PHUSICOS

According to nature

Deliverable D2.4

Nature-based solutions implemented in PHUSICOS

Work Package 2 – Case study sites: large scale demonstrator sites and supporting concept cases

Deliverable Work Package Leader:
NGI

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Project information

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Summary

This final deliverable from WP2 in PHUSICOS summarizes all NBS interventions implemented in the project. The report also briefly describes the four proposed interventions which were not implemented and the reasons behind their cancellations. Many of the NBS measures were described in previous deliverables, D2.2 and D2.3 (both shortly summarized in the current report). These measures are also described in this report, but the ones proposed after D2.3 (month 36) are described in somewhat more detail. Where available detailed design of the measures is also included in the descriptions, as are photos of the implementation and/or completed measures. The report also contains a table with full overview of the NBS interventions with proposal and implementation dates, as well as total and PHUSICOS budgets.

The various PHUSICOS proposals were spread between three large-scale demonstrator case sites, the Serchio River Basin in Italy, the French and Spanish Pyrenees, and the Gudbrandsdalen valley in Norway, and two smaller concept cases, the experimental Kaunertal case in Austria and the more retrospective / learning case of the Isar River in Germany. A total of 15 approved proposals were implemented. Of these, 11 are physical interventions and 4 are educational, Living Lab, and dissemination activities. The physical NBS measures are mitigating a wide range of hazards, flooding, debris flows, erosion and shallow slope instability, rock fall, and snow avalanches.

At the demonstrator case site Serchio River Basin, Italy, the hazards are flooding and runoff of soil and pollution from farmland. The implemented NBS are buffer strips along irrigation canals, a purification- and sedimentation basin, and modifying canal cross sections for improved hydraulic capacity. In addition to help mitigating the flooding problem, the measures form important parts of a long-term strategy to improve the ecological conditions of Lake Massaciuccoli, as required through the EU Water Framework Directive. Along with information on design of the measures, the plant species used, both on land and in the canals and sedimentation basin, are also listed. An additional activity at the Serchio River Basin case site is an educational- and dissemination action termed the 'NBS-lab', which uses the experiences from the technical measures in the area, as well as other PHUSICOS examples, to increase the understanding and interest for NBS among students and professionals at all levels. Several classes were held, and this activity is also planned to continue after PHUSICOS.

In the French and Spanish Pyrenees, all hazards to mitigate with NBS are related to gravity-driven processes in steep terrain. In the French Capet Forest, release of snow avalanches is mitigated with afforestation, where the plantations are protected by wooden tripods until they have grown large enough to have the necessary protective effect, after 20-30 years. The NBS are integrated with a large number of older, more traditional 'grey' measures, some of which also act as protection for the new plantations. Various rockfall and erosion mitigation measures have been installed at two locations along an important road between France and Spain, RD-934 and A-136 in France and Spain, respectively. Both locations are high-risk sites, where rocks in the road pose significant hazards. At the location in Artouste, France, the release of rocks is mitigated by various wooden- and stone structures to fix individual rocks on the till surface and

bedrock ledges with a release potential, all in combination with sustainable forest management. In Santa Elena, on the Spanish side, erosion, shallow instability, and release of rock fall from a steep cut through a glacial till ridge (a terminal moraine) are mitigated with terracing using dry masonry walls and timber gabions. The terraces are planted with local bushes and trees, which eventually will ensure stability also beyond the lifetime of the wooden gabions. The final NBS intervention in the Spanish Pyrenees is at Erill-la-Vall in Catalonia, where debris flows are sourced from thick till deposits, exposed in steep gullies. The implemented measures are again terraces built up by local rocks in combination with wooden gabion structures and planted with local vegetation. Together with existing 'grey' measures this will lift the erosional level and increase the surface roughness of the debris flow paths.

At the demonstrator case site in the Gudbrandsdalen valley in Norway, interventions have been implemented at two different watersheds with flooding problems. At a site in Øyer municipality, the Trobekken creek has been reopened along a ca. 120 m stretch which previously was previously in an underground pipe. The creek path has been re-designed with more bends, a check dam is constructed, and a 'blue-green' park area is established, which also has a certain retention capacity during floods. The area along the creek is vegetated for erosion control, and two fenced-in test fields are established, where the native vegetation is allowed to develop undisturbed. The implemented measures form part of a total package of measures, also traditional grey ones, to protect a new development for family housing, which was put on hold because of lack of flood mitigation measures. The other intervention in the Gudbrandsdalen case site is the modification of a approximately 150-year-old dam in a tributary watershed to the main river of Gudbrandsdalslågen. By strengthening the dam, establishing a new discharge threshold to expand the fluctuations between maximum and minimum lake levels and improving the spillway, Lake Svintjønna can hold back up to 330.000 m^3 of water and thereby retain and evenly distribute a 200-year flooding event over 48 hours. The peak flood downstream is thereby reduced, and more response time gained. Another activity conducted at the Gudbrandsdalen case site is a stakeholder Living Lab proves in the municipality of Skjåk, which has been repeatedly hit by flooding. This process was not meant to lead to physical implementation, but only to conduct a stakeholder involvement process 'from scratch', defining the problem and discussing different solutions. Finally, the process ended by assessing the potential of utilizing old waterways, originally made for irrigation purposes, with regards to their flood retention potential. This will be further tested in a MSc thesis in hydrology, but this will take place after PHUSICOS.

The Isar River concept case comprised NBS measures conducted in the Isar river in Munich in the Isar restoration project, which ended in 2011. The main aim of including it in PHUSICOS was the learning potential, in particular regarding the comprehensive stakeholder involvement performed in the restoration project. PHUSICOS activities were mostly teaching- and dissemination activities, comprising consortium 'look-and-learn visit', webinars, summer- and spring schools using PHUSICOS case sites, both on-line and physically in the field. In addition, activities have included supervision of students, production of podcasts and films, and support to other projects.

The second concept case site has been the Kaunertal Valley in the Austrian Alps. This is an experimental site, with the objective to enhance and optimize growth of adapted vegetation to reduce erosion and sediment loss from barren regions such as road cuts or ski slopes. This was done by carefully selecting microbes that interact with plants and influence erosion effective traits such as increasing leaf area or root density, using only indigenous plants and microbes. The experiments have been carried out both in the laboratory, where different mixtures of seeds and microorganisms have been tested, and in test plots in Kaunertal, where erosion has been measured. Larger-scale demonstration was delayed due to the Covid pandemic, but eventually a unique seed mixture is sprayed over a total of 10.000 m^2 in the Kaunertal ski resort, with and without microbiome. However, results will first be available in the growing season of 2023, i.e., after PHUSICOS. In addition to the physical experiments and implementation, the Kaunertal group has had an extensive outreach activity, including films, e-learning modules, newsletters, lectures and excursions, and exhibitions.

To summarize, most of the measures were implemented late in the project. Some are just very recently completed. Because of this, the monitoring of both the benefits and co-benefits has, with few exceptions started late, implying that much of the monitoring will take place after the project and therefore without PHUSICOS funding. For some of the locations, the monitoring has not even been started and is only in the planning stage. For others, such as the interventions in the Serchio River Basin, instrumented monitoring and sampling started already in 2020. Another location from which long time series already exist, is Erill-la-Vall, where some monitoring has been in place from 2007, because of research work done in the area at an earlier stage. An observation, however, is that most of the established and planned monitoring focuses on the physical part, directly related to the risk reduction potential, and less on the co-benefits of NBS. This should be improved as the lack of knowledge and some sort of quantitative assessment of NBS co-benefits are largely missing. This report gives an overview of the monitoring, whereas deliverable D4.7 from work package four gives more details on the ongoing and planned monitoring at all sites.

As upscaling is an important aspect of PHUSICOS, the upscaling potential, also comprising replication, is discussed for each of the sites and interventions in a semi-quantitative way. For some of the interventions several specific locations with potential for replication, and at some locations plans for similar measures are made. For others, only qualitative discussion on the possible use in similar geological and topographic settings, often within the same region, are made. To assess the potential for specific areas or locations outside of the region or landscapes of the PHUSICOS sites have been difficult, but the overall conclusion is that all the PHUSICOS interventions have large upscaling potentials. PHUSICOS activities have also led to several spinoff projects as well as still pending proposals, in which the PHUSICOS experience forms a crucial background. Some of these are briefly described in the report.

Implementing NBS at the case sites have not been without challenges and barriers, and this also resulted in the cancellation of some proposed interventions. Barriers and enablers for NBS implementation are discussed in publications and another PHUSICOS deliverable, D5.4 from work package five, and are only summarized in this report. A key element in many of the barriers is the lack of knowledge of NBS and their co-benefits, as well as lack of success stories and proof of NBS functionality. The work with implementing the PHUSICOS interventions and overcoming barriers, have also led to a number of lessons learned. A short summary of the most important ones include:

- Projects like PHUSICOS need time. Even five years may be short.
- Planning is crucial to reduce the time and ensure that projects are actually realized.
- Stakeholders must be involved at the earliest possible stage.
- Monitoring must comprise both the hazard mitigation part and the many co-benefits, and the monitoring must be planned and budgeted for early in the process.
- Maintenance needs vary, but will always be there, and should also be planned and budgeted for early.

These are elaborated more in the report and are all lessons which should be brought forwards in new projects.

Provided their success, which may not be evident until after several years, the interventions and other activities employed in the PHUSICOS project may all help mainstreaming NBS for disaster risk reduction (DRR) in the future.

Contents

1 Introduction

PHUSICOS will demonstrate the viability and up-scalability of nature-inspired solutions for reducing the risk of extreme weather events in rural mountain landscapes through implementation of such solutions in case study sites in Europe. The case study sites comprise three large-scale demonstrator sites and two supporting concept cases. Since the case studies form the backbone of PHUSICOS, over 45% of the PHUSICOS budget is dedicated to the implementation of NBSs at the case study sites. Work Package 2 (WP2) is responsible for the process and procedures for selecting the NBSs to be implemented, as well as for the implementation of the measures themselves.

This report, deliverable D2.4 is linked to all WP2 tasks; Task 2.1 (Selection of NBSs to be implemented), Task 2.2 (Implementation of demonstration sites) and Task 2.3 (Implementation of NBS at concept sites) as described in the DoA – part A. This deliverable provides an overview of the NBSs approved and implemented during the project. However, included in the report is also an assessment of challenges, which has resulted in delays of most of the NBS interventions.

Figure 1-1 Overview of the PHUSICOS demonstrator (green symbols) and concept case (red symbols) sites.

2 Brief summary of previous deliverables

Deliverable D2.1 '*Procedures for distribution of funds and tenders*' (NGI, 2018) describes shortly the five case sites and the natural hazards they are facing. It describes the NBS solutions the proponents were starting out with in a process with stakeholder involvement to reach NBS implementation in accordance with local interests and needs. The report describes the procedures for proposing NBS interventions to the project, and defines the selection criteria, which largely follows the key performance parameters described in the PHUSICOS proposal. The selection criteria should also be aligned with the NBS evaluation framework to be developed under Task 4.1 of WP4, and the report therefore also shows the relationship between the initial selection criteria and the WP4 performance evaluation criteria.

As the entities responsible for the case study sites would have to procure goods and services, short descriptions of the relevant counties' regulations for public procurement are included in the report, as well as the EC regulations of 'best value procurement'.

Finally, the report describes the selection- and approval process itself, which is done through an iterative process and a final voting among the 15 members of the Steering Committee, and the distribution of the EC funds, which cannot be used until the NBSs are approved by the Steering Committee. A template for the NBS proposal, which should not exceed 10 pages, is included as an appendix in the report.

Deliverable D2.2, ' *Overview of submitted and approved NBSs for implementation during months 1-14*' (NGI, 2019) summarizes the NBSs proposed for the three large scale demonstrator sites and the two smaller concept case sites during the first 14 months of the project. The report also summarises the process for submittal and evaluation of the proposals, which was slightly changed, compared to that described in deliverable D2.1, due to experiences gained during the first year, and discussions among the consortium partners (Figure 2-1). All proposals have been handled and evaluated following this procedure.

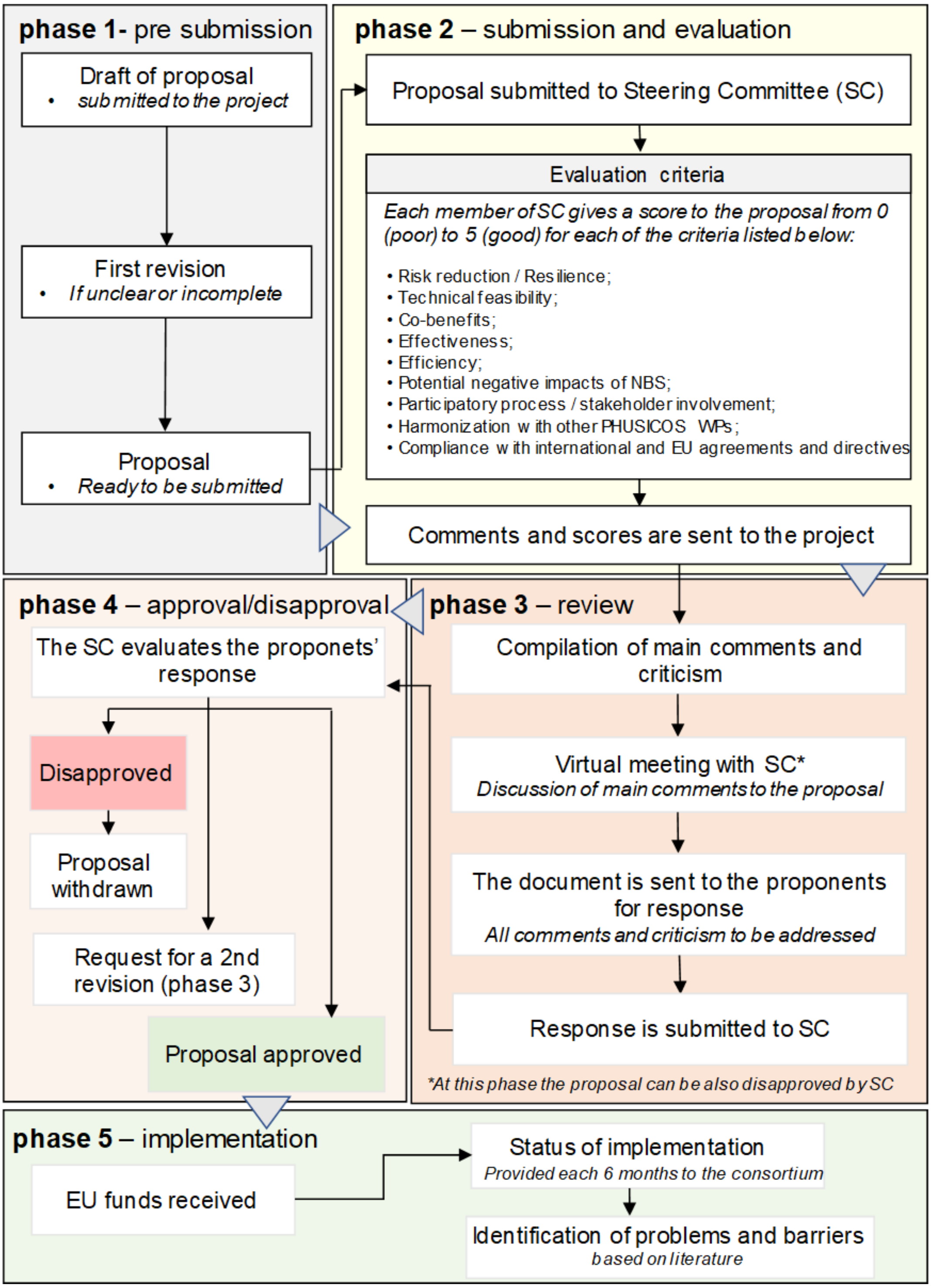


Figure 2-1 Flowchart showing the proposal approval process established in the PHUSICOS project.

During the first 14 months, proposals had been submitted from all the case study sites. One of the three demonstrator sites, the Pyrenees, had already 5 individual NBS proposals under review. The two other demonstrator sites, Gudbrandsdalen, Norway and

Serchio River Basin, Italy, had submitted one proposal each and had both indicated NBS measures for their next proposals. The concept case at Kaunertal, Austria had submitted their only proposal, whereas the other concept case, the retrospective case from the Isar River, Germany, had proposed and already hosted the first of several planned learning visits.

The deliverable also discusses the close links to the other WPs of the project, with particular emphasis in WP3, dealing with stakeholder involvement, and WP4, on assessment framework for short- and long-term monitoring of the interventions and their effects. During the project's first 14 months, site visits to all three demonstrator case sites had taken place, and the report includes a brief report from the visits, as an appendix.

<u>Deliverable D2.3</u>, *'Overview of submitted and approved NBSs for implementation during months 15-24'* (NGI, 2020) follows up deliverable D2.2 and summarizes the NBSs proposed for the three large scale demonstrator sites and the two smaller concept case sites during the next 10 months, i.e. through April 2020. In addition, the report also provides summarizes of the development after month 14 of the NBS projects which were reported in deliverable D2.2 (i.e. submitted and approved during the first 14 months). It also, as D2.2, discusses the links to other WPs.

During M15-M24, three new proposals had been submitted from the Serchio River Basin demonstrator case site and one from the Isar River concept case. The proposals from the Serchio River Basin comprised another set of vegetated buffer strips in an area of different soils from the first one, and a sedimentation basin, through which water from the two areas of buffer strips would flow. Hence these NBS measures together formed a system for reducing soil loss from erosion and avoiding transfer of pollutants to the canals and eventually to Lake Massaciuccoli. The proposal from the Isar River concept case was for an NBS summer school aimed at young professionals and students, to be held over a 10 day period in September 2020, as a joint effort between project partners TUM, CTP and BRGM. However, this event was changed to an on-line event due to the Covid-19 pandemic situation, which appeared that spring.

At the time of reporting, all the case sites had faced various challenges, in addition to the Covid-19 pandemic, which led to implementation delays. These challenges were described in the report and are also described and discussed by Solheim et al. (2021). They will be further summarized in the present report.

3 Overview of NBS proposed and approved in PHUSICOS

A total of 19 NBS activities have been proposed to the Steering Committee during PHUSICOS (Table 3-1 and Table 3-2). Of these, 15 are physical interventions at sites. Four are educational- and outreach activities (webinar and spring school of the Isar case are treated as one activity). Of the 19 proposals, four were called off (Table 3-2).

Table 3-1 All approved PHUSICOS NBS interventions.

Site	Proposal	Submitted	Revised (reqst. by WP2)	Approved	Budget (EUR) Total / PHUSICOS	Completed
DS-Gudbrandsdalen, Norway	Skurdalsåa flood retention	28.05.2021	08.06.2021	10.09.2021	79 616 / 42 492	15.12.2022
DS-Gudbrandsdalen, Norway	Living Lab facilitator, Skjåk	08.01.2021	No revision.	15.03.2021	31 399 / 21 100	LL process only
DS-Gudbrandsdalen, Norway	Øyer, Flood control	06.04.2021	30.04.2021	17.06.2021	1 006 250 / 603 750	13.01.2023
DS-Serchio River Basin, Italy	Buffer strips along canals in the area of Lake Massaciuccoli	11.03.2019	27.03.2019	08.06.2019	255 667 / 149 400	23.11.2020
DS-Serchio River Basin, Italy	Extension of buffer strips to area with different soils.	20.12.2019	18.02.2020	14.05.2020	393 083 / 229 700	23.11.2020
DS-Serchio River Basin, Italy	Retention/ sedimentation basin.	20.12.2019	18.02.2020	14.05.2020	860 164 / 502 640*	31.08.2022
DS-Serchio River Basin, Italy	Educational 'NBS Lab'.	20.12.2019	18.02.2020	14.05.2020	52 194 / 30 500	Ongoing educational activity
DS-Serchio River Basin, Italy	Improve hydraulic capasity of canal system	20.05.2021	08.06.2021	23.08.2021	250 100 / 150 060	31.07.2022
DS-Pyrenees, Spain	Santa Elena, Spain. Erosion/Landslides	30.04.2019	No revision	05.07.2019	662 151 / 397 291	04.2023
DS-Pyrenees, France	Artouste, France: Rock fall	30.04.2019	30.08.2019	14.11.2019	393 881 / 236 329	04.2023
DS-Pyrenees, France	Capet Forest, Baréges, France: snow avalanches	30.04.2019	19.07.2019	28.09.2019	376 179 / 225 708	31.07.2022
DS-Pyrenees, Erill-la-Vall	Debris flow from till deposits, Erill-la-Val, (Spain)	17.03.2021	04.05.2021	29.06.2021	357 830 / 214 698	20.10.2022
CCS-Isar River, Germany	Look and learn' visit; workshop and excursions	19.12.2018	Per 01.02.21	22.01.2019	890 / 540	20.03-22.03.2019.
CCS-Isar River, Germany	Summer School sept. 20 and spring school May 22.	10.02.2020	14.02.2020	09.03.2020	66 722 / 28 615	02.04-11.04.2022
CCS.Kaunertal, Austria	Altitude adapted and microbe assisted seed mixture.	22.02.2019	06.03.2019	22.05.2019	854 000 / 840 000**	2023

** Of these about 10% are savings to spend in improvement works or activities*
*** Of these 35 000 are for sub-contracting*

Table 3-2 PHUSICOS NBS proposals called off or rejected

Site	Proposal	Submitted	Revised (reqst. by WP2)	Approved	Budget (EUR) Total/PHUSICOS	Reasons for cancellation
DS-Gudbrandsdalen, Norway	Jorekstad - receded green flood barrier	19.12.2018	14.01.2019	20.02.2019	1 250 000 / 732 000	Detailed design done. Preliminary stopped for political and bureaucratic reasons. Eventually cancelled for economic reasons. Cost 100% higher than originally estimated.
DS-Pyrenees, France	Torrents, Bastan River (France)	30.04.2019	19.07.2019	28.09.2019	635 712 / 381 427	Called off by owner (PVLG). Cannot guarantee completion within the project period and consider the economic risk too high.
DS-Pyrenees, France	Torrents, Socques (France)	30.04.2019	n/a	n/a	522 000 / 313 200	Called off by CTP/BRGM. Proposed NBS may not work at this site.
DS-Pyrenees, Spain	Port Ainé	30.09.2020	17.11.2020	SC negative. Major revision required to avoid rejection.	950 837 / 232 804	Called off by proponent (Ferrocarils de la Generalitat de Catalunya) before required revision

With few exceptions, the NBS interventions have been delayed. This has several reasons (Chapter 9) but has resulted in only near-completion for some of the measures at the end of the project. However, what remains is mostly the final details and cleaning up after the construction work, which in some cases had to wait for spring conditions. These final activities are not covered by PHUSICOS funding but are covered by the 40% non-PHUSICOS funding required for each of the interventions. The delayed completion does, however, affect the monitoring programs.

3.1 Monitoring and maintenance of NBS interventions

Monitoring of the effects of the implemented interventions is essential to build up an evidence base for NBS and thereby help reducing the barriers connected to lack of knowledge and scarcity of success stories for NBS (Chapter 9). As the implementation at most of the sites have been delayed, monitoring of the effects is at highly different stages, and range from just being planned (several interventions), to monitoring since long before the PHUSICOS project (the Erill-la-Vall site). The monitoring should also cover co-benefits in addition to the interventions' risk reducing potential, and PHUSICOS work package 4 (WP4) has developed a comprehensive assessment framework for this as deliverable D4.1 (PHUSICOS, 2019d) and further described the monitoring needs and the technology options in deliverable D4.3 (PHUSICOS, 2020c). The methods developed have been successfully applied to the Concept Case Isar and resulted in two scientific publications and numerous oral communications at international conference. As a base for all future assessments, baseline studies have been carried out for all the demonstrator case sites and compiled by project partner University of Naples. Estimates of what stresses the planned interventions can withstand, from the baseline data and using various climate change scenarios, are reported in deliverable D4.4 (PHUSICOS, 2022).

A significant challenge caused by the delayed implementation at the demonstrator sites, is that most of the monitoring must be established and performed post-PHUSICOS, and therefore without the project's funding. Therefore, only carefully selected indicators will be followed up by the site owners and their research partners. Most of the on-going and planned monitoring is related to the risk reduction ambit, and efforts must be made to include co-benefit monitoring, including indicators on the ambits for society, local economy, technical and feasibility aspects, and environment and ecosystems. Further details of the monitoring, both ongoing and planned, are given in each of the case site chapters (Chapters 4, 5, 6, 7 and 8).

All the NBS interventions require some maintenance. The needs vary greatly between the measures and may range from replacing dead plants to repair of wooden or stone constructions, emptying sedimentation basins and repair of check dams. This is briefly described for the interventions in the three large-scale demonstrator sites (Chapters 4, 5, and 6). Only few of the intervention sites have had this well planned, cost estimates made, and responsibility distributed. An important learning point (Chapter 10) is therefore that both monitoring- and maintenance needs must be assessed in the planning phase of the measures. Costs must be estimated and budgeted for, and responsibilities defined.

3.2 Upscaling possibilities

By upscaling we here mean both increasing the size or areal extent of the measures and their replicability. As most of the PHUSICOS NBS interventions are laterally large, typically covering whole river causes or valley sides, evaluating the upscaling potential in terms of replicability at other relevant sites is most relevant. This can be on a regional, national, or even European scale. The upscaling possibilities, as well as the base for assessing them, vary from site to site, and are therefore discussed under each of the interventions at the sites (Chapters 4, 5, 6, 7 and 8).

4 Demonstrator case site Serchio River Basin, Italy

The proponent of the NBS interventions in the Serchio River Basin demonstrator case site in Tuscany, Italy is the Autoritá di Bacino Distrettuale Appennino Settentrionale (ADBS), which is the organization responsible for management of river basins in this part of Italy.

The problems to solve in this area is runoff of soil and pollutants from the farmland to irrigation canals and from there to the nearby Lake Massaciuccoli on the Tuscan coast. The proposals from ADBS (Table 3-1, Figure 4-1), are mainly designed to reduce this runoff from the farmland. In addition, the area around the lake has a flooding problem, and the flood mitigation capacity will also be increased through the proposed measures. The lake is highly polluted by agricultural activity and has a salinity comparable with that of sea water. Fulfilling the EU Water Framework Directive requires improvement of the ecological state of the lake. This can be done by a combination of measures in the surrounding farmland and measures to avoid significant lowering of the lake water level during droughts, to prevent sea water from penetrating into the lake through the main canal connecting the lake with the sea. The latter will be mitigated by diverting freshwater from the nearby Serchio River to the lake through a diversion pipeline. This is an activity outside of PHUSICOS. Specific measures within the farmland south-east of Lake Massaciuccoli are PHUSICOS activities.

The farmland is dissected by sets of irrigation / drainage canals (PHUSICOS 2019a). The group of proposals submitted to PHUSICOS form a system of NBS measures to prevent transfer of soil and pollutants from the farmland to the canals and ultimately to the lake. The NBS interventions consist of buffer strips along canals in two zones with different soils, clayey and peaty (Figure 4-1). The canals of both zones drain into a proposed vegetated sedimentation basin before the water is forwarded to the lake through the existing pumping system. Additionally, the cross-sectional shape of another set of canals, also leading to the sedimentation basin, was modified to improve the hydraulic capacity of these canals. These four interventions form a system to reduce the transfer of soil particles, nutrients and pollutants (e.g. pesticides) from the farmland to the canals and eventually to the lake. It will also have a flood reducing effect in avoiding sediment clogging of the canals and provided by a better hydraulic capacity. Since the buffer strips, the sedimentation basin and the canal modifications all form component of a joint mitigation system, their monitoring and upscaling potential are discussed together (Chapters 4.5 and 4.6).

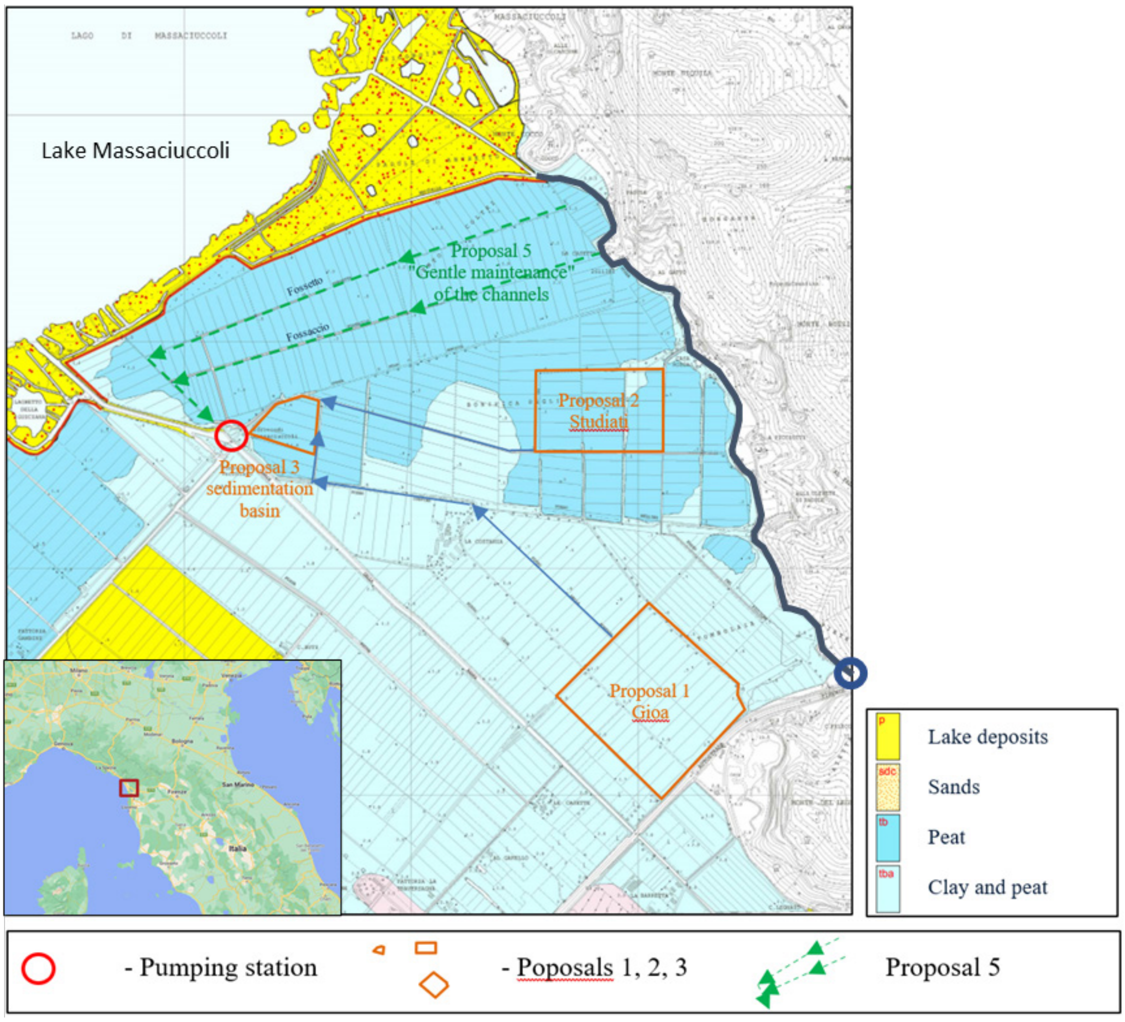


Figure 4-1 Overview of the surficial geology and proposed interventions at Lake Massaciuccoli, Italy. The pumping station is an existing infrastructure and not part of PHUSICOS. Proposals 1 & 2 are the buffer strips, whereas proposals 3 and 5 are the sedimentation basin and the canal modifications, respectively. The heavy blue line in the north-east is the Fossa Nuova Canal, through which the water is lead from the Serchio river via a pipeline with outlet at the blue circle.

The buffer strips, the sedimentation basin and the NBS-Lab are all described in previous deliverables, D2.2 and D2.3 (PHUSICOS 2019a and 2020b), whereas the canal modifications (proposal 5) were proposed later than month 24 of the project and are therefore not described in previous deliverables.

Another approved proposal from ADBS was to set up an 'NBS-lab', aimed at disseminating knowledge of NBS to students as well as professionals, in particular local and regional practitioners, planners and technicians. The sessions are performed as a combination of field visits and classroom work and are to a large degree based on the PHUSICOS experiences.

4.1 Two areas of buffer strips (Proposal 1 and 2)

The buffer strips in the two areas were the first PHUSICPOS interventions to be completed, on 23.11.2020. The design of the strips and the selection of plants covering the strips have been done in close cooperation with University of Pisa, Italy. The strips are 3 m wide and planted with 23 kg/ha of a mix of Festuca arundinacea (40%), Lolium pe-rennis (50%), Trifolium repens (5%), Trifolium subterraneum 5% in both the Studiati area and the Gioia area (Figure 4-1,Figure 4-2, Figure 4-3, Figure 4-4). The width of the strips was a matter of discussion, and the resulting width of 3 m was a compromise between the scientific experience and the farmers' willingness to provide land. The agreement was reached through an active Living Lab process. Following this, the involved farmers showed considerably more enthusiasm and established a stronger 'ownership' to the interventions. They were also the ones to carry out the physical work, using their own machinery and personnel. In addition to preventing runoff of pollutants from the farmland, the strips will also prevent runoff of sediments and thereby clogging of the channels, which also serve as a flood mitigation measure.

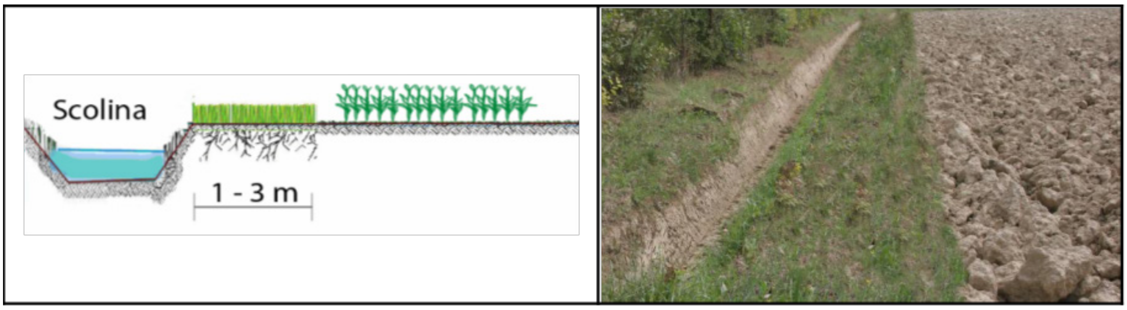


Figure 4-2 Sketch and generic example of a vegetated buffer strip implemented along an irrigation/drainage canal ('Scolina' is the Italian word for canal) (illustration by Autorità di Bacino del Fiume Serchio—ADBS).

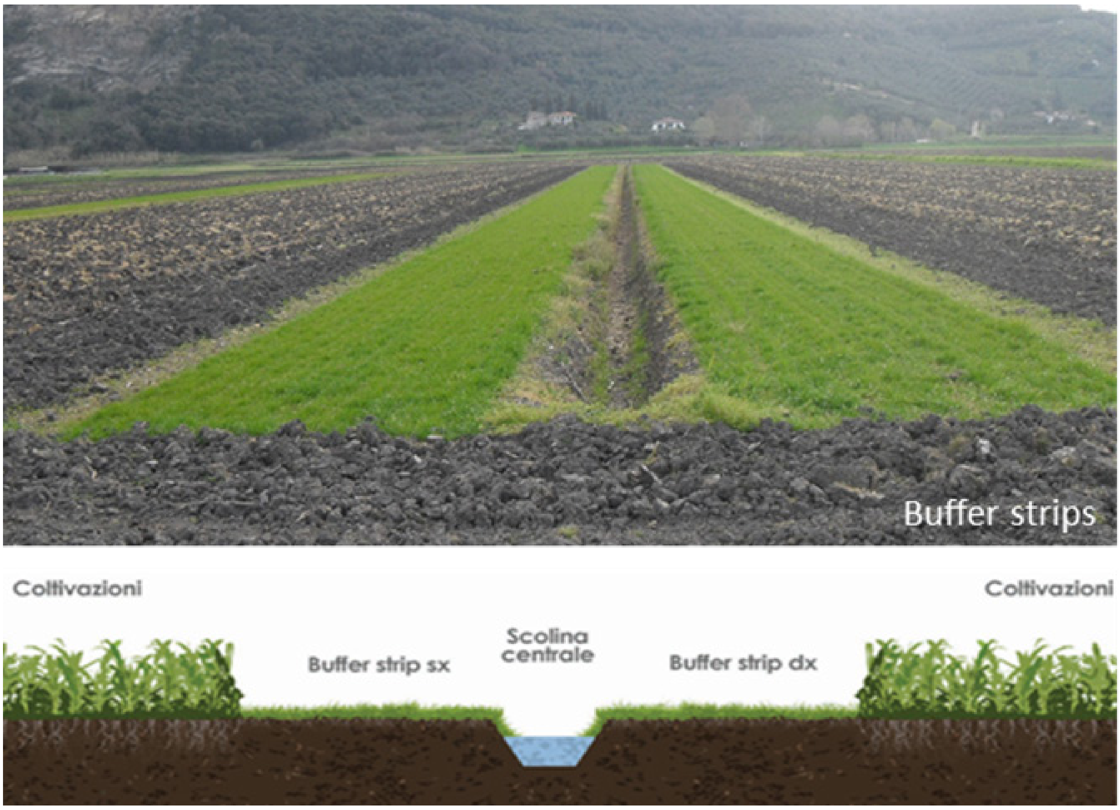


Figure 4-3 Photo and section through a buffer strip implemented along an irrigation canal in the Studiati area (illustration by Autorità di Bacino del Fiume Serchio—ADBS).

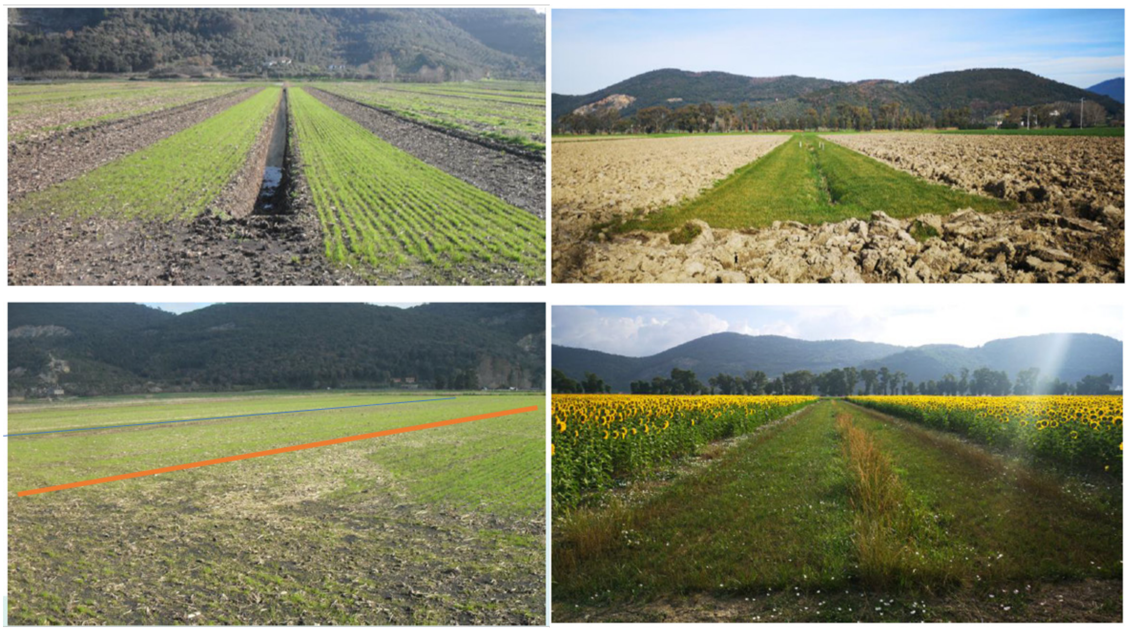


Figure 4-4 Buffer strips in the Studiati (left) and Gioia (right) areas. In the lower left photo, the orange line marks the boundary between cover crops and buffers strip, with the canal marked with a thin blue line (Photo: ADBS)

4.2 Sedimentation basin (Proposal 3)

The sedimentation basin forms an important subsequent element in the NBS measures to reduce runoff of sediments and pollutants from the Studiati and Gioia fields. The basin is designed by the Reclamation Consortium Authority with the support of ADBS and external collaborators. The construction started on 04.04.2022 and was completed on 31.08.2022. The basin is 160 m wide, 250 m long and has an average depth of 1 m. For the filling and emptying phases, a threshold was created equipped with clapet valves arranged on three pipes each with a diameter of 800 mm. The threshold is protected by a wooden palisade (Figure 4-5, Figure 4-6, Figure 4-7).

The basin is vegetated with water plants of Phragmites australis and Thypha latifolia selected for optimal uptake of pollutants (nutrients and pesticides). Both are species known to Tuscan farmers. The application of these species as purificators, due to their high ability to absorb nitrates and phosphates, can be regarded an innovation with respect to the locality. This type of designed retention basin enables the farmers to contribute to environmental protection with active interventions using renewable and completely natural resources, rather than with passive behaviour, based on the renunciation or limitation in the use of crop inputs.

The sedimentation basin project was modified and updated based on input from the stakeholders during the Living Lab process, to better integrate into the environmental and landscape context. Based on this, additional vegetated areas and a zone designed for nesting birds were established. These additional zones have been vegetated using arboreal plants along banks surrounding the basin and canal leading into it. Within the resting area for birds Alnus glutinosa, Fraxinus Angustifolia and Salix spp., have been planted in squares of 6 x 6 m or 5 x 5 m. The basin has access for machinery required for maintenance, including removal of trapped sediments after flooding events.

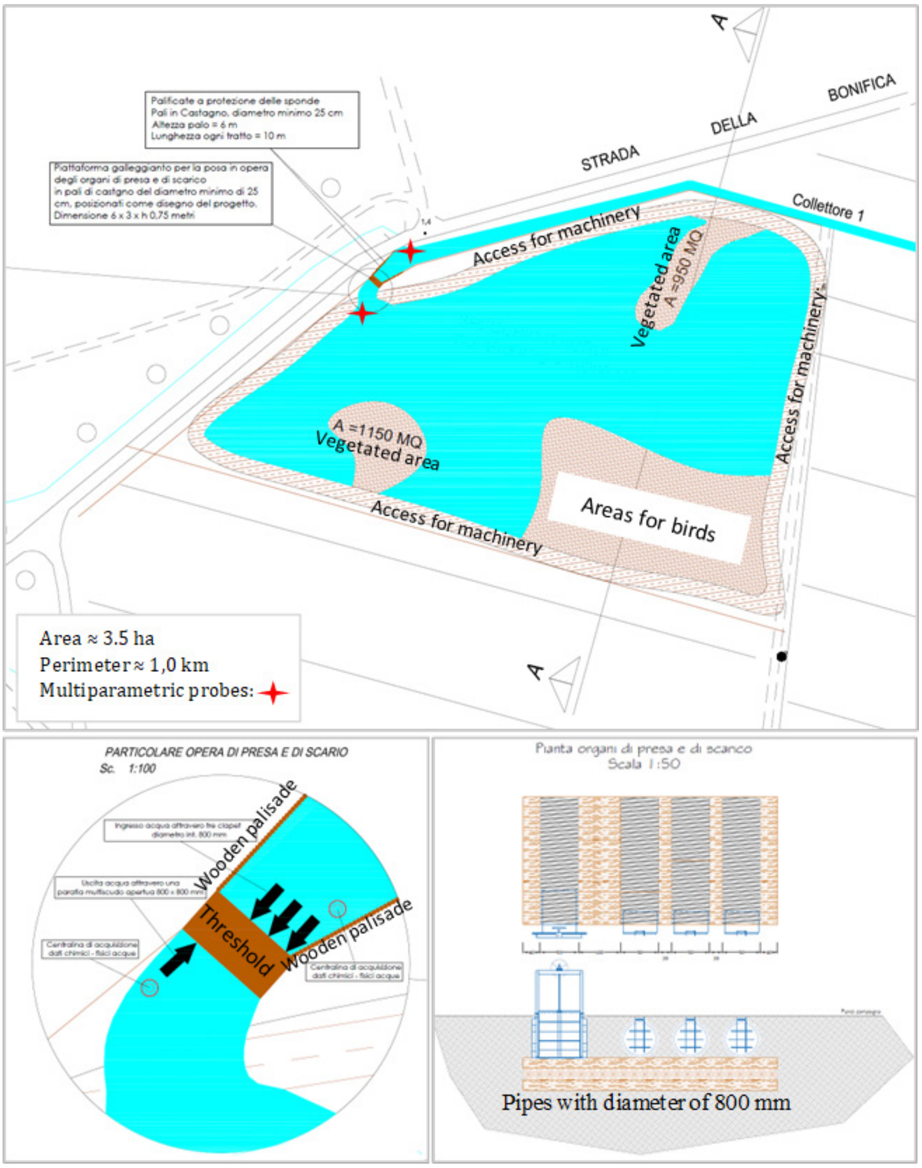


Figure 4-5 Technical details from the design of the sedimentation basin (Source: ADBS)

Figure 4-6 Photos of the pipes with clapet valves through the threshold (Figure 4-5) (Photo: ADBS)

Figure 4-7 The sedimentation basin after completion (Photo: ADBS

4.3 Canal modifications (Proposal 5)

This intervention was the last to be proposed from the Serchio River Basin demonstrator case site. It was approved by the project's steering committee on 23.08.2021 and implementation was completed on 31.07.2022. The main objective of this measure is to improve the hydraulic capacity of selected canals to increase their efficiency for flood prevention. Besides geometric modification of the canals the modifications also comprise establishment of bank vegetation intended to slow down the water flow and reduce bank erosion. This has previously been a problem, often clogging the canals after intense runoff events. The two canals to be modified (canals Fossetto and Fossaccio) are of the intermediate of three size classes and collect water from a series of the smaller canals (Figure 4-1).

The modification consists of changing the cross section of the canals (Figure 4-8). The original trapezoidal cross section is enlarged by constructing small floodplains along the banks, increasing the effective section of the canals during flooding events. Furthermore, the modified cross section provides a better environment for the bank vegetation, which in addition to mitigating against erosion, also will have an ability to absorb pollutants. The bank vegetation consists of Phragmites australis and Thypha latifolia. The implementation work for this measure, as for most of the other work on the interventions in this area, was mainly carried out by the local farmers with excavators, and therefore was relatively simple and fast.

Different sections of the canals have been modified in three different ways, depending on the width of the original canal and the conditions of the banks (Figure 4-8, Figure 4-9, Figure 4-10):

Type 1. Wide original canal: Unaltered canal profile but with 6 m wide buffer strip and vegetation on the bottom and banks.
Type 2. Intermediate width of original canal: Excavating one bank to widen the canal, 6 m wide buffer strips and vegetation on the bottom and banks.
Type 3. Narrow original canal width: Excavating both banks to widen the canal, 6 m wide buffer strips and vegetation on the bottom and banks.

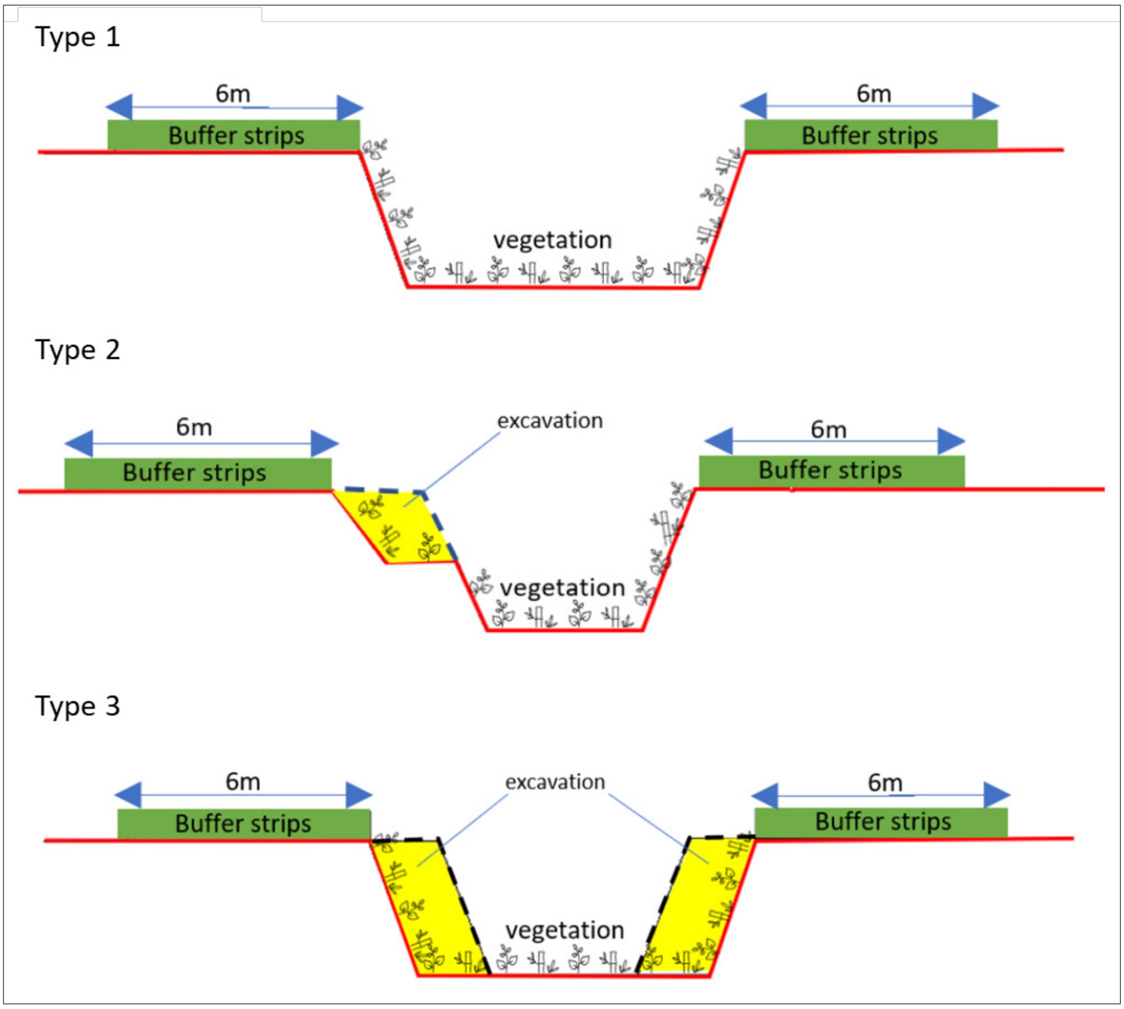


Figure 4-8 Sketch showing three different ways of modifying the canals.

Furthermore, at selected locations, wooden palisades were installed to stabilize and set back the embankments (Figure 4-9).

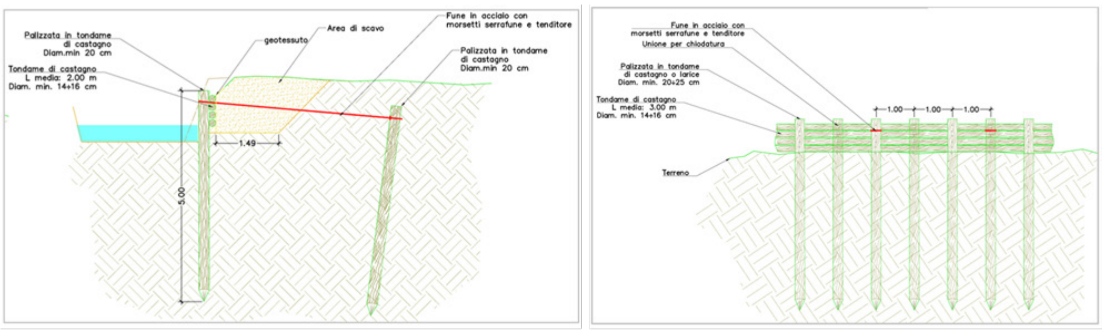


Figure 4-9 Sketches showing the use of wooden palisades. The palisades are anchored by single poles in the ground behind the palisade (left figure).

Figure 4-10 The Fosetto (left) and Fossacio (right) canals before (upper) and after (lower) modification. (Photos: ADBS)

4.4 'NBS Lab' (Proposal 4)

The NBS Lab proposal was approved on 14.05.2020 and is ongoing. This is an educational NBS program combining classroom and field activities, aimed at both students and professionals at all levels. The activities have been divided in three levels (Figure 4-11), with different goals, both designing NBS to solve specific natural hazards problems, and to educate students from local technical schools in NBS techniques and sustainable management of the land. The sessions have focused on the measures being implemented around Lake Massaciuccoli but have also comprised designing measures to mitigate against landslides from the steep slopes to the NE of the lake, which occasionally fail and deliver large amounts of sediments to the canals and the channels, in addition to creating problems for infrastructure.

The NBS-Lab activities have been affected by the COVID pandemic, but ADBS has been able to conduct sessions also through this period, using on-line classrooms. Several PHUSICOS partners have given lectures at the sessions.

Figure 4-11 Schematic of the NBS-Lab, with examples from classroom, - field, - and laboratory sessions. (Figure and photos: ADBS)

4.5 Monitoring and maintenance

Monitoring of several key parameters were initiated shortly after the completion of the NBS implementations. In the area south-east of Lake Massaciuccoli there are a total of 17 monitoring stations for regular periodic sampling and 6 stations with probes for automatic continuous monitoring (Figure 4-12, Figure 4-13, Figure 4-14). Furthermore, two probes have been inserted for continuous monitoring to obtain information on the main physical and chemical parameters of the incoming and outgoing water in the sedimentation basin (Figure 4-15). These two probes measure the same parameters as the probes in the other automatic stations.

The first manual sampling data started from October 2020 while the continuous monitoring system started to deliver data from April 2021 (Table 4-1). As the loss of soil and the runoff of nutrients and pesticides are the main issues, much of the monitoring is focused on physical and chemical indicators, measured in surface waters within the canals (Figure 4-13). Data acquired from both the sampling and the automatic monitoring comprise temperature, turbidity, conductivity, turbidity, pH, dissolved O2, redox potential, Nitrate, Ammonium and Trace elements. However, as the interventions are also expected to have a flood risk reducing potential, water level is an important indicator to monitor as a function of precipitation, and gauging stations are therefore installed.

The monitoring is done partly in collaboration with the University of Pisa (Department of Earth Sciences – DST). All acquired monitoring data are available on a web-platform (user- and password controlled). In addition, project partner University of Siena, Centre of GeoTechnologies (CGT) has carried out detailed geomorphological and geophysical measurements both from the ground, from the air with a 'gyroplane', and by using satellite data. CGT monitoring comprises surface elevation, subsidence measurements with Persistent Scattering radar Interferometry (PSI), drone-based surveys of crop conditions, Soil Moisture Index, turbidity in canal waters, and detailed DEMs and orthophotography. These are all measurements planned to repeat, although the frequency has yet to be determined. This will most likely vary between the different measurements.

The co-benefits are also considered in the monitoring program. Parts of the Environment and ecosystem ambit is covered by the physical and chemical measurements through the sampling program and the automatic probes. However, interview surveys with a wide range of local and regional stakeholders are planned for societal and economic co-benefits, in addition to sampling and game cameras, etc. for ecological monitoring.

Further details on the monitoring program and preliminary results are found in PHUSICOS deliverable D4.7 (PHUSICOS, 2023).

Table 4-1 Overview of the monitoring at the four interventions in the Lake Massaciuccoli area.

Name	Implementation	Status Monitoring	Type of monitoring
Intervention 1 (Proposal 1) **Buffer strips/Cover crops** South area of Massaciuccoli's lake	Completed	Active From October 2020 To: as long as necessary ADBS has an agreement with DST	**Traditional monitoring system** with sampling every 15 days of surface and underground waters and connected to the portal: PHUSICOS http://131.114.22.25/phusicos/ UN: adb_user PW: mass321
Intervention 2 (Proposal 2) **Buffer strips/Cover crops** South area of Massaciuccoli's lake	Completed	Active From April 2021 To: as long as necessary ADBS manages the monitoring system	**Continuous monitoring system**: 4 probes installed and connected to the portal: https://powerbi.microsoft.com/it-it/
Intervention 3 (Proposal 3) **Sedimentation basin** South area of Massaciuccoli's lake	Completed	Being activated From October 2022 To: as long as necessary ADBS manages the monitoring system	**Continuous monitoring system**: 2 probes installed and being activated https://powerbi.microsoft.com/it-it/ UN: phusicos1@nexman.it - PW: Phus1c0s1!
Intervention 4 (Proposal 5) **Management of idraulic net** South area of Massaciuccoli's lake	Completed	Active From October 2020 To: as long as necessary ADBS has an agreement with DST	**Traditional monitoring system** with sampling every 15 days of surface and underground watersand connected to the portal: PHUSICOS

Figure 4-12 Manual periodic sampling (left) and continuous, automatic monitoring system (right) (Photo: ADBS)

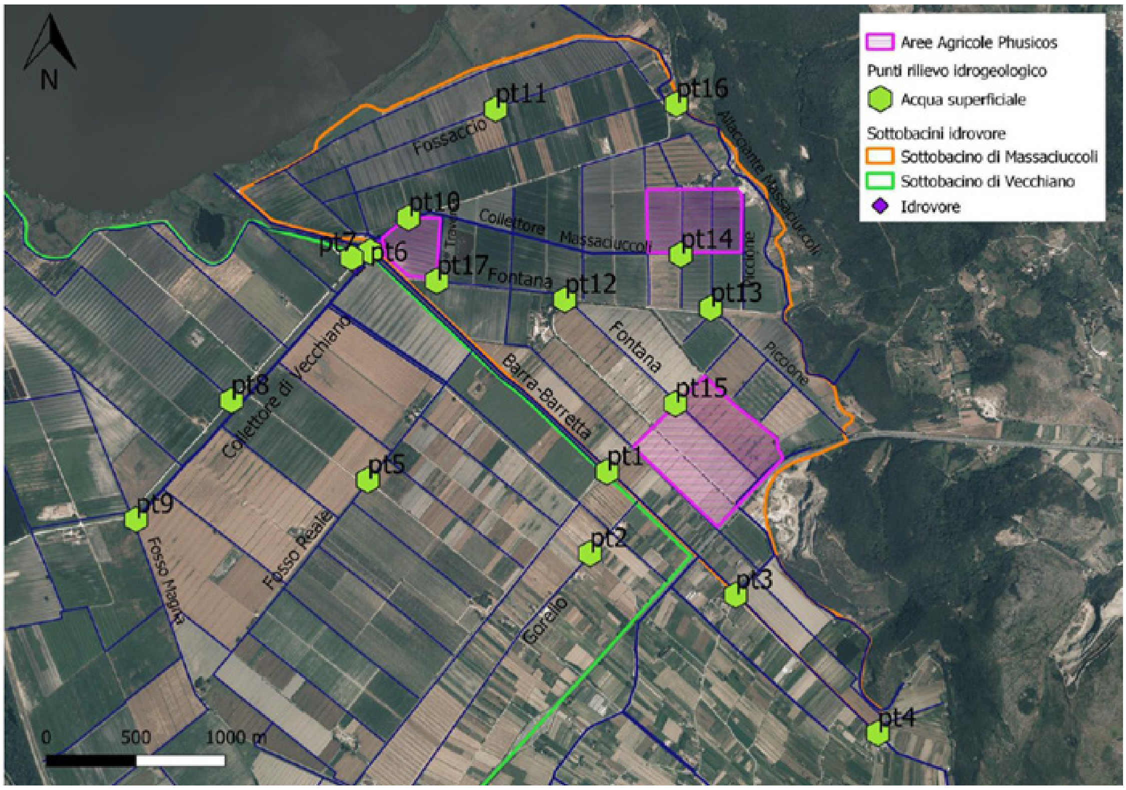


Figure 4-13 Overview of monitoring stations (green hexagons) for surface water within the canal network in the study area.

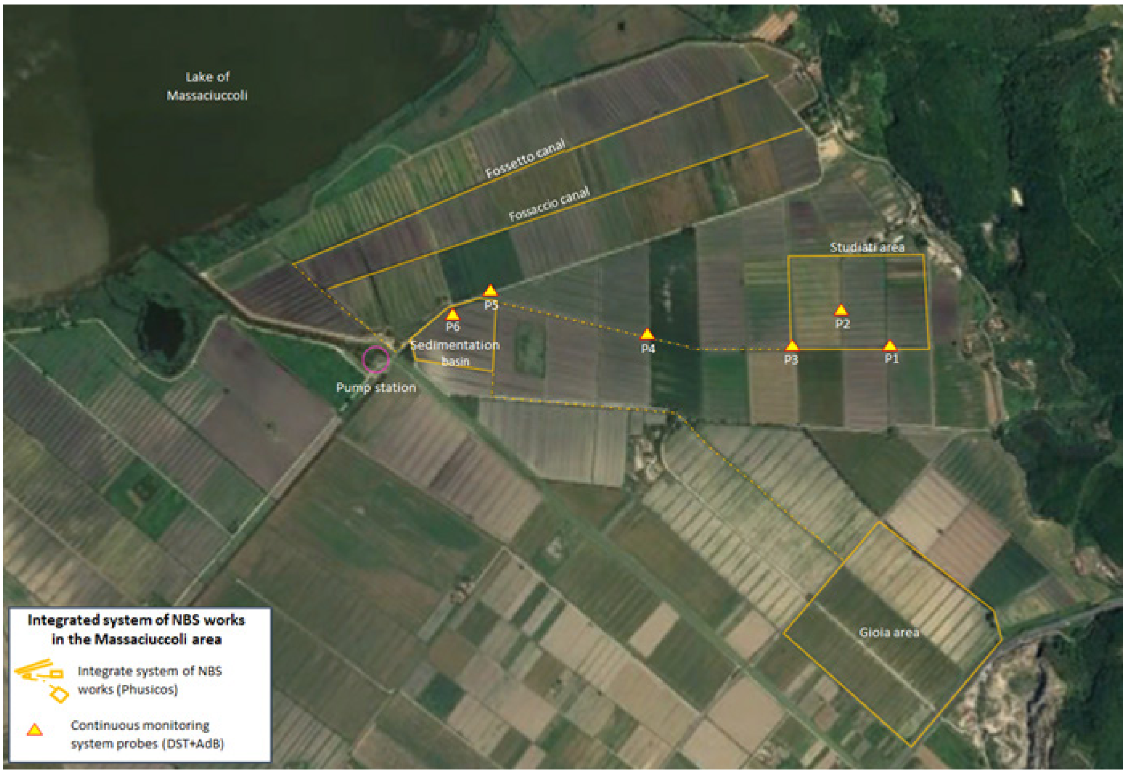


Figure 4-14 Overview of probes (yellow triangles) for automatic, continuous monitoring 0f surface water parameters in the study area.

Figure 4-15 Photos of the monitoring probes at the intake and outtake of the sedimentation basin. Their locations are marked in Figure 4-5 (Photo: ADBS)

Maintenance is required for the implemented interventions. These include emptying of sediments in the sedimentation basin, whenever necessary, as well as regular maintenance and replacement of plants, both on land and in the canals and basin. In addition, the buffer strips should be subject to careful tillage, avoiding the heaviest machinery. Furthermore, the strips need mowing, and in the Lake Massaciuccoli area attempts are made to create a market chain for the products generated from the maintenance and harvesting from the buffer strips, cover-crops and the sedimentation basin in order to remunerate the farmers. This could, in combination with Payment for Ecosystem Services (PES), help overcoming an economic barrier for implementation of NBS.

4.6 Upscaling potential

Due to the heavily degraded environmental conditions of Lake Massaciuccoli, measures are required for large areas around the lake. The measures implemented in PHUSICOS cover only a relatively small part of the total agricultural area surrounding the lake. However, through the intense stakeholder involvement hosted by ADBS, and also through the NBS-Lab, interest has spread to many farmers currently not involved in the PHUSICOS measures. Hence, the upscaling potential is large in this region, and there is no doubt that upscaling with similar measures to a larger part, or all of the area affecting the lake, would have a great positive effect on the ecological state of the lake, in addition to reducing the soil loss from the farmland.

Looking further at Italy, the replicability potential is high in all areas where agricultural pressure is strong and vulnerability to soil erosion is high. The measures can be implemented individually or in combination. Interventions like buffer strips and reduced tillage along these can be used in most areas, also those different from the lake Massaciuccoli area. Construction of sedimentation basins or artificial wetlands, combined with vegetated buffer strips can be adopted in most low-land areas of the country, as well as in similar areas in other countries. Particularly vulnerable to erosion are those areas which leave the farmland barren between the farming periods, typically comprising growth of cereals and industrial crops. Areas particularly predisposed to host NBS like those of the Lake Massaciuccoli area and with many similar problems, include (N. DelSeppia, pers. Comm., 2023):

- Pianura di Pisa e pianura di Grosseto (Tuscany Region)
- Orbetello Lagoon (Tuscany Region)
- Valle del Magra (Liguria Region)
- Pianura Padana (Emilia-Romagna Region)
- Maremma Laziale (Lazio Region)
- Pontine countryside (Lazio Region)
- Lago di Patria (Campania Region) (a lake with many similarities with Lake Massaciuccoli)

These areas display physical conditions which would favour NBS interventions similar to those applied in the Lake Massaciuccoli area. Common characteristics include flat topography, often with active subsidence, easily erodible soils with high organic content (peats, silts and sandy silts), intensive agricultural activity, and farmland immediately upstream of densely populated areas, with limited flood retention capacity.

Buffer strips along waterways are required by law in most European countries but is not always followed up. In addition, the maintenance of the strips is important, as is the selection of plants to use, avoiding the use of heavy machinery and reduce tillage on the strips.

In Italy, buffer strips are mandatory (Ministerial Decree 27417/2011) for agricultural surfaces facing "bodies of water" except for drainage canals, minor ditches, canals for water supply for irrigation and 'hanging' water bodies or with raised banks compared to the ground level.

The canals in the Massaciuccoli area are classified as secondary network for irrigation purposes, and therefore buffer strips are not mandatory for these canals. Furthermore, the buffer strips created in this area have more complex characteristics because they, in addition to preventing runoff from the farmland, are also constructed to prevent erosion in the canals, and therefore must include the entire bank of the canals. This is in the interest of the farmers, as erosion leads to canal widening and thereby reduction of the cultivable area.

One of the barriers to NBS interventions, such as buffer strips, in the agricultural sector is due to their often-substantial areal extent, which reduce arable agricultural land, negatively impacting on the economic income of farmers. In the area SE of Lake Massaciuccoli, the NBS interventions cover about 15% of the agricultural area. However automatic compensation systems should be introduced and NBS should be considered for Paid Ecosystem Services (PES). In Tuscany, the process of recognizing NBS as PES has started, and a technical discussion is ongoing. This is considered fundamental for the mainstreaming of NBS in the agricultural domain, and therefore for real upscaling.

Another important barrier for implementing NBS is the scarcity of well documented success stories (Chapter 9). Therefore, the significance of the monitoring programme at Lake Massaciuccoli cannot be overestimated. If positive effects of the measures, individually and/or jointly, can be documented after some time of operation, these NBS implementations can foster upscaling and transfer activities to larger regions.

4.7 Serchio River Basin summary

The implemented NBS interventions in the Serchio River Basin demonstrator case site are integrated parts of a strategy to reduce runoff of soil and pollutants from the farmland to Lake Massaciuccoli. Jointly with the planned diversion pipeline from the Serchio River (not a PHUSICOS measure) these measures will contribute to an improved ecological state of the lake, as well as reduced soil loss from the farmland. In addition, as the canals also serve a flood reduction purpose, avoiding canal clogging improves the flood prevention capacity of the area. The NBS-lab uses the experiences from the technical measures in the area, as well as other PHUSICOS examples, to increase the understanding and interest for NBS among students and professionals at all levels, and it is an important contribution to advertise for the dissemination and implementation of future NBS measures.

Challenges experienced have mostly been related to the requirement of arable farmland and potential compensation for this. Hence, the width of the buffer strips and the land to be taken up by the sedimentation basin have been subjects for discussion. Controversies have been solved through close interaction between ADBS and stakeholders in several

Living Lab sessions. These led to a stronger sense of ownership among the stakeholders, in particular the farmers and their organizations. It also led to greater enthusiasm for the project and, not the least, a greater interest, also among other farmers in the region that were not directly involved in the PHUSICOS measures. The larger farms in the area are organized as companies, and they were also contracted to do the construction work.

Monitoring equipment was installed shortly after the first buffer strips implementation, and therefore monitoring data have become available for up to two years before the end of the project. Baseline data were acquired in collaboration with the project partner Centre of Geotechnologies (CGT) of the University of Siena, while chemical monitoring was established in cooperation with the University of Pisa. Further details on the monitoring activities are described in Chapter 4.5, and in deliverable D4.7 (PHUSICOS, 2023).

The methods used around Lake Massaciuccoli are not new and innovative, considering the use of buffer strips and sedimentation basin. However, the careful selection of plants to be used in the buffer strips, as well as the combination of sedimentation basin and modified canals is regarded as original with respect to current practice. The creation of permanent grassy strips at the edges of the fields and the use of cover crops represents new elements in the local standard cultivation technique. The farmers are introduced to the concept of using plants for mainly agro-environmental purposes, and thereby contribute to environmental protection with active interventions, instead of passive behaviour, such as reduced soil tillage or fertilizer doses.

The innovation in the interventions also lies in revitalizing some well-known measures together with the farmers. As such, the Living Lab process has been crucial, where the measures have been designed jointly with the involved farmers. Furthermore, the combination of the NBS measures with the transfer of freshwater from the Serchio River is a new approach to improve the ecological condition of the lake and may prevent more drastic restrictions for the farming around the lake. Spreading the NBS concept through the Living Labs, based on the measures implemented in PHUSICOS fostered awareness and attention for NBS across sciences, disciplines, professions, and generations.

Extensive monitoring is implemented in the areas affected by the measures, mainly focussing on water discharge, turbidity, and chemical components. This will over the coming years form a solid base for evaluating the measures. These data also provide decision support for potential necessary modifications. A program for assessing the non-physical co-benefits still needs to be developed.

The upscaling potential is considered high, as there are numerous similar settings both in the same region, and elsewhere. A benefit for potential upscaling is the great interest for the project shown by stakeholders and farmers that have been involved. If monitoring results clearly demonstrate positive effects, it is expected that more farmers, who have been introduced to the project through the Living Lab sessions, will be interested in applying the same methods. We recommend that after a few seasons, cost-benefit analysis should be performed that considers the positive effects, including the co-benefits, in relation to the loss of agricultural land to the buffer strips and the sedimentation basin. At the centre of evaluation is the amelioration of the ecological state of the lake, which is required by the European Commission. However, the full effects on the lake ecology will become apparent only after the implementation of the diversion pipeline from the Serchio River.

5 Demonstrator case site the Pyrenees

NBS actions in the Pyrenees demonstrator case site are organized through the Consorcio de la Comunidad de Trabajo de los Pirineos (CTP). However, the individual interventions are proposed and organized by different regional organizations, on both the Spanish and the French side. A total of seven proposals have been submitted from the Pyrenees. Four of these have led to implemented interventions (Table 3-1, Figure 5-1), whereas three have been called off, for various reasons (Table 3-2 and Chapter 5.5).

The NBS interventions in the Pyrenees cover a wide range of hazards including debris flows, erosion and shallow instability, rock fall and snow avalanches. Two areas for rockfall mitigation are situated along the same highway between Spain and France (A-136 / RD-934). At Santa Elena, Spain, rockfalls are initiated from a road cut through a till ridge. At Artouste, France, rock ledges and loose surface blocks in a large hillside deliver rocks to the road. One NBS intervention targets the prevention of snow avalanche release in the Capet Forest, above the French village of Barèges. The last intervention is to prevent debris flows, eroded from an area of thick glacial till deposits, threatening the Catalonian village of Erill-la-Vall. The NBS interventions in Santa Elena, Artouste, and in the Capet Forest, are all described in Phusicos deliverables 2.2 and 2.3 (PHUSICOS, 2019a, 2020b), whereas the proposal for Erill-la-Vall was submitted after month 24 and is therefore not described in previous deliverables.

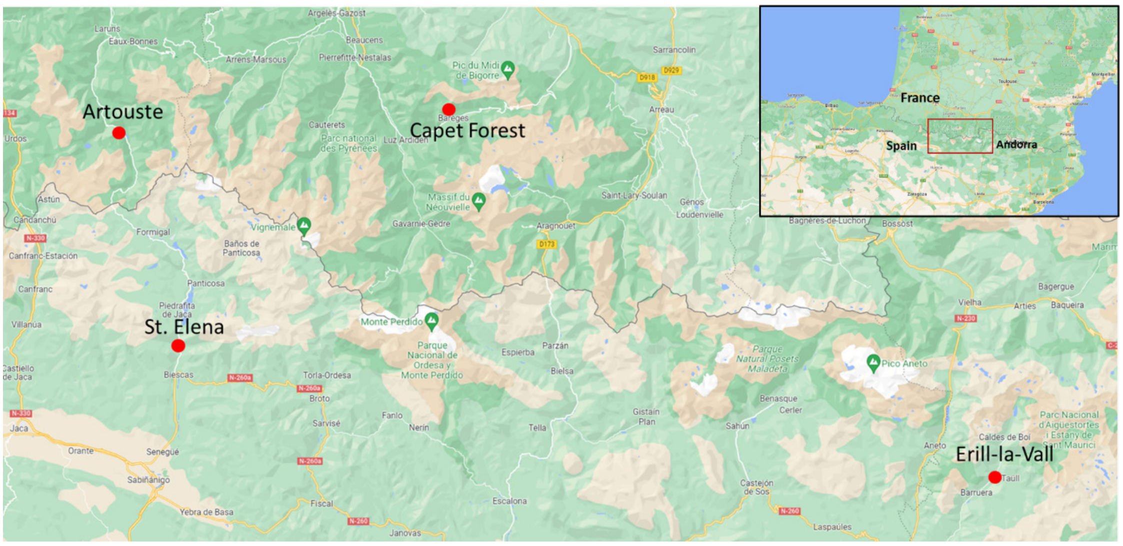


Figure 5-1 Map showing the location of the interventions in the Pyrenees.

Three NBS proposals were called off. Two of these were to mitigate flooding from torrents in the Bastan Valley and at Socques, both in France. The reasons for their cancellation are discussed below (Chapter 5.5). The third cancelled proposal was from the Port Ainé ski resort in Spain. This proposal received critical comments from the PHUSICOS Steering Committee and a major revision, both on the scope and the concept, was required to make the proposal score high enough on the selection criteria (Figure 2-1) and thus in line with the PHUSICOS concepts (PHUSICOS 2019). Following this, the proponent decided to call off the proposal.

The interventions in the Pyrenees are completed towards the end of the project, and therefore, the monitoring will mostly take place post-PHUSICOS. This puts limitations to the level of monitoring as the activities must be financed by the site owners, without the project funding. Baseline data exist for all the sites and form a solid platform for assessing the benefits and co-benefits of the interventions. At one site, the debris flow mitigation in Erill-la-Vall, physical monitoring data have been acquired since 2015, and this will continue. At other locations, monitoring is being planned but fully set in operation yet. This is described for each of the Pyrenees interventions, below.

5.1 Unstable till slope at Santa Elena

<u>Proponent:</u> EGTC Pirineos - Pyrénées (in cooperation with CTP and BRGM)

The slope at Santa Elena, Aragon, Spain (Figure 5-1) has been pointed out as one of the high-risk locations along road A-136, which is an important route between Spain and France (road RD-934 in France). Instability in a steep slope, cut in a thick till deposit (Figure 5-2) and subsequent erosion from this site threatens the road. The site is a terminal moraine landform evolved by the confluence of two valley glaciers during the last glaciation ('Würm' glaciation, ending appr. 16000 years BP). With low road visibility and high traffic speed at the site, risk is mainly connected to rocks lying in the road. Mitigation with rockfall nets has proved insufficient and release of boulders and smaller rocks due to erosion has persisted.

The measures implemented at St. Elena consist of terraces formed by a 5 m high dry masonry wall at the base followed by 10 terraces constructed using wooden logs (Figure 5-2, Figure 5-3). The log constructions are in the form of timber gabions (Figure 5-3 C, D), and these are filled with local sediment and a 10 cm layer of organic soil on top for planting of bush vegetation on the terraces. In addition, ca. 1 m deep holes are filled with organic soil at 3 m intervals along the terraces for the planting of larger trees. Each log terrace step is roughly 2 m high. The width of the construction is 32 m at the base and narrows off to ca. 20 m at the upper, 10th terrace.

Two access roads were built. The first on the left side of the site, to build up the first five terraces. This first access was then to be replaced by another on the upper right side, taking advantage of an existing tractor road to the side of the slope. The first access road was used until the gradient was too steep for the construction machines. The terraces are built as an access road into the slope, large enough to allow the path of mini construction machines: a mini dump truck and a mini excavator. The wooden gabions closest to the access road are first filled to allow access for the construction machines. They are overfilled with sediment to ensure that the wooden gabions are not broken by the weight of the construction machines. Then the second gabion is being filled. Once, all the gabions are filled, the farthest gabion along the access road is prepared with the adequate level of sediment and organic soil for the planting. The same operation is being done until the gabion closest to the access road is finally prepared. Then the terrace is ready for the plants to be used, and the next terrace level is built the same way.

The construction work started out quite slow, but as experience was gained, the process went faster, as the construction company got more used to the working process as well as to use mini construction machines. During a site visit in October 2022, the 7th terrace was under construction (Figure 5-2), and completion was planned for late November or early December. However, rapidly increasing prices particularly for wood caused problems and the work was stopped. Cost estimates were revised, unused funds from the interventions at Artouste were transferred to Santa Elena, and a new call for tenders for the last phases of the construction was published. The same construction company was then contracted to build the last three terraces and thereby complete the intervention. Weather conditions then stopped the start-up of the work for some time, but completion is now estimated for mid-April 2023.

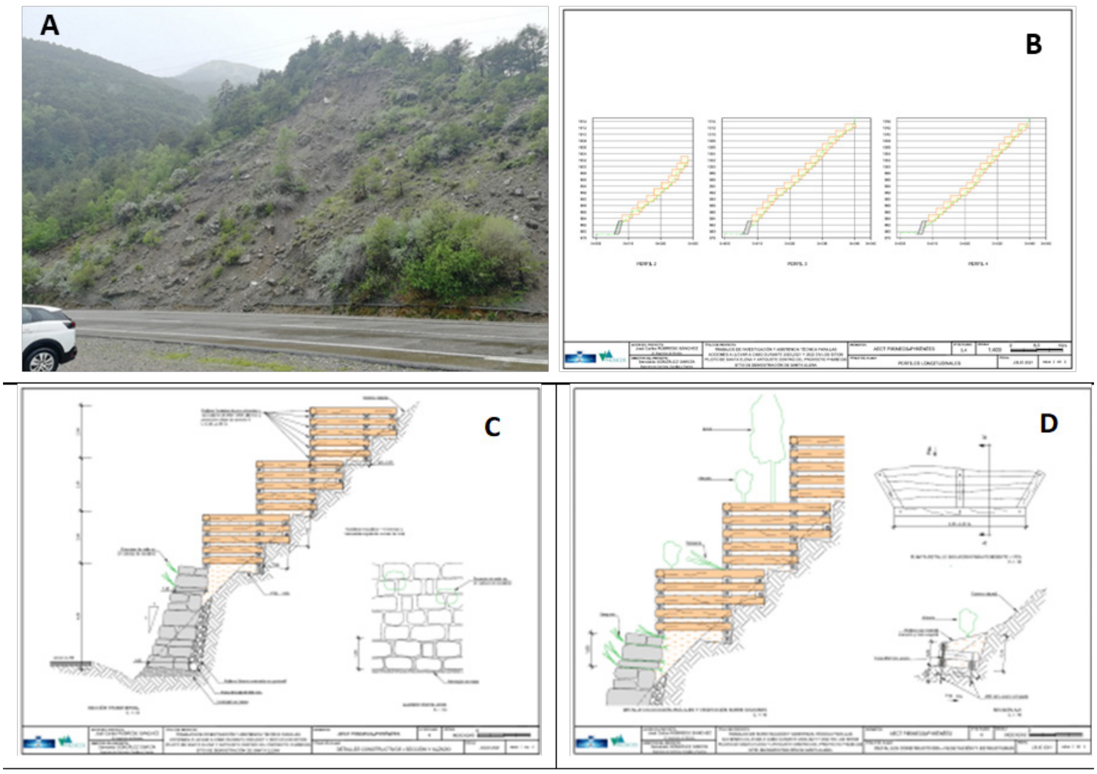


Figure 5-2 A) The till slope at Santa Elena in June 2019. The original net solution can be seen in the lower part of the slope, along the road. B) Three different longitudinal profiles, showing the gradient and the distribution of the wooden gabions along the till slope. C) Construction details showing the dry stones wall and wooden gabions. D) Construction details showing the vegetation to be planted, trees and bushes.

All dug-out material is used in the construction, mainly for fill of the gabions. Additional sediments and organic soil had to be brought in to enhance the revegetation process. All plants used are local and adapted to the climate, altitude, and the local geology (glacial till) (*Pinus sylvestris, Betula pendula, Sorbus aria, Populus nigra, Salix capraea, Hippophae ramnoides and Salix eleagnos*). The *Hippophae ramnoides* is a shrub particularly recommended for stabilizing slopes. Its roots distribute rapidly and extensively, and in addition provide a non-leguminous nitrogen fixation role to surrounding soils.

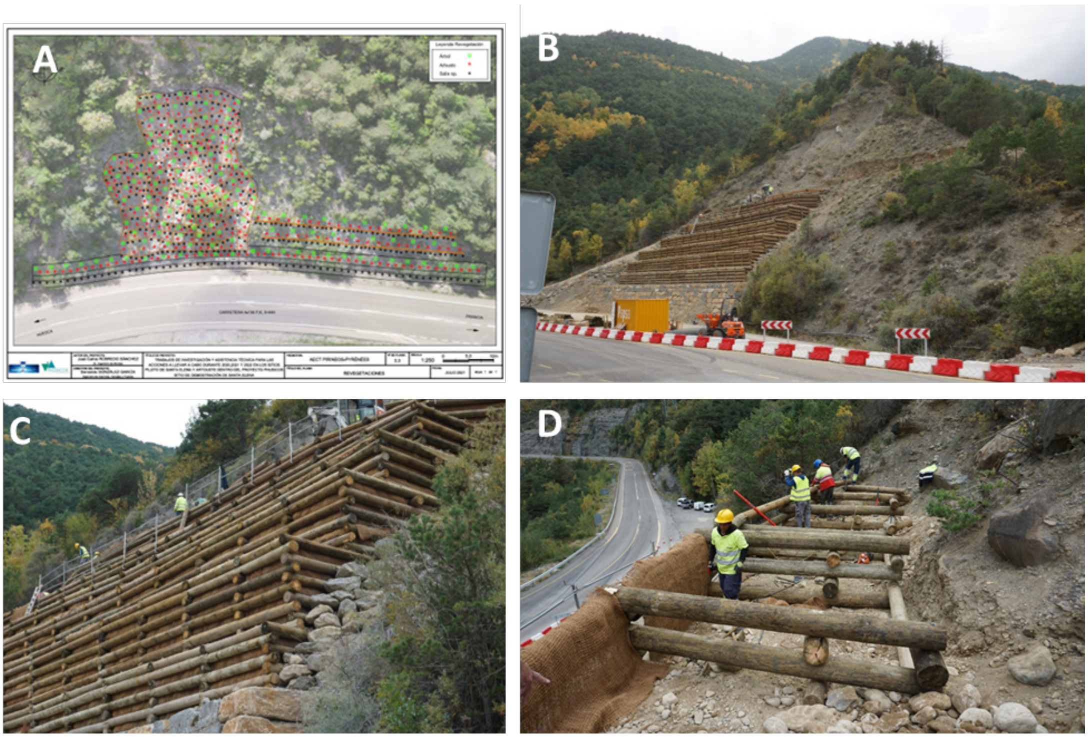


Figure 5-3 A) Overview of the terraces, dry stones wall and types of vegetation planned in July 2021. B) The St. Elena slope on 11. October 2022. The road has been temporarily moved. The 7th of the 10 planned terraces is being built. C) Close-up of the wooden terraces. D) Construction of the wooden gabions supporting the terraces. Notice the use of coconut mats on the outer parts of the gabions that prevent spill over of sediment.

5.1.1 Monitoring and maintenance

At Santa Elena the NBS intervention targets the mitigation of erosion and boulder fall from till slope deposits with rocks and sediment lying in the road causing the highest damage. The site is already covered by a web-camera surveying the conditions on the road. This is probably the most important monitoring of the risk reducing effect. The webcam was mounted to follow the construction of the measures. It is mounted on a pole on the opposite side of the road and covers the slope and the road below. The camera will be kept and operated for at least 5 years after the implementation. The imagery also enables to monitor the growth of the planted vegetation on the terraces. This is important, as eventually, after ca. 20-30 years, the wooden gabions will no longer be the main protective agent, and the vegetation itself is expected to maintain stability of the slope.

Further monitoring plans consist of establishing a calendar of revision with regular, quarterly inspection and corresponding reports. Additional visits will take place after heavy precipitation (rain and/or snow) and/or after any adverse natural events (earthquakes, extreme temperatures, extreme freeze/thaw, etc.). Drone flights for detailed topographic surveying will be carried out annually and in case of significant changes are observed on the webcam or by physical inspection. Stability of the slope, monitored by visual inspections and detailed topography, is particularly important during vegetation rooting, especially during the first three years after plantation.

Many of the co-benefits, such as effects for the society and local economy will also be monitored, mainly by interview surveys with various stakeholders, such as commuters and other users of the road, road maintenance personnel, local authorities, private businesses, and the local company contracted to carry out the construction work at Santa Elena.

The average traffic density at Santa Elena is above 4.000 vehicles per day. In the past, many incidents involving material on the road have occurred, but few accidents have been reported, partly by in-time maintenance work and possibly also by chance. Speed is often high at the site and due to the terrain conditions the visibility is low, so there is little time to react in case of obstacles in the road. Therefore, road-users' sense of safety is an important parameter to monitor through the interviews.

Maintenance of the interventions are required, particularly during the first years. Clearing of weeds will be carried out to favour bushes and trees with deeper root systems. Furthermore, the wooden and stone constructions will be inspected and repaired if necessary until the vegetation has grown enough to secure the slope.

Cost of the planned monitoring has been estimated to ca. 6000 €/year, whereas annual costs for maintenance of the vegetation are estimated to 5000 € for the first three years, thereafter, decreasing to 1000 €, and eventually ca. 500 €/year after 10 years.

Further details on the monitoring program are found in PHUSICOS deliverable D4.7 (PHUSICOS, 2023).

5.1.2 Upscaling potential

Most of the Pyrenean valleys have slopes with till deposits, which may be intervened with measures like the ones in Santa Elena. Many also threaten critical infrastructure, such as roads, railroads, dams, or other kinds of infrastructure. The required characteristics of each slope would be:

- Dimensions and height of the slope.
- Gradient of the slope.
- Type of material and granulometry.
- Accesses for the construction phase.
- Vegetation to be implanted.

During a visit to the Santa Elena site on 27. March, 2023, several local and regional decision-makers participated; the General Director of Roads and Infrastructures of the Government of Aragon, Spain, the Mayoress of Biescas and the President of the Alto Gallego region. They have now confirmed the intention of replicating NBS measures like the ones at Santa Elena and Artouste (Chapter 5.2., below) at three other sites along the same important road, at Escarilla (two locations with Santa Elena-type measures) and Panticosa (Artouste-type measures, see below).

Further replication of the measures will be taken up during other meetings with the regional government's road authorities and other local and regional decision-makers. Specific locations of slopes threatening critical infrastructure will be identified, with the intention of preparing projects for stabilizing a multitude of selected slopes with measures inspired from the ones developed by PHUSICOS.

Examples of old, large-scale NBS / hybrid measures in the Pyrenees

It is important to acknowledge that terracing and revegetating are not new measures, and large old examples can be seen in at least two locations in the region. Measures in Arratiecho, close to Biescas, ca. 5 km south of Santa Elena, were implemented in 1905 and consist of a combination of terraces built up by dry masonry walls, afforested with local tree species (Figure 5-4). In addition, a spillway for torrents and debris flows along the main stream course was constructed, with energy-breaking weirs, also by dry masonry. Today the area appears as a forested hillside from the distance (Figure 5-4), and landslides have not caused a problem during the last >115 years.

These works in Arratiecho as well as others in the Aragon Valleys were designed and implemented by forestry engineers from Huesca, Aragon (Pedro Ayerbe Allué, Benito Ayerbe Aísa and José María Ayerbe Vallés). They made an outstanding and pioneering contribution to the Spanish forest hydrology during the 20th century. In particular, they worked on mitigation against torrents and snow avalanches in the Upper Gállego River and near the town of Canfranc, and the great mitigation works of the international railway station of Los Arañones (below). All these are examples of early NBS or hybrid solutions which work after decades of operation. More information can be found in different scientific papers and historical documents (Fabregas Reigosa et al., 2012; Garcia & Soba, 2013, and https://oa.upm.es/34688/1/INVE_MEM_2014_186583.pdf)

In the example from Canfranc, some 20 km north of Jaca, Aragon, Spain, large scale measures were implemented in the beginning of the 20th century to protect the village and particularly the railway station of Los Arañones (Figure 5-5). The slopes at the time were mainly barren pastures with some open forest and snow avalanches were the main threat in addition to debris flows and rockfall. To mitigate the hazards, the Spanish government conducted a 10-year program of civil engineering works and reforestation. Many walls and barriers both of dry stone masonry and use of cement were constructed in release areas and in snow avalanche and debris flow paths. At the same time, access paths for people and transport of materials with horses and donkeys were constructed. These civil engineering works were followed by a huge reforestation project, in which several million plants were placed in the slopes. These were of various species and have been tested in plant nurseries in the area before they were introduced to the slopes.

Today, the village of Canfranc experiences few snow avalanche- and landslide events. Occasional large avalanches may reach close to infrastructure, but no damage has been recorded for the last decades. Except for the highest zones of the valley side, the area appears as a largely forested valley (Figure 5-5) and the walls, access paths as well as other preventive structures are only seen when hiking in the forests, as for the measures in Biescas.

Figure 5-4 The slope at Arratiecho before the mitigation works started (A), through the implementation (B,C) and at present (D,E). The yellow and red stippled lines mark the same locations. A) The slope before mitigation measures. B) Photo from the construction of the measures, 1905. C) After the completion of the construction work, 1910. D) The slope seen from the distance in 2013. E) Detail from within the slope.

Figure 5-5 The Los Arañones railway station in Canfranc. The forests in the surrounding hill slopes were planted in the beginning of the 20th century.

5.2 Rock fall at Artouste

<u>Proponent:</u> EGTC Pirineos- Pyrénées (in cooperation with CTP and BRGM)

The hazard at Artouste is caused by rockfall, sourced from both exposed rock ledges and loose blocks resting on the steep till-covered slope. The site is adjacent to the hydropower dam of Artouste, where the RD-934 road descends in sharp turns from the height of the reservoir level to the base of the dam. The slope is steep and falling rocks often hit the road and cause hazardous situations. In 2013 a fatal accident happened when a car got a direct hit. As immediate measure, the municipality has mounted 200 m of rockfall nets in one steep section above the road in 2022 (Figure 5-6 A). NBS interventions are to be established in other sections (Figure 5-5). Older, existing measures include two galleries to divert falling rocks across the road at spots where ravines meet the road, and one location with a rockfall net on top of a retaining wall, which stabilizes a road cut.

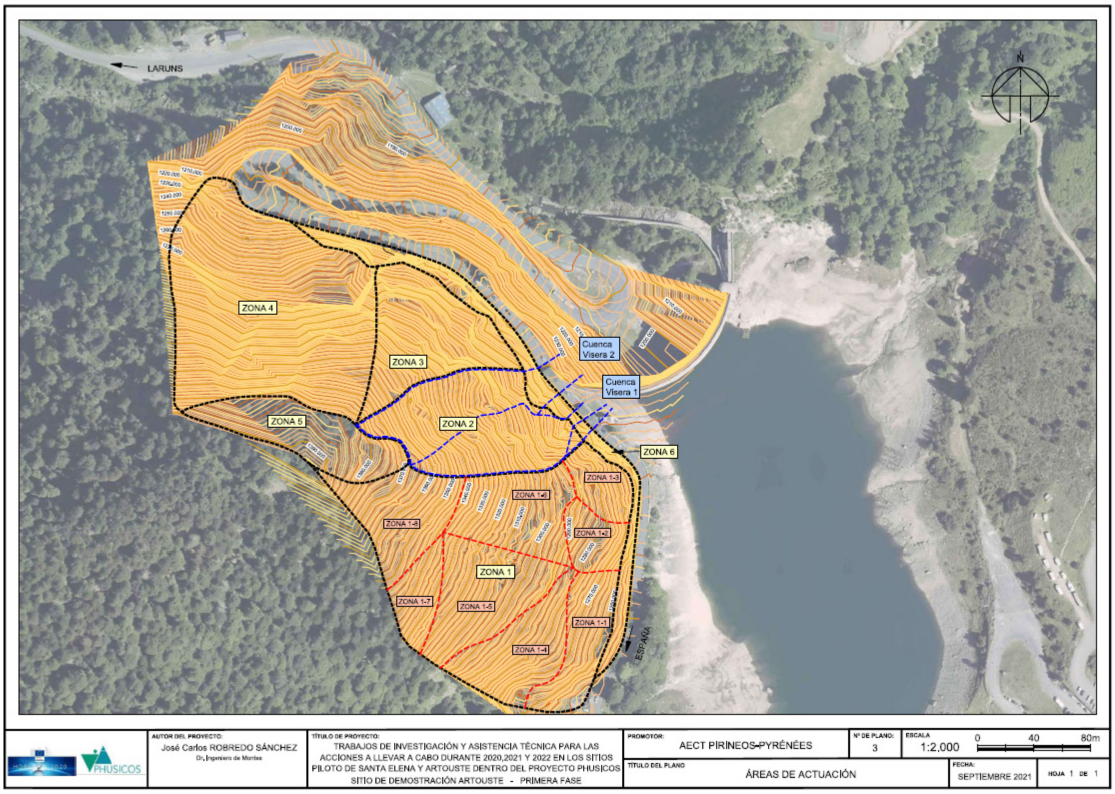


Figure 5-6 Map of the different sections of the whole site of Artouste

The site has been divided in 6 zones (Figure 5-6) based on geotechnical characteristics. After discussions with stakeholders (landowner and manager of the protected area and forest), it was decided that PHUSICOS would intervene in zones 1 and 5.

Zone 1 is a medium-high slope where the rocky substrate, composed of quartzite, marble and a granodioritic intrusion is partially covered by a colluvium and has a high density of trees. Several escarpments in the slope have stratification and fracture patterns, which can lead to rock detachment. Given the slope gradient, potential block size, the density of the vegetation and the character of the colluvium, most unstable blocks are not expected to have a long runout. Some hits on the road, however, cannot be excluded.

Zone 2 represents a snow avalanche path with a very steep slope gradient. This path can also act as a channel for rockfall from source areas in zones 1, 2 and 3. The trajectories of these rockfall lead to galleries over the road (Figure 5-7 A), built for snow avalanche protection. These prevent larger block to reach the road but because they have a gridded roof, smaller block can still fall on the road.

Zones 3 and 4 are secured by various traditional, grey measures. The two zones have roughly opposite slope orientation, NNW and SSE, and are separated by a crest. In Zone 3, as in Zone 1, escarpments form potential release areas for rockfall. The boundary between Zones 3 and 4 is formed by the lithological change from marble rocks to the granodioritic intrusion. This escarpment constitutes the main source area for large blocks affecting Zone 4. Blocks from this step can be larger than 1m^3 and reach high velocity and increasing energy on the steep slope. Where Zone 4 meets the road, a wall has been built (Figure 5-7 B) to prevent blocks from falling onto the road. Avalanche fences were constructed along the road in Zone 3 (Figure 5-7 C) that also stop falling rocks. The municipality mounted an additional 200 m of rockfall nets in 2022 (Figure 5-9, A) to protect the road section where a fatal accident occurred in 2013.

Zone 5 is the highest and at the same time being farthest away from the road. Considering its position with respect to the road, the medium-low slope angle and the high density of trees, the probability for rocks released from this zone reaching the road is considered low but still high enough to justify some measures.

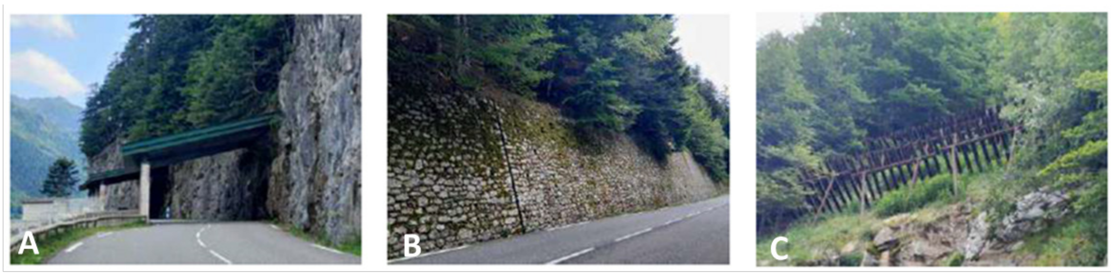


Figure 5-7 Photos of older existing measures. A) Galleries for snow avalanches installed at the confluence of Zone 2 with the road. B) Masonry wall built at the intersection of Zone 4 with the road. C) Avalanche fences that act as shields against falling blocks at the intersect of Zone 3 with the road. (Photos by EGTC Pirineos- Pyrénées)

Work in the Artouste slope was greatly delayed from the original plan partly due to bureaucratic reasons and the need for obtaining permissions. The area is in the core of the Pyrenees National Park and the park authorities initially were sceptic to any work being done in the forests of the Artouste slope. Significant efforts and time were invested in negotiating with the park authorities for a collaboration protocol that could be agreed upon and signed by all stakeholders in the area, which was eventually achieved.

The NBS interventions proposed and approved in Zones 1 and 5 consist of different structures made by wood and/or local stones (Figure 5-8). The solutions rely on active measures (manual stabilization and/or timber structures) to stabilize the source areas and passive measures (mixed wood and/or stone structures) to slow down and/or divert rocks in their trajectories enhancing the protective role of the forest. Initially, the slope morphology was surveyed in detail with ground-based Lidar (Terrestrial Laser Scanning). In addition, a handheld Lidar was used to map the forest in detail, comprising each individual tree. The entire slope including the release zones is forested mainly with pine and birch. The forest therefore plays an important protective role. Following the Lidar surveys, all release zones as well as individual loose blocks have been mapped and marked with flags indicating the type of measure to be implemented (Figure 5-9 B & C). Smaller rocks were simply moved by hand to stable positions behind trees or groups of trees.

The measures implemented in the slope are primarily the construction of different wooden structures but also local stones are used to stabilize some of the exposed ledges (Figure 5-10, Figure 5-11 and Figure 5-12). The logs used are taken from local forests (not in the Artouste slope, though). They are moisture-protected in the lower ends, anchored in the ground by long iron rods and either bolted or tied together in the top ends (Figure 5-10, Figure 5-11 and Figure 5-12). Each structure is designed individually for the individual block or ledge they stabilize.

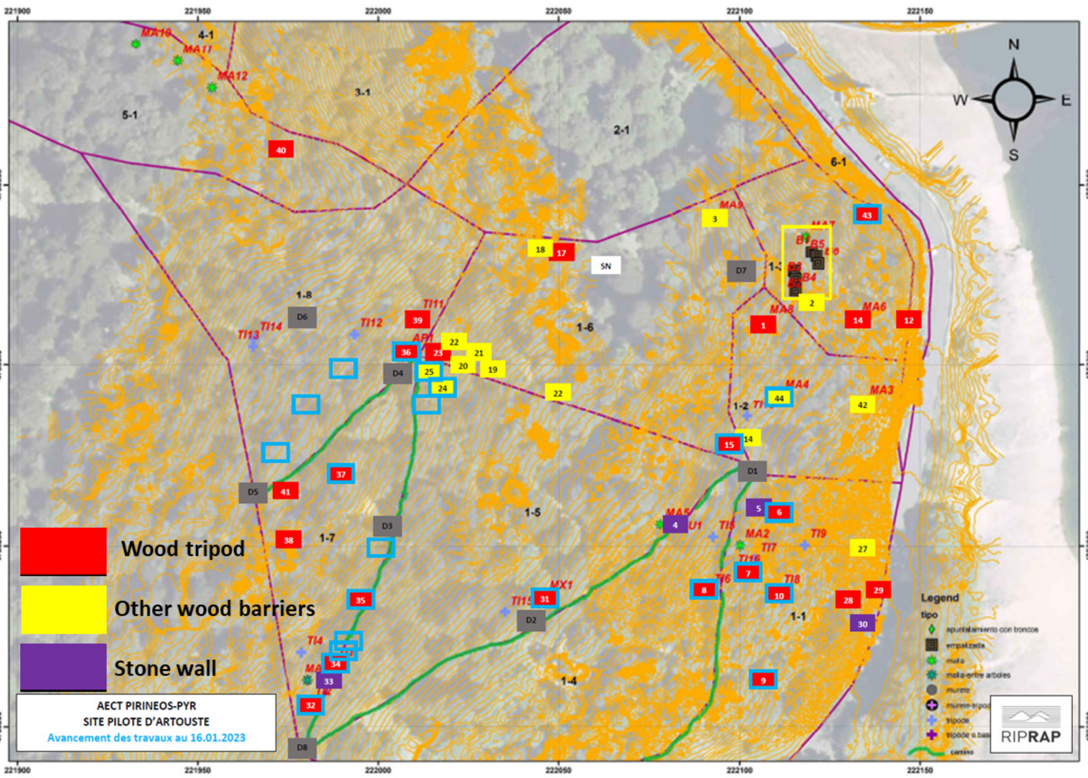


Figure 5-8 Map of the different sections of Zone 1 and the implemented classes of measures, tailored for each source location.

As many of the PHUSICOS interventions the solutions implemented at Artouste should be classified as a hybrid solution. They do not include a component of increased growth or increased biodiversity. However, the solutions are selected to minimize the footprint of construction and to preserve the natural environment to the highest possible degree. All materials are lifted in by helicopter so no new access roads for machinery have been build. After the material was in place on the slope all structures are built by hand to avoid any use of heavy machinery on the ground. Removal of or damage to trees was carefully avoided as the natural forest also serves as a protective agent for rockfall. In total, the selected solutions are considered more environmentally gentle compared to traditional solutions made of concrete, nets, and more extensive bolting.

In addition to the PHUSICOS measures, some cutting of trees are being done by the Pyrenean National Park or the French Forest Office (ONF) as part of the site management and hiking path maintenance. The cut trunks are placed between living trees to further increase the protective role of the forest.

As the area also is a popular starting point for mountain hikes information posters were placed at four locations near the road and at starting point of hiking paths (Figure 5-9 D).

Figure 5-9 A) Newly established rockfall nets in one section of the slope at Artouste. B) A loose boulder, which is flagged to indicate type of protective structure to be implemented. C) Rock ledge, potential source of rock fall, flagged for NBS protective measures. D) Poster at the Artouste slope, informing about the project and the NBS measures to be implemented.

An additional activity related to the Artouste site is that test facilities for rockfall NBS measures are established both in La Peña Estación, Spain, in the premises of the company doing the wood works and at an open-field site close to Artouste, France with similar characteristics as that of Artouste. The facilities will comprise indoor full-scale tests of various solutions partly constructed. Different construction techniques and wood species will be tested. The main goal is to test the rockfall impact on rigid barriers made of wood, which should be designed to withstand the dynamic load. The best design and wood species will then be tested in the open-field full-scale test site at Gourzy, Eaux Chaudes, ca. 10 km north of the Artouste site, in the municipality of Laruns. Here, various block shapes will be tested against full-scale measures in instrumented field tests. The test facilities will be active after PHUSICOS, and the University of Madrid will be an active partner in the testing. The indoor lab testing is planned to start in the winter of 2022/23, whereas the open-field testing will start in the spring/summer of 2023. Testing will be done with relevance for both the Artouste and Santa Elena sites. The tests are to be planned in detail but will comprise testing the flexibility of various tree species and sizes, as well as testing of structures like those of Santa Elena. Follow-up and further testing will be conducted beyond the PHUSICOS project. The municipality of Laruns has shown enthusiasm and support and wish to promote the area as a reference site for this type of testing. Furthermore, the Scientific Committee of the Pyrenees National Park has also expressed their interest for this part of the project.

The innovation of this intervention lies in using mixed techniques by implementing a rock protection technology that has been used mostly with grey materials (metal fences, nets, concrete galleries) and replace it with wooden frames combined with forest management practices. It also lies in the close cooperation and agreements with the numerous national, regional and local actors. The measures, once tested and found functional, have a large upscaling potential as similar problems and restrictions exist in many valleys of the Pyrenees as well as elsewhere.

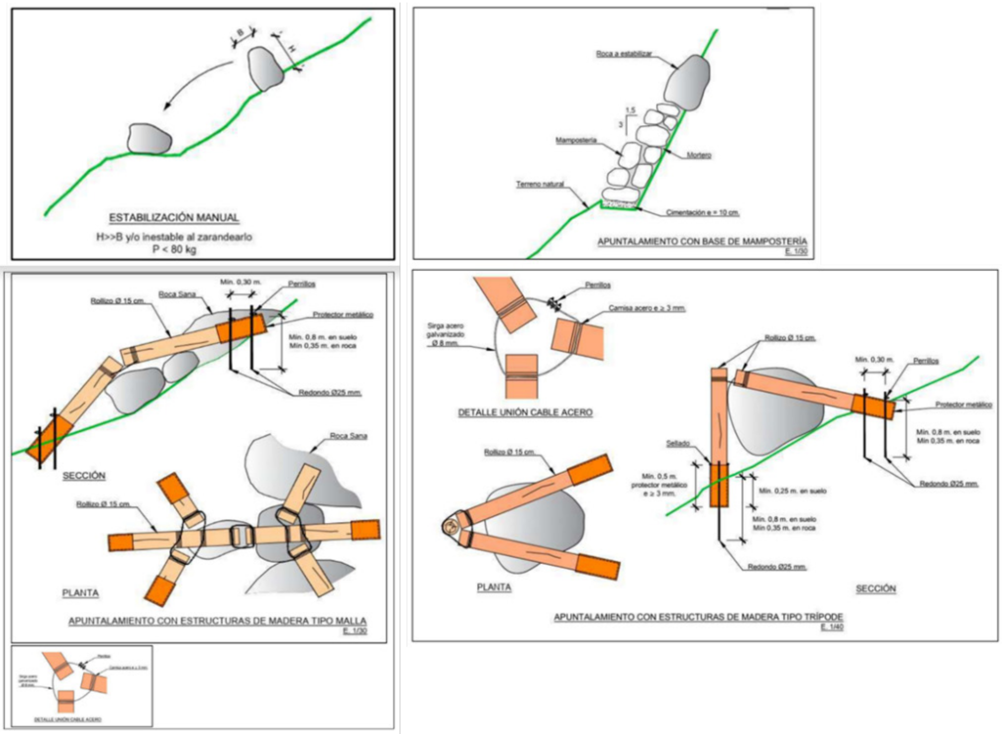


Figure 5-10 Design of protective ('active') measures for stabilizing of individual blocks to be implemented at Artouste. Annotations in Spanish.

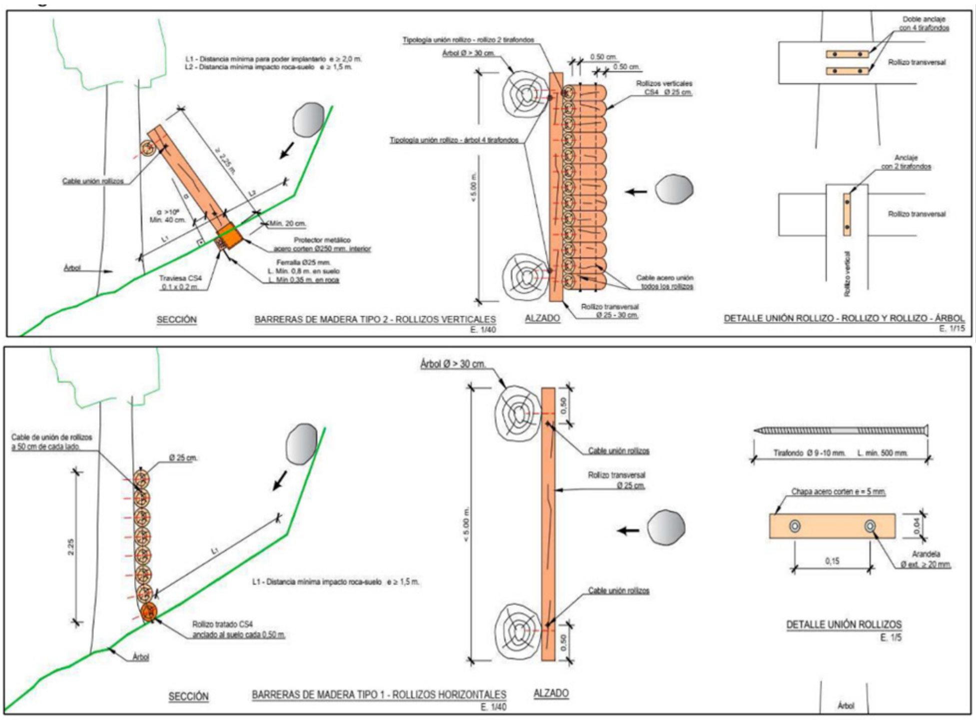


Figure 5-11 Design of protective ('passive') structures using existing trees for support, at Artouste. Annotations in Spanish.

Figure 5-12 Examples of implemented protective structures (based on design principles of ***Feil! Fant ikke referansekilden.*** *in the slope at Artouste (Photo: S. Fábregas)*

5.2.1 Monitoring and maintenance

NBS implemented by PHUSICOS are aimed at reducing the probability of rockfall hitting the road and to improve the protective role of the forest. Monitoring will mostly consist in regular visual inspections and corresponding reports on the state of the solutions and on the adequate management of the forest, ensuring its healthy state and degree of regeneration.

The EGTC Pirineos – Pyrénées is engaged for 10 years of monitoring of the solutions installed in the slopes at Artouste. They are currently (before the end of PHUSICOS) also establishing a protocol and calendar for ordinary and extraordinary visits and reports to ensure the status of the solutions, follow-up, and control of the state of the protective forest and other vegetation in particular its health and degree of regeneration. The monitoring, particularly on the road, will be shared with the unit in charge of road maintenance and management from the Departmental Government (CD64).

As part of the visual inspections of the site, the Hazard Control Index (Indice de Maîtrise de l'Aléa - IMA) developed by the French Forest Office (ONF) in "Guide de Gestion des Forêts Pyrénéennes à rôle de protection" (ONF, 2016) will be used to assess the level of protection provided by the forest compared to the baseline (before the interventions). The aim is to increase the IMA from the current low to medium (IMA=2/5 – 3/5).

Environment and ecosystems monitoring will also be part of the regular visits, with inspection of tree health and the general state of the vegetation in the slope. Furthermore, co-benefits related to society and local economics will, as for Santa Elena, be monitored through interview surveys with various stakeholder groups.

Assessing the maintenance needs of the installed measures will be part of the regular inspection visits and will be included in the protocol and calendar for visits, as the 10-year engagement of EGTC Pireneos-Pyrénées also cover maintenance. Maintenance need will comprise repair and replacement of the timber- and rock constructions when needed, in addition to ordinary forest management. Possible new loose block, exposed by tree-fall or frost-heave, will be fixed.

The cost of monitoring and reporting is estimated to 3.000 € / year. This covers also routine maintenance during the first years. Potential increase of this with time, is not yet accounted for. Further details on the monitoring program are found in PHUSICOS deliverable D4.7 (PHUSICOS, 2023).

5.2.2 Upscaling potential

All Pyrenean valleys could be intervened by this kind of measures. However, this is limited to the block dimensions that these solutions can stabilize (about 1,5 tons) or stop/hold (about 0,5 tons). Site characteristics to evaluate for similar measures are:

- Slope length, height, and gradient.
- Type of material and probable block size.

- Accesses for the construction.
- Protective role of the forest.

During ordinary meetings with the Departmental Government unit in charge of road management and maintenance, specific locations threatening critical infrastructure will be identified with the goal of planning further mitigation measures like those implemented at Artouste and not the least those further developed through the testing in the facilities described above.

Many mountain regions on the northern hemisphere, which were glaciated during the last glaciation expose large areas of steep slopes covered by glacial till. Hence, there are potentially numerous areas with conditions like those at Artouste, with surficial boulders, either glacial erratics or rockfall blocks, and exposed bedrock ledges from which blocks can be released. Consequently, the potential for using similar techniques is huge. In Norway, as an example, a large portion of the road and railroad network run along forested valley sides with similar conditions as at Artouste and similar interventions have never been tested. The NBS implemented at Artouste may not be the best solution for every location, but if monitoring at Artouste documents a success story from this site, the motivation to test out these types of implementations could increase, both in Norway and elsewhere. Results from the test facilities in La Peña Estación (laboratory scale) and Gourzy Eaux Chaudes (full scale) will also add to the upscaling of these NBS.

5.3 Snow avalanches at Capet Forest

Proponent: The French Forest National Office (ONF), service of Mountain Terrain Restoration (RTM) in association with the French State represented by the Departmental Direction of the Territories (Hautes-Pyrénées) (in cooperation with CTP and BRGM).

The hazard at the Capet Forest site is from snow avalanches along the 'Midaou' avalanche path. Numerous avalanche events reached the village of Barèges, the last event being in 2013. The slope and the release area have numerous old 'grey' protective structures, the oldest ones from the mid 1800's and according to ONF's Laurent Lespine is a 'museum of avalanche protection structures'. Due to the prevailing wind direction, the snowpack may build up higher than the ca. 4 m high existing structures (Figure 5-14). In 2013, an avalanche was initially released in the upper ca. 0.3 m of snow exceeding 4 m snow height (L. Lespine, pers. comm., 2022).

The oldest grey structures in the slope were the first ones to be implemented in France, and consist of steel fences, concrete structures, and terraces built by dry masonry walls (Figure 5-14 A & B). These constructions aimed at accumulating soil for plants to grow and to increase the macroscopic roughness of the terrain. Some of the oldest structures included iron poles meant to mimic trees installed by the military in the 19th century. In total, there are 981 grey structures with a total length of 6 km. They are all mapped in detail, and they are inspected for necessary maintenance every 3 years. These structures are meant to co-exist with the new NBS measures. The grey measures are designed to protect against avalanches with a return period of 100 years. ONF estimates an investment need of 15 mill. Euro for total protection by additional grey measures plus the cost of regular maintenance (30k€ to 50k€ per year).

The implemented NBS measure is afforestation by planted trees of 9 different species (*Pinus uncinata, Larix decidua, Abies concolor, Picea engelmanii, Pinus cembra, Pinus ponderosa, Pinus bougetii, Pinus sylvestris, Cedrus deodora*) all of which are considered to be adapted to the climate and elevation (1800-2200 m asl.) of the site. Supported by PHUSICOS and ONF-RTM, a student from the École Nationale Supérieure des Sciences Agronomiques de Bordeaux carried out a detailed study on the best adapted tree species to face natural hazards in mountainous areas considering climatic, topographical and soil conditions and also accounting for climate change. This study, carried out in 2019, set a base for the afforestation in Capet. The plants are either protected by the 88 newly built wooden tripods (Figure 5-14), by the existing grey structures, or by existing natural groups of trees. The plants are planted in polygons downslope of the protective structure. In total there are 257 polygons, 189 big polygons with 30 plants in each and 68 small polygons with 16 plants in each (Figure 5-13), totalling about 6758 trees, which were planted over a period of 4 years with the same age of plants in each polygon. The wooden tripods are also meant to serve as protection structures against avalanche release during their existence and until the planted trees grow high enough and develop a stem thickness to act as effective protection against avalanche release in ca. 20-30 years. This is particularly important in barren areas with little or no existing vegetation or grey structures (Figure 5-14 C).

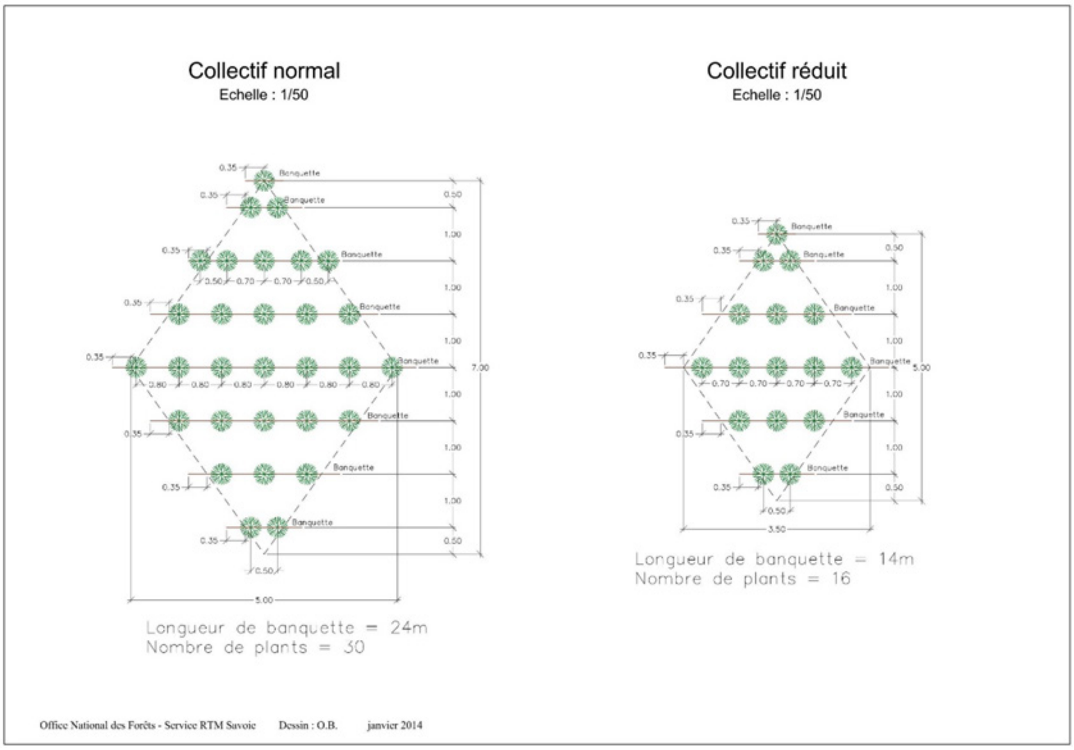


Figure 5-13 Design example of the planting in two different configurations, 7x5m / 30 plants (left) and 5x3,5m / 16 plants (right), respectively.

Recent reforestation work in Capet resumed in 2018 after it had previously been neglected. The implementation with PHUSICOS started in 2020 with preparatory works of tripods establishment and earth-moving and was completed in the summer of 2022. Currently, ONF-RTM is building a permanent shelter / cabin at the site where maintenance personnel can stay for several days. This is not part of the PHUSICOS funding but will also be useful regarding inspection and maintenance of tripods and plants.

The experience with the NBS installations is that some of the tripods were damaged by snow creep and had to be repaired. Different orientations and construction details were tested. In addition, several plants have died (Figure 5-14 D). The 'survival rate' seems to vary with soil thickness, but other factors such as local topography and exposition may also influence the growth. A certain loss is expected and even required, since the plants in each collection (polygon) are planted too dense for proper growth of all (Figure 5-14 D). During a site visit in October 2022, a significant difference in size was observed between the most recently planted trees (summer 2022) and the first ones, which were planted in 2019.

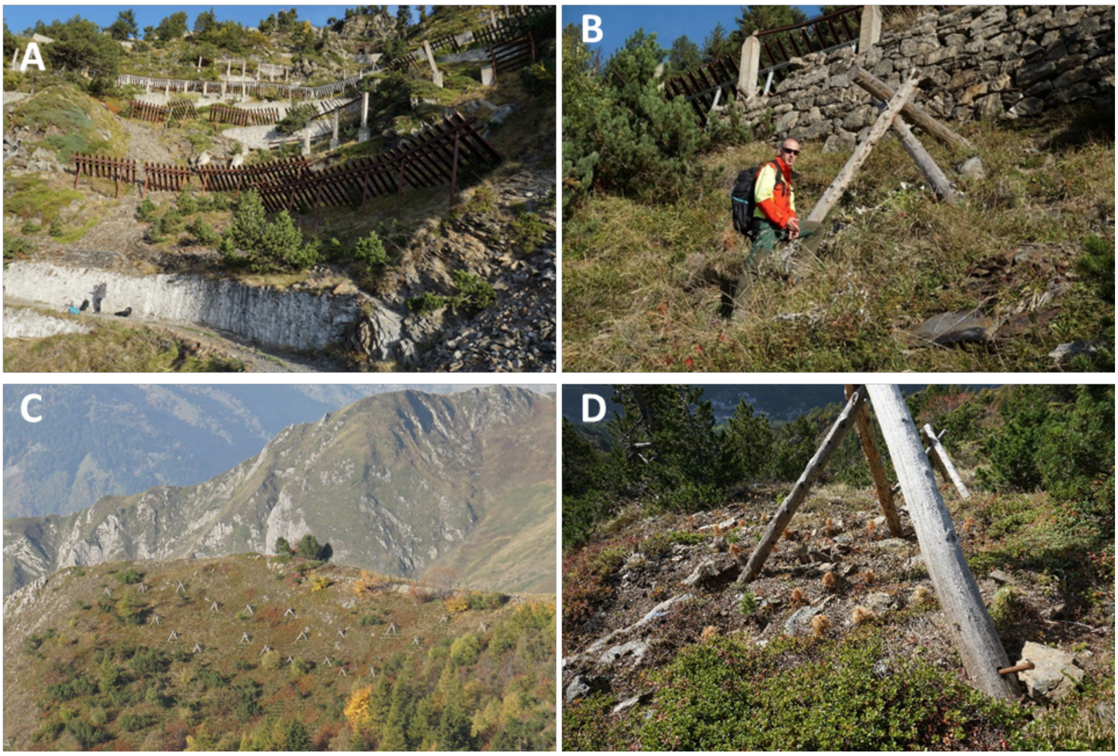


Figure 5-14A) 'Grey' structures in the slope above the access road from the helicopter platform to the construction site for the shelter. B) One of the tripods for protection of new plants. C) Tripods protecting plants in a more barren part of the avalanche release area. Natural forest and old grey structures can be seen in the foreground. D) Example of plant collection where most plants have died, but still enough for the purpose seem to survive.

5.3.1 Monitoring and maintenance

At Capet, hazard monitoring is based on detailed documentation of avalanche occurrence. Automatic instrumentation to monitor snow height will be installed in 2023. A snow LIDAR flight was carried out with the support of PHUSICOS at the end of February 2023. Regular follow-up of the state of the structures and plantations will be carried out. Furthermore, pressure will be monitored by an instrument mounted on one of the avalanche fences. Despite this being on a 'grey' structure, it will record all avalanches hitting the structure.

In addition, a collaboration with the French Research Concil - CNRS in the 'Envirosciences-Pyrénées' project aims to create catalogues of hydro-gravitational and tectonic events in two specific territories of the Pyrenees: the Pays Toy and the Béarn. Lack of detailed information on the location and date of occurrence of these phenomena in the Pyrenees has raised the need to deploy dense networks of multi-parameter measurement stations. By the end of 2022, about fifty autonomous real-time stations will be deployed for 10 years in both territories, with locations in both valleys and upper slopes. The intention is that also Capet Forest is included in this network of stations, which is important as seismicity may also trigger avalanches. Each station will consist of a seismological, meteorological and GNSS recording device. The School and Observatory of Earth Sciences (EOST, Strasbourg) and GéoAzur (Nice) have designed and built a prototype of a modular and low-cost integrated station, associating several types of sensors (4.5 Hz geophone, GNSS receiver and meteorological station), a high-frequency digitization module, a communication module, and a power supply module (mainly by solar energy), planned also for installation in the Capet Forest.

Co-benefits of the interventions at this site include possible effects on the environment and ecosystems, societal effects, and potential effects on the local economy. The former of these will be investigated through monitoring of plant health in the plantations, monitoring of plant mortality and re-planting if needed. Societal and economic co-benefits will be monitored through annual meetings with authorities, and through interview surveys with stakeholders, including the general public (sense of safety) and local businesses (Tourist business, maintenance company, helicopter company, etc.).

Maintenance of the NBS will comprise continued inspection and repair of tripods if these are damaged, until the planted trees are high and solid enough to act as protection, i.e., in the first 20-30 years. Furthermore, tree health and mortality will be assessed, and new plants added where necessary. On the other hand, trees may also have to be removed from some of the plantation polygons as they are planted too dense if thy all survive and grow. As the existing grey measures need regular maintenance, the NBS maintenance will be an integrated part of this, with ONF as the responsible entity.

Further details on the monitoring program are found in PHUSICOS deliverable D4.7 (PHUSICOS, 2023).

5.3.2 Upscaling potential

This combination of grey infrastructure and plantation has a great replicability potential in areas exposed to avalanches. Indeed, the life span of grey infrastructure is extended by planting trees. RTM-ONF has identified and is currently working on a project implementing similar solutions at three locations with avalanche hazards: La Mongie (Hautes-Pyrénées), Bagnères de Bigorre (Hautes-Pyrénées)and Peyresourde (Hautes-Pyrénées).

Forests have a well-documented effect on the release probability for snow avalanches (NGI, 2013). They affect the microclimate around the trees in a way that reduces the release probability. A positive radiation balance in forests affect transition in the snowpack and the development of surface hoar. The canopy coverage is the most important factor, as it affects the distribution of snow falling on the ground and may disrupt the persistence of weak layers. Bauerhansl et. al (2010) conclude that a coverage of 50-70% (species dependant) is sufficient to prevent release of large avalanches in the Alps. In addition, the trees have an anchoring effect on the snowpack. Avalanches are often released in windblown snow, which will also be positively affected by forests. Forests will also have a breaking effect on the runout of avalanches (Anderson & McClung, 2012), but for large avalanches and if avalanches are released and are allowed to gain velocity and energy forests have a more limited effect (NGI, 2013). Lied (1979) estimated that a dry slab avalanche will reach its maximum velocity after only 40 times the release fracture hight, i.e., usually within less than 100m. Therefore, the size and orientation of open areas, e.g., clear cuts are important, as is the reforestation of such open areas. All these described characteristics are important in deciding areas where measures like those in the Capet Forest may be implemented.

There are numerous avalanche prone areas where the release zones are barren or contain sparse forest cover only, and which therefore have a potential for afforestation as a mitigation measure. Barren zones can be natural, caused by elevation, soil conditions or be a result of forestry or wind throw. Replanting in clear-cuts is an obvious measure. Snow avalanches can release in clear-cuts and reach high velocity if the open area is extensive enough in the down-slope direction. Release areas above the treeline is a larger challenge, but with climate change, the elevation of the treeline may increase in many areas and planting above the current treeline may therefore be successful in some areas. In the Capet Forest area, the Midau avalanche path was chosen for the interventions. The neighbouring avalanche path, the Theil, also poses a threat to the infrastructure in the valley, but its release area has less favourable soil conditions for a successful afforestation campaign with more challenging topography and a generally thinner soil cover with larger areas of exposed bedrock.

Quantifying the upscaling potential is difficult and must be assessed from region to region. However, one relevant example could be the issue of forestry and clear-cut practices in the western parts of Norway most of which is also prone to snow avalanches. Forests cover 38% of the Norwegian land base. Approximately 52% of the productive forests in western Norway occurs in areas with steep terrain (20° and higher) out of which 33% are located in terrain steeper than 27°. Much of this forest consists of spruce, which was planted some 40-60 years ago and in extensive areas forests are ready to be harvested today. Where clear-cutting is applied, re-forestation is important to minimize conditions where avalanches can be released. Similar situations may exist in other countries and regions for example the Alps and the Carpathian Mountains.

Grey measures like snow fences cover many release areas in the Alps. If these fences are located below or closely above the tree line, these zones could also be areas for afforestation, where the fences would serve as initial protection. This is also a focus of the 'GreenRisk4Alps' project (https://www.alpine-region.eu/projects/greenrisk4alps). The main objectives of this project are:

- To overcome conflicts and resistances with new mitigation alternatives through science-based communication support.
- To implement innovative ecosystem and forestry-based risk management for natural hazards by generating recommendations and guidelines adapted to local practical, socioeconomic, scientific, and political needs.
- To create a Forest & Risk Management Workbook – a new standard for forestry management integrating needs for effective natural hazard risk management

Success of the implemented interventions in the Capet Forest will only be evident in 20-30 years but would then add to the growing acknowledgement of such sustainable solutions.

5.4 Debris flow mitigation in Erill-la-Vall

Proponents: Vall de Boí Municipality and Department of Sustainability and Territory of the Government of Catalunya (in cooperation with CTP)

The Erill-la-Vall site in Catalonia, Spain, is threatened by erosion and debris flows from a thick (>50m), boulder-rich, till-covered mountain slope (Figure 5-15, Figure 5-16 and Figure 5-17 A). Numerous smaller gullies feed debris into the main debris flow channel, and debris flows may eventually reach the Village of Erill-la-Vall (Figure 5-16), in the Vall de Bois municipality. Slope instability and debris flows in this area have been investigated within a PhD thesis in 2007 (Raïmat, 2007) that initiated on-site monitoring for the last 15 years.

A first mitigation measure, a stiff barrier (a wall) below the steepest part was filled up by debris within only 2-3 years. A flexible barrier (a debris flow net) was subsequently established upstream of the wall at significantly lower cost. This was also filled up, but both measures form steps that dissipate energy and elevate the erosional level. There is an instrumented drill hole from 2007 ca. 20-30 m behind the current slide scarp (Figure 5-17 B) with piezometers and suction measurements. The borehole was continuously cored down to bedrock at 55m depth discovering a deforming layer of ca. 1 m thickness at 19-20 m depth. Other on-site instrumentation comprises a rain gauge (1 minute temporal resolution) and a micro-seismic network.

The annual precipitation of the area is about 1100 mm/year mainly in the fall and spring. However, intensive showers in July-August seem to have the worst effect on the debris flow initiation. Interpretation of the monitoring data shows two different processes (C. Raïmat, pers. Comm., 2022). Heavy rain triggers immediate response in the surface sediments with erosion and downslope transport of debris and larger blocks, which are abundant in the till material (Figure 5-17 A). However, a piezometer at 30 m depth in the borehole shows a response to heavy rain after 10-15 days and this may trigger larger, deep-seated events. Such an event occurred in 1907, after a long period of rain (Raïmat, 2007).

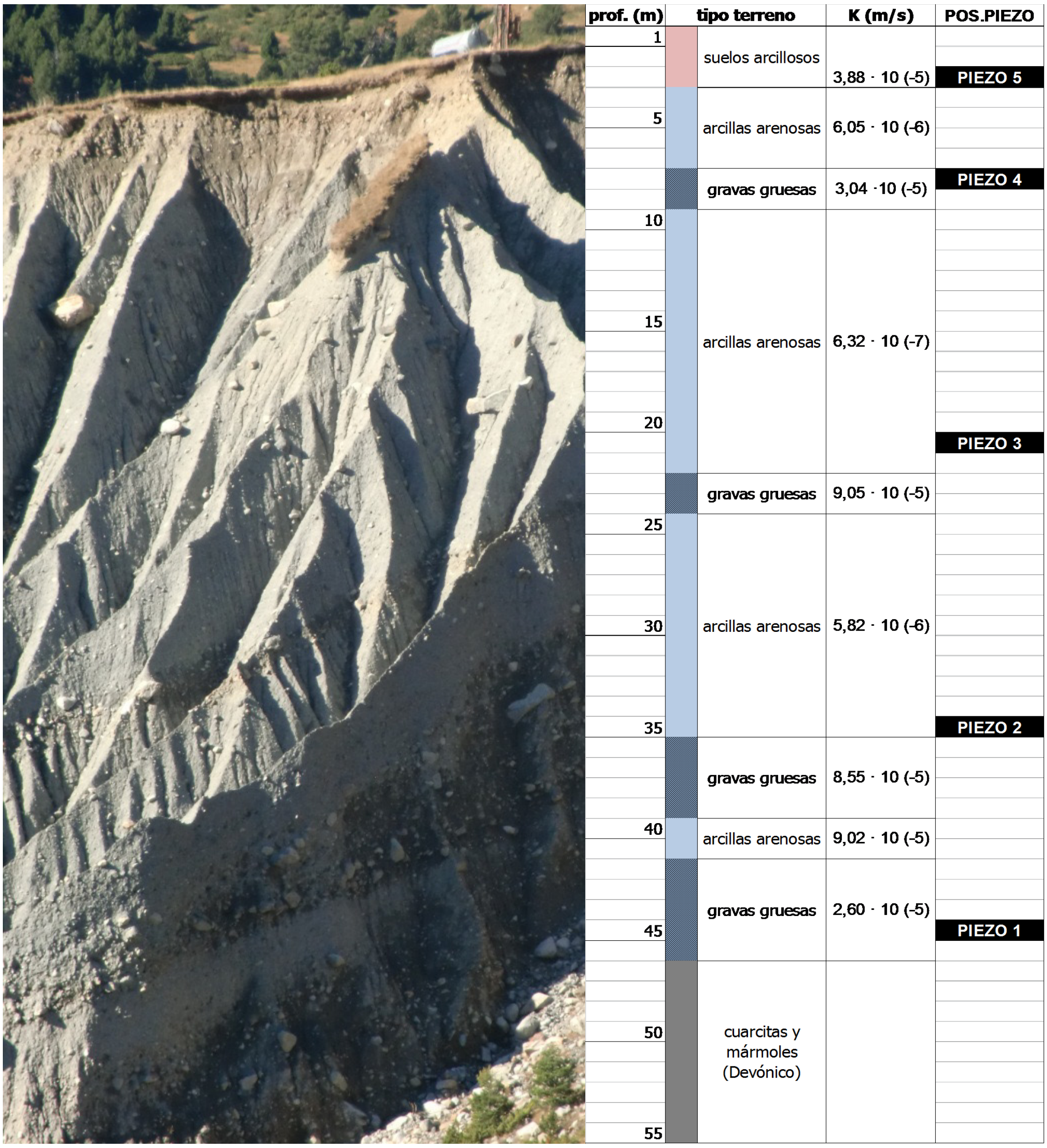


Figure 5-15 The complete till section at the Erill-la-Vall site, with stratigraphy and position of piezometers (figure by C. Raïmat).

The NBS measures consist of terraces constructed by dry stone walls and timber (Figure 5-18, Figure 5-19). These are constructed in the lower parts of the steepest part of the two main gullies. The terraces are to be covered with organic soil and planted with local vegetation; grass, bushes, and trees (Figure 5-19 A). Soil and turf from the area is used, and natural fertilizers from local grazing animals are used on the terraces. About 2500 plants will be used, all local species (*Betula pendula*, *Salix purpurea*, *Salix caprea*, *Rhamnus alpina*, *Viburnum opulus*, *Corylus avellana*, *Prunus spinosa*, *Fraxinus excelsior* and *Salix sp.*). The terraces are constructed starting from below and as high up as possible with an excavator (Figure 5-18). The job was done by a small, local company and an enthusiastic excavator driver, who got interest for the project and saw this as a challenge. This is mentioned because most larger construction companies probably would not have taken on this job due to high economic (as well as physical) risk.

The effects of the measures have been modelled with RAMMS-Debris flow, in cooperation with WSL, Switzerland. There is a high resolution (2 cm) DTM for the area, measured by drone-based LiDAR (Figure 5-20). A new debris flow net will be installed downslope of the terraces, between the existing net and the terraces, to create another step and prevent further lowering of the erosional base. The costs for the net and its implementation are not part of the PHUSICOS funding.

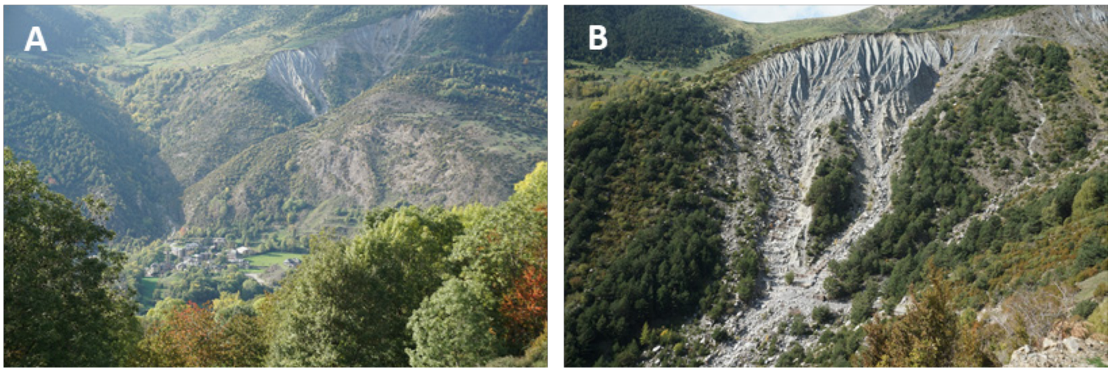


Figure 5-16A) The Erill-la-Vall site seen from the other side of the valley. The source area for debris flows in the upper part of the photo, and the village in the lower, central part. B) The release area for debris flows

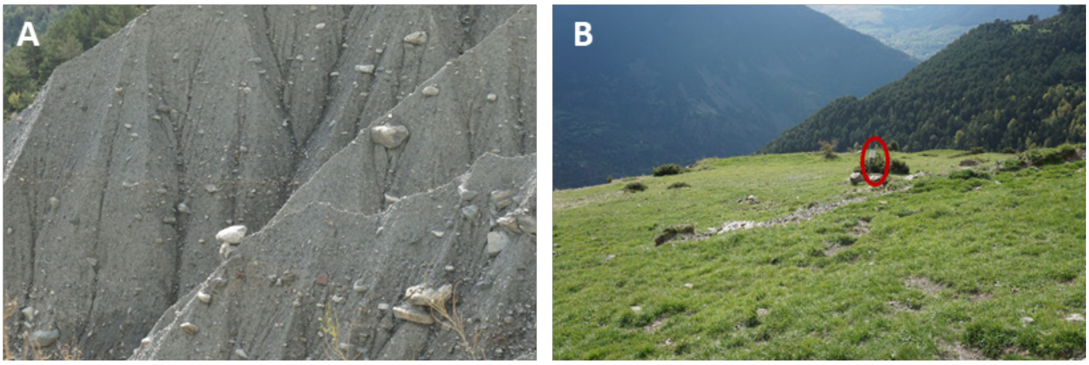


Figure 5-17A) The boulder-rich till, which is easily eroded and feeds the debris flow paths during periods of heavy precipitation. B) The borehole location, marked by a white box (inside red oval) at the bush near the middle of the photo, ca. 20-30 m behind the back scarp.

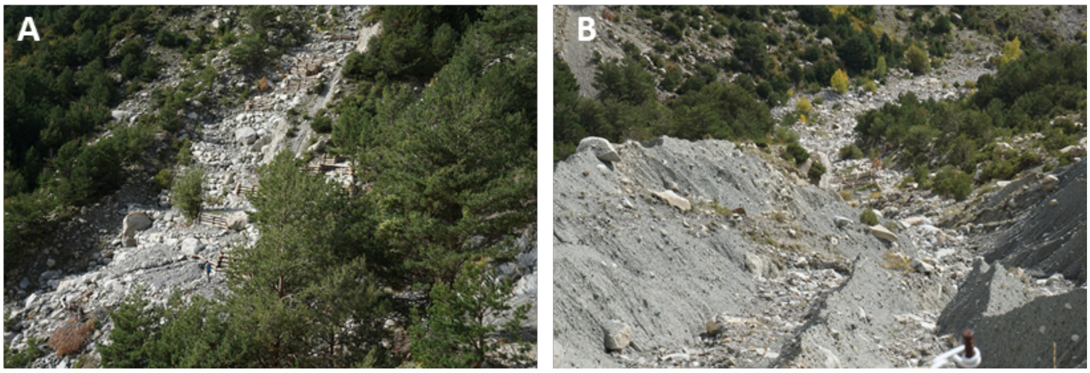


Figure 5-18A) The terraces constructed as part of PHUSICOS. These are constructed both of timber and of large local stones. B) Looking down one of the main gullies. The newly established PHUSICOS measures are seen in the middle of the photo.

Figure 5-19A) Close-up of one of the terraces, with grass taken directly from one of the local pastures. All terraces will be planted with grass and other local bushes and trees. B) Close-up of the construction, anchored by iron rods, pushed at least 2 m into the ground.

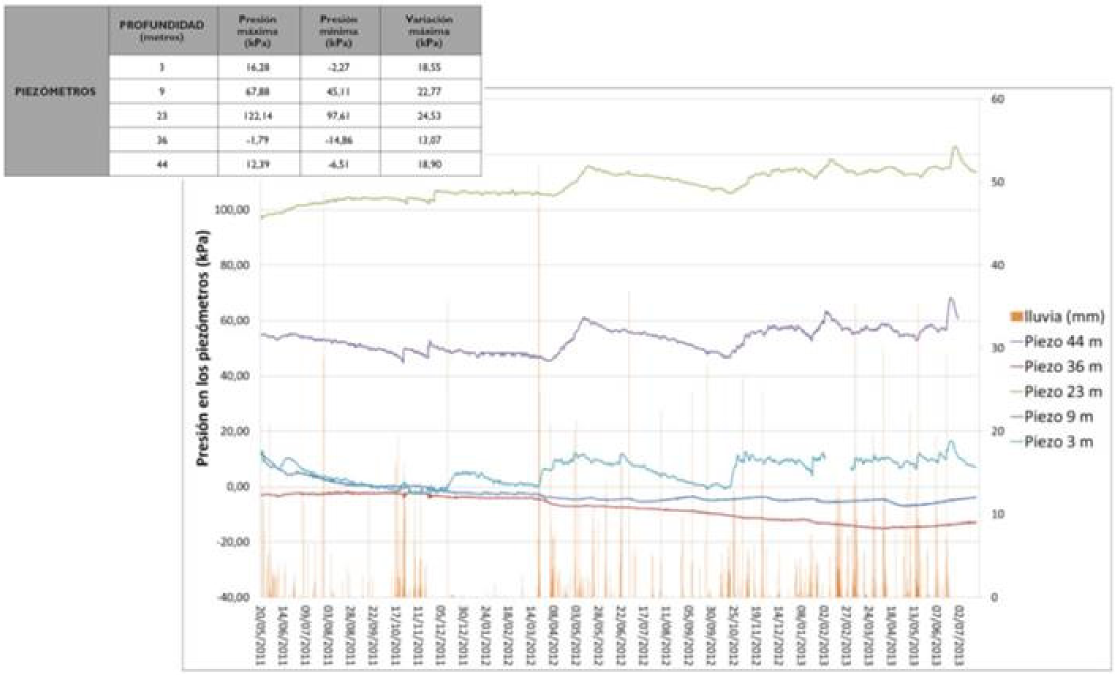
Figure 5-20 Detailed 3D model of the Erill-la-Vall site, before PHUSICOS measures are implemented. The older flexible and fixed barriers can be seen in the red and yellow circles, respectively.

5.4.1 Monitoring and maintenance

The Erill-la-Vall site has had monitoring equipment installed since 2007. The monitoring equipment was further expanded in 2009 and finalized in 2021 with the support of the PHUSICOS project. Acquired data were used as a major part of a PhD thesis on debris flow hazard at the site (Raïmat, 2018). The installed monitoring equipment includes a weather station, a micro-seismic network, turbidity and flow measurements in the gully, and a series of piezometers installed in a borehole drilled to bedrock behind the landslide scarp (Figure 5-15, Figure 5-17 B).

All physical monitoring data are available through a web portal (https://tinyurl.com/Erill-la-Vall) open to the public. Figure 5-21 shows one example of monitored piezometer data and rainfall. The goal is to establish a near real-time early warning system for the area.

In addition, co-benefits related to environment and ecosystems, societal effects, local economy, and technical and feasibility aspects are monitored through regular visits, maintenance of the installations and interviews with stakeholders. Further details on the ongoing and planned monitoring, as well as preliminary results are reported in PHUSICOS deliverable D4.7 (PHUSICOS, 2023).



	PROFUNDIDAD (metros)	Presión máxima (kPa)	Presión mínima (kPa)	Variación máxima (kPa)
PIEZÓMETROS	3	16,28	-2,27	18,55
	9	67,88	45,11	22,77
	23	122,14	97,61	24,53
	36	-1,79	-14,86	13,07
	44	12,39	-4,51	18,90

Figure 5-21 Example of monitoring data from the borehole behind the slide scarp at the Erill-la-Vall site. Pore pressures from 5 piezometers are shown vs. daily rainfall between May 2011 and July 2013.

The interventions themselves are not expected to need heavy maintenance, but the wooden structures must be inspected and may be repaired if needed and possible. Planted vegetation may be damaged, e.g., by falling rocks eroded from the till (Figure 5-17 A) and may therefore need replacement. However, the installed monitoring facilities and the software and web portal will need regular maintenance, which is estimated at a yearly cost between 3000 and 5000 € for labour, dashboard updating and, batteries.

5.4.2 Upscaling potential

There are several such sites in this part of the Pyrenees, with thick till deposits and debris flow problems. The Erill-la-Vall case is the best known and probably the most serious one with regards to risk. However, 11 gullies affect urban areas in the region Vall de Boí, and 9 of these are being evaluated for the possibility for mitigation measures similar to those implemented in Erill-la-Vall. Furthermore, in the Lleida province, at least 35 gullies represent similar hazard, so the upscaling potential is great in the Pyrenees, and probably also elsewhere.

5.5 Cancelled and rejected interventions in the Pyrenees

The first two of the following three cancelled proposals are described in reports D2.2 and D2.3 (PHUSICOS 2019a and 2020b).

Torrents, at Socques, France. This intervention was called off before the approval process in the Steering Committee had started, because the proposed NBS measures were considered inadequate to significantly reduce the risk when extreme events occur. Furthermore, it would be too expensive to upscale the measures to an extent more likely to fulfil the purpose and the uncertainty regarding its risk reducing potential would still be there. Additionally, the national park status of the area set limitations to the measurement's construction.

Torrents in the Bastan Valley, France. The NBS interventions proposed and approved at this site were split between two locations. Firstly, a stretch of the Bastan River, of about 1 km length, was planned to be restructured to lower both the water velocity and the erosive capacity. The measures composed a combination of a 'step and pool' long profile of the river and a terraced cross profile to create more space for floods along the river combined with erosion control using local rocks. The other part of the proposed interventions was to remove a concrete construction that forms an obstruction for natural flow at the confluence point where the Bastan River enters the main Gavernie River. This was to be combined with erosion control and a small, receded barrier.

This NBS intervention was called off due to political, economic, and bureaucratic reasons. The organization responsible for this proposal, the PVLG, was uncertain that they could complete all the work during the time span of the PHUSICOS project even with the proposed one-year extension of the project. Local elections and the possibility of having a new local government and mayor also adhered to this. As expenses obtained after the project's end cannot be refunded by the EU, the PVLG found the economic risk too high, and their general assembly voted against the project.

NBS in the new carpark at the Port Ainé ski resort. The interventions at Port Ainé were proposed by Ferrocarrils de la Generalitat de Catalunya in cooperation with CTP. The proposal comprised the use of local wood and vegetation for stabilization of slopes and erosion control for a new car park at the ski resort. This proposal was quite critically reviewed by the PHUSICOS Steering Committee. Various elements of criticism included that the parking would be built anyway and that some of the proposed elements were not true NBS, but more related to making the area look nicer. Furthermore, a car park to promote more traffic to a ski resort is not part of an environmentally sustainable development despite the argument that the measures could reduce risk for the users of the resort. The Steering Committee therefore required a major revision of the proposal including rethinking of the interventions and the scope. The proposal was thereafter called off by the proponents.

5.6 Pyrenees summary

The PHUSICOS interventions implemented in the demonstrator case site 'Pyrenees' comprise measures to reduce the hazard from snow avalanches, erosion, rockfall and debris flows and as such represents the most variable of the project's case sites. The activities are coordinated by CTP, but the proponents and 'owners' of the implemented measures are the regional organizations ONF-RTM (the Capet Forest site), EGTC Pirineos - Pyrénées (Santa Elena and Artouste sites), and the Municipality of Vall de Boi (the Erill-la-Vall site). Due to various challenges (Chapter 5 and Chapter 9), all interventions except the ones in Capet Forest have been delayed but all have been implemented before the completion of the PHUSICOS project. Unfortunately, due to the late implementation, monitoring will have to take place beyond the PHUSICOS project.

The NBS solution for snow avalanches is afforestation in the avalanche release areas. The planting is done in polygons of up to 30 plants, each polygon protected by wooden tripods, existing vegetation or by existing 'grey' mitigation measures. Nine different tree species are used, all local and adapted to the altitude and climate of the region, also taking climate change into account. Estimated time for the trees to grow enough to be effective is 20-30 years.

Terracing by dry masonry and wooden gabions is the implemented solution to mitigate against erosion and rock fall from the steep till slope in Santa Elena, where fallen rocks on the road cause high risk. The terraces are planted with local bushes and trees, with deep roots to stabilize the slope even after the wooden gabions degrade. Rock fall in the slopes at Artouste is also mitigated using wood, as the measures consist of different timber structures to stabilize and fix potentially loose blocks on the surface and exposed rock ledges. Along with the NBS interventions in Santa Elena and Artouste are also established testing facilities for rock fall protection, an indoor full-scale facility in La Peña Estación, Spain, and a full-scale test site in Gourzy Eaux Chaudes, 10 km from Artouste. These testing facilities will test different tree types- and dimensions, and different wooden constructions, and will be operational beyond PHUSICOS.

The hazard from debris flows in Erill-la-Vall is mitigated by vegetated terraces built by local stones and whole-log gabions. The debris flows are sourced by erosion in thick till deposits, and the measures are built up in the lower parts of the two main gullies. They are vegetated with local grass and bushes and will work in combination with rigid and flexible barriers downslope of the terraces. Monitoring has been ongoing at this site for 15 years, and in-situ measurements in a 55 m borehole indicate a potential slip layer at 15-20 m depth. The implemented measures are mainly designed for shallow, rain-induced instability, whereas deep-seated failures are difficult to prevent. However, the implemented structures, including a rigid and two flexible barriers, may reduce the entrainment and run-out by adding rugosity to the flow path, and prevent deeper erosion.

Monitoring at the four intervention locations will mainly take place beyond PHUSICOS, except for at Erill-la-Vall, where the existing monitoring activities will continue.

The innovation aspect for the Pyrenees demonstrator case site lies in the application and modification of established techniques to new settings. Afforestation to prevent snow avalanche release is used in many places, also in the Pyrenees, but the design of the planting scheme and the additional wooden tripod protection are new. Terracing for stabilizing slopes is also a traditional technique, but the use of wooden gabions combined with vegetation in a till slope like Santa Elena is not common practice. Furthermore, the wooden structures to stabilize and fix rocks in Artouste is also a new concept, which will be further tested in the established test facilities. Of particular interest is the proof that the terracing in the very erosive gullies of the Erill-la-Vall slope will have the wanted effects.

Challenges for the implementations encountered in the Pyrenees are mainly bureaucratic and related to the procurement process as well as to obtain necessary permissions to do the work particularly in the Pyrenees National Park area, where the Artouste site is located. Both for the Capet and the Erill-la-Vall sites, local interest and enthusiasm were important enablers and ensured fast initiation of the work. The Erill-la-Vall site was proposed very late in the project, after the Port Ainé proposal was called off. Here the local authorities were really a major driver for the implementation of NBS measures.

All Pyrenees interventions have upscaling potential, as similar hazards pose a risk to buildings and infrastructure in many parts of this region as well as in other regions and countries. Several sites in the Pyrenees are already being considered for similar measures as the ones implemented during PHUSICOS. The monitoring of the interventions, both regarding their risk reduction effects and their different co-benefits will be important for the continued use of the same techniques at other locations. Monitoring of physical parameters regarding the resilience has been going on in Erill-la-Vall since 2007, whereas monitoring both there and at the other sites are planned and partly started, focusing on all the ambits defined in the PHUSICOS WP4 framework for assessment of NBS (PHUSICOS, 2019D)

6 Demonstrator case site Gudbrandsdalen, Norway

The Gudbrandsdalen valley in central south Norway, regularly experiences severe floods as well as landslides, most often caused by heavy precipitation in combination with snowmelt. A large part of the catchment of the main rivers in the area are high mountains and delayed snowmelt in the spring, combined with precipitation, has caused disasters in the past.

In total, four proposals have been submitted and approved for the Gudbrandsdalen demonstrator case site (Figure 6-1), all related to flood problems. The first proposal, a receded flood barrier, described in Deliverable D2.2 and D2.3 (PHUSICOS 2019a and 2020b), was unfortunately cancelled before implementation (below). Two other proposals comprise various NBS measures to mitigate against flooding in smaller tributary rivers to the main Gudbrandsdalslågen river, whereas the last approved proposal is to establish a Living-Lab base for NBS flood mitigation purposes in a side valley to the main Gudbrandsdalen Valley.

The interventions in the Gudbrandsdalen demonstrator case site were completed late in the project, and monitoring will therefore be in effect only after the project. The extent of monitoring will also depend on available funding. The planning of the monitoring is done in cooperation between Innlandet County Authority and NGI, as their project research partner. NGI will also take part in the follow-up and analyses of the acquired monitoring data.

A comprehensive set of baseline data was compiled from both the Øyer and the Skurdalsåa sites, forming a solid background for the evaluation of the monitoring data.

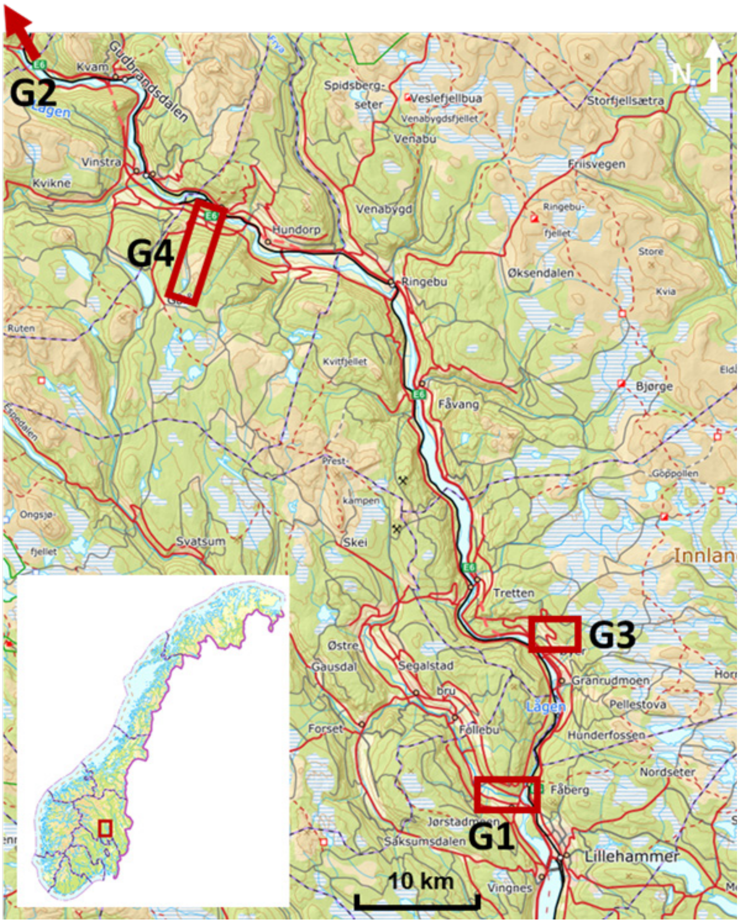


Figure 6-1 Overview of the sites in Gudbrandsdalen, Norway. G1: Jorekstad, G2: Skjåk, G3: Trodalen, G4: Skurdalsåa

6.1 Flood mitigation in Trodalen, Øyer

Proponent: Øyer municipality and Innlandet County Authority

The NBS interventions at the Trodalen site in Øyer municipality was proposed on 6. April 2021, and is therefore not described in previous deliverables D2.1, D2.2 or D2.3 (PHUSICOS, 2018, 2019a, 2020b). Øyer municipality, just north of the town of Lillehammer, Norway, started a development project to establish 220 units of family housing for roughly 500 people in an abandoned gravel pit (Figure 6-2). However, after the first houses were built, the project was put on hold due to potential flooding problems and lack of adequate flood protection.

Potential problems in the larger river, Søre Brynsåa River, NW of the development area, will mainly be handled by traditional measures, whereas NBS are installed in the Trobekken Creek (Figure 6-2). The Creek has a flooding problem during heavy precipitation events. It is closed in the lower part and led through a pipe which ends in S. Brynsåa west of the houses.

The implemented measure consists of the following interventions:

- Opening the creek and re-meander it in an open solution below the houses, i.e. through the green area between the built houses and the road in Figure 6-2.
- Establish the zone around the re-opened creek below the houses as a buffer zone with retention capacity during flooding, whereas it will appear as a green recreation area in 'normal' periods.
- A check dam in the creek, roughly where the red circle is placed in Figure 6-2.
- Erosion protection with vegetation along the creek upstream of the check dam
- Two fenced-in test-fields were established to monitor undisturbed re-growth of the natural flora. There was also a plan to test out a slightly different plant community in the blue/green park area, to see if plants normally growing further south could be interesting for this area in light of the foreseen increase in temperature due to climate change. However, due to scepticism from the County Governor's office, this suggestion was not fully implemented. The plants to use along the creek and in the test-fields were suggested in cooperation with PHUSICOS partner AgenceTer.

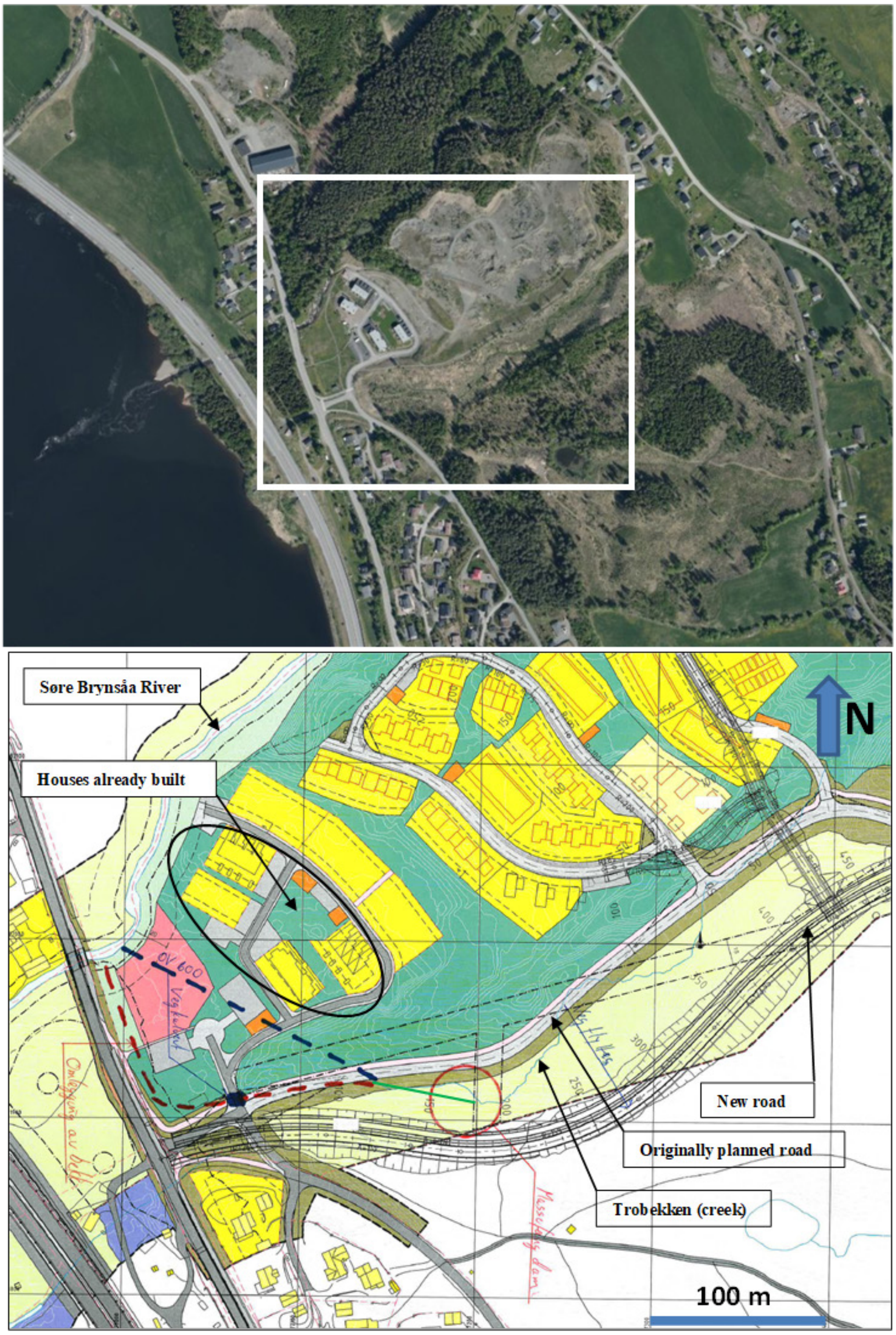


Figure 6-2 Map and aerial photo of the situation in Trodalen, Øyer, prior to interventions. The extent of the lower map is indicated by the white square. The PHUSICOS NBS interventions take place in Trobekken Creek, in the ravine to the south-east and in the green area south-west of the buildings. The green line and then dark, stippled line indicate roughly where the Trobekken Creek is piped.

The proposal was approved by the Steering Committee on 17.06.2021, after a revision following comments. Approval was given by 11 of 12 responders (three partners were involved in the proposal and therefore not eligible to vote). The reason for declining the proposal by one partner was that it was a mixed grey-green solution and therefore did not contain enough real NBS elements in the view of the one partner.

Following approval, all necessary regulatory steps were taken during the time interval until the physical implementation started in June 2022. A consultant was chosen to do the detailed design of the measures after a call for tender. The competition for the physical work was also carried out in parallel with handling the regulatory work. Along with this, the list of plants to be used was also debated between the relevant parties, including the Innlandet County Governor's office, to avoid alien species. The final list of plants to be used and the planting plan are presented in Table 6-1, and Figure 6-3.

Table 6-1 List of plant species used in Trodalen, Øyer municipality, Norway.

Trees	Bushes	Perennials
Alnus incana	Corylus avellana	Carex nigra
Alnus glutinosa	Salix caprea	Juncus effusus
Betula pendula ´Dalecarlica´	Salix cinerea	Lythrum salicaria
Pinus sylvestris	Sambucus nigra	Phalaris arundinaceae
Populus tremula	Ribes nigrum	Phleum pratense
Sorbus aucuparia	Prunus spinosa	Typha latiflora

The bids for the physical work revealed that the estimated price in the proposed budget was too small. This was during a period of increased prices for most goods as well as fuel and services, and the winning bid was neither the most expensive nor the cheapest. The call for tender received 10 bids, and the difference in total budget between highest and lowest among the 5 best was less than EUR 100.000,- for the total cost (i.e. including the extra 40% to be covered by external (non-PHUSICOS) sources). Hence, best value for money is achieved and can be documented. After a quick round in the Steering Committee on the increased budget, which regarding the 60% to be covered by PHUSICOS increased from EUR 406.275 to 603.750, the revised budget was approved. The chosen bidder was a local construction company.

By running all these processes in parallel, the necessary permissions were all granted in the spring 2022, and the work could start in early June. The implementation has thereafter proceeded without problems and was completed on 13.01.2023.

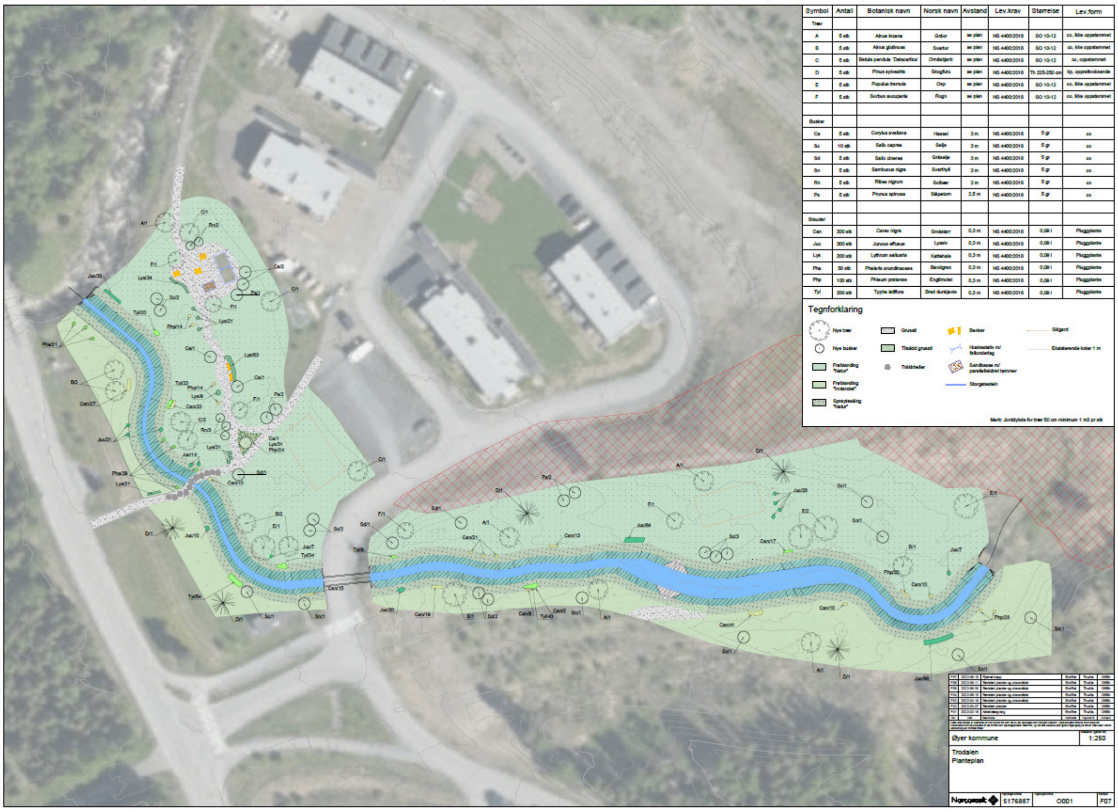


Figure 6-3 The planting plan at Trobekken, Øyer.

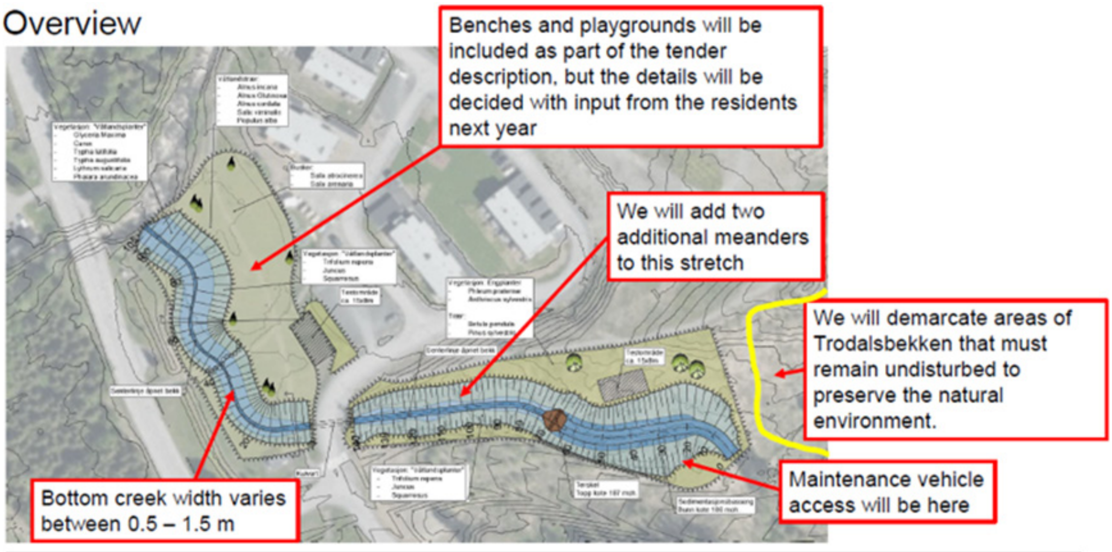


Figure 6-4 Part of the detailed design of the measures in Trodalen. Small annotations are in Norwegian. (Design by Norconsult AS)

Figure 6-5 Drone photos of the Trodalen site after completion of the interventions, but before planting is fully completed. Upper: Overview of the whole intervention. Lower: The lower part, below the houses, where Trobekken ends in Søre Brynsåa. One of the two fenced-in test fields for plants in the lower foreground. These were still not in place when the upper photo was taken. (Photos by Øyer municipality).

6.1.1 Monitoring and maintenance

Because of the late implementation of the measures in Øyer, physical monitoring of the effects of the interventions is not in place. The following is therefore suggested monitoring, which would have to be implemented after PHUSICOS. However, a comprehensive baseline study of ambits and main indicators from WP4 of PHUSICOS (Deliverable D4.1, PHUSICOS, 2019d) was carried out as a good base for future monitoring, which should focus on:

1. Verifying the condition of the channel
2. Assessing the retention- and sediment storing effect of the weir/check dam and the blue-green park area
3. Assessing potential erosion along the channel
4. Documenting the ecological state/biodiversity in the creek
5. Document reestablishment of vegetation in the two test areas

Condition of the channel refers to that the nominal geometry of the channel is maintained that it is not filled with debris or vegetation, the substrate is intact, and the vegetation of the surrounding area is healthy.

The weir creates a partial retention of upstream water and results in a controlled flow of water over the weir to the lower portion of the stream. Monitoring of the water depth behind the weir provides data to estimate flow rates in the stream and to assess capacity utilization. Monitoring of turbidity in the water indicates erosion and sediment transportation processes. Local precipitation and other weather variables should be collected using a dedicated weather station at the site. Data collection over time from the weir and the weather station can yield correlations between capacity utilization and local / regional precipitation.

The condition of the channel is important to ensure that the flow of the stream is not impeded by accumulating sediments, other debris in the streambed, or if erosion of the banks or channel bed is damaging the channel. This can be done by 4 approaches:

1) Remote monitoring:
    a) Publicly available aerial photography; comparisons after new campaigns
    b) Optical or other types of satellite data, also for vegetation growth / health, repeat every 3-5 years
    c) Drone based photogrammetry in regular (yearly) campaigns and after flooding events
2) Turbidity measurements in the channel or basin
3) Crowdsourcing (citizen observations of given parameters or anything unusual – Figure 6-6)
4) Inspections, at regular intervals and after flooding events

Figure 6-6 Example of crowdsourcing. A sign describes the NBS implementation, which purpose it serves, what sort of things to look out for indicating problems and provide an email address where citizens can send a photo and information if they observe something considered to be of interest.

Co-benefits for the environment and ecosystems will be done by physical inspections oand regular sampling for assessing water quality and aquatic biodiversity, as well as the re-establishment of the vegetation along the creek, and, particularly in the two test areas. For societal and local economy co-benefits, interviews with stakeholders will be performed. These include municipal and regional authorities and the inhabitants of the area regarding their perception of the surroundings, including safety after the interventions. The local construction company to which the work was subcontracted, will also be interviewed regarding their experiences and potential for new, similar jobs.

Asa part of the regular inspection visits and inspections following flooding event, maintenance needs will be evaluated. Øyer municipality is responsible for and will carry the costs of maintaining the measures. This will mainly consist of plant management and replanting, removing weeds and mowing of grass fields. In addition, the check dam will need occasional removal of sediments, but this is not expected to occur frequently. After major flooding events, the streambed may also need gravel replenishment.

Further details on the monitoring are reported in PHUSICOS deliverable D4.7 (PHUSICOS, 2023).

6.1.2 Upscaling potential

Measures like creek-opening, re-meandering and weirs for trapping sediment are used together or separately many places, particularly in urban settings. However, implementing these measures here is new to the rural area of Gudbrandsdalen. Without PHUSICOS it is most likely that the flood problem would have been solved with traditional barriers and increased capacity of the pipe. Provided positive monitoring results and, not the least, the satisfaction of the inhabitants of the area, there are many new developments in the Innlandet county and in Norway as a whole, where these measures can be implemented. Particularly re-opening of creeks is becoming more mainstream in cities, but not so much in rural regions. Hence, the project in Øyer could be an eye-opener.

An example of a new development area in Lillehammer municipality may use the Øyer case as inspiration. This is in a more urban setting, where a housing development is now in the planning and regulation process. The municipality suggests opening of a closed creek and greening the whole area in order to facilitate more retention capacity while also ensuring increased well-being for the inhabitants.

Another example where the County is in dialogue with a municipality, is Ringsaker, to the south of Lillehammer. The municipality is in the process of re-establishing an artificial creek originally made for industrial purposes in the 17th century, which led to the establishment of Brumundal as an important industrial community. This creek is mainly closed today, and the municipality is looking into opening the creek up to facilitate public use of this waterway as a landscape element.

Innlandet County Authority, as the regional planning authority, is requesting that all the 46 municipalities in the county takes a restrictive stance towards closed creeks and promote the opening of creeks where feasible.

6.2 Flood retention in Skurdalsåa

Proponent: Sør-Fron municipality and Innlandet County Authority

The NBS interventions in Skurdalsåa River in Sør-Fron municipality was proposed on 28. May 2021, and is therefore not described in previous deliverables D2.1, D2.2 or D2.3 (NGI, 2018, 2019a, 2020b). The Skurdalsåa River (Figure 6-8) is one of many steep tributary rivers to the main river Gudbrandsdalslågen. These tributary rivers often have relatively small catchments, and therefore responds quickly to precipitation events and to snow melt. They are steep and often characterized by erosion and sediment transport during extreme events, which in some cases may transform into debris flows. Roads, houses, a school, a kindergarten, and a sports facility are situated adjacent to the lower part of the river, and the infrastructure has experienced repeated flood damage in recent years. The river course has several bottlenecks, mainly caused by location of buildings and other infrastructure, but also due to culverts and bridges not dimensioned for the present (or the future) flood situations. Trees and other debris blocking the river at these bottlenecks have caused problems during flooding.

The Skurdalsåa River has its outlet from an old dam (1870) in Lake Svintjønna (Figure 6-9), high in the catchment, and is ca. 7 km long from the lake to its confluence with the main river (Figure 6-8). The total catchment is about 15 km^2, consisting of farmland, wetlands, small lakes, and mountain landscapes ranging in altitude from 200 to 1030 m asl. The catchment of the lake at 958 m asl. is only 3.2 km^2. Still, however, hydrological calculations reveal that the proposed measures (below) can retain and evenly distribute the peak flood for 48 hours (in a 200-year flood event). Thereby the peak flood can be reduced, and more time is gained for proper response downstream.

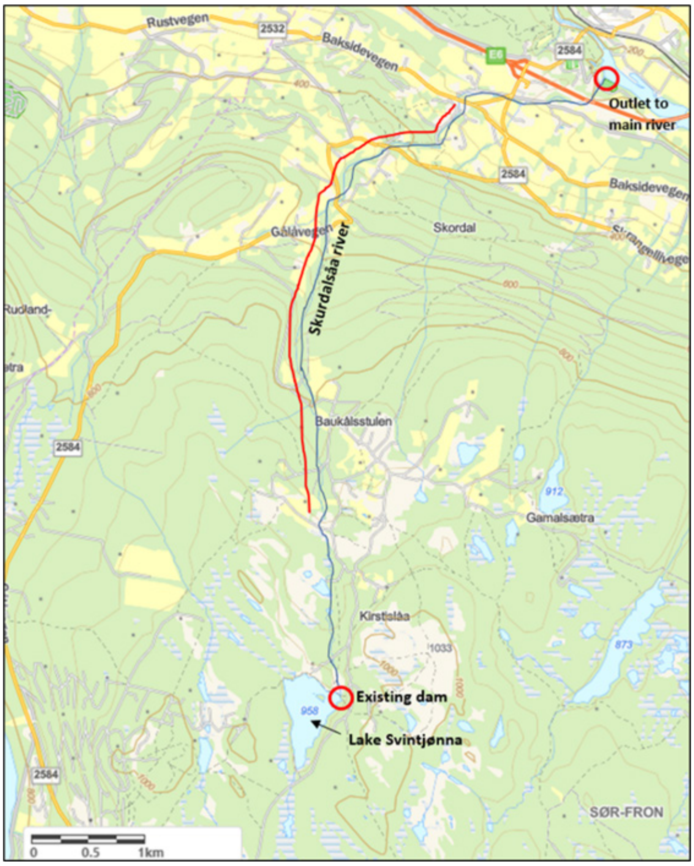


Figure 6-7 Map of Skurdalsåa. The red line along the river marks the section where selected clearing of vegetation is required.

The proposed and approved interventions covered by PHUSICOS consist of:

- Modifying the old dam (built around 1870 and still used for irrigation purposes), by lowering the discharge gate and reinforcing the dam (Figure 6-10)
  - The new discharge gate will allow 0.7 m lower lake level than at present, whereas the upward regulation height remains 0.8 m, as of today. The total regulation possibility will then be 1.5 m, and the lake can hold back 330.000 m³ of water in a flood situation, provided that the lake is initially tapped to its lowest level.
- Improving and extending the spillway (Figure 6-11)

Additional measure to be implemented over time comprise:

- Some selective clearing of vegetation which may fall into and block the river downstream, will be carried out in the late spring 2023

In addition, there are initiatives to improve and/or replace under-dimensioned culverts and bridges, but this is not part of PHUSICOS, and may happen over some years.

Figure 6-8 The existing old dam at Lake Svintjønna. The measures will increase the dam height by ca. 0.5 m and establish a new gate and threshold, with automatic monitoring of the lake level.

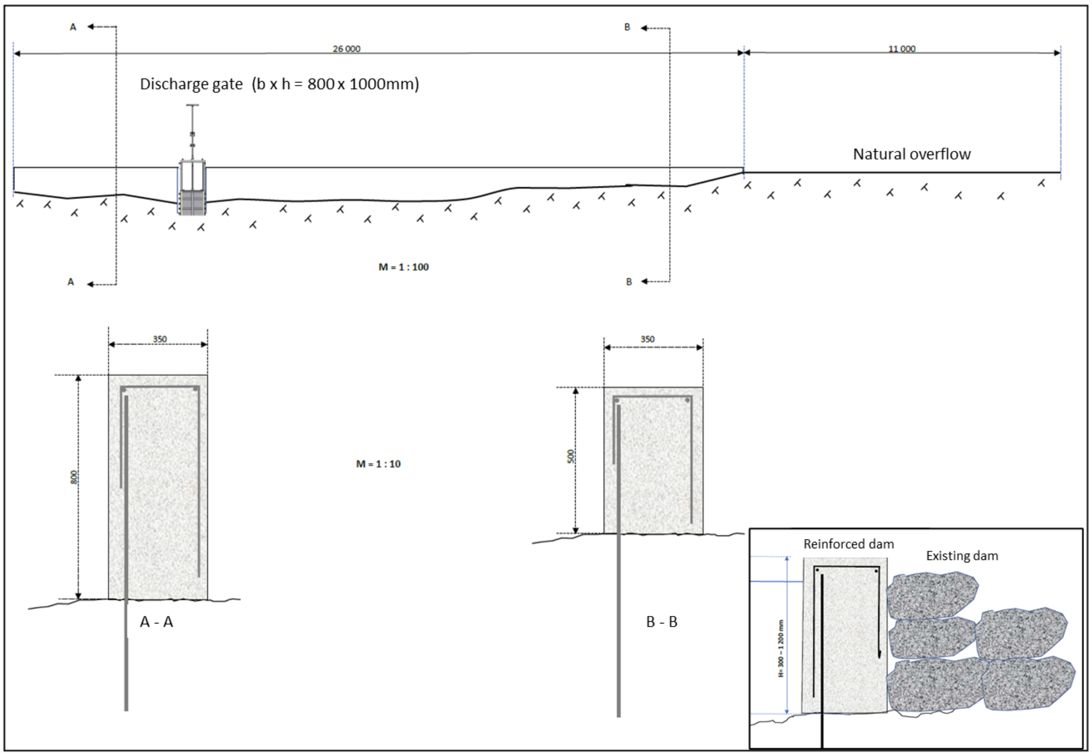


Figure 6-9 The reinfoced dam at Lake Svintjønna. A section through the old, existing dam and the reinforcedmen in the lower right of the figure (design by Eidefoss Vannkraft AS)

The physical work on the Lake Svintjønna dam and spillway started on 21.11.2022 and was completed by the end of the year. Final cleaning up will be done in the spring, after the snow melting, as part of the project's externally (non-PHUSICOS) funded activities. The work had to be done in the fall, when irrigation of farmland was no longer necessary, and the lake could be tapped to accommodate the necessary work on the dam. However, the whole intervention has been delayed by more than one year, mainly due to regulatory issues, further described in Chapter 9. When eventually all permissions were in place the work had to be done in very cold (-20-25 °C) and difficult conditions (Figure 6-11).

Ownership of the lake and the dam, with its irrigation rights are shared between 6 of the local farmers. These have formed a dam cooperative ('damlag') and registered as a business entity in the Norwegian business registry. As such, the dam cooperative could be contracted to carry out parts of the work on the project, using their own machinery. A local construction company was contracted to carry out the remaining work. Because of the very short time between the necessary concession was given and the deadline for the project, an ordinary tendering process could not be carried out. A local constructor was therefore contacted before the concession decision was made. This company is based in the neighbourhood of the river and could take on the job with an upper budget limit based on the allocated project funding for the intervention. Work exceeding this limit was to be carried out pro bono, by the dam cooperative. The contractor further subcontracted parts of the work to another local company, on his own risk. With the additional work done by the dam cooperative partners, the cost was kept within the allocated budget.

Figure 6-10 The new, deeper spillway from the Lake Svintjønna dam.(Photo: Ole Johan Kolseth)

6.2.1 Monitoring and maintenance

As for the interventions in Øyer, the measures in Skurdalsåa were completed very late in the project (end of December, 2022), and physical monitoring of the effects has not been implemented. However, a comprehensive baseline study of ambits and main indicators from WP4 of PHUSICOS (Deliverable D4.1, PHUSICOS, 2019d) was carried out as a good base for future monitoring, which should focus on:

a) Local weather parameters, particularly precipitation, by a dedicated weather station deployed at the location.
b) Verifying the condition of the dam and, particularly the discharge gate; periodic visual inspection and photographic documentation by regular visits or crowdsourcing (Chapter 6.1.1), particularly after flooding events.
c) Verifying the volume of water retained by the dam by a non-contact sensor based on radar, which alleviates problems associated with water in the dam freezing and using the sensor to gauge water retention capacity.
d) Continuing the registration of flood damages in Skurdalsåa. Compare this to historical data, to see the effect of the measure.
e) Measure the effect of more frequent and bigger fluctuations in the water level in Svintjønna (probably too comprehensive but would be interesting).

Regarding environment and ecosystems, investigations should be carried out to assess the effect of possibly bigger fluctuations in water level in Lake Svintjønna, as well as the ecological state along the river. Potential societal and economic benefits will be monitored through interviews with various stakeholders, such as farmers (use the water for irrigation), inhabitants along the river, cabin owners, fishing associations, etc.). For local economy, assessing possible changes in property values due to reduced flood risk would also be of interest.

Maintenance needs should be minimal for this intervention and will be handled and covered by the dam cooperative. The main feature to inspect and maintain is the discharge gate. Furthermore, regular vegetation management along the river is needed, to avoid fallen trees and other debris clogging bridges and culverts, but this is already done on a regular basis, and is not part of the PHUSICOS measures.

Further details on the monitoring are reported in PHUSICOS deliverable D4.7 (PHUSICOS, 2023).

6.2.2 Upscaling potential

Many old watering systems connected to lakes and ponds, dammed by farmers in the 18th and 19th century, exist throughout the Gudbrandsdalen Valley. However, there is no official record of these. Several approaches have therefore been used to gather information about old dams, that potentially could be used to upscale what have been done at Svintjønna, Skurdalsåa river. This study only focused on the valley of Gudbrandsdalen and have not looked at the potential in the rest of Norway.

Information about lakes, built dams, and aerial photos were gathered in a GIS project. Then all the available dam structures were reviewed, together with aerial photos and information about the lake that was dammed. Dams were rejected if the lake was connected to hydropower or regulated, or the dam was a huge concreate structure. Then the remaining dams were studied through the aerial photos. The lake had to be in connection to a river, that eventually reached a larger river. Dams which could be identified on the image, and looked like an old dam, were included.

Other sources have also been used to verify potential dams, and to find new ones that had not been identified with GIS. Several people with knowledge about old watering dams, and waterways where contacted. In addition, the web was searched, with particular interest in local historical societies' webpages, as well as published books and documents. Information about waterways used by farmers were also traced, to see if they were connected to a lake with a dam-structure.

In total 46 potential dams were identified (Figure 6-12, Table 6-2), and there are probably many more in this area that were not identified. There is an uncertainty whether all these dams could be used in upscaling, and some of the dams might be more suitable than others. Further investigation and fieldwork are needed to decide the potential, and this overview is only intended to illustrate the potential. Some of the river/dam systems presented in Table 6-2 represent several lakes/ponds in the same river system. Therefore, some of the names are repeated.

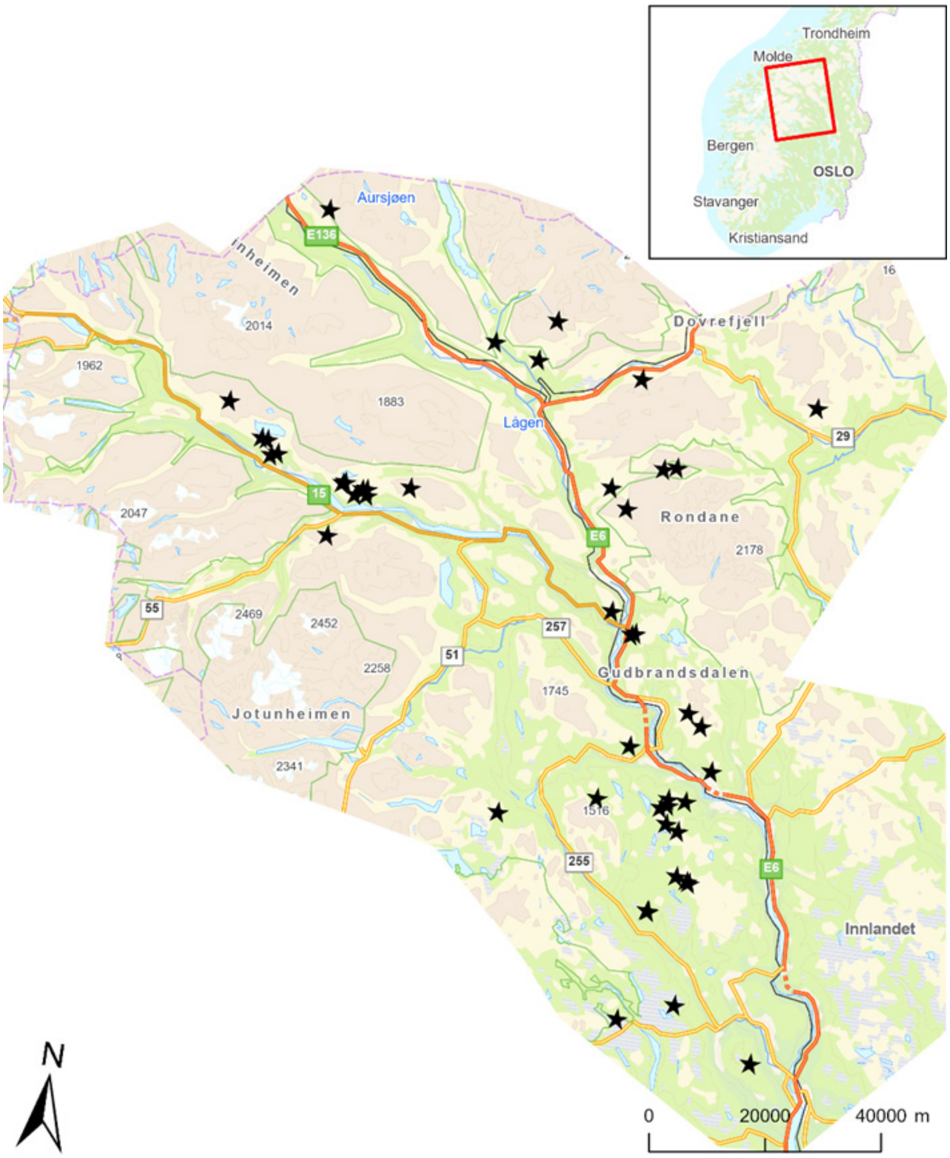


Figure 6-11 Overview of the identified dams with possible potential for flood retention in Gudbrandsdalen, Norwa.

Table 6-2 Overview of rivers and lakes with presumably old dams, meant to illustrate the upscaling potential in this region.

Name lake	Name river	Catchment lake [km²]	Catchment river [km²]
*Åsteppingi	Nordre Sagelvi	4.66	10.65
*Nørdre Storteppingje	Nordre Sagelvi	0.92	10.65
*Nørdre Veslteppingje	Nordre Sagelvi	0.34	10.65
*Svarttjørnin	Nordre Sagelvi	0.52	10.65
Øvre kverngrovtjønne	Kverngrovi	0.11	1.8
Nedre kverngrovtjønne	Kverngrovi	0.48	1.8
Vikateppingi	Nørdre Grøna	1.18	4.6
Vittingstjørni	Vittingje	3.55	4.92
*Einingstjønne	Einingje	0.96	3
*Forbergtjønnin	Fjuken	0.73	1.65
*Kitilstadtjønne	-	0.06	3.29
*Flåtåtjønne	Aura	0.26	132
*Kroketetjønne	Gjøingi	1.35	13.83
Kroktjern	Gravbekken	0.9	15.55
Storvatnet	Gravbekken	10.12	15.55
Ryddølstjønne	Ryddølsåe	0.72	44.52
*Langtjønne	Ryddelsåe	1.45	44.52
Haukskardtjørni	Haukåi	4.76	13.67
Gortjønne	Gorbekken	2.79	8.37
Lomtjønne	Grøna	0.99	161.36
-	Grøna	2.83	161.36
Svinsmyra	Svinsåri	0.65	0.96
*Søreinbuvatnet	Tveråe	2.63	12.78
Kleivrudtjønne	Kleivrudbekken	0.14	1.58
*Nedre Svarttjønna	Solhjemsåe	1.05	6.06
*Butjønne	Solhjemsåe	0.63	6.06
Smiubotnane	Botnbekken	2.16	2.99
*Afstjønna	Sula	6.12	41.11
Teppingsmyra	Trilla	0.69	5.76
Langvatnet	Ulbergsåa	5.73	9.06
Svintjønna	Skurdalsåa	3.18	11.6
Blandtjønna	Hellåbekken	0.2	5.58
Storstultjørna	Hellåbekken	4.42	5.59
Andortjønna	Andorbekken	8.56	8.8
Gåslona	Gåsa	7.31	67.77
-	Storgrovbekken	0.43	3.25
-	Storgrovbekken	0.41	3.25
Ekkermyra	Ånåa	1.87	8.69
Svintjønnet	Ånåa	0.77	8.69
Ormtjønnet	Ormtjønnbekken	1.23	8.79
Valåtjønnet	Valåa	3.06	69.19
Liavatnet	Sagåa	0.23	10.17
Putten	Lomma	2.86	25.65
Høgsætertjønna	Møgla	6.13	7.33
Hølstjønna	Hølsa	60.7	61.08

**) These lakes have been mentioned in one or several sources, including collected information from local history societies, people with interest in the local history, local historical societies' webpages, published books and documents, and collected databases. The other lakes have been found by map analyses of dam-structures in the region.*

6.3 Living Lab in Skjåk

Proponent: Innlandet County Authority

Skjåk is a municipality in a side-valley to the northern part of the main Gudbrandsdalen valley and is known for being the driest municipality in Norway, with an annual rainfall of less than 300 mm. Most infrastructure, public offices, farms, and family housing is therefore located close to the river. Traditionally this has not caused many problems, but effects of climate change may change the pattern and the intensity of flooding events. In October 2018, Skjåk experienced a flood that had all the markers of a spring flood. An extreme early snowfall followed by unseasonably warm temperatures and precipitation led to a flood that left a lot of damage in its wake. Skjåk municipality is now faced with having to find viable measures that will reduce risk across many dimensions: human life, economic value, ecological state, and not the least, make people feel safer.

The PHUSICOS activity in Skjåk does not aim at implementing measures but is meant to be a full Living Lab (LL) process, starting from scratch with co-defining the problem(s) and where stakeholders reach an agreement upon a nature- based solution that will be effective and with co-benefits beyond increased resilience. The process leading up to suggested measures is thus of higher importance for PHUSICOS than implementation of the measure. In this context, the concept of nature-based solutions is new. Therefore, a goal in this process is to introduce viable alternatives to traditional grey solutions and encourage new ways of thinking when faced with the consequences of climate change. It is in any case considered unrealistic to both have a full Living Lab process and implement the measure within the project period. The solutions agreed upon, would then be available for possible post-PHUSICOS implementation.

The LL process started with an open meeting in August 2019. About 30 people were present, comprising political and administrative representatives from the municipality and the county, landowners, and representatives from NGOs and the civil society. This meeting was to kick off the whole participatory process, and the focus was largely on nature-based solutions as a concept. Unfortunately, the COVID-19 situation hindered further physical meetings during the next 2,5 years. Innlandet County Authority, responsible for the process, felt that physical meetings were necessary in this early phase, when the building of trust was a high priority. The County Authority has, however, done a stakeholder mapping in cooperation with TUM, to establish a core stakeholder group of approx. 10 people, and conducted four in-depth interviews with stakeholders.

To proceed with the process after the lifting of Covid restrictions, an external facilitator was hired to run the project. After a tendering process, the company 'Skappa Knowledge Park' was contracted. The word Skappa means “to create” in the local dialect, and the company is encompassing the whole Gudbrandsdalen Valley. With its strong ties to the valley, using them as facilitator also adds to the local business and economy. As Innlandet County Authority is the regional planning authority as well as having other regional roles that could affect proposed measures, a 'neutral' facilitator to drive the process forwards was seen as necessary. The Living Lab process will then gain more legitimacy and thus make the process itself more resilient.

Old waterways in Skjåk as a flood retention measure

During the LL sessions, it was clear that evaluating the use of old waterways for flood prevention was an issue that all stakeholders could agree upon. Because of the very modest annual precipitation in this region, most farmers established waterways leading water for irrigation as well as for household from lakes and ponds in the mountains surrounding the valley down to the fields and the farms (Figure 6-13 and Figure 6-14). The existing waterways were mostly established in the 18th and 19th century, and many are still in use. Although these waterways are made to mitigate drought, their flood retention potential has never been properly assessed. This was the topic for a joint field trip and LL session carried out on 17.08.2022. The six participants comprised the Mayor and Vice-Mayor of Skjåk municipality, the municipality's nature advisor, a representative from Innlandet County Authority, the facilitator from Skappa Knowledge Park and the WP2 leader from the PHUSICOS project. The field trip followed two of the waterways and inspected source lakes with their dry masonry dams. It was agreed to assess the possibilities further through a master thesis in hydrology. This has now been established at the University of Oslo, Department of Geosciences, but will not be concluded until June 2024. The thesis will assess the total capacity of all the waterways in municipality and discuss what modifications can be done to increase the flood retention capacity. The measures implemented at Lake Svintjønna in the Skurdalsåa intervention (above) is of interest as many of the dams sourcing the waterways have similar possibilities for modification. Furthermore, similar waterways are established in many of the Gudbrandsdalen Valley municipalities, and the upscaling potential is therefore great.

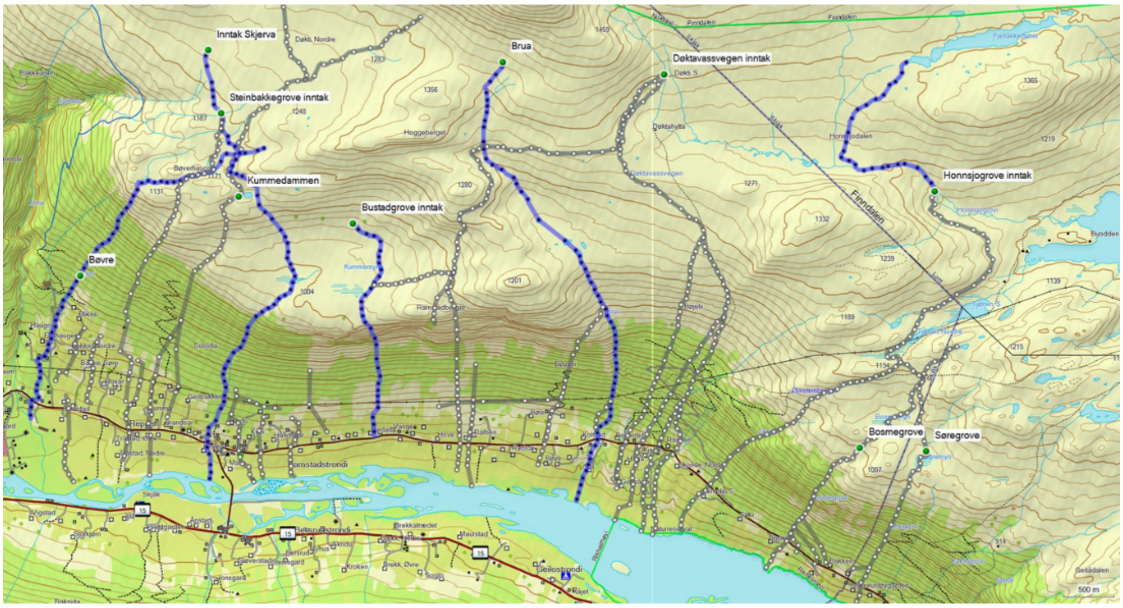


Figure 6-12 Map of old waterways in a part of Skjåk municipality. The grey lines are man-made waterways, whereas the blue lines are natural creeks.

Figure 6-13 Example of dam with controllable gate (rod with wheel) sourcing one of the waterways.

After the Covid lockdown period came to an end, Skappa, together with Innlandet County Authority, held three more Living Lab meetings, including the field trip. The first meeting post-pandemic was organized in a café-style workshop. During this workshop, the facilitators were looking for open discussions about possible NBS that would suit the municipality. It quickly became clear that the old waterways were something they all felt pride in and identity around. Having found this common ground, the group was eager to find out whether these waterways could have a dual purpose in the context of climate change: to be used as irrigation during arid seasons, while having the potential of retention capacity during flood events.

The second post-COVID meeting was the field trip described above, in which the PHUSICOS facilitator could get a closer look at how these waterways and dams high up in the catchment area looked like. While the question of the retention capacity of these waterways and dams is still to be answered, the fact that the PHUSICOS project was partaking in the discussions and the physical study of them, gave the local stakeholders a sense of being seen, listened to and left them with a sense of optimism.

The concluding LL meeting in February 2023 confirmed this impression. The local stakeholders expressed both a renewed interest and optimism about possible new uses for these waterways, and a much stronger knowledge about NBS in general. They were eager to find new project opportunities for exploring the topic further, and Innlandet County Authority stated its clear intention to do the same. The news that NGI will employ a master student to look further into the waterways and dams and its retention capacities were welcomed. Upon the conclusion of these studies in 2024, it is believed that the municipality, together with the County, will have much clearer knowledge about the potential and impact of using the waterways as an NBS measure in further project development.

6.3.1 Upscaling potential

Numerous similar systems were made for irrigation purposes in the 18th and 19th century, as well as before, in Norwegian valleys, particularly in the south-eastern part of the country, with low annual precipitation. Many of these dams are not registered and therefore the potential is difficult to quantify. It will however, be similar to that described for the case in Skurdalsåa (Chapter 6.2.2), and in fact, the list of potential dams in Table 6-2 also comprises dams made for the waterways in Skjåk.

6.4 Cancelled intervention in Gudbrandsdalen

The first proposal submitted and approved at the Gudbrandsdalen demonstrator case study was for constructing a receded flood barrier up to 200-300 m away from the river Gausa, a large tributary river to the main river Gudbrandsdalslågen, in Lillehammer municipality and immediately north of the town (PHUSICOS 2019a, 2020b) (Figure 6-1). The measure was meant to provide more space for the river, allowing the control and confinement of flooded areas during extreme events, both maintaining the riparian vegetation on the floodplain and reducing flood velocity. This would consequently the erosional power and transport capacity of the river which, during flooding events, cause significant deposition in the confluence between the two rivers, which further amplifies the flooding problem.

The intervention was first significantly delayed for reasons related to the procurement process for the detailed design of the measure, and also because the municipality had to revise the area plan for the region. During the required public hearing of the plans, some of the stakeholders had concerns which had to be handled by the municipality. These problems were described in Deliverable D2.3 (PHUSICOS 2020b).

During the process with the detailed design of the measure, it turned out that the cost of constructing the barrier was at least twice as high as what was estimated in the proposal. The proposed cost was based on an estimate done by a consultancy firm in 2017, i.e. a relatively recent estimate as the measure was planned in 2018. Several attempts were made to find external funding to cover the extra costs, but without success. Therefore, the decision to call off the intervention was taken in the summer of 2021.

Despite the cancellation of the intervention, the efforts and the funding spent have value. The design of the receded barrier is done for potential later use. Significant baseline data were acquired and have been the base for modelling studies performed by project partner University of Naples (UNINA) (PHUSICOS, 2022). Furthermore, the process also demonstrated several important barriers to NBS implementation, described by Solheim et al. (2021) and summarized in chapter 9 (below).

The flooding issues at Jorekstad are still in focus and the area is part of other research projects. Other nature-based solutions are being evaluated. Thus, there are reasons to believe that a NBS measure may be implemented here in the future.

6.5 Gudbrandsdalen summary

After the cancellation of the receded barrier along the Gausa river at Jorekstad, three sub-projects have been proposed and approved at the Gudbrandsdalen demonstrator case site. Two involve physical implementation of NBS for flood mitigation, whereas the last is a Living Lab process, in which stakeholders are involved from the beginning, in co-defining the problem and the NBS solution.

In Øyer, north of Lillehammer, NBS to mitigate flooding in the Trobekken creek have been implemented in the form of re-opening of a formerly piped section of the creek. In addition, a check-dam have been constructed, the creek has been re-meandered and the slopes of the ravine in which the creek flows have been re-vegetated. The area where the creek was formerly underground in pipes has been turned into a park area with the open creek, grass and bushes. This area will serve as a flood basin and retain water in extreme situations, before the creek enters the larger Søre Brynsåa river. Included in the measures are also two 8x15 m test fields, where the growth of plants of a slightly warmer climate (from more southerly parts of Norway) can be compared with the existing local vegetation. The re-vegetation in the test fields will be followed up as part of the monitoring program.

The Skurdalsåa river in Sør-Fron Municipality is a typical steep tributary river to the main river Gudbrandsdalslågen. The catchment is only 15 km^2, and the river responds quickly to increased water supply, mostly as rain, but sometimes in combination with snowmelt. The river runs from an outlet in an old dam in Lake Svintjønna, constructed around 1870 for irrigation purposes. Hydrological analyses estimate that by modifying the dam, peak flood of a 200-year flood event can be retained by up to two days. The measure implemented here comprises modifications of the old dam to allow for a larger variation in water level, to increase the retention capacity, combined with improvement of the spillway from the dam. These measures will be combined with selected clearing of some of the vegetation down-stream, which may fall into and clog the river. Later, improvement or replacement of bridges and culverts will be necessary, but this is not part of the PHUSICOS project.

The LL process in Skjåk municipality was started in 2019, but then hindered by the Covid 19 pandemic. In 2022, the process is continued, this time with a hired external facilitator, and the main focus is now towards the possible use of old (150-250 years) waterways, leading mountain water down to the farmland for irrigation purposes. A MSC thesis at the University of Oslo will perform hydrological analyses to assess the potential retention capacity of these waterway systems and the lakes that source them. Measures similar to the one implemented in Skurdalsåa may be a solution.

The implemented measures are not innovative when seen separately. The innovation lies in the process of agreeing with important stakeholders on the NBS concept. One might argue that the measures are hybrid solutions, rather than true NBS. This also demonstrates the need for pragmatism in designing sustainable solutions. The NBS concept is rather new and not well integrated in the planning process in the rural municipalities of Norway, and therefore it can also be considered innovative to use these interventions rather than just starting with traditional grey measures, which in both cases would imply dikes along the riverbanks. The use of old dams, made for irrigation purposes, has not been tried for flood mitigation in Norway before.

The upscaling potential is large, particularly for the Skurdalsåa measures, as there are numerous similar dammed lakes and ponds in the area of Gudbrandsdalen. Therefore, monitoring of the effects of the measures will be very important. This can possibly also lead to a revision of the Norwegian dam regulations, to avoid regulatory barriers, such as those experienced for the dam in Lake Svintjønna (Chapter 9). Constructed waterways are also a common feature in the Gudbrandsdalen region, and therefore the potential use of these, in combination with slight dam modifications, can have a great potential for flood risk reduction, at least in the tributary rivers in this region.

7 Concept case site Isar river, Germany

Proponent: Technical Univ. of Munich (TUM) by Aude Zingraff-Hamed and Gerd Lupp

The Isar river concept case is a 'retrospective case' focussing on NBS practices along the river Isar in Bavaria, Germany. Measures to reduce flood risk and improve the ecological state of the river and its immediate surroundings were taken several years ago and the previous Isar restoration project ended in 2011. This site is considered a significant role model site for the PHUSICOS project, regarding the assessment of both the implemented measures and the participative process of stakeholders' involvement. The objectives of the concept case are illustrated in Figure 7-1.

Figure 7-1 Objectives of the Isar concept case (A. Zingraff-Hamed)

The Isar concept case activities have primarily been focused on various aspects of capacity building through workshops, dissemination, teaching, and consulting. Besides a podcast series published in online podcast platforms, e.g., Spotify, three major activities were also implemented: a 'look-and-learn' visit for the PHUSICOS consortium and two summer / spring schools for international students, emerging scientist, and practitioners.

7.1 'Look and learn' visit 2019

The Isar concept case hosted a 'look and learn visit' to the Isar for the PHUSICOS consortium partners in March 2019. This comprised field excursions along the river in the vicinity of Munich (Figure 7-2) and to the upper reaches of the Isar. The participants visited the various implementation sites, met with experts and stakeholders who were parts of the co-design of the solutions, and received technical information, as well as information about other, ongoing and future projects. The planning and management of the Isar restoration project included, in addition to increasing the area's flood resilience, improvement of the biodiversity and preservation of cultural heritage, such as some of the bridges. The presentations during the workshop part of the visit provided good insights in the economic values of the Isar, i.e., the hydroelectric power production and the value represented by increased quality of life and high tourism standing of the riverine area, that have been combined to a high performance flood protection strategy. Potential conflicts were another topic during the workshop, which raised the awareness among the participants on the often-underestimated potential conflict levels which may arise during such projects.

Moreover, a visit to the hydraulic test facility, where model experiments had been carried out prior to the implementation of the measures, was also included (Figure 7-3).

Figure 7-2 The PHUSICOS group during the 'look-and-learn' visit along the Isar in March 2019.

Figure 7-3 Visit to the hydraulic test facility, where all measures to be implemented were tested hydraulically in down-scaled models.

7.2 On-line Summer school 2020

The planning of a summer school in July 2020 started in the fall of 2019. The intention was to invite young professionals and students from a range of relevant professions (scientists, government regulators, various industry sectors, spatial planners, engineers, architects, technical experts, market actors, etc.) for a ca. 10-days combined classroom and field training sessions to focus on:

- Risk mitigation
- Ecological status improvement
- Social value increase
- Economic benefit
- Upscaling and replicability for NBS

The field training sessions were meant to take place both at the Isar and at PHUSICOS sites in the Pyrenees, in collaboration with PHUSICOS partners CTP and BRGM. Several dissemination activities were planned in combination with the physical summer school, such as inviting local press at the various sites and producing a ca. 10-minute movie from the school.

Due to the Covid pandemic in the spring of 2020, the plans were changed to an online webinar to be held in September 2020. The webinar took place in the period 7-16 September 2020 and attracted 19 students from 15 countries (Jordan, Pakistan, India, USA, China, Indonesia, Iran, Germany, Brazil, Nepal, Australia, France, Nigeria, Mali, Chile) (Figure 7-4). Field studies were of course not possible, but all the planned topics were treated and several of the PHUSICOS partners gave presentations during the webinar. The sites in the Pyrenees were presented on-line, however, at this point no implementation had yet started. Hence, the students were able to 'plan and design' interventions to mitigate the hazards at the sites. In summary, the webinar came out very successful and the students expressed their appreciation for the content. Many participants joined also the second capacity building event. The originally planned physical summer school was held as a spring school in April 2022 (Chapter 7.3, below).

Figure 7-4 How the participants of the 2020 summer school / webinar presented themselves.

7.3 Spring School 2022

A spring school was organized on 2-11 April 2022, hosted by TUM in cooperation with Observatoire Pyrénéen du Changement Climatique, BRGM, and CTP. The school was organized with both classroom work and field studies in Germany and in the Pyrenees. A total of 15 students participated (Figure 7-5), representing 11 countries in Asia, Africa, Europe, and the Middle East and North- and South America. The school qualified for 3 ECTs.

In Germany, the participants studied the mitigation of a variety of hazards:

- Moosach Cultural Landscape, Freising, Germany- Flood risk mitigation
- Weihenstephan Mountain, Freising, Germany- Forest management for debris slide mitigation
- Moosach Reopening, Freising, Germany- Urban heat island mitigation
- Isar Restoration, Munich, Germany- River restoration
- Alter Hof and Marstallplatz Public Squares, Munich, Germany- Urban heat island mitigation

In the Pyrenees, the PHUSICOS localities of Artouste, St. Elena, and Erill-la-Vall (all described in chapter 5) were visited (Figure 7-6). A film crew followed the spring school (Figure 7-6) and a film is under production.

Several aspects related to NBS were discussed during the spring school, including not only the risk reduction capacity and the co-benefits of NBS, but also topics related the society and politics. The themes covered were:

- Introduction to NBS
- Policy and decision-making mechanisms
- Collaborative Landscape planning
- NBS assessment

- River restoration as NBS
- Riparian regeneration
- River and Society
- Hand-on learning via case site visit
- NBS Future perspectives

Figure 7-5 Students and teachers of the PHUSICOS 2020 spring school. (Photo: Aude Zingraff-Hamed).

Figure 7-6 Participants of the PHUSICOS 2020 spring school visiting the Erill-la-Vall demonstrator case site. The film crew in the back. (Photo: Aude Zingraff-Hamed)

The NBS concept in general as well as international differences regarding NBS were topics for discussions during the spring school, and some 'take-home-messages' reported by school-responsible Aude Zingraff-Hamed are:

- Participants of the Spring School expressed confidence in the effectiveness of NBS for natural hazard mitigation based on the cases they witnessed at the demonstrator sites. However, NBS is still in its early stages and should not be oversold as the panacea to all socio-environmental challenges, as its limits are not well known yet.
- In the Global North, more studies are needed to particularly settle the concerns of decision-makers on the effectiveness of NBS. In the Global South, NBS is seen as a bridge between pre-existing development gaps and climate-related risks as well as a conduit towards climate-resilient development.
- The potential of NBS in the Global South is particularly high as that part of the world is rapidly urbanizing and NBS could provide a judicious approach for strategic planning. There, the integration of NBS in landscape and city planning could help to prevent a repetition of planning failures in the Global North.

7.4 Other activities

- Various support to the PHUSICOS work packages, particularly WP3, WP4, and WP5.
- Production of an 'Isar Film' in 2019 (PHUSICOS Isar River Concept case Look&Learn 2019 - YouTube)
- Compilation of NBS inventories for the Alps (2020) and the Pyrenees (2021).
- Supporting and upscaling of the NBS interventions to the Isar tributaries, in particular the Amper.
- Supporting the follow-up Isar Plan 2.0, in workshops, stakeholder involvement and experience with various interventions.
- Cooperation and exchange of experience with other river restoration projects, such as the Danube, Aire (France), Yolo (USA), and Kumasi (Ghana) (PhD thesis).
- Hosting workshops and convening conference sessions
- Production of a podcast for NBS, with conversations with PHUSICOS partners.
- Supervision and support of several MSc theses and one PhD thesis.
- Various publication and dissemination activities, interviews, film production, etc.

7.4.1 Monitoring and maintenance

As the Isar River concept case is a retrospective case, there is no monitoring on behalf of the PHUSICOS project here. The Isar restauration project has had its own monitoring since the project ended in 2011. The monitoring data have been used to implement the WP4 assessment framework see (Pugliese et al. 2020, Pugliese et al. 2022). Maintenance of the measures along the Isar in Munich has been and still is extensive, but the main focus for PHUSICOS has been on the stakeholder involvement, and further information on the maintenance is therefore not sought or described.

7.4.2 Upscaling potential

PHUSICOS partner TUM has been active in activities related to restoring other rivers, using similar methods as for the Isar, in particular regarding the involvement of stakeholders. Activities have focused on tributary rivers to the Isar, but in addition, collaboration projects have been and are conducted with organizations and universities in both the US and in Ghana, on similar topics for rivers in these countries. It is obvious that the Isar restoration project in Munich has a great upscaling potential world-wide, particularly in urban areas, but also in more rural areas where development is planned, and where good and early planning might exclude the need for later restauration.

7.4.3 Synergies and collaborations

The Concept Case Isar focused on capacity building also to other research projects e.g.,:

- INTERREG Danube Flood Plain - The PhD candidate Francesca Perosa was supervised by Dr. Aude Zingraff-Hamed and inspired by the Isar experiences. She investigated the added value of integrating ecosystem services values in the decision-making process. Her hypothesis was that, as in the case of the Isar restoration, the intention to implement a solution with co-benefits leveraged the implementation of a NBS. Ecosystem considerations within the Living Lab process at the Danube should encourage NBS implementation as well.
- H2020 funded project CONEXUS used the Isar Concept case as an ‘good example to follow’ within one of its first deliverable to inspire NbS implementation in South America.
- MOPGA funded project PORTAL - The PhD candidate Titouan Dubo discovered the Concept Case Isar during the webinar in 2020. Interested by the stakeholder constellation and the context of the decision-making process, he decided to investigate those of the cases inventoried in the PORTAL web platform. To do so, he realized a research stay at TUM. Results of his PhD thesis will be summarized in a joined publication with TUM.

7.5 Isar River summary

The main objective of the Isar River Concept Case is capacity building within PHUSICOS, as well as for other experts, various stakeholders, students, and the public at large through various dissemination activities. In addition, the concept case supports other river restauration projects and demonstrates the performance and viability of NBS.

The first of the main activities was a 'look-and-learn' visit for the PHUSICOS partnership in 2019, which included visit to sites along the Isar, visit to the hydraulic laboratory facilities where modelling studies of the interventions were done, as well as workshops with key stakeholders in the Isar Project. The role of close collaboration with all stakeholder groups was emphasized as a key factor of success, and the best way of avoiding potential conflicts. A film on the Isar restauration was made after the visit.

In 2020, the Covid pandemic made the Isar concept case group turn a planned summer school into a webinar, held in September 2020. 19 international students from 15 countries participated in the one-week webinar, and all gave positive feedback. This encouraged planning of another physical course, this time organised as a 10-days spring school in April 2022. 15 international participants, representing 11 countries visited the capacity building event. The spring school comprised field studies at the Isar and its tributaries in Germany and at the PHUSICOS demonstrator case site in the Pyrenees, visiting all the locations where NBS interventions were planned or under implementation. A film is under production from the spring school.

A number of additional activities have been undertaken by the Isar concept case group, and includes support to other PHUSICOS WPs, production of NBS interventions in the Alps and the Pyrenees, support to other projects, production of podcast and films, supervision of MSc and PhD students, as well as presenting at international and national conferences and workshops and publishing in scientific journals.

8 Concept case site Kaunertal, Austria

Proponents: University of Vienna & the Paris Lodron University of Salzburg (PLUS)

The Kaunertal concept case is an innovative research project with the aim of revegetating barren slopes in high alpine areas, such as those left by road construction or ski slope development, devoted to reducing erosion from these slopes. The targets of the measures in the Kaunertal Valley are a) testing the potential of high alpine plant species in reducing erosion and b) identify microbes with the ability to assist the plants in establishing in areas prone to soil loss. Thereafter, the aim is to use the local microbes to enhance plant growth, exclusively applying autochthonous species without introducing external species and microbes into the area. Agricultural applications show that microbes have the potential to affect relevant plant traits and to help plants to tolerate stress, such as dry and cold conditions, which the seeds and plants may encounter in the alpine sites. Focus is on plants with large leaf surfaces and a large root system since these traits are considered to be most effective against soil erosion.

The work has been a combination of laboratory and field experiments using plots in the slopes left by the rapidly retreating glacier of the Kaunertal Valley as proof-of-concept sites, where the effectiveness of elevation-adapted plant species assisted by microbes in erosion reduction is to be demonstrated. The measures have a large upscaling potential, and the most efficient seed-microbe mixtures are applied in implementation sites to demonstrate the applicability.

In the case of the Kaunertal Valley, erosion reduction has a direct economic value, as the deposition of eroded sediments in the area's hydropower reservoir reduce the functionality for the power generation and caused costs of nearly 16.4 M Euro in one year (2017) only. Results of the experiments in the Kaunertal Concept Case may also be of interest for other PHUSICOS sites, such as some of the sites in the Pyrenees (above), and other locations vulnerable to erosion, such as ski slopes, etc.

Field and laboratory activities

The planned activities (Figure 8-1) were greatly affected by the Covid 19 pandemic and have been delayed by one year. This was also partly affected by low availability of the seeds to be used.

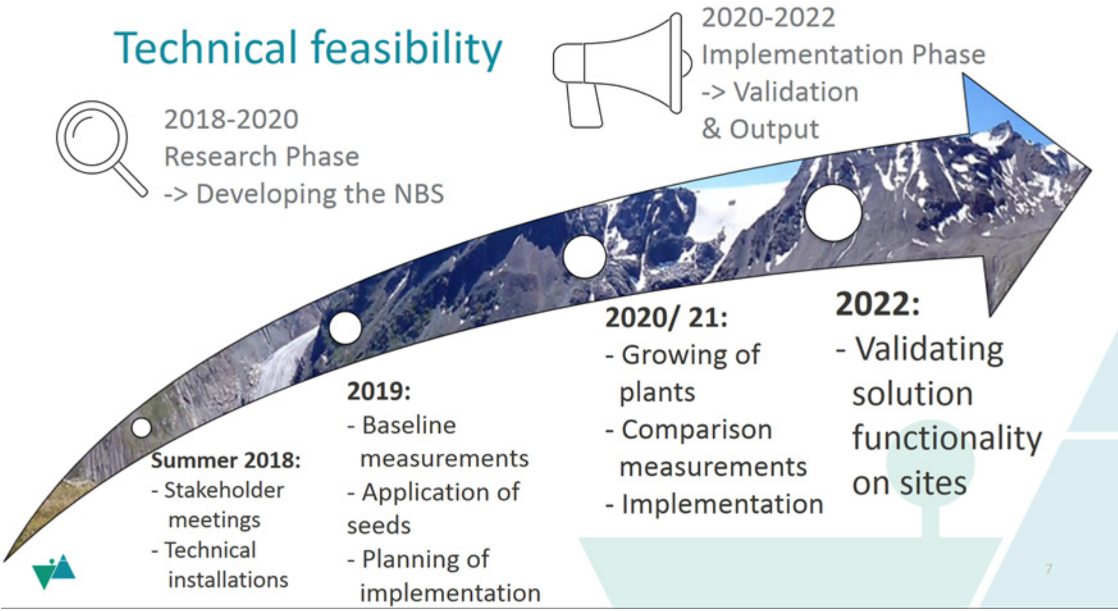


Figure 8-1 The planned activities at the Kaunertal Concept Case site, as presented in the project proposal.

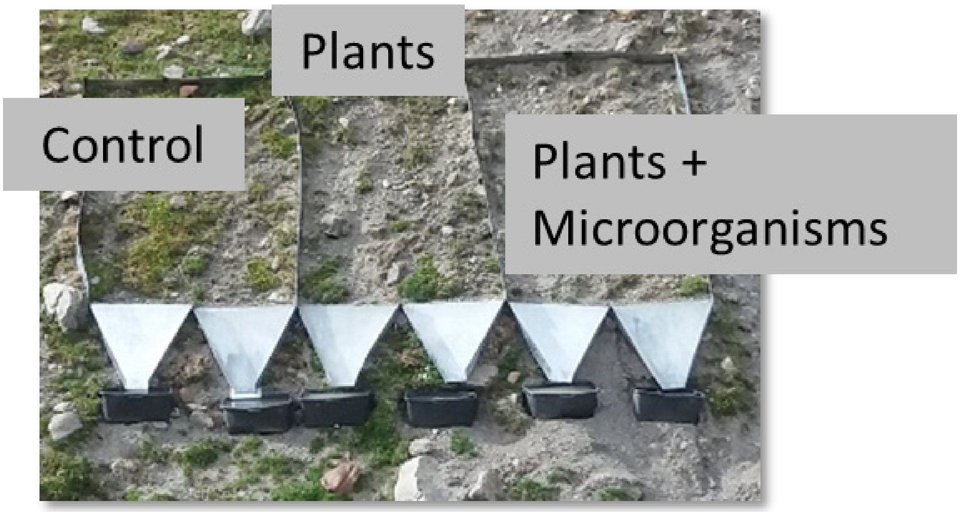


Figure 8-2 Example of one of the 20 test fields in which the erosion reduction was tested. Each installation had three 2x3m plots and was composed of a control plot with no intervention, a plot treated with plant seeds only and a third plot with a mixture of seeds and microorganisms.

The main activities can be summarized as below:

2018 and 2019:

- Set-up of 20 test sites, each with 3 x 6m^2 plots (Figure 8-2).
- Installation of hydro-meteorological monitoring.
- Quantification of soil erosion from these sites using sediment collectors.
- Defining a characterization of plants and microbe communities to identify plant, bacteria and fungus species well suited for an application.
- Isolation and screening of local bacteria to understand the impact of each single bacteria on the local vegetation (growth of plants, leaf area, root density, point of germination).
- Various dissemination activities (below).

2020 and 2021:

- Continuing measurements of erosion and hydrological parameters.
- Seeding of the 60 plots at the 20 sites with standardized seed mixtures and bacteria, as well as hydroseeding of 100 smaller 'miniplots' with local plants. All had to be manually seeded since the instruments cannot hydroseed with high spatial accuracy as it was needed in the test plots.
- Proof-of-concept for different bacteria in greater sample sizes in the laboratory. In total more than 420 different microorganisms from both plants and soil have been investigated in the laboratory.
- Validation measurements between different treatments in the field.
- Dissemination and publication activities (below).

With Corona appearing in the spring of 2020, and the Kaunertal being close to the 'epicentre' of Corona in Europe, several activities had to be postponed. Corona problems also forced the partner company responsible for the development of large-scale hydroseeding technique and the off-site implementation to withdraw from the project. A new company had to be subcontracted and the selection of test areas then had to be postponed as proof-of-concept was not complete. Hence, the planning of implementation with key stakeholders was postponed to the fall of 2021, and hydroseeding at implementation sites was performed in 2022.

Main results of the test site activities before large-scale implementation include the following:

- The critical plant coverage for reducing erosion is ca. 30%, whereas a coverage of >75% almost eliminates the erosion in the test plots (measured as sediment yield from the plots)
- Campanula Barbata ('bearded bellflower') was found to be the most suitable plant, as it responded most significantly with changes in erosion by effective trait development through microbe interaction. However, functionally diverse plant communities seem to be most effective in reducing the erosion and to enrich the microbial composition.

- The seed mixture applied to the test sites led to increased vegetation cover at all test sites, both with and without microbiome. At 44% of the sites a statistically significant increase of vegetation cover was achieved in plots with mixed-in microbes compared to those without microbes added.

2022 and 2023:

- Implementation by deploying seed mixtures through hydroseeding at a total of 10.000 m^2 on road cut slopes at 6 different test sites (Figure 8-3) and one ski slope site.
- Vegetation survey to further investigate the germination of seed mixtures.
- Deinstallation of experimental test plots.
- Monitoring and evaluation of results from the larger scale implementation to follow in summer / fall 2023 (outside PHUSICOS).

The results of this larger-scale implementation will not be seen until the growth season 2023 and in the years to come.

Figure 8-3 One of the road-cut sites where the seed-bacteria mixtures are deployed at larger scale (Photo: Sabine Kraushaar).

Dissemination and outreach activities

The Kaunertal concept case group has had very active dissemination activities throughout the project. The activities include:

- Several meetings with all stakeholder groups, including shepherds and hunters, authorities, environmental agencies, nature park administration, companies, and other groups active in the area. The stakeholder contact has led to necessary permissions and important support from the local community, the agricultural union and the nature park authorities.
- Workshops and teaching sessions with school children from the area including field visits.
- Field courses with students form different German and Austrian universities.

- Production of e-learning videos for students (MOOCs)
- Regular children university workshops
- Locally: Issuing bi-annual newsletters.
- Excursions with local inhabitants.
- Film production for the German / French TV program ARTE and the Austrian ORF
- Long-term museum exhibition in the local community.
- Presentation at a public science day ('Forschungsfest') by the Austrian chamber of Commerce at the Vienna City Hall.
- Popular science publications (YouTube videos, newspaper articles, podcast, tweets).
- Publication in peer-reviewed scientific journals and presentations in national and international workshops and conferences.

Besides making PHUSICOS and the innovative research activities in the Kaunertal wider known, the dissemination and stakeholder activities have generated to a positive attitude towards the activities and much support locally and within the important stakeholder groups.

8.1.1 Monitoring and maintenance

Monitoring activities within PHUSICOS: For the Kaunertal concept case the monitoring of the experimental work included the erosion measurements, vegetations cover density and species composition at the 20 test plots (Chapter 8). This is now completed, and the test plots are dismantled.

Planned monitoring activities after PHUSICOS: Further monitoring will be in the form of observing the effect of the demonstration at the larger scale sites in the growth season of 2023 and beyond. Implementation site monitoring will be happening outside PHUSICOS and are provided by the University of Vienna and PLUS. Multi-temporal terrain analysis using UAVs and structure from motion analysis as well as repeated terrestrial laser scans will allow the quantification of erosion. A detailed vegetation analysis including cover density and species composition will further give insights on the differences between test areas with and without microbiome supported seed mixture.

Optimum monitoring activities in case of further funds: In the optimal case the demonstration sites should be monitored once a year for the following 5 to 10 years. This would allow to determine if the local seed mixture is reliably reseeding itself year after year and if the measures positively impact stability. Furthermore, a colonialization of species from the bordering stable areas is favoured and should be documented, since it would enhance succession and biodiversity.

The Kaunertal concept case group has also carried out a number of dissemination and outreach activities (Chapter 8), and although this has not been monitored, this has created a much stronger local enthusiasm for the implementation of NBS and sense of ownership for the seed mixture method, which is reflected in the regularly requested consultation of our knowledge by the municipality and the local ski resort, and the further use of the seed mixture for new erosive areas.

As the Kaunertal interventions are experimental pilot studies, no maintenance is carried out or planned, except for the now dismantled test plots. The only maintenance foreseen in larger implementations of the method, is potential re-seeding.8

8.1.2 Upscaling potential

The idea of using microbiome-assisted seed mixtures to enhance natural vegetation has a huge upscaling potential, not only in the Alps, but world-wide. Envisioning a positive result of the ongoing large scale demonstration further replications have already been performed:

A) The local ski-resort already used the developed seed-mixture on all areas in Kaunertal that were required to be re-vegetated by the regional district commission (new road constructions sites, new ski slopes etc.)
B) The local head of office of the Kaunertal municipality contacted PHUSICOS for further implementation on road construction sites throughout the valley. Sites are being carefully evaluated since the seed mixture developed is eco-sensitive to altitudes above 1700m.

Further upscaling of the NBS was planned in the framework of two H2020 proposals (ECOSENSE and Alpine-NBS, both unfortunately not approved). The Kaunertal Case is envisioned to become a lighthouse case for neighbouring valleys Pitztal and Ötztal, which both expressed interest in using the same mixture. Additionally, through local networks, the CEO of an Argentinian ski-resort also wanted to explore the idea and suitability for their use. However, funds were not admitted. Any upscaling outside the local ecosystem of course would need an adjustment of seed-mixture and the microbiome composition and is restricted by the economic availability of these commodities. However, the idea of supporting natural vegetation with a microbiome tailored to stability functionalities of plants is universally transferable.

In addition to ski areas, barren areas vulnerable to erosion in steep topography, induced for example by glacier retreat, landslides, and other processes, which threaten infrastructure or have other negative consequences, can benefit from enhanced growth of the natural vegetation for stabilization. Further examples are road- or railway cuts, construction sites, abandoned open-air mines, scars after shallow landslides, etc.

8.2 Kaunertal summary

The Kaunertal concept case is a singular, but highly innovative part of the PHUSICOS project. The objective of this case site was to enhance and optimize growth of adapted vegetation to reduce erosion and sediment loss from barren regions, e.g., following glacier retreat or road cuts or ski slope construction. Enhancing plant growth is done by carefully selecting microbes that interact with plants and influence erosion effective traits such as increasing leaf area or root density. Only indigenous plants and microbes have been selected for the application.

The work has been performed in the laboratory and in several test plots at various locations in the Kaunertal Valley. Each installation had three 2x3m plots and was composed of a control plot with no intervention, a plot treated with plant seeds only and a third plot with a mixture of seeds and microorganisms. Sediment export form all plots was monitored over a period of 4 years. Many different seed mixtures and seed-bacteria mixtures have been tested in the lab. Laboratory experiments proved that local bacteria enhanced the erosion-preventive functionalities of local plants. Furthermore, it was shown that a market-available and height-adapted seed mixture with commonly available microbiomes (used in agriculture), tested on sites in the Kaunertal Valley, could enhance vegetation growth and stability.

Demonstration at larger scale was delayed mainly due to the Corona pandemic, but also other problems, such as difficulties getting enough seeds have affected the project's progress, and proof-of-concept had to be obtained from the small plots before larger-scale demonstration experiments. Finally, a unique seed mixture for the Kaunertal Valley was prepared and implemented for altitudes >1700m. This seed mixture is now tested on areas totalling 10.000m^2 in the Kaunertal ski resort with and without a commonly available microbiome. Results are awaited in the coming growth season, in September 2023 (after PHUSICOS).

The concept case group from UNIVIE and PLUS have also had an extensive dissemination and outreach activity, aiming at all groups and levels in both the scientific and the civil society. This includes films, e-learning modules, newsletters, lectures and excursions, exhibitions, etc. Within the Kaunertal case study site, two PhD thesis are being prepared with a number of scientific publications published and others in preparation summarizing the research outcome.

9 Challenges and barriers

The NBS implemented in PHUSICOS are based on modifying the vegetation cover and/or managing the excessive amount of surface water runoff during extreme events in rural landscapes throughout Europe. Each of the large-scale demonstrator sites in Norway, Italy and in the French and Spanish Pyrenees have several locations with different problems to be tackled by NBS interventions. The challenges and barriers at the sites are described and discussed by Solheim et al. (2021).

Furthermore, Martin et al. (forthcoming) have elaborated even more on NBS barriers, based on literature studies, and in a new PHUSICOS deliverable (PHUSICOS 2023) comparisons are made between barriers related to traditional grey measures and NBS. The discussions in PHUSICOS (2023) are also based on interviews with constructors and consultants involved in both grey measures and NBS, and with public stakeholders in Norway.

Most NBS related literature is from urban settings, but many of the barriers experienced in rural settings have the same root causes as the ones described from urban areas, and the main barrier-creating mechanisms are institutional factors, resistance among stakeholders and technical and economic issues. The key element, however, is the lack of knowledge about the ability of NBS to deliver a series of co-benefits in addition to their risk-reducing effects and that long-term thinking is required to see the effect of many of these co-benefits. In Table 9-1, the barriers encountered in PHUSICOS are linked to the classes defined by Sarabi et al. (2020). For descriptions of the named PHUSICOS NBS interventions (sub-projects in Table 9-1), see Solheim et al. (2021). Note that experienced challenges often relate to more than one barrier in Table 9-1. The most important ones are marked in bold and briefly described below.

Lack of Political Will and Long-Term Commitment

This barrier led to cancellation of two interventions in the Bastan Valley, France, which were both approved by the project's steering committee. An additional element here was that the timing matched with local elections, with the prospect of having a more sceptic local government elected.

Lack of Sense of Urgency Among Policymakers

The largest of the proposed NBS interventions in the Norwegian demonstrator site was called off, partly because of economic reasons, but partly also because of political prioritization, where the intervention was 'competing' with other topics, which were considered more urgent.

Lack of Supportive Policy and Legal Frameworks

This barrier affected another intervention proposed and approved in the Norwegian demonstrator case site. Flood mitigation in the river of Skurdalsåa was based on modifications of an old (ca. 1870) dam to increase the retention capacity of the river's source lake. A system for dam classification and concession, designed for larger hydroelectric dams, led to significant delays in the start-up of this project.

Lack of Public Awareness and Support

This relates for a large part to a lack of knowledge: about NBS as effective mitigation measures, but also regarding the potential co-benefits of NBS. Such scepticism and lack of knowledge will of course lead to lack of support, both at official levels and among stakeholders. This has been experienced in several of the PHUSICOS interventions.

Property Ownership Complexities

PHUSICOS' NBS interventions are planned and implemented on both public and private land. This has led to both challenges and possibilities. NBS interventions may be area-demanding and this, often combined with skepticism and economic agendas, has caused delays and cancellations. In the Pyrenees, the fact that some of the locations are in national parks have also caused problems and delays, due to strong regulations of what can be allowed in such areas.

Time Needed for Public Procurement

This may be an underrated challenge, but which has been experienced in both Norway and the Pyrenees. Procurement must follow the national legislations, including necessary, often long deadlines, evaluation of tenders, etc. In Norway, PHUSICOS also experienced an official complaint from one of the losing bidders, resulting in a full new round with call for tenders, etc. Although not a serious showstopper, the procurement process may lead to significant delays, which again may be critical in a time-limited project like PHUSICOS.

Other Factors

As shown in the study by Martin et al. (in prep.), a number of other factors form barriers to NBS implementation. In the Norwegian demonstrator case site of Gudbrandsdalen Valley, gravel outtake from rivers after large flooding episodes is an important income for some of the farmers with land in areas where sediments eroded during the floods deposit. This may make the landowners less interested in flood mitigation measures.

Conclusion

A common denominator for the experienced and reported barriers to NBS implementation is a lack of knowledge leading to skepticism. In particular, the advantage NBS have over other adaptation strategies in their ability to deliver multiple benefits is too poorly known among all relevant stakeholder groups. Therefore, communication to and involvement of all stakeholders in NBS projects at an early stage are crucial factors for success. If possible, one should try to quantify the real value of the co-benefits over time.

Table 9-1 Barriers for the implementation of NBS. Nos. 1–15 are from (Sarabi et al., 2020). Nos. 16 and 17 are based on PHUSICOS experiences. Challenges may relate to more than one potential barrier. Bold text marks the barrier considered most important for each example (from Solheim et al., 2021)

	Barriers:	PHUSICOS NBS sub-project	Comment
1	Lack of political will and long-term comitment	**Bastan Valley, Pyrenees, France;**	Potential lack of will after local elections.
2	Lack of sense of urgency among policymakers	Jorekstad, Gudbrandsdalen, Norway	
3	Lack of public awareness and support	**All sites**	Public awareness of the problem(s) but not of NBS as a viable solution.
4	Risk aversion and resistance to change	Bastan Valley, Pyrenees, France;	
5	Silo mentality		Not yet experienced in PHUSICOS
6	Misalignments between short-term plans and long-term goals	Jorekstad, Gudbrandsdalen, Norway;	Jorekstad: tthe merger between counties.
7	Lack of supportive policy and legal frameworks	**Skurdalsåa, Gudbrandsdalen, Norway;**	
8	Lack of design standards and guidelines for maintenance and monitoring		Not yet experienced in PHUSICOS
9	Lack of skilled knowledge brokers and training programs	All sites	Inadequate knowledge of NBS and, in particular their co-benefits.
10	Functionality and performance uncertainties	Jorekstad, Gudbrandsdalen, Norway; **Socques, Pyrenees, France**; Bastan Valley, Pyrenees, France;	
11	Percieved high cost	Jorekstad, Gudbrandsdalen, Norway; Bastan Valley, Pyrenees, France;	
12	Lack of available financial resources	**Jorekstad, Gudbrandsdalen, Norway;**	
13	Lack of financial incentives	Jorekstad, Gudbrandsdalen, Norway;	
14	Property ownership complexities	Jorekstad, Gudbrandsdalen, Norway; **Serchio River Basin (SRB), Italy**; Socques, Pyrenees, France;	SRB: some discussion regarding the land needed for the sedimentation basin.
15	Space constraints.		Not yet experienced in PHUSICOS
16	Procurement	Jorekstad, Gudbrandsdalen, Norway; Bastan Valley, Pyrenees, France	
17	Other factors	Gudbrandsdalen, Norway;	Income from gravel out-take after flood events.

10 Lessons learned / PHUSICOS legacy elements

Many of the lessons learned during the project relate to the barriers, described above (Chapter 9). However, the following elements are considered important for future NBS projects:

Planning

In PHUSICOS, many of the planned interventions, as described in the original project proposal, appeared well planned. However, when the project started, it became apparent that this was not the case for all, and the detailed planning was time-consuming. Many elements needed considerations and clarifications, which were not properly considered before. Examples comprise

- Detailed *design of the interventions:* This is often subcontracted to an external consultant, and not all have the right experience and competence to design NBS. Furthermore, the design takes time and often the design phase uncovered that the original cost estimate was too low, as was the case for Jorekstad in Norway (Chapter 6.4).

- *Permissions, property issues and regulations:* These are all elements important to consider, and which may cause project delays. This certainly occurred in PHUSICOS and included property issues in Jorekstad, Norway (Chapter 6.4), permissions related to national parks at Artouste in the Pyrenees (Chapter 5.2, and dam regulations for the intervention in Skurdalsåa, Norway (Chapter 6.2.
- *Early stakeholder involvement:* To create enthusiasm and a sense of ownership to the intervention, stakeholders of all levels should be involved at an early stage. There is generally very limited knowledge about the positive co-benefits that NBS can provide, and proper information and discussions around this may help overcome scepticism. The interventions in the Serchio River Basin case site (Lake Massaciuccoli) in Italy (Chapter 4), and at the concept case site in Kaunertal (Chapter 8) are good examples of this. There is also a huge learning potential from the stakeholder involvement in the Isar concept case (Chapter 7). From this case, some elements are mentioned as particularly important success factors:
    - A broad participation of the civil society
    - An open-minded local and regional administration
    - Multi-scale and multidisciplinary round table discussions
    - Neutral facilitation and mediation helped to overcome conflicts.
    - Trust and confidence between the stakeholders

Monitoring

As most of the NBS interventions in PHUSICOS were delayed, and some not completed until very near the end of the project, monitoring results will first be available long after PHUSICOS. Exceptions include Erill-la-Vall in the Spanish Pyrenees (Chapter 5.4), where monitoring had been going on for 15 years due to other projects, and at Lake Massaciuccoli, Italy (Chapter 4), where some of the interventions were completed early due to good planning and early stakeholder involvement. Monitoring, therefore, must be planned in detail in parallel with the planning of the NBS itself. Baseline data should be acquired before the implementation of the NBS, for the same elements as planned for the monitoring, including both benefits (resilience) and co-benefits. Monitoring should then start immediately after the implementation is complete.

When vegetation is a significant part of the NBS, time is required to prove NBS efficiency, for example afforestation in the case of avalanche protection in the Capet Forest (Chapter 5.3). Monitoring also require funding, which may last for many years. This needs to be budgeted for as well as one must have clearly defined responsibilities for both acquiring the monitoring data, and to analyse and report them. If possible, monitoring data should be made available to stakeholders, through accessible web portals or other means, such as for Erill-la-Vall in the Pyreneees (Chapter 5.4.1) and the interventions by Lake Massaciuccoli in Italy (Chapter 4.5). Because one of the main barriers to NBS implementation is the lack of proof of their efficiency and good success stories, proper and well documented monitoring and dissemination of results are important.

Maintenance

NBS are not maintenance-free. Required maintenance will vary from site to site and is intervention-specific. It may vary from forest management and replanting of dead plants, such as in Capet Forest, replacing damaged logs in the slopes at Artouste, mowing the buffer strips at Lake Massaciuccoli to maintaining the threshold in the Skurdalsåa dam. However, the maintenance should take place for many years and must be planned and included in the cost estimates. Responsibility for the maintenance must also be defined. Hence, this should also be part of the planning, along with the monitoring and the implementation proper.

Accepting hybrid solutions

Most of the PHUSICOS interventions may be classified as hybrid solutions, rather than 'true NBS'. Exception may include the buffer strips at Lake Massaciuccoli, Italy, the erosion mitigation in the Kaunertal valley, Austria, and the afforestation in Capet Forest, the French Pyrenees. The experience to bring forward is that some pragmatism is needed. Certain problems may be solved by true NBS alone, whereas for some a traditional grey solution may be the only feasible possibility, e.g., to protect life and property.

The measures implemented in PHUSICOS differ on a scale between 100% NBS and 100% grey. The closest to the grey structure is probably the improved dam at the Skurdalsåa case in Gudbrandsdalen, Norway (Chapter 6.2), whereas other interventions are very close to the other end of the scale. When evaluating measures, considering what the alternatives would be is important. As an example, the rockfall interventions in the slope at Artouste, the French Pyrenees (Chapter 5.2), will probably not increase the biodiversity of the slope, and part of the constructions may appear 'grey'. However, the alternatives would imply the use of heavy machinery, establishment of access roads for the construction, cutting of trees, etc. Similarly, the alternatives to the intervention in Skurdalsåa (Chapter 6.2) would be traditional barriers along significant lengths along the river.

In connection to this point, it is worth mentioning the Norwegian guidelines for climate adaptation, which states that nature-based solutions must be explicitly addressed as an alternative to be assessed along with any grey solution. Should the NBS solution be dismissed, the reason must be substantiated (https://lovdata.no/dokument/sf/forskrift/2018-09-28-1469/kapittel_4-%201#kapittel_4-1), further elaborated in https://www.miljodirektoratet.no/ansvarsomrader/klima/formyndigheter/klimatilpasning/veiledning-til-statlige-planretningslinjer-for-klimatilpasning/vurdere-naturbaserte-losninger/).
At present, this is only a 'soft' guideline, without consequences if not followed. However, guidelines like this, particularly if spread and made more regulative, will eventually lead to wider use of NBS and various forms of hybrid solutions where this is possible.

Sharing experience

Finally, interventions like those implemented in PHUSICOS, and in particular when monitoring data and results appear, must be used to teach and inform all types and levels of actors involved in disaster risk reduction (DRR). This is being done with good results at the demonstrator case site in Italy, where also other farmers than directly involved in the measures around Lake Massaciuccoli have become interested in applying similar measures in their fields. The PHUSICOS measures have also been used as examples in the 'NBS-Lab' activities performed by ADBS in Italy (Chapter 4.4), where different classes of actors, from students to professionals participate. Another related activity is the webinar and spring school arranged by project partner TUM, in collaboration with CTP, using both the Isar case and the NBS implementations in the Pyrenees as cases and 'outdoor classrooms'. A final example is a two-day seminar hosted by CTP, in Laruns, France, in mid-April 2023, with participants from technical entities, both private and public, in which practical, technical issues in planning and implementing NBS will be treated.

11 Concluding remarks

- A total of 15 NBS activities for DRR are implemented in PHUSICOS. Of these 11 are physical interventions and four are educational- and dissemination activities. Four additional proposed physical interventions were cancelled (3) or rejected by the project's Steering Committee (1). All interventions are described in detail in this report.
- Three sites are large scale demonstrator sites:
  - The Serchio River Basin, Tuscany, Italy, where NBS are implemented to reduce runoff containing soil particles, nutrients, and pesticides from farmland to a system of irrigation canals and eventually to the currently highly polluted Lake Massaciuccoli. In addition, the interventions are aimed at reducing the flood hazard.
  - The Pyrenees in both France and Spain, where NBS interventions are implemented to reduce the hazards from snow avalanches (Capet Forest, France), debris flows (Erill-la-Vall, Spain), rockfall (Artouste, France and Santa Elena, Spain), erosion, and slope instability (Santa Elena, and Erill-la-Vall, Spain).
  - The Gudbrandsdalen Valley, Norway, where NBS are implemented to reduce flood hazards in two rivers (Skurdalsåa and Trobekken, Øyer).
- Two smaller concept case sites comprise:
  - The Isar River, Munich, which is a retrospective case to learn from. The interventions were completed several years ago, and the main learning experience is from the stakeholder involvement processes.
  - The Kaunertal case site in the Austrian Alps, where innovative experimental work has been carried out to reduce erosion and instability in barren slopes (e.g., after deglaciation). Different mixtures of seeds and local biota are used to enhance vegetation growth, and thereby more rapidly stabilize the slopes.

- As the implemented NBS interventions mitigate a variety of natural hazards (flooding, debris flows, erosion, slope instability, rockfall and snow avalanches), they will provide important additions to the knowledge base of NBS functionality.
- The educational- and dissemination activities are reaching out to a variety of stakeholder groups, from school children to technicians and construction companies, mainly using PHUSICOS case sites as examples.
- A number of barriers have been met in the process of implementing the NBS interventions. Some have led to cancellations of planned measures, and most of them confirm the main barriers in the published literature, and the process of overcoming these add to the knowledge and experience database.
- Learned lessons are many, but the most important ones include
    - Projects like PHUSICOS need time. Even 5 years may be short.
    - Planning is crucial to reduce the time and ensure that projects are actually realized.
    - Stakeholders must be involved at the earliest possible stage.
    - Monitoring must comprise both the hazard mitigation part and the many co-benefits, and the monitoring must be planned and budgeted for early in the process.
    - Maintenance needs vary, but will always be there, and should also be planned and budgeted for early.
- Monitoring of the PHUSICOS implementation sites will persist for many post-PHUSICOS years. Systems and responsibilities for handling, storing, analyzing, and disseminating these important data are now being made.

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