA project [3]. It is based on the creation of ecological refuge areas for biodiversity, which are permanently flooded and promote the development of biodiversity. They are designed using self-filtering materials to allow plants to grow whilst protecting the waterproofing system. These refuge zones allow water to be retained and are not drained, in order to preserve aquatic ecosystems. The drainage system is designed to prevent the accumulation of stagnant water whilst allowing for natural renewal.

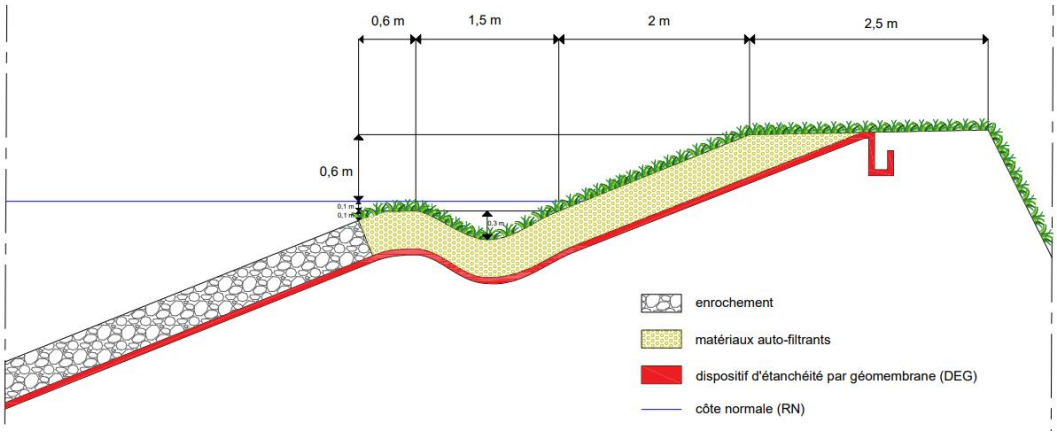


Fig. 3. *Design of a refuge zone in the upper part of the reservoir*

The creation of functional habitats represents an innovation compared to the traditional design of reservoirs. The BECCA guide recommends that these areas be maintained at a constant water level of 20 to 30 cm, thereby allowing the growth of hydrophytic and helophytic plants and providing a permanent habitat for local wildlife, such as amphibians, insects, small mammals and birds. These features also help to stabilise embankments and limit erosion, whilst promoting biodiversity.

Refuge zones are designed using self-filtering materials (0–125 mm), as detailed in the guide. These materials provide erosion resistance, retention of fine particles, support for plant growth and protection of the geomembrane waterproofing system (DEG). The presence of vegetation, which may include woody plants or small trees in the cut, helps prevent degradation of the self-filtering material layer. Filling the voids with fine materials creates a substrate that promotes root growth and stabilises the materials.

The design of the DEG must be adapted to the presence of ecological refuge zones. In particular, the positioning of the geogrid anchors must be carefully considered to avoid a 'drum effect' that could occur where the DEG is positioned over the ecological refuge zone. The guide proposes two solutions to counter this drum effect, whilst ensuring the continuity of the waterproofing provided by the geomembrane. These are based on the principle of increasing the load exerted on the geogrid in order to weigh down the entire DEG.

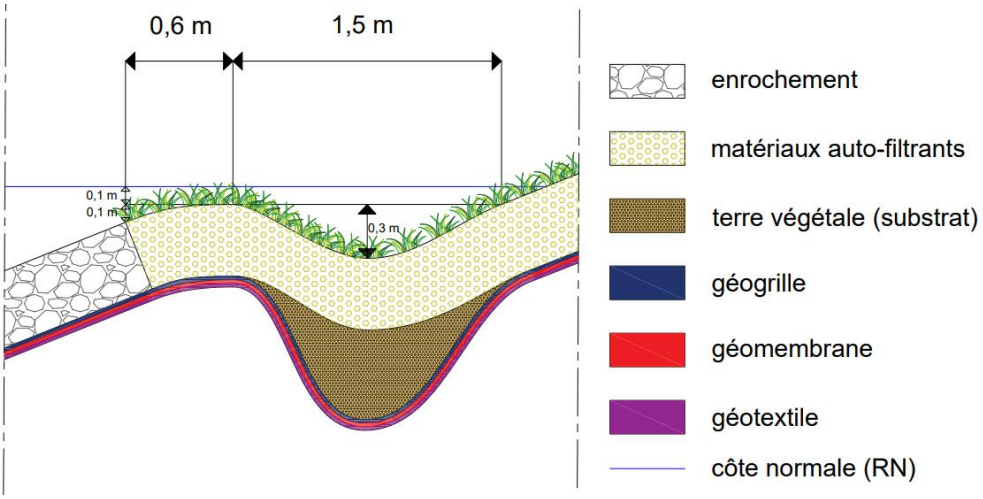


Fig. 4. *Cross-section of a narrow refuge zone with containment*

6. Assessment of the compatibility of vegetation with geomembrane waterproofing system

An experimental study was conducted to assess the interaction between the underground systems of helophyte plants (roots and rhizomes) and the waterproofing geomembranes used in high-altitude reservoirs [3]. The aim was to verify that the proposed vegetation techniques do not pose any additional risk to the safety of the structures. Experiments in rhizotrons (Figure 9) enabled the underground development of three helophyte species to be monitored over a 10-month period in contact with a 1.5 mm PVC-P geomembrane commonly used in reservoirs.

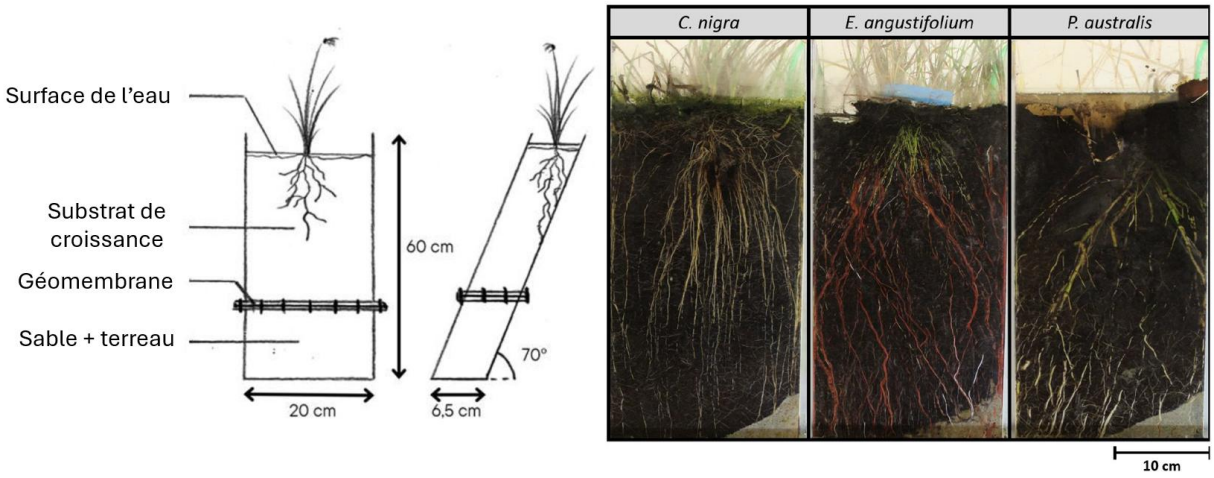


Fig. 5. *Diagram of the rhizotrons used in the experiment and photographs of the underground systems of the three helophyte species studied at the end of the experiment. The waterproof geomembrane is visible at the bottom of each photograph.*

Two of the species tested, Carex nigra and Eriophorum angustifolium, are already being used in experiments to revegetate reservoirs. A third species, Phragmites australis, known for the vigorous growth of its rhizomes and its ability to penetrate certain waterproofing materials, was included as a more aggressive reference species. Observations revealed contrasting root architectures depending on the species, with a theoretical degradation potential increasing from Carex nigra to Phragmites australis. Following a contact period of 100 to 200 days with the geomembrane, visual, mechanical and chemical analyses were carried out. The results showed no degradation of the geomembrane under the experimental conditions, including for Phragmites australis. This work suggests that the use of suitable herbaceous plants can be considered in reservoir revegetation projects, with no identified impact on the integrity of the waterproofing system.

7. Floating rafts to promote biodiversity in reservoirs with significant tidal ranges

A floating vegetated raft was assembled and installed in a high-altitude reservoir to encourage colonisation by the local biodiversity (Figure 6). Helophytes (Carex nigra and Eriophorum angustifolium covering an area of 21.2 m²) and hydrophytes (Chara globularis and Chara vulgaris covering an area of 5.4 m²), all collected from ponds and wetlands within a 10 km radius of the reservoir, were transplanted onto the raft. Thanks to a suitable anchoring system, the raft follows even the most extreme fluctuations in water level.



Fig. 6. *A floating plant-covered raft (A) with helophytes (B, D) and a submerged central section covered with hydrophytes (C).*

One year after planting, in the summer of 2025, the vast majority of plants had survived (Figures 5B and C); the helophytes showed significant root development. At the same time, monitoring of faunal biodiversity was established, including an inventory of amphibians, aquatic invertebrates, adult odonates and zooplankton. The macro-invertebrate communities on the raft are dominated by chironomids but also host other taxa such as odonate larvae. No amphibians have been observed on the raft to date. In 2026, the continuation of these monitoring activities will enable an assessment of the effectiveness of the structures in terms of fauna colonisation and their ability to provide resources and shelter.

8. Waterproofing and stability : solutions tailored to the challenges of mountain sites

In mountainous areas, soils are often poorly impermeable due to their heterogeneous grain size or high permeability. Foundations may also be at risk of dissolution, particularly in karst or gypsum-rich areas. To address these challenges, waterproofing solutions rely on geomembrane waterproofing systems, supplemented by nature-based solutions for better environmental integration.

Geomembrane waterproofing systems (GWS) are chosen for their high-performance waterproofing and durability. The presence of the geomembrane requires systematic covering to limit the impacts of UV radiation, frost or mechanical impacts. This covering can be achieved using various protective layers, topped with locally sourced riprap. A layer of topsoil may be incorporated into the riprap in the area above the normal operating level to improve landscape integration. For older high-altitude or hillside reservoirs that have not been lined (which is to be avoided), it is recommended that their banks be re-profiled to achieve gentler slopes, compatible with full lining. Finally, it is generally recommended to use light-coloured geomembranes (grey or beige) rather than black ones, to avoid excessively high temperatures that are detrimental to biodiversity.

Drainage is another key aspect of the design. Drains, constructed from local granular materials (gravel, sand), are combined with geotextiles to prevent clogging. Perimeter ditches at the foot of the embankment help to limit sediment inflow into the reservoir and preserve water quality.

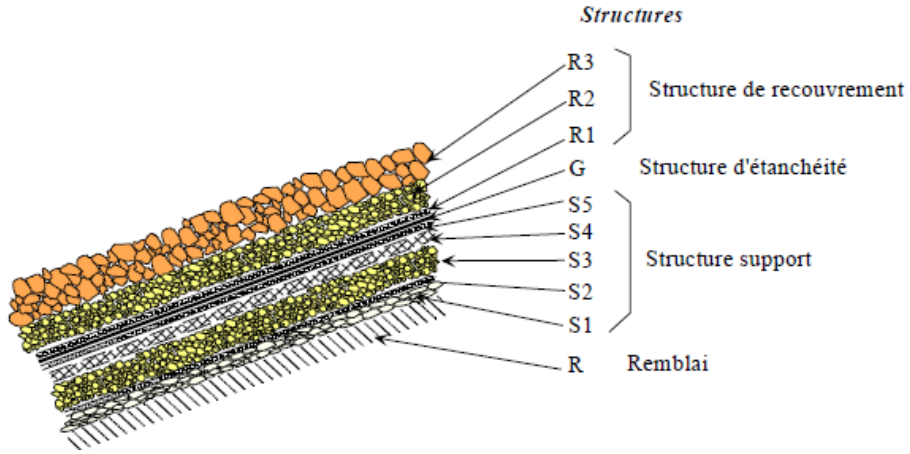


Fig. 7. *Example of a DEG with a support structure suitable for aggressive subgrade materials and semi-permeable backfill materials*

9. Engineering firms with multidisciplinary expertise in the design of retention systems integrated into their surroundings

The design of hillside and high-altitude reservoirs that are integrated into their surroundings requires two distinct areas of expertise:

- Dam engineering: this involves a wide range of interrelated skills, including the fundamentals of civil and geotechnical engineering, as well as hydrology, hydraulics, monitoring, etc.
- Ecological engineering: this involves skills relating to restoration ecology and engineering, often referred to as ecological engineering. The aim here is to restore and rehabilitate natural or man-made environments, drawing on natural processes.

10. Conclusions

The mountainous regions of the French and Italian Alps are undergoing significant climate change, with increasingly dry summers and winters with less snowfall. These changes have a direct impact on water resources, agriculture and hydroelectric power generation. In this context, hillside and high-altitude reservoirs can offer solutions to mitigate these socio-economic impacts, provided they meet certain criteria during their development.

In this context, the European BECCA project – Sustainable and Safe Basins for Ecology, designed for Adaptation to Climate Change – funded by the European Interreg ALCOTRA France-Italy programme, proposes design elements for safe reservoirs and the rehabilitation of existing reservoirs using nature-based techniques. This project focuses particularly on the France–Italy cross-border area corresponding to the Alpine arc, but the results are widely applicable beyond this to other mountainous or foothill regions.

As its main deliverable, the BECCA project presents, in a guide of recommendations [1], a technical framework for the design, construction and rehabilitation of these structures, incorporating nature-based solutions (NBS), whilst balancing safety, hydraulic performance, protection against natural hazards, sustainability and environmental respect, using local materials and ensuring careful integration into the landscape.

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