
# Soil Mapping and Process Modeling for Sustainable Land Use Management

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interface and the soil strength properties might provide useful insight in terms of the preparatory and triggering conditions in soil, but in order to do so, focus on sites equipped for snow-gliding assessment is needed.

In the future, snow-gliding susceptibility maps could be used to identify the areas most prone to snow-glide avalanches on a large scale, while statistical models might provide threshold values for the most relevant soil, snow, and weather parameters, to be used as an early warning monitoring system for the most dangerous sites shown in the map.

## Sustainable Land Use in Construction Projects (Switzerland)

In Switzerland there currently exist two important instruments for environmental and soil protection within construction projects outside official construction zones. First the Environmental Impact Assessment, second the instrument of the Environmental Protection Expert for Construction Projects (EPECP), and for soil-related construction projects, the Soil Protection Expert for Construction Projects (SPECP, recognized by the Swiss Soil Science Society). The expert's duties are prescribed in the Swiss Standards (SN 640583) and he or she has discretionary power (Bono et al., 2014). In Switzerland the necessity of soil protection on construction projects is widely accepted. As the quality check of the Swiss Soil Science Society revealed (BGS, 2015), the SPECP has become a successful and effective instrument for chemical and physical soil protection since its introduction in 2001. The SPECP's tasks are to accompany building projects from the planning and authorization phase to the submission and construction phases, and finally to the follow-up phase.

Although various laws, regulations, and guidelines clarify soil protection in general, practical guidelines that include an integrated approach for the mountainous and alpine region are still missing. Protection methods adapted to lower altitudes are often not applicable in alpine areas. Due to enhanced construction activities, the alpine environment is under increasing pressure. Different sites illustrate that destructive construction methods lead to long-term damage. Therefore preemptive and protective methods are necessary. It is of utmost importance that the heterogeneity of the alpine nature (see "The Alps and Their soils" section) is incorporated within the solution-finding process in construction projects.

In the Swiss alpine territory little basic information exists for the work of EPECP/SPECPs. Large-scale geological and hydrogeological maps, occasionally vegetation maps and maps of protected areas, might be available. High-resolution relief plans are a valuable and oftentimes accessible tool. Other information, such as geomorphological observations or estimations of water balance or land use, as well as the overlapping of different factors, is obtained through on-site assessment by the EPECP/SPECP. Usually, additional soil core samples or soil profiles help to characterize soil formation and soil properties, as well as the related ecosystem functions. Oftentimes, detailed soil maps are unavailable. The financial input needed to prepare high-resolution soil maps for construction sites is generally not deemed to be justifiable.

These were the basic conditions that the EPECP/SPECP (Nina von Albertini, the author of this section) in charge of the street-renewal project at the Julier Pass of the Cantonal Civil Engineering Office encountered. The project entailed the significant enlargement and a partly new path of the pass road. During the execution phase from 2008 to 2013, important new embankments (fillings and cuttings), road dismantling, protection dams against avalanches, and renaturations of stretches of water were executed (Fig. 8.44). 230,000 $m^3$ of material was moved and 18 ha affected. The vegetation plans showed agricultural land, different alpine

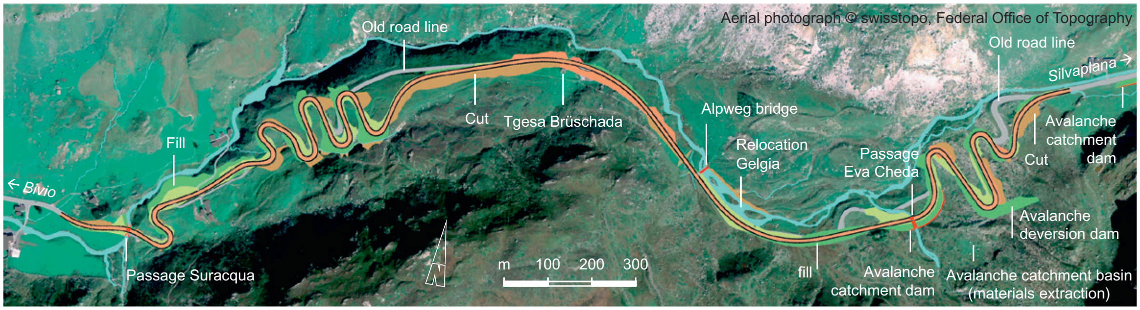


FIGURE 8.44 Part of the construction project at the Julier Pass with the new alignment of the road, filling and cutting constructions, avalanche barriers, road dismantling, and further elaborated constructions. Builder and plan: Cantonal Civil Engineering Department Graubünden.

grasslands, alpine heaths, scree vegetation, avalanche deposit zones, spring vegetation, and fens, as well as watercourses with riparian zones. Based on point-based soil samples the EPECP/SPECP elaborated a soil protection concept. This phase enabled knowledge of the territory to be gathered and the development of practicable ideas.

At the Julier Pass the thickness of soil layers varied from raw soils with a minimal soil cover to depths of up to 1 m. The heterogeneity, not only of the soils (Fig. 8.45), but also of the developed ecosystems, called for interdisciplinary approaches and protection measures in order to ensure that the complex key conditions were respected. Conventional alpine greeneries of the last 30 years show that usually the site-specific vegetation with its original heterogeneity is lost. As Curtaz et al. (2014) demonstrated, rebuilding soils often leads to the nonreversible homogenization of the soil's composition and horizons as well as a simplification of the relief (Fig. 8.46A). In addition, soil losses and work delays resulting from bad weather conditions can occur as a logical consequence of the customary method of loading, transporting, depositing, reloading, and, finally, positioning the soil.

Therefore in this special case, it was essential to develop new methods that would enable the preservation or rebuilding of the heterogeneous and interconnected structures. Consequently, for the elaboration of adequate soil protection measures the SPECP not only had to deal with little existing data and a degree of high complexity, but also to make allowance for the necessity of an interdisciplinary overview and the extensive

FIGURE 8.45 Soil profile at the Julier Pass at a hillside location rich in organic matter and with a high presence of boulders. *Source: photo: N. v. Albertini.*

applicability of the chosen methods in various ecosystems. Additionally the methods needed to be economically acceptable and easy to integrate into the construction process.

The direct-shifting of soil and its vegetation, as realized and further developed at the Julier Pass, is the ideal solution to the aforementioned challenges in the context of alpine conditions. As shown for the Julier Pass in the analysis of site-specific resemblance in Marti (2015), this way of adapting the landscape enables the integration of technical construction in a plausible way without destroying the character of the landscape. The restoration of a natural, well-adapted relief by means of direct-shifting is feasible even with low labor input (Fig. 8.46B).

In order to successfully plan the direct-shifting method and to determine its costs the thickness of the soil and its layers and the presence of soil skeleton on the surface and within the soil profile is the most important information. In direct-shifting the soil is lifted up together with its vegetation cover by using a large excavator shovel and redeposited within the reach of the excavator on newly prepared subsoil in one single movement (Figs. 8.47 A and B and 8.48).

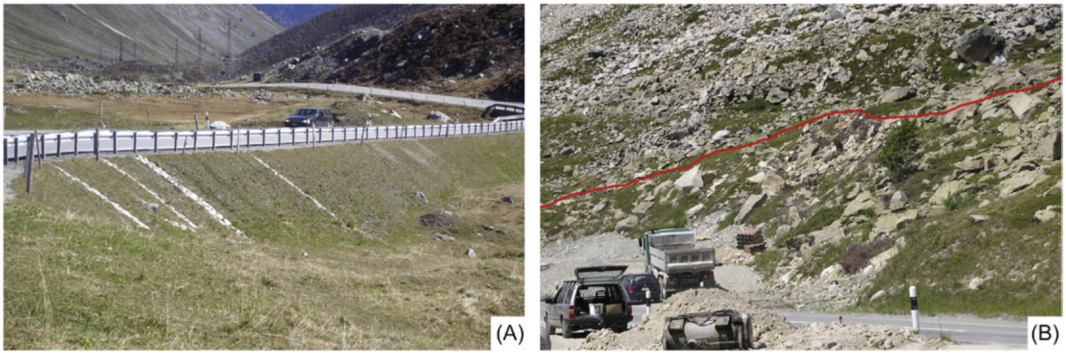


FIGURE 8.46 (A) A conventionally constructed embankment with technical drainage. The forming of the relief, the soil, and the vegetation are not adapted to the environment of the site. (B) A direct-shifted, completely new embankment is shown below the red line; above is the natural terrain. Compare to Fig. 8.49A, where the slope is being shifted. *Source: photos: N. v. Albertini.*


FIGURE 8.47 (A) Extraction of fen sods (Flachmoor-Soden) in the area of the future alignment of the road. (B) Direct placement of the fen sods in the newly prepared area. *Source: photos: N. v. Albertini.*

Thereby, the complex is loosened and slightly disrupted. Compared to conventional handling the soil experiences only minimal physical interference. As an ecosystem with its specific components, the soil remains comparably functional and heterogenic.

Therefore the method can be applied even under nonoptimal weather conditions. Regarding the short vegetation and construction season in the Alps, this is a very positive characteristic in terms of project costs. Thanks to a reduction in deposit surfaces, temporary access roads or technical protection against erosion and seeding, direct-shifting allows savings as regards time and the cost of transport, machines, and labor.

The preservation of the autochthonous ecosystems enables the continued existence of soil material in its typical layering, including root horizons, soil organisms such as mycorrhiza (Graf and Frei, 2013), the seed pool, and the growing vegetation. Consequently, erosion risk is kept low without any high-input technical methods. Marti (2015) demonstrated this even in the case of slopes with more than 30° inclination and with almost immediate effect (Fig. 8.49A). Only minimal erosion occurs in the variable spaces between the sods with accumulation in the close proximity (Fig. 8.49B).

As noted by von Albertini and Regli (2012), about 65% of the newly built embankments (mostly alpine grasslands) as well as about 2,000 $m^2$ of fens and riparian zones were successfully compiled by direct-shifting of sods, including their root horizons (Figs. 8.47A–8.51A). The direct-shifting even included the transfer of boulders with their proper lichen

FIGURE 8.48 Newly built fen 10 months after direct-shifting. *Source: photo: N. v. Albertini.*

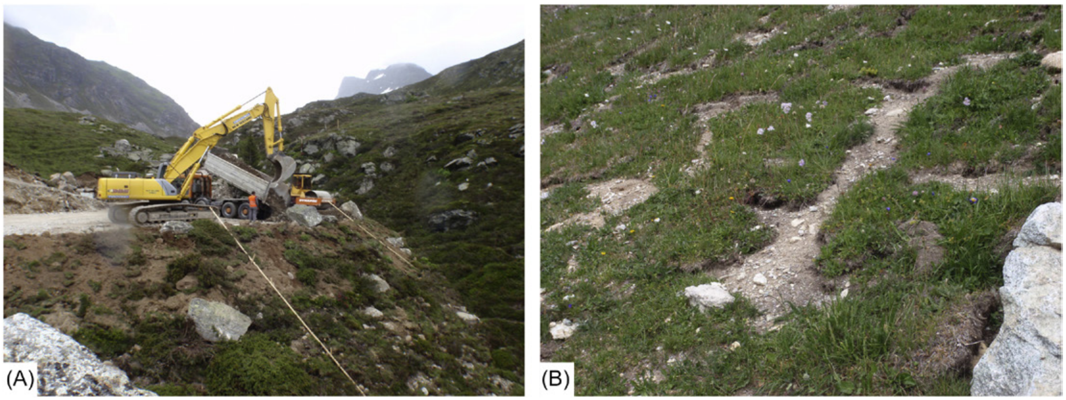


FIGURE 8.49 (A) Advanced filling construction with direct-shifted sods integrating structural elements such as boulders and dwarf shrubs. The sods and their root horizons are removed from behind the excavator as the filling gains height. (B) Sod mosaic with irregular gaps 1 year after direct-shifting. Before the emergence of complete vegetation cover through the expansion of the autochthonous flora, small-scale erosion and accumulation of soil material within the gaps may occur. These processes can be accepted as they contribute to site-specific heterogeneity. *Source: photos: N. v. Albertini.*

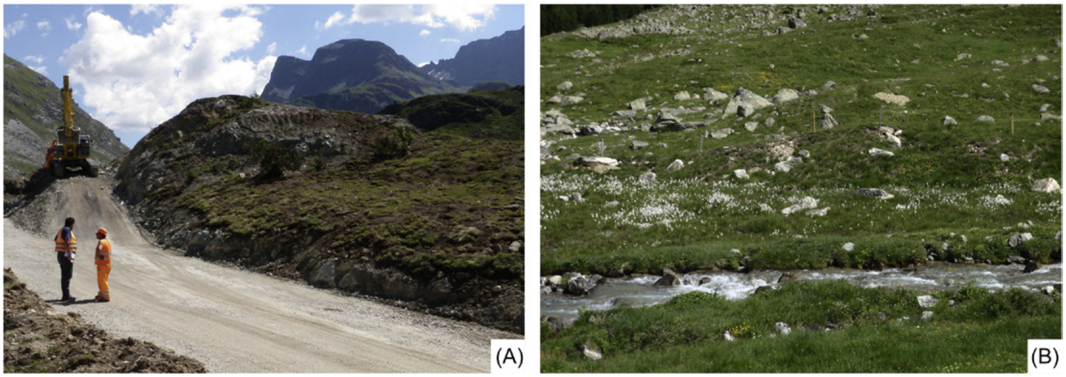


FIGURE 8.50 (A) A recently constructed, direct-shifted slope adapted to its natural surroundings. The terrain was lowered up to 7 m. (B) The newly built fen from Fig. 8.47, 4 years after direct-shifting (below the fence, shifted alpine grassland followed by fen vegetation). *Source: (A) photo: Tiefbauamt Graubünden; (B) photo: N. v. Albertini.*

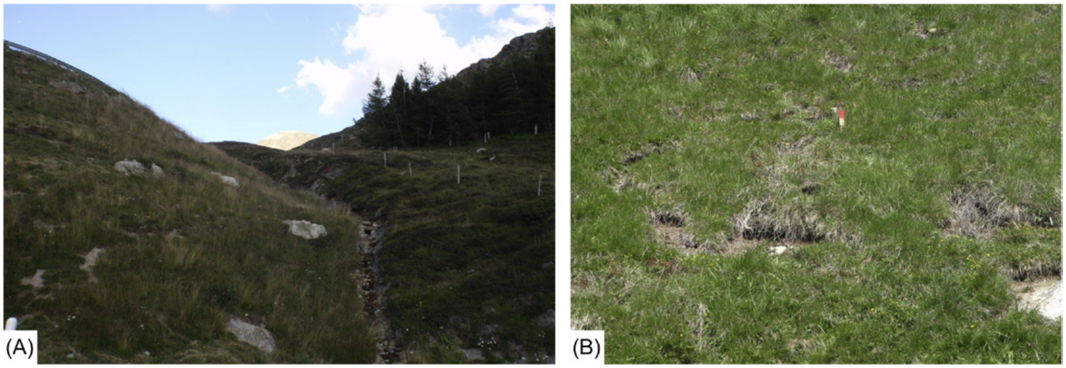


FIGURE 8.51 (A) The same slope as in Fig. 8.49A less than 2 years after completion. Right of the newly built creek is the natural terrain, on the left the direct-shifted slope. (B) The same surface as shown in Fig. 8.49B 3 years after the shifting. The autochthonous sod vegetation has colonized most of the gaps. *Source: photos: N. v. Albertini.*

or dwarf shrubs. Floristic monitoring (von Albertini, 2014) was able to show that 3 years after construction 80% of nearly 200 mechanically shifted dwarf shrubs had survived (Fig. 8.46B). Furthermore, the number of species, the composition of vegetation, and the coverage of vegetation in direct-shifted areas and in natural surroundings corresponded highly. Moreover, there was no import of alien species and varieties caused by seeding, which reduced the settling of problematic species or neophytes. To conclude, direct-shifting leads to a reduction in the overall impact on soil, flora, and fauna in the construction area over space and time.

In the context of the Julier Pass road project the method of direct-shifting was further developed and broadly implemented. This becomes evident following a review of the literature, such as the guidelines for the revegetation of high-altitude areas (Locher-Oberholzer et al.,

2008) and the guide for natural revegetation in Switzerland (Bosshard et al., 2013) or Krautzer et al. (2012). In these publications, sod transplantation usually gets marginal attention and is often only mentioned in combination with seeding, and with a feasible realization limited to spring and autumn. Unfortunately, in the literature, the assumption that sod transplantation is very laborious and feasible only with manual labor, thus quickly leading to high costs and time overruns, is incorrect and widespread.

In Wittmann and Rücker (2012) a technically and floristically successful implementation seems to have been carried out. The consideration of the landscape aesthetic, though, seems to have the potential to be further developed, as was shown by Marti (2015) and von Albertini (2014) with regard to the Julier Pass. Furthermore, in Wittmann and Rücker (2012), sod transplantation was always realized in combination with the previous removal, the temporary deposit, and the subsequent placement of a so-called "inter soil". On the contrary, on the Julier Pass, the direct rearrangement of sods including their entire root zone was realized without any separation and with intermediate positioning.

Just as important as the direct-shifting of the soil is the building of a rough subsoil as an appropriate base for the sods to be imported. Thereby the heterogeneity of the macro- and microrelief has to be rearranged also in the terrain's subsoil. In this context, it has been observed that heterogeneous transfer, including the structural elements, leads to structural and material interdigitation. Consequently, a positive effect on infiltration combined with a reduction in erosion and landslide risks results.

Depending on the availability of sods, it is possible to restore a tighter or looser mosaic, integrating the structural elements as blocks or shrubs (Fig. 8.51A). Thanks to the existing seed pool in the soil material, as well as to the vegetative and seed spread parting from the sods, the in-between spaces will be colonized in the short term (about 3 years) with site-specific vegetation (Fig. 8.51B). Therefore the combination of direct-shifting with spontaneous greening represents a low-priced and effective solution. It not only enables the achievement of vegetation cover that sufficiently protects against erosion, but it also eliminates the necessity to import seeds.

Thanks to direct-shifting the stabilizing function of the vegetation and its root activity is reestablished within a short time, also demonstrating the importance of keeping the disturbance of soil organisms and the concomitant microbial activity at a minimum. Transplanting purely peeled vegetation sods to newly arranged soil layers may facilitate drifting and concomitantly enhance the possibility of landsliding. To lower such risk, Wittmann and Rücker (2012) propose securing the sods using ground anchors or nails and to additionally cover the surface with an erosion blanket. Nevertheless, such bioengineering methods lead to higher costs, are less natural, and due to the clean layering the erosion risk remains high for a longer period. Therefore an experienced SPECP and careful execution can be as important as the technique itself. The goal should be a holistic approach and low input solutions. In order to achieve successful implementation of this complex task, it is essential that the SPECP communicates in a competent manner with the various partners, especially with the permission-granting authorities, the project planners, the construction management, and the construction workers. A well-informed machine operator handles soil with care.

Due to the low accessibility of high-resolution soil maps for alpine areas the SPECP has to provide project-related soil data based on soil profiles or soil core samples for the environmental impact study and for the planning phase. Of further importance is indirect information obtained through geology, topography, and related geomorphodynamics, aspect, vegetation and its cover rate, as well as knowledge of the water balance in the surroundings of the project. The combination of indirect and directly obtained information helps decision-making with regard to protection measures and efficient construction methods. Considering the difficult conditions, it is absolutely necessary for the SPECP to be equipped with quality site-specific knowledge. Within the context of construction projects, not only time and money are scarce resources, but also good soil specialists. Therefore ensuring methods for work with DTMs and aerial images would be a good addition to work with soil data (see "Methods, Status, and Relevance" section). As the construction proceeds, the SPECP will obtain more detailed soil information on the site. Unfortunately the data so collected is often not integrated into existing data pools and therefore this information subsequently becomes inaccessible or even lost.

Soil type, water dynamics, soil horizons, grain size distribution, soil structure, and the presence of soil skeleton are the necessary soil data within alpine construction projects. In general, maps can provide basic information, but decisions on handling methods should be based on holistic comprehension of the site, and its ecosystems and landscape. Whether soil data can act as a restrictive factor and therefore be integrated into guidelines for soil protection and soil handling is difficult to generalize. With regard to rare ecosystems, such as very dry areas or wetlands, soil data could arguably determine protection measures. Regarding the use of soil data in alpine construction projects a few questions remain open and thereby signify the need for further research in this area:

1. Is the time and financial expenditure needed for area-wide soil maps too high compared to their utility and possible impact on decision-making procedures?
2. Does the value of soil maps at a scale of 1:25,000 depend on the possibilities of combining them with DTMs, microclimate and water balance conditions, existing soil data, and risk maps, or are topography and the water balance more significant variables than the soil type when seeking to identify adequate protection solutions?
3. Should the data obtained by soil experts at construction projects be collected? How could its quality be guaranteed or made uniform?

The presented method of direct-shifting achieves one major goal: to minimize the environmental impact and destroy as little of the environment as possible. The formerly accepted destruction, "desertification", and homogenization of surfaces accompanying construction projects can nowadays be avoided. The method as proposed in this section combines the process of direct-shifting with controlled spontaneous autochthonous greenery and represents a practicable and low-priced solution to maintaining site-specific biodiversity. However, the success of environmental and soil protection on construction sites is based on the EPECP/SPECP's ability to constructively and positively communicate with the construction personnel.

The specific know-how gained in the process of adapting such new methods should be further developed, disseminated, and also be made accessible across national borders. In addition, binding guidelines adapted to the alpine environment should be provided in addition to basic soil data on a scale of 1:10,000. Fortunately, in some EU countries, the introduction of EPECP/SPECPs is already proceeding. Switzerland should act preemptively in this sector and implement corresponding guidelines as soon as possible.

The experience obtained within the framework of the Julier Pass project shows that the proposed direct-shifting is not only an efficient greenery method, but also represents an extensive construction technique with far-reaching positive impact. Soil protection, environmental and nature conservation, landscape protection, and time and cost savings can be covered by a single technique. Direct-shifting therefore can significantly contribute to sustainable land-use within the context of construction projects in heterogeneous areas such as the Alps, a requirement postulated by the Alpine Convention (Art. 2, 2.d "Soil conservation", 1995).

## CONCLUSIONS AND OUTLOOK

Against the background of soil land-use examples in "Traditional Land-Use Types and Related Long-Term Impacts on Soils" section, the case studies in "Mapping and Modeling Soils in the Alps" section should provide answers related to soil-survey and soil-information use in the Alps. They all illustrate a high degree of diversity regarding aims, scales, and methodological approaches. Nevertheless, all of them try to meet the specific requirements of Alpine landscapes. Furthermore, most of the case studies aim to use soil information to support land-use planning. On the basis of these examples and with regard to the need for future improvement by integrating soil information into land management decisions, the following issues should be emphasized:

1. Soil information is vital for a wide range of land-use planning and management activities that aim to be sustainable and resource efficient.
2. Soil maps for the Alps should not be less detailed than they are at a scale of 1:25,000.
3. Besides soil types, soil maps should include information on the most relevant physical and chemical soil properties in order to meet the demands of site-specific land use and management.
4. For planning issues, soil maps should be interpreted in terms of soil potential and vulnerabilities, considering ecological processes and functions as well as susceptibility to various threats.
5. For special planning cases, soil information must be spatially detailed and more specific.

Taking this into consideration and also realizing the high costs of soil surveys in the field, the following challenges are evident:

1. Soil surveys should provide data that can be used flexibly in GIS systems.
2. Soil information should be a constitutive part of any ecosystem-oriented landscape research or management; data should always be combined with other geoecological information.
3. Soil classification systems should be more flexible (e.g., within the hierarchy) to better integrate the soil information into other classification or evaluation systems.
4. Soil surveys should be more focused on soil properties in order to obtain data that are more applicable and free the user from soil classification. Soil property data that can also be complemented by measurements provide important input for the calculation of pedotransfer functions.
5. In order to reduce time and costs, soil-survey fieldwork should be supported, combined, and improved by the integration of DSM techniques. The DSM approaches can also be used to further differentiate already existing soil maps/information. Nevertheless, ground-truth soil surveys are not deemed to be replaceable by methods providing purely digital and remote sensing data.
6. DSM, using different geo-informatics approaches, in particular helps to extrapolate soil property point data to wider areas, independent of SMUs. At the same time, we should bear in mind that the prediction of

soil-forming factors largely depends on the availability and accuracy of data.
7. Currently, new soil data collection methods, e.g., remote sensing and geophysics, provide new possibilities to support soil surveys. For instance, demand-oriented UAV-flights (UAV = Unmanned Aerial Vehicle) can be performed in order to produce both detailed aerial images as well as digital elevation models, which, in combination, are perfectly suitable for identifying soil-vegetation complexes above the timberline. In this context, intensive collaboration between methods and disciplines is necessary.
8. Considering the wide variety of soil-survey methods, scales, and systematics, cross-border soil data and knowledge transfer in the Alps should be expanded, for instance by using some type of cross-border, sustainable soil-management platform.

Ranging from carbon stock estimates to the management of construction sites, the diversity of the presented case studies shows how different soil data applications can be in the Alpine environment. Nevertheless, this short overview cannot replace intensive cross-border communication and the exchange of best practices regarding soil data exploitation. International communication amongst the Alpine countries and regions is also needed in order to overcome data incompatibility (e.g., soil classification differences) and to promote cross-border cooperation in the management of the Alpine territory.

In any case the scale of soil information seems to be crucial and should be addressed through the intensive collaboration of the soil scientists of the Alpine countries. An optimal framework can be achieved by combining soil overview maps at a scale of 1:25,000 with application-specific soil maps, e.g., at a scale of 1:5,000. Such detailed soil maps and data can be prepared when (1) general soil maps are available, (2) contemporary soil data collection methods are utilized, and (3) data processing methods are applied.

As the parent material presents the basis for soil development, the detailed genetic and spatial differentiation of quaternary deposits is particularly important. Unfortunately, data on these relatively thin sediment strata are often not represented in geological maps. Consequently the utilization of geological maps with their units may lead to insufficient or, in the worst case, incorrect conclusions and misleading soil information.

Nevertheless, all these scientific efforts will be in vain if the stakeholders are not convinced how, which, and to what extent soil information should be integrated into land-use decision-making processes in order to ensure sustainable development. Regrettably, soils are often only regarded as a homogeneous surface for agricultural production and are used according to subjective criteria and tradition. In order to strengthen a new level of soil awareness, more intensive communication between the end users of soil information (decision-makers, administrations) and soil experts is needed. Focusing on soil properties, on the one hand, and embedding soil information in a landscape context may contribute to a better understanding of soil and consequently more sustainable and rational planning and management decisions. Nevertheless, in order to promote soil-related issues in practice, also the legal frameworks must be improved.

The chapter presented contributes to creating focused, purpose-driven, and applicable soil information and thereby better exploitation of soil information in support of sustainable development in the Alps. It highlights specific challenges that need approaches and solutions tailored to the specifics of the Alpine landscape. Furthermore, the variety of examples and methods from these five Alpine countries evidences the existence of an interdisciplinary and transdisciplinary scientific and lay community that aims to meet soil-related challenges in the Alps on an international level.

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Case Study C5 ("Mapping Land Suitability to Mountain Viticulture (Aosta Valley, Italy)" section), Project Alpter: Terraced landscapes of the alpine arc
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# Soil Mapping and Process Modeling for Sustainable Land Use Management

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A theoretical and practical approach to soil mapping and modeling as it applies to sustainability and land management

*Soil Mapping and Process Modeling for Sustainable Land Use Management* provides and synthesizes the most up-to-date worldwide interdisciplinary research from experts working in soil mapping and land management. It is the first reference to address the use of soil mapping techniques, applications, and modeling for sustainability from both a theoretical and a practical perspective. Providing practical examples to help illustrate the application of soil process modeling and maps, Soil Mapping and Process Modeling for Sustainable Land Use Management provides the reader with the information necessary to utilize the latest techniques, as well as their importance for land use planning. It is an essential tool for professionals and students in soil science and land management. The use of more powerful statistical techniques are increasing the accuracy of maps and reducing error estimation enabling professionals to bridge the gap between soil modeling and sustainable land use planning.

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