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Assessment methodologies and mitigation measures for the impacts of road projects on soils – ROADSOIL

Examples from Norway and Switzerland of soil handling in infrastructure projects

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CEDR Call 2019: Soils

Assessment methodologies and mitigation measures for the impacts of road projects on soils – ROADSOIL

D6.1 Guidelines for soil handling in infrastructure projects from planning processes to construction work in field

D6.2 Material for education in soil properties relevant for construction companies and drivers of machines used in road construction

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Executive summary

Soil management in road projects has been sparsely described in scientific literature. Systematic studies following road projects during the different phases of the planning process, the construction period, and evaluation of the results seems to be absent both in scientific literature and other written reports. The information presented in this report is based on pulling together fragmented knowledge from many sources, resulting in the best and most updated synthesis of available data. Many of the techniques and procedures presented in this report are still under development, as methods are continuously improved in practical road projects by soil experts in cooperation with construction companies. Most of the examples of road projects included here are from Norway and Switzerland, whose relevant solutions can be modified and adapted to regulations and varying conditions throughout Europe.

It is important to address soil management issues as early as possible in the planning of road projects. Plans for the reuse of soil and stone materials within the road projects must be evaluated as part of the Environmental Impact Assessment (EIA) and according to the EUs waste directive. It is recommended to make a detailed soil survey along the route of the chosen road corridor, as detailed soil information is needed for proper soil management during the construction phase. The information from the soil survey makes the basis for the soil management plan for the road project. Such soil information is also useful for the outcome of field training courses for construction companies and their construction machine drivers at construction sites. It is recommended to implement processes for utilizing uncontaminated soil materials within the road construction area instead of using surplus materials for filling depressions or other landfill areas.

The recommended primary principle for soil restoration in road construction projects is to reconstruct soil layers horizon by horizon. For example, the B-horizon material is placed on the C-horizon surface, while the A-horizon materials are the topsoil on top of the B-horizon material. Therefore, it is recommended to strip soil material horizon by horizon and store soil materials sorted separately, in A-horizon piles and B-horizon piles. Mixing of subsoil materials from the B- and C-horizons should be avoided, as this causes loss of soil structure and makes the material more compact. Transport of soil material within the road project must always be on temporary access tracks/roads to minimize the risk for compaction damage. Such access tracks/roads may be placed above the B-horizon. When the management area is restored back to the original land use, such as cultivated or forested land, the B-horizon needs to be loosened with excavator before replacement of the A-horizon in order to restore natural soil functions.

Procedures for soil moisture measurements and the determination of soil moisture thresholds for different soil management operations are very important in reducing the risk of severe compaction damage.

During storage of soil materials in the construction period it is important that invasive alien species (IAS) are controlled. It is recommended to seed soil storage piles with perennial grasses which are mowed several times a season. Mowing of grasses has good effects on both IAS and perennial weeds. For road projects known to contain IAS, it is very difficult to ensure that the IAS will not reappear after project completion. It is also very important to implement measures to avoid erosion from storage of B-horizon material, as such soil material is more susceptible to erosion than topsoil material.

Consulting soil experts during the planning and construction phases of road projects has improved the quality of soil management resulting in reduced soil compaction damage and less agricultural yield reduction in road project zones. The Swiss training system for soil experts for construction projects has been very successful and contributed to successful restoration of soils after road construction. We recommend implementing similar training systems in other European countries. The competence of soil management by the operators

of construction machinery, however, needs to be improved. Targeted training for machine drivers on site in different projects in Norway has been very successful, where the focus is on soil properties that can be easily observed from the driver's seat.

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1 Introduction

This ROADSOIL report focuses on soil handling in infrastructure projects. As in the report from WP 4 (Geiges *et al.* 2022), this report describes soil management in the two phases of planning and construction. We go into deeper detail with recommendations, partly documented in reports and papers, and partly based on recordings at construction sites. In the latter, cooperation with construction companies has been very valuable to figure out procedures that can be successfully carried out in practice.

The following issues are covered in this report:

- Systems for temporary storage of topsoil (with increased organic matter content compared to subsoil) and subsoil, with respect to static load, avoiding erosion and collapse of soil structure, and minimizing the risk of spreading invasive species and weeds.
- Recommended procedures for soil processing, which increase the reuse of soil and unpolluted masses from the road construction and reduce the land-take for building up landfill areas.
- Measures for erosion control during temporary mass storage related to climatic conditions (e.g., heavy rain, snowmelt).
- Layer-by-layer soil rebuilding with construction machines to minimize compaction for agricultural areas, new forest areas, and roadsides.
- Procedures for placement of soil horizons for different land use, such as agriculture and forestry, at permanent mass storage sites.
- Development of criteria for maximum load of machinery related to actual moisture conditions and soil properties to avoid severe soil compaction, especially relevant for construction work in a humid climate with high precipitation and long-lasting rainy periods.
- Suitable machinery and procedures for loosening of compacted soil layers, such as methods commonly used by construction companies, do not give the expected results.
- Methods for mixing stones and boulders sorted from till with rock material from tunnelling and other rock work, making it possible to obtain materials for roadbuilding and other building processes.
- Combining fine fractions of crushed rock material (0-2 mm, 0-4 mm) with soil materials from road projects into soil mixtures suitable for use at roadsides and greening areas along roads, or to be sold for urban greening in general.
- Treatment of peat soils in road projects has been sparsely documented by scientific studies, but some practical recommendations on this topic are included.

Polluted soil materials should be treated according to the legislation for pollution and waste in different countries, as the threshold values for contamination vary between countries. In general only unpolluted soil materials should be reused in the root zone for plants. Slightly polluted soil materials may be used below the root zone for plants and at areas not intended for plant growth according to national regulations. After suitable washing can gravel, stone, and boulder fractions be sorted out as unpolluted materials, while the fine fraction consisting of organic matter and mineral material in the silt and clay fractions will remain contaminated.

Training in soil management at construction sites is normally not given at any level in education systems from technical colleges to universities. In this report we present the curriculum developed on this topic in Switzerland and the practical course material developed in Norway.

Understanding the properties of the different soil horizons is very important for the management of soil in road projects. A short introduction to the definitions of soil horizons. slightly modified from FAO (1990), is presented:

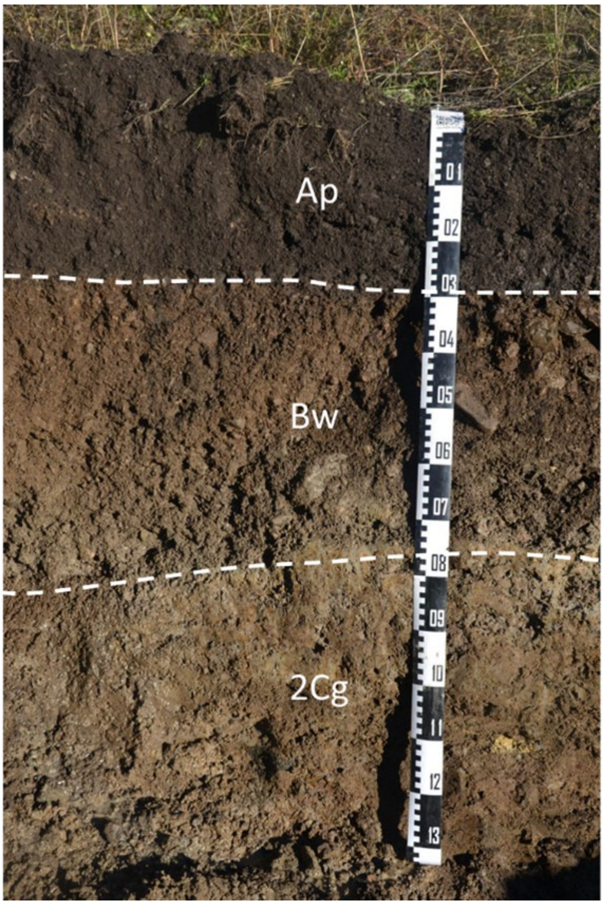
H horizons or layers (Histic horizon): Layers dominated by organic material, formed from accumulation of undecomposed or partially decomposed organic material at the soil surface, and which may occur underwater.

A horizons: Mineral horizons formed at the surface are characterized by an accumulation of humified organic matter intimately mixed with the mineral fraction. A-horizons may show properties resulting from cultivation, pasturing, or a different kind of disturbance, or have a morphology which is different from the underlying B or C horizons.

B horizons: Horizons formed below A and/or H horizons, showing pedogenetic processes as illuvial concentration; removal or accumulation of carbonates; residual concentrations or coatings of sesquioxides that make the horizon a darker, more intense, or more reddish colour than the underlying horizon; structure formation is granular, blocky, or prismatic; tends toward brittleness.

C horizons or layers: Horizons or layers, excluding hard bedrock, that are little effected by pedogenetic processes.

R layers: Hard bedrock underlying the soil.



Plough layer (Ap), weathered horizon (Bw), subsoil with gley (Cg) Photo: Trond Knapp Haraldsen

2 Focus on soil protection in planning road projects

2.1 Planning at different levels

Planning of infrastructure projects normally consists of different levels of details. The first phase belongs to regional planning. At this stage, different routes for new roads are proposed and evaluated based on existing information in databases, maps, governmental plans, and different legislations. The different alignments of corridors (Dienststelle für Nationalstrassenbau [DNSB] 2020, Transport Infrastructure Ireland 2022) is often a part of the primary evaluation, where the landscape, preserving cultural heritage, protecting agricultural land, and mitigating environmental impacts are considered for selection of alternative strategies going into more detailed planning phases.

As new roads and highways influence parts of municipalities, the next step in the planning is to make plans for parts of the involved municipalities. This can be challenging, as neighbouring municipalities may have different opinions on selection of the alternatives. It is common to perform Environmental Impact Assessment (EIA) at this level of planning. The EU EIA directive emphasises measures to avoid and compensate for land take. Until now, there has been limited focus on mitigating the effects on soils during construction. Randrup & Dralle (1997) found that severe soil compaction measured as very high bulk densities occurred at all studied construction sites, causing severe limitations for plant growth. To prevent unintended soil compaction, they recommended making zones at construction sites where traffic of construction machines was controlled. In the protected zones there should be no traffic of construction machines. There is a general requirement to focus on the need for reuse of soil materials and suggesting suitable areas for temporary mass storage at this planning level. In recent years, there has been an increasing focus on management of excess materials in major infrastructure projects. This is partly due to compliance with statutory requirements, but also because developers and contractors are realising that better planning of excess material management can lead to environmental and financial benefits. The goal is to ensure responsible, predictable, and more resource-efficient management of excess soil and stone whilst protecting the interests of the environment, climate, and land use, as stated by Norwegian Environment Agency (2021).

The EU's waste directive define clean excavated soils as follows: "The waste status of uncontaminated excavated soils and other naturally occurring materials which are used on sites other than the one from which they were excavated should be considered in accordance with the definition of waste and the provisions on by-products or on the end of waste status under this Directive" (European Commission 2008). A normal starting point will usually be to determine if the soil is contaminated and classified as waste. The definition of project area is important for classification of soil material with respect to waste status. If the soil material is managed within the project area, unpolluted soil materials are not classified as waste. The soil materials are not classified as waste if they can be used for demands outside the project area (Environmental Protection Agency 2019, Swedish Environmental Protection Agency 2022). As there has been identified conflicts between the EU's waste directive and national legislation in EU countries regarding management of uncontaminated material of the highest quality, there are ongoing discussions on this topic (InfoCuria 2022).

Hale *et al.* (2021) has published an overview about legislation and practice for reuse of soils in several European countries: France, Norway, Portugal, Slovenia, Sweden, Switzerland, England, and Wales. Their study also included non-European countries, including Australia and Canada. The study of Hale *et al.* (2021) identified four main groups of barriers for reuse of excavated soil:

- Regulatory barriers; including complicated legislation, lack of guidelines for reuse, long application time for permit for reuse, and unclear ownership of reused soil.
- Organizational barriers: including lack of knowledge and relevant understanding, lack of holistic and early planning for possible reuse, and contracts not designed for reuse of excavated soil.
- Logistical and economic barriers; including supply and demand for excavated soil is not always available, lack of intermediate storage capacity and limited permitted time for storage, extra costs for each logistical step, and no economic incentives for reuse compared to landfilling.
- Material quality barriers: rigid geotechnical requirements, uncertainty on environmental risks, uncertainty about the quality of improved soil related to lack of technical and accepted protocols for technical specifications, and preference for virgin materials.

2.2 Reuse of soil in infrastructure projects

As the EU is striving towards becoming a smart, sustainable, and inclusive economy by the 2020s, increasing the reuse of excavated soil is a necessity (Hale *et al.* 2021). The Irish Environmental Protection Agency (2022) has developed guidelines for national practice for management of greenfield soils, which is in accordance with the EU’s waste directive. In the detailed planning phase of road projects, there are possibilities to include plans for reuse of soil and stony materials. Finding suitable areas for mass storage, both temporary and permanent (with specified intended end use), is challenging as there are a lot of possible conflicts related to nature conservation, soil protection, and other issues. In recent road and railway construction projects in Norway, a plan for soil management is demanded at this planning level, as it is almost impossible to get the plans approved at municipality or regional/county level without such a plan. Although there are guidelines for making such plans, the competence in soil science varies between the consultants making such plans. In general, the plans follow the guidelines developed by Vestfold and Telemark County (2021), but they also may include recommendations from Hauge and Haraldsen (2017) or Thorsteinsen et al. (2022).

Two Norwegian Road projects have been studied in the ROADSOIL project during their planning phase: E6 Roterud-Storhove, Innlandet County, and E6 Kvithammar-Åsen, Trøndelag County. In these projects, soil management was based on the principles given by Hauge and Haraldsen (2017) and further improvement was implemented. In both projects, the construction companies have used soil experts in the detailed planning phase. Involvement of soil experts in the planning phase of road projects may result in solutions which are beneficial both for the economy of the projects and for the possibility to restore more agricultural soil and green nature areas.

According to act concerning the cultural heritage archaeological investigations must be carried out in the areas of planned road projects. Soil investigations in the trenches the archaeologists use have been very fruitful as such horizontal sections show differences in texture, soil colours and can be used to identify drainage systems. However, the archaeological investigations are not focused on soil management and better protocols for soil handling in archaeological projects on cultivated land will reduce the risk for compaction damage and may reduce the need for high economical compensations to the farmers for yield loss. A closer cooperation between soil experts and archaeologists in infrastructure projects is therefore encouraged.

Although Låg (1981) described the first restoration and relocation of soil for agriculture in a road project, the first large Norwegian road construction project with focus on reuse and reconstruction of soil was introduced in the planning of E18 Retvet-Vinterbro, which started in

2012. The Norwegian Public Roads Administration aimed to recultivate similar areas of agricultural land with the same production capacity as the permanent land take, which was about 40 hectares of agricultural land. This was demanded by the government for the plan to be approved. In this project, a detailed environmental assessment was performed, including specific reports on soil properties and quality, yield level on agricultural soils, and specific plans for soil relocation at several farms. The plans were approved in 2015 by the two municipalities involved, but the construction phase of the project has not started due to other governmental priorities. The principle of restoration and relocation of agricultural soils, however, has been implemented in more or less all recent infrastructure projects in Norway.

3 Soil management under road construction

Soils and climate vary considerably across Europe, making it challenging to create guidelines relevant for all types of conditions. Procedures which function quite well in countries with long periods of drought (as in Mediterranean countries) will not necessarily function well in countries with very humid climate like Ireland and coastal parts of Norway. The soil's bearing capacity for construction machinery is strongly influenced by soil moisture conditions. Using the Terranimo® model for relevant soils in dry, moist, and wet conditions clearly illustrate this point. Work operations which can be done without risk for compaction damage on dry soil may cause severe and persisting damage on wet soils. In areas with peat soils and water-logged mineral subsoil, soil material may start flowing out, causing landslides in sloping terrain. As peat soils have very low bearing capacity, road construction at peatland areas is very challenging both due to management of ground water and bearing capacity for construction machinery.

As there are free movement of workers within EU and associated countries, such as Norway, it is common that construction companies from abroad are engaged for road building projects in other countries. Although there is some overarching EU legislation which are implemented as national laws in the different European countries, the report by Geiges *et al.* (2022) documented a large diversity in national legislations on soil protection issues. It is very important that foreign companies are fully aware of the different legislations and standards that apply in different European countries as well as knowledge about soils, weather, and climate. This is very important related to heath, environmental and safety issues, as landslides and severe erosion may occur related to management of wet soil materials.

3.1 Temporary storage of soil

Areas for temporary storage of soil material are needed in all road construction projects. Optimal areas should be close to the location for final respreading, but the use of agricultural land for storage of soil should be avoided if possible. The best system is to strip the soil layer by layer and store the material from the A-horizon and B-horizonly. The quality of the subsoil material will be restricted if B- and C- horizon materials are mixed. Such mixing of subsoil material leads to loss of soil structure, reduction in hydraulic conductivity, increased risk for compaction damage, and restricted root growth after reconstruction of the soil profile. This in turn leads to decreased crop yields over the long term, which is commonly observed after past road projects.

Storage of soil in piles of different height and volume is the most common solution, but there are many problems related to such storage like erosion, leaching, weeds, and invasive alien species (IAS).

To reduce the risk of erosion from soil piles and avoiding problems with establishment of weeds and alien invasive species, it is recommended to seed the piles with perennial rye grass (*Lolium perenne*) or other perennial grass species, which need to be cut three times a season to reduce the establishment of perennial weeds. This measure is effective for discouraging most unwanted weeds with large root systems and several invasive alien species, such as *Solidago canadensis* and *Lupinus polyphyllus*. This strategy is doubtful for reducing spread of barnyard grass (*Echinochloa crus-galli*), however, as this species has an ability to make new shoots with flowers and seeds after being cut. It is very important to remove barnyard grass plants manually at an early stage before the spread makes it almost impossible to combat this species (Øverland 2021).

The risk of erosion at piles with B-horizon materials need special attention as such material is more susceptible to erosion than topsoil material. Storm water episodes may cause severe erosion and measures for protection water courses are needed.

Covering soil piles with textiles tested in a building project at the Norwegian University of Life Sciences, Ås, Norway.

Photos: Trond Knapp Haraldsen

Many problems related to storage of soil were identified during the project period 2015-2021:

- The geotextiles flew away in windy periods. It was difficult to find optimal solutions for holding the geotextiles in place.
- There was a high density of weeds between the soil piles, and wheel tracks from construction machinery used for soil management caused severe compaction (Photo A).
- The seed bank in the soil still had germination capacity after storage.
- Although the textiles were permeable, the soil material in the core of the piles was very moist even after long drought periods, while the soil close to the textile cover was dry.
- Rodents, namely the European water vole (*Arvicola amphibious*), found shade under the textiles and multiplied into a large population during the storage period, causing damage on crops at adjacent agricultural fields.

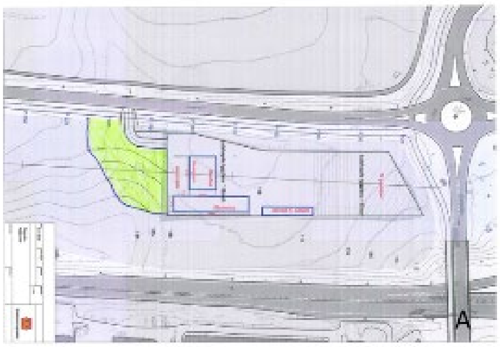
After the stored soil had been transported from the storage area, the soil was severely compacted and eroded (Photo B). Soil loosing of the B-horizon, 30-40 cm, by excavator and replacement of the topsoil (plough layer, Ap-horizon) strip by strip was needed to restore the production capacity of the agricultural land (Photo C). Yield measurement showed that the measures were successful. There were no significant differences in wheat yield between the restored and the reference area (Photo D). The mean yield of wheat at the restored area in 2021 was 6230 kg ha^{-1}, while the yield at the reference area was 6400 kg ha^{-1}. The restored area is now in normal production for agricultural crops.

The soil loosening process by excavator shown in the example from at the Norwegian University of Life Sciences (see box example of soil piles, p.14), is a technique originally described as successful by Rolf (1993) for soils used in urban greening. The method has been modified in recent years by NIBIO for use at agricultural areas in applied projects in Norway. It is very important that the loosening of the B-horizon shall not reach so deep that drainage pipes may be affected. As shown in the box example, this method can fully restore the productivity of agricultural land after temporary mass storage and similar activities in construction projects. The method has also been improved for use in urban areas by Virginia Tech (2019).

Cultivation on long-term temporary stored topsoil in a road project

When the project administration office for the road projects E18 Retvet-Vinterbro and E134 Oslofjordtunellen, Norway, was prepared for construction on an agricultural area, the topsoil was placed adjacent to the area instead of being stored in piles. The intention was to use soil for cultivation during the construction period of these projects, which was estimated to be at least ten years. The soil was placed around the project office area (yellow area in Photo A), but it was not seeded immediately. Severe erosion subsequently occurred on bare soil the first winter (Photo B), and weeds from the seedbank in the soil germinated and developed strong growth the following growing season (Photo C). After measures for weed control during cultivation of winter rape, the area was seeded with winter wheat (Photo D). Thus, the area will both produce agricultural crops during the construction period and weed control will be easier to perform.

To avoid problems with erosion and weeds it is strongly recommended to seed shortly after placement of the soil.



Photos: Trond Knapp Haraldsen.

To avoid problems with weed and alien species on soils during storage, cultivation on stored topsoil has been successfully implemented in some road projects (see example "Cultivation on long-term temporary stored topsoil", p. 15).

There are different recommendations about the height and layout of soil storage piles between different countries. In Switzerland, the recommended height of A-horizon material piles is a maximum 1.5 m and B-horizon piles is a maximum of 2.5 m (Schweizerischer Verband der Strassen- und Verkehrsfachleute [VSS] 2019). The Swedish guidelines describe a maximum pile size of 2.5 m height and 6 m width, where soil properties and terrain need to be considered for detailed layout (Trafikverket 2021). The static load of soil piles is of importance for subsoil compaction if soil materials are piled on agricultural fields. The transport of soil material in and out of the storage area may also cause severe soil compaction. If possible, storage of soil piles should be avoided on agricultural fields. Soil loosening of B-horizon from soil piles with an excavator, as shown in the box example at p. 14, is recommended after storage of soil on agricultural land.

In several infrastructure projects in Norway, areas with shallow soil cover and partly bare rock have been used for such temporary soil storage. An alternative to soil storage in piles is making larger soil heaps at areas with sufficient bearing capacity for construction machines. The advantage with large heaps is area efficiency, while the disadvantage is large variation in soil moisture within the heaps. When heaps get as large as 3-4 m, it is recommended to create smaller piles of 1.5 m height, 2-3 days before transport to the field placement. The soil moisture content within the small piles will be very uniform due to capillary transport of water.

3.2 Respreading and relocation of soils horizon by horizon

The principle for respreading or relocation of soils is to rebuild the soil profile horizon by horizon (Figure 1). As reported by Geiges *et al*. (2022), several countries have published specific guidelines describing proper soil restoration on areas which were temporarily used during road construction or gravel excavation (e.g., Department for Environment, Food and Rural Affairs2009, Fachbeirat für Bodenfruchtbarkeit und Bodenschutz, Arbeitsgruppe Bodenrekultivierung 2012, Schweizerischer Verband der Strassen- und Verkehrsfachleute [VSS] 2019, Hauge and Haraldsen 2017, Thorsteinsen *et al.* 2020). Common recommendations in the guidelines are:

- Soil material from A- and B-horizons should not be mixed but stripped separately and should be stored separately to conserve soil structure and the living conditions of the soil organisms.
- After restoration, only minimal agricultural intervention (e.g., without heavy machinery) should take place on the soil for a period of several years, because freshly restored soils are very susceptible to compaction.
- Management of soil materials should preferably occur when the materials are slightly moist.
- Measurements of soil moisture should be taken during the construction period.

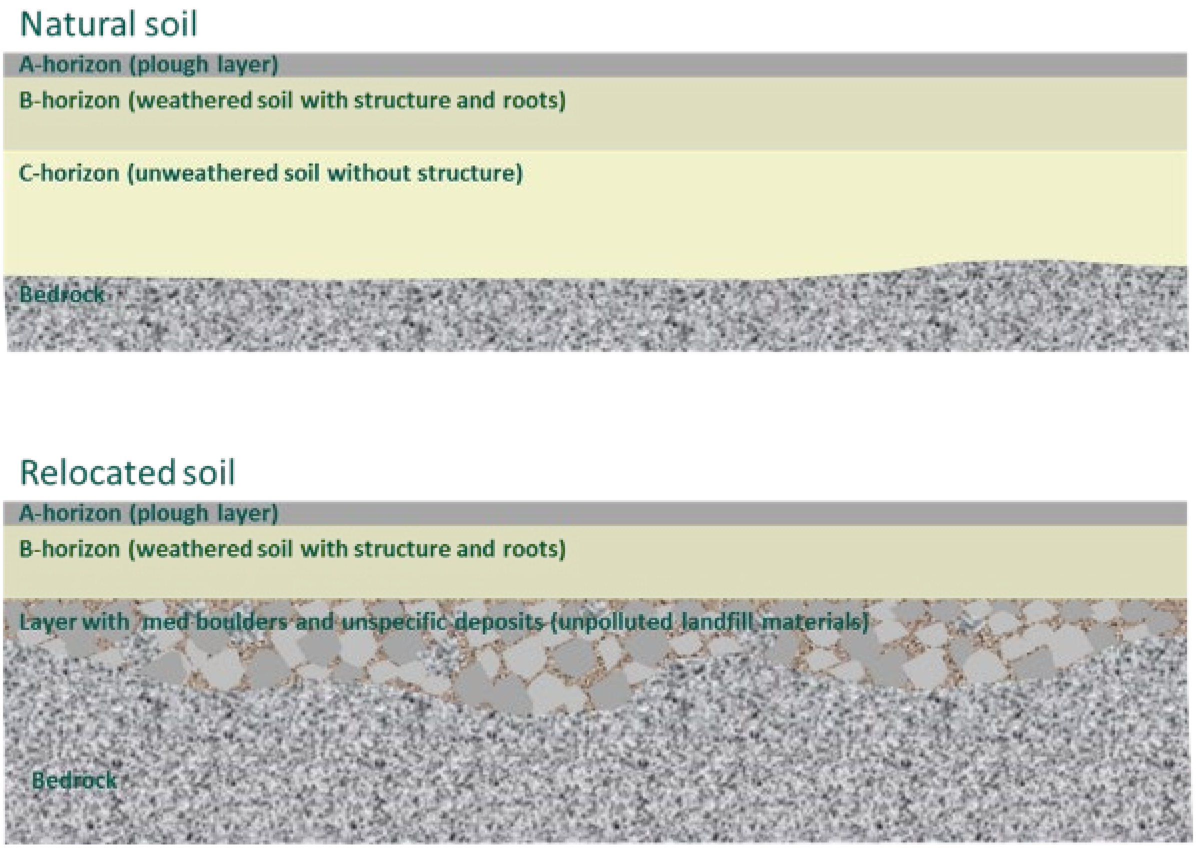


Figure 1. Generic profiles of a natural and restored soil. Source: Modified from Hauge and Haraldsen 2017.

Experiences both from Switzerland and Norway show that the restored agricultural fields after respreading or soil relocation may have equal production potential as the original soils (Stettler *et al*. 2010, Anda 2016). The benefit of careful soil handling during the restoration process was proved in several Swiss studies. Up to the 1990s, only the separate heaping of sub- and topsoil was common practice, and soil moisture at the time of earth work was not considered. This resulted in poor soil structure, heavy compaction, and water logging of restored soils (Friedli *et al*. 1998). Consequently, farmers often complained about decreases in yield. Based on this experience, soil protection measures on construction sites were increasingly called for in the EIA process. Among the first good examples of proper soil handling is the soil restoration after the building of an open-cast tunnel along the A5 motorway in northwestern Switzerland. A soil expert supervised the earth work and made sure that the soil was manipulated only under dry conditions. The soil was very loose after heaping and consolidated in the first three years, including bulk density and precompression stress increasing while coarse pore volume decreased (Kaufmann *et al.* 2009). The soil remained in very good conditions for plant growth, however, and even ten years later, the restored soil was less compacted than a reference soil area that had the same agricultural management (Tobias *et al.* 2018).

3.3 Reuse of soil for natural revegetation

Restoration of natural vegetation along new roads using natural topsoil from road projects has been investigated in several studies. As there is insufficient information about the prior soil characteristics at restored sites, as well as the duration and location of stockpiling, it is difficult to suggest procedures for optimization of mitigation measures. Only examples are presented in this report, and processes need to be adapted to local and site-specific conditions.

The technique of using the natural seedbank in the topsoil for restoration has been widely recommended. Skrindo and Halvorsen (2008) found that unfertilized topsoil provided a revegetation result in better accordance with the indigenous vegetation than did subsoil. Although the restoration technique originally was concluded as successful, clearing the woody vegetation along the road has led to a massive spread and invasion of *Solidago canadensis* (Figure 2a).

Restoration of nature protected areas along roads is very challenging in places with high risks for reintroduction of IAS. In the nature protected area Åkersvika (RAMSAR), Hamar, Norway, all soil with alien invasive species was landfilled and only soil without a viable seedbank (B-horizon material) was used for reconstruction of the wetland area along the E6 highway. *Solidago canadensis* has reappeared in this area following restoration (Figure 2b), clearly indicating that starting without a viable seedbank is not sufficient to ensure that IAS will not reappear. There are many examples of failures in nature restoration projects that resulted in massive invasions of IAS, although measures to prevent the reestablishment of IAS were implemented. Proper long-term maintenance is required to avoid IAS.

One of the problems with the concept of natural revegetation is controlling the species composition after the construction work has finished. Johansen *et al.* (2007) tried to re-establish peat vegetation in a road project. The species composition differed significantly between restored and undisturbed plots, indicating incomplete restoration after 8 and 9 years. Soil moisture, pH, slope, and microtopography were the most important environmental factors for species composition. *Polytrichum* mosses had a high percentage cover in restored (30%) compared to undisturbed control plots (1%) where *Sphagnum* mosses dominated. The low soil moisture level in the restored areas was most likely limiting the establishment of *Sphagnum* mosses, considered as key species of the typical peatland environment (Johansen *et al.* 2007).

The Canadian peat restoration guide have been successfully used for restoration of peatlands (Quinty and Rochefort 2003) in both Canada and USA in recent years. This guideline is mainly used for the restoration of peat harvesting areas where regrowth of *Sphagnum sp.* is desired. Although the approach specifically addresses northeastern America, the principles in the guideline will also be of interest for restoration of European peatlands.

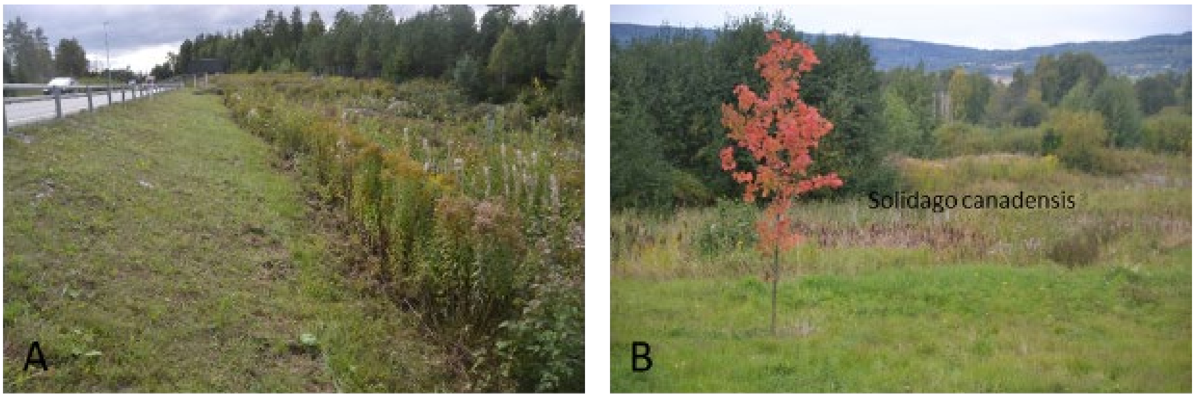


Figure 2. Establishment of Solidago canadensis along E134 in Frogn, Norway after clearing of woody vegetation (A), re-establishment of Solidago canadensis after nature compensation measures in the E6 road project at the RAMSAR area Åkersvika at Hamar, Norway (B). Photo: Trond Knapp Haraldsen.

The Swedish Life to ad(d)mire project was specialized in restoring hydrology in wetlands. Special efforts have been made to increase areas of *Sphagnum sp.* regrowth and nesting ground for wader birds. In the project, 35 Natura 2000 mires and wetlands in Sweden have been restored during 2010-2015. In total, the project has restored hydrology in more than 2,800 hectares of drained mires, removed trees and shrubs in 1,800 hectares of overgrown wetlands, and restored 15 hectares overgrown wet meadows for renewed haymaking. A synopsis of the experiences made when restoring mires in the project Life to ad(d)mire is presented by (Rova & Paulsson 2015). The described restoration actions include various examples of blocking and filling of ditches, as well as tree and shrub removal with different techniques.

Mehlhoop *et al.* (2021) evaluated several road projects in Norway after natural revegetation strategies had been used. They found a significantly higher species richness and diversity in restored plots compared to reference plots, and an increased similarity of species composition over time. Species composition was most like reference plots in naturally revegetated plots and active seeding seemed to reduce both species and functional trait composition. They concluded that it is unrealistic that the defined target vegetation will develop on restored sites. They also pointed out the need for defining a realistic and achievable target vegetation for each road construction project in relation to land use, adjacent vegetation type, and successional stage, such as forest edge instead of core interior forest. They found that seeded areas may be efficient for establishing a rapid vegetation cover to prevent erosion, but not for re-establishing natural vegetation composition. At sites of natural vegetation, no maintenance procedures are normally practiced, as a natural succession is preferred.

To establish special types of vegetation, an investigation of the soil properties at locations where such vegetation has developed in nature is needed. Collection of seeds from such vegetation is recommended, combined with use of special soil mixtures, which should be close to the properties of natural soils. This concept was successfully used for the establishment of drought tolerant vegetation and wetland vegetation at the former Oslo airport Fornebu, Norway (Haraldsen and Pedersen 2005). For building a shallow soil like the local weathering soil, a mixture based on fine fraction of crushed clay schists and limestone together with compost was used, while a mixture based on clayey subsoil was used for the wetland areas. Both soil mixtures were made on soil materials locally available, and the results had a high aesthetic quality (Figure 3).

Figure 3. Using local soil resources for establishment of drought tolerant vegetation on bedrock (A) and wetland vegetation along constructed water mirror at the former Oslo airport Fornebu, Norway (B). Photo: Trond Knapp Haraldsen.

A high focus on biodiversity in European legislation has emphasized the need for seeds of local heritage. There are genetic differences within species of grasses and herbs, and use of local/regional seed blends are recommended. Such blends are available for different parts of Norway and there are also available native seeds from other European countries, such as Switzerland and UK. Many seed manufacturers often sell seed mixtures of European origin which may not be suitable according to the local or regional climatic conditions. It is therefore very important to verify the heritage of the seeds.

3.4 Manufactured soil for urban greening along roads

When road construction projects are performed in urban areas such as cities and villages, soil for urban greening is required. In urban environment is it important to establish a variety of aesthetically attractive designs of grass fields, perennials, lignoses, and woody vegetation (Figure 4). Generally, there has been little focus on the properties of artificialized soils which are typically found along urban streets and roads (Cornu *et al.* 2021).

Soils for urban greening/landscaping are predominantly manufactured soil mixtures, produced by sorting out boulders and stones, and mixing mineral and organic soil materials. Such soils are called manufactured soils. Another group of artificial soils are the Technosols, which are soils that contain a high proportion (at least 20% in the first meter of the profile) of anthropogenic materials, or artifacts, resulting from human technologies, such as crushed bricks, concrete, and glass, or a continuous impervious layer (e.g., geomembrane or a technic hard material) within 1 m depth (IUSS Working Group WRB 2022).

The concept of Technosols represent a balance between the use of waste materials as replacement of natural resources and the requirements of waste legislation. The combination of waste mineral materials and composts of sewage sludge have been found to have good physical properties as a growing medium for urban greening (Cannavo *et al.* 2018, Yilmaz *et al.* 2018). The results demonstrated the feasibility of the process of building fertile soils from cultural by-products, ready to be planted as soon as they are safely produced for human and environmental health (Vidal-Beaudet 2023).

Figure 4. Green structure of grass, lignoses, and tree plantings established in construction soil mixtures based on reused soil materials along Snarøyveien, Fornebu, Norway. Photo: Trond Knapp Haraldsen.

The first guideline for soil quality requirements for construction soils in Norway was developed as a part of the project at the former Oslo airport in Fornebu (Haraldsen and Pedersen 2001). Based on experience in landscaping projects and research projects combining organic and mineral waste materials (Haraldsen and Pedersen 2003, Bøen and Haraldsen 2011, Haraldsen *et al.* 2014), recommendations for construction soils/Technosols have been made for road projects (Norwegian Public Roads Administration 2018). The recommendations have been further developed with respect to layering and soil depth for different types of vegetation in Norwegian Standard NS 3420-K (Standard Norge 2022). Recommended particle size distribution for construction soil is shown in Figure 5. The principles for soil layering of urban soils in NS 3420-K is generally relevant and coincide with literature in urban greening (Vidal-Beaudet 2023).

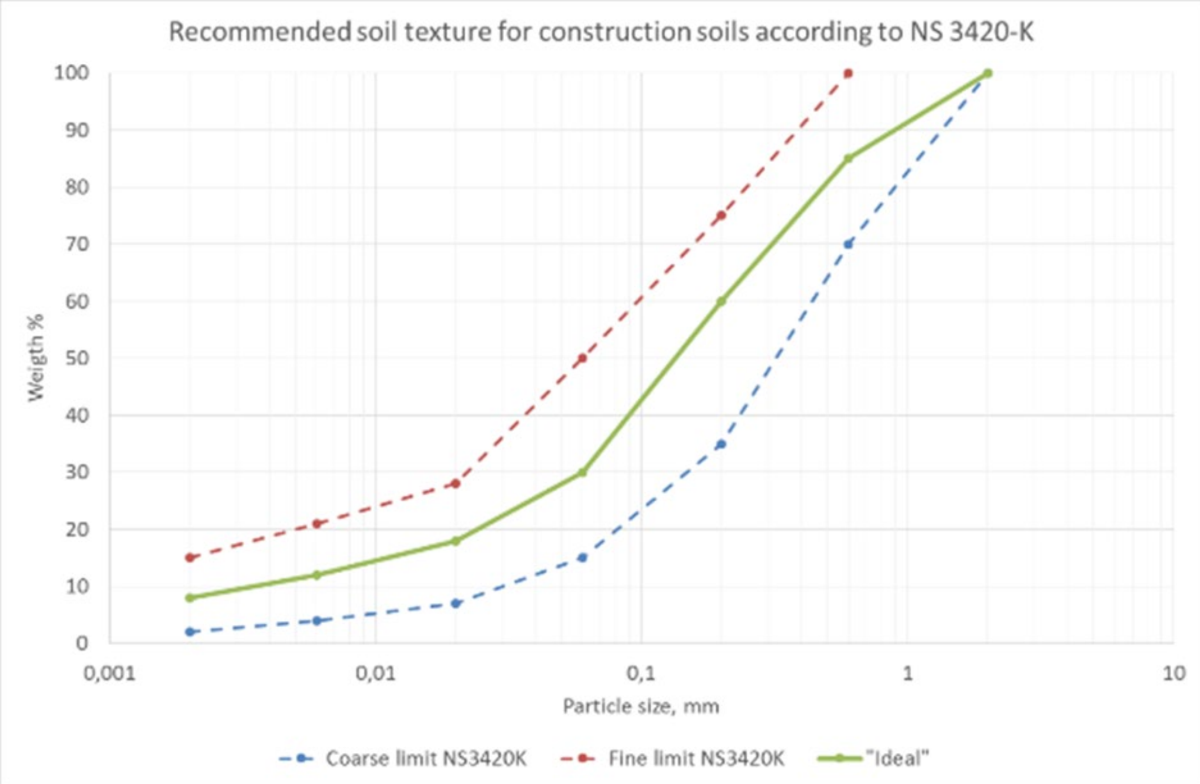
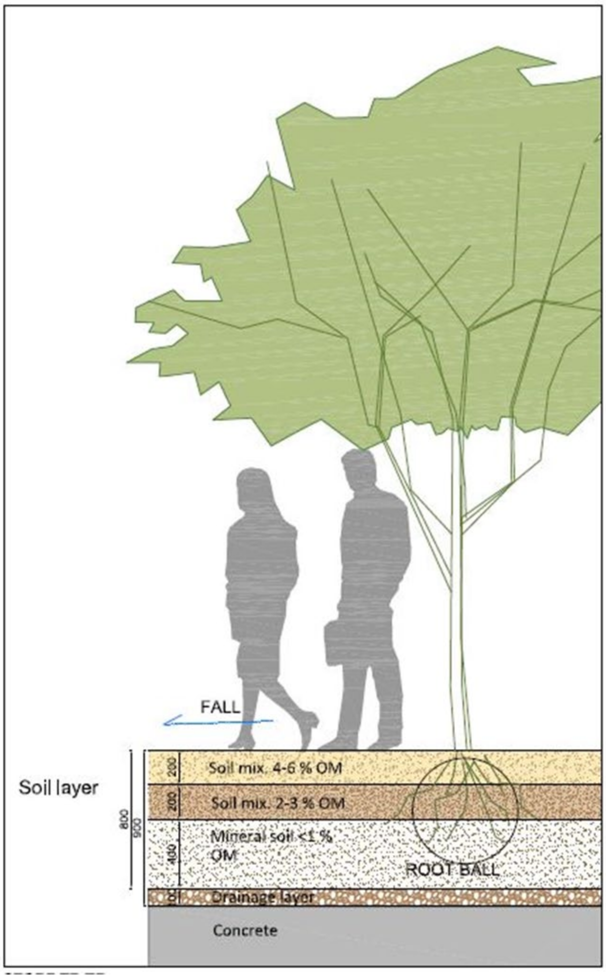


Figure 5. Recommended particle size distribution for construction soils according to NS 3420-K. Illustration: Trond Knapp Haraldsen.

Measures for storm water management are important when roads are built in cities and other urban areas where a large part of the surface is already sealed (e.g., paved). Establishment of rain gardens and swales along roads can be a solution. There is a demand for suitable manufactured soil mixtures for such installations with sufficient infiltration rate, hydraulic conductivity, and water retention properties. Laukli *et al.* (2022 a,b) studied the function of raingardens along Bjørnstjerne Bjørnson's Street in Drammen, Norway, and found that splashes and de-icing salts had large impact on the survival of perennials. Splashes from the road also negatively impacted the perennials' survival of erosion episodes.

An example of a Technosol construction in a Norwegian road project, Oslo

The urban greening construction in Queen Eufemia's Street in Oslo on an 800 m concrete bridge founded to bedrock, represents a Technosol within 1 m soil depth. This is the first full scale urban greening project in Norway using the recommendations for soil construction which later have been implemented in the procedures of the Norwegian Public Roads Administration (2018) and the standard NS 3420-K (Standard Norge 2022). Evaluation of the construction was presented at Eurosoil 2021 (2021). The illustrations were made by Dronninga Landskap AS (www.dronninga.com).



The soil requirements for trees in Queen Eufemia's Street were based on:

- Higher soil organic matter (SOM) content in the upper topsoil layer (4-6%), lower SOM (1-3%) in the lower topsoil layer, and less than 1% SOM in the mineral soil.
- The same soil texture for all soil layers.
- At least 0.80 m soil layer above drainage layer, preferably 1 m.

For lignoses the soil layers were 0,6 m deep, combining a topsoil layer (4-6% SOM) and a subsoil layer of mineral soil. For grass the soil layers was 0.4 m deep, combining the same soil layers as for lignoses. A drainage layer was placed below the soil layers and above the concrete.

Landscaping with green area including tree planting from 2014 at Queen Eufemia's Street in Oslo. Photo: Trond Knapp Haraldsen, August 2022.

3.5 Mass storage of soil – problems for future land use

As described in Chapter 2, uncontaminated excavated soil material is classified as waste if it is transported outside the project area without any intended plan for land use.

In infrastructure projects in Norway, the plans normally describe permanent mass storage areas for disposal of surplus soil materials within the project areas. Then the surplus soil materials will not be classified as waste. In the plans future vegetation development at such areas is also described. Such areas may be classified as compensation areas to be used as agricultural land or forest after the completion of the projects. Caterpillars and heavy construction machines normally are used at such sites. This cause the soil surface to be covered by tracks, resulting in water ponding at soil surface, indicating that the soil is very compacted (Figure 6). The result is poor physical properties for growing agricultural crops, causing low yields and poor economy for the farmers.

Small crop yields after subsoil compaction with heavy agricultural machinery are well documented in scientific literature (Piccoly *et al.* 2022). However, crop yields of mass storage fields prepared for arable farming has sparsely been studied. Haraldsen (2019) compared yields of spring wheat at a mass storage area of clay soil from a road project (Technosol, artifacts as pieces of iron (rebar) and concrete was mixed with the clay) prepared for arable crops to normal cropland in the same area in the period 2014-2016 (Table 1). There were significantly lower yields from the Technosols compared to the normal cropland, and a large variation in crop growth within the area of Technosols easily to observe in the field (Figure 7) and indicated by large standard deviations in Table 1.

Figure 6. Use of caterpillars for levelling out soil materials at mass storage area for unpolluted soil cover the soil surface with tracks and cause deep compaction into the subsoil (Photo: Trond Knapp Haraldsen).

Figure 7. Variable growth of spring wheat at mass storage area with Stagnic Technosol (Mass storage, top in Table 1). Photo: Trond Knapp Haraldsen.

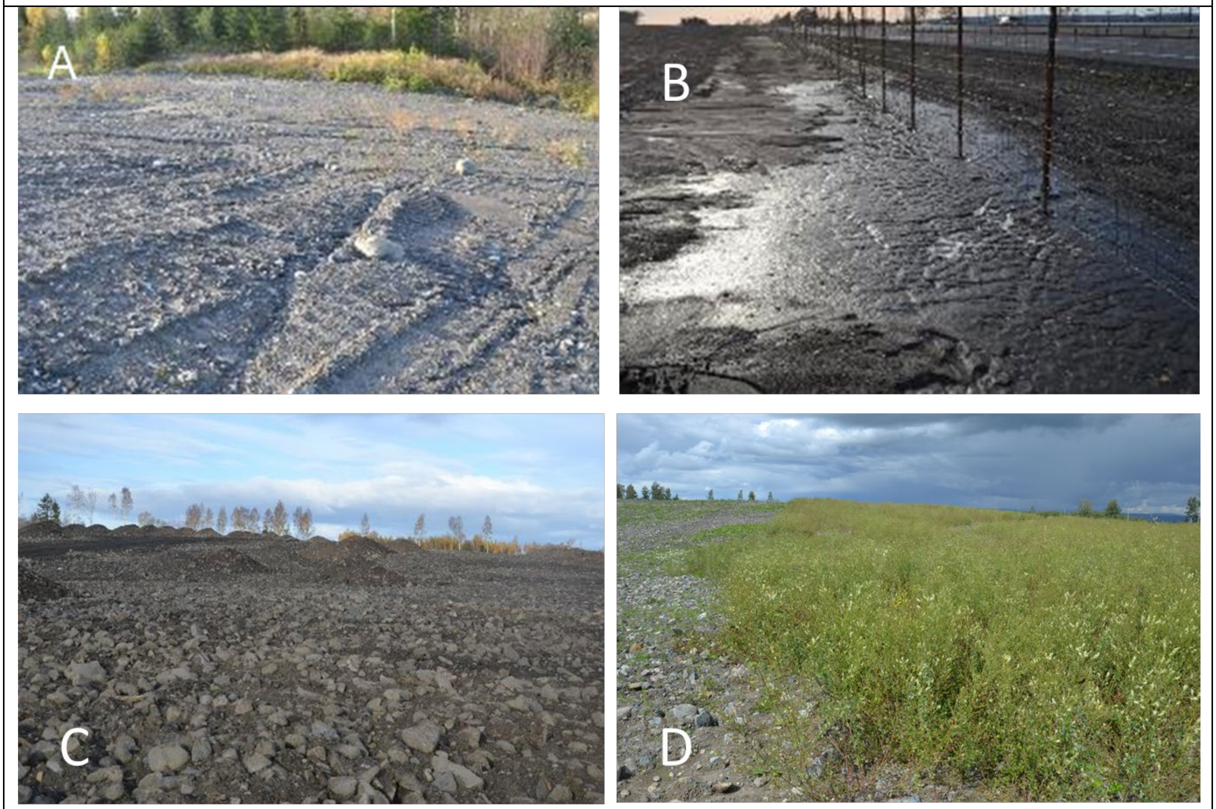
Table 1. Yield of wheat grain (spring wheat, Triticum aestivum) at plots on agricultural land in Vestby, Norway, 2014-2016. Means followed by different letters are significantly different (P<0.05) (modified after Haraldsen 2019).

Land use	Soil classification, WRB	Soil texture	Yield of wheat, kg ha^{-1}	Standard deviation
Agricultural land	Umbric Stagnosol	Silty clay loam	7510a	796
Agricultural land	Umbric Fluvisol	Silt loam	6840a	618
Mass storage, slope, used for agriculture	Stagnic Technosol	Silty clay loam	4100b	1396
Mass storage, top, used for agriculture	Stagnic Technosol	Silty clay loam	4350b	1142

In many infrastructure projects the intention has been to establish agricultural production after filling with soil masses. The soils at such sites are mostly classified as Technosols. The productivity varies considerably. Some sites have not come into agricultural production, while others are productive immediately after soil restoration is completed. In this report two contrasting examples are shown. Both were intended to be possible to cultivate after finishing the construction.

An expensive and ineffective method for converting a mass storage site to agricultural land

This example is from the road project E6 in Stange municipality, Norway. The area of the landfill was originally forested but had good soil quality for potential agricultural production. After landfilling of soil materials from the road project the soil should be of similar quality as before.



The landfill area of seven hectares was covered with different types of subsoil stony masses, and soil infected with IAS was buried deeper than 2 m from top of the mass storage area.

- The soil material in the upper 1 m was so compacted by caterpillars and other heavy construction machines that even weeds did not grow (Photo A)
- Due to the compacted soil severe erosion occurred and the soil material sedimented at the road verge (Photo B).
- To bringing the area into possible cultivation and limit severe erosion, excavators were used for soil loosening and the removal of stones and boulders. The erosion problem was solved after soil loosening (Photo C) but the process of stone removal and restoring good topsoil will continue for several years.
- After the soil was loosened and some stone and boulder removal were completed the area has been invaded by *Melilotus albus*, in Norway classified as an invasive alien species with a high potential for spread (Photo D).

The process of restoring a mass storage area into intended agricultural production (as shown in the example) takes many years and is very expensive. The process includes:

- Loosening of soil and sorting out stones and boulders with an excavator.
- Mechanical stone removal.
- Placement of new topsoil.
- One season of growing pioneer crop species (*Vicia villosa*, *Phacelia tanacetifolia*, *Trifolium incarnatum,* and *Lolium multiflorum*) (Figure 8).

Figure 8. Restored agricultural land with pioneer crops at a permanent mass storage area where soil loosening, and stone removal were done before placing a manufactured soil/Technosol as a new A-horizon (Photo: Trond Knapp Haraldsen)

The ROADSOIL solution for making agricultural land at permanent mass storage areas

Main idea: Reconstruction of the soil profile to ensure normal root development in the A- and B-horizons and avoid severe compaction damage in the subsoil.

Study area: Riis farm, Ås municipality, Norway

Photo: Erling Fløistad

In this project, soil material was transported to the mass storage area, horizon by horizon. First the A-horizon was stripped, transported to the reception area by trucks, and stockpiled. Then the B-horizon was stripped and transported to the area. Finally, the C-horizon masses were transported to the reception area for permanent mass storage and used for landscaping.

The system included the following elements:

- Transportation of soil into the different parts of the area was performed on access tracks, which also has a drainage function as stones were used in drainage system (Photo A).
- Soil material was received horizon by horizon, and stored separately as A-piles, B-piles, and C-piles.
- Soil was reconstructed with C-horizon material in bottom, B-horizon material in the middle, and A-horizon material as the top layer (Photo B).
- Transportation of soils from storage piles was carried out on frozen soil in winter or in dry periods in summer when the soil has good weight-bearing capacity (Photo C).
- Excavator was used for placement of soil horizon by horizon (Photo C).
- Areas with wheel tracks were loosened with an excavator before placing the next horizon.
- Mechanical stone removal was carried out when soil material had too high stone content (>10% by volume).

By this method the area could be seeded with cereals shortly after the A-horizon was placed and levelled out. As seen in Photo D, the growth of spring barley (*Hordeum vulgare*) is normal and normal yield is expected already for the first growing season.

The success of the system attracted interest from construction companies and the system has been presented in an educational video produced as a part of the ROADSOIL project.

3.6 Processing soil materials from construction sites for reuse

In construction projects, including infrastructure projects, a positive mass balance is common, and surplus of topsoil and subsoil materials must be placed at mass storage areas either inside the project area or transported to an official offsite site. The quality of soil materials delivered to mass storage areas varies and is often a mixture of stony topsoil and subsoil material (commonly with >10% by volume of stones and rock boulders, sometimes also skeletal soil material with >40% of the volume of coarse materials >6 cm). Sorting out fine soil from such stony soils is widely used in many countries.

Such soils often have a poor reputation due to:

- Seed bank in soils cause problematic germination of weeds.
- Soil material may contain plant pathogens.
- Varying quality and properties between different batches from the same soil production company.
- Limited documentation of the soil products.

The experience with reuse of soil material at the former Oslo airport in Fornebu, showed that it was possible to manufacture standardized soil qualities based on reused soil materials. The key for such production is that all soil materials used in the processing of soil mixtures must be analysed and documented. Based on the analyses (texture, organic matter, and chemical properties) production descriptions can be made. In addition, a control of the soil brought in for reuse is required to ensure it is free from invasive alien species and plant pathogens. A declaration from experts having carried out survey on invasive alien species at the construction site is needed. Based on a risk assessment and available knowledge about status on *Avena fatua* and quarantine pests and plant diseases at the construction sites it is possible to ensure that risk organisms will not follow the soil.

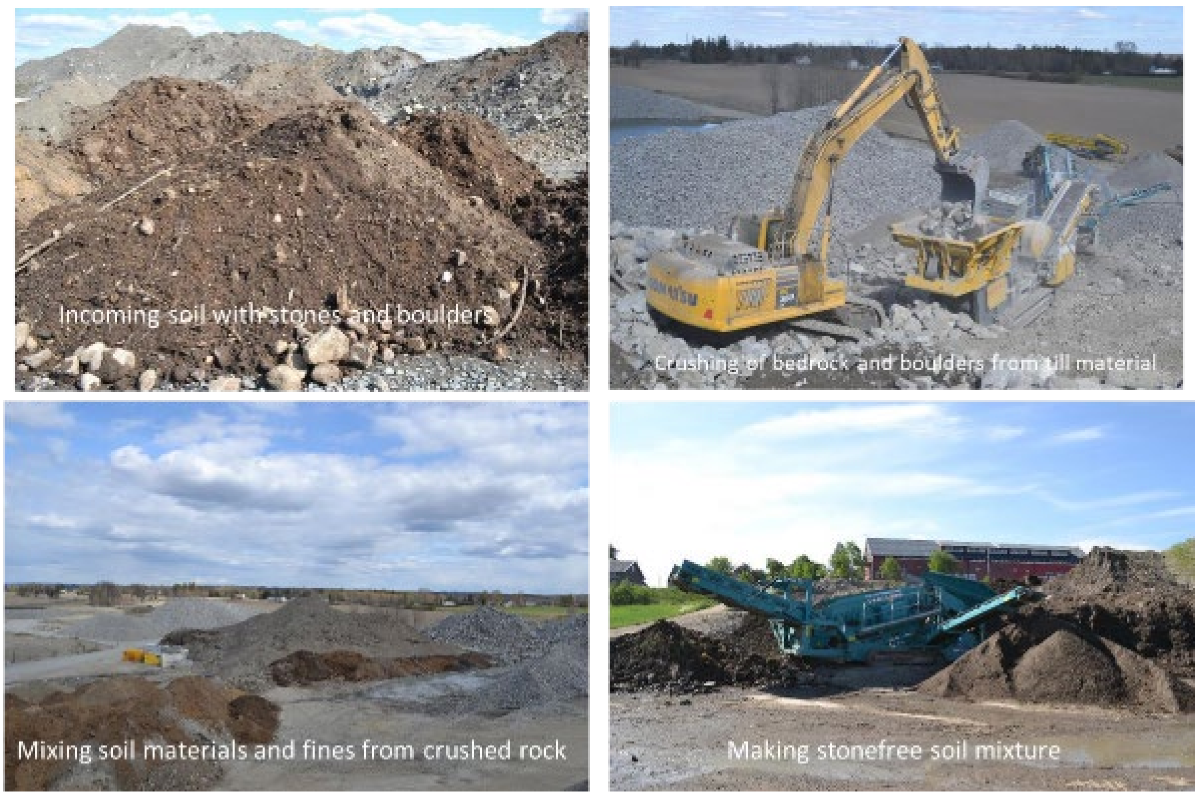


Figure 9. Manufacturing Technosol for urban greening mixing reused soils and rock materials from construction projects. Photo: Trond Knapp Haraldsen.

Successful production of manufactured soil/Technosol from soil materials sourced from construction projects need a systematic logistic approach (Figure 9):

- Storage of different soil qualities in different piles where the origin of the soil material is known and documented. By this storage system of A-horizon piles with different texture and B-horizon piles with different texture it is possible to satisfy the requirements for internal quality control procedures. It should always be possible to check out the quality of all ingredients of a soil mixture when deviating results are found by quality control.
- Crushing and sorting a mixture of blast stones, sorted stones, and boulders from soil materials into fractions suitable for use as building materials.
- Mixing of soil materials from A- and B-horizons and fine crushed bedrock materials (0-2 or 0-4 mm) according to a recipe developed to satisfy a given standard (e.g., NS 3420-K, Standard Norge 2022). Such soil mixtures can be made both for use as topsoil (replacing A-horizon) and for subsoil (replacing B-horizon). The crushed rock material should not have concentrations of heavy metals above the requirements for unpolluted materials.

To stimulate a shift into a more circular economy, it is recommended planning of areas in road projects to be designated for the processing of soil materials into both manufactured soils/Technosols and stone fractions which can then be utilized back into the road projects or used externally of the project. Such systems for soil production and utilization of stone fractions may be described as a part of a road project, as the main purpose is to reuse resources needed in the road project. If soil and stone materials from a road project are delivered to a company outside the project area, the materials are classified as waste, and the upgrading of these materials to a viable product is an end-of-waste process where the regulations on waste and pollution must be met. Such soil processing areas will reduce the need for permanent mass storage as processing of soil materials will make viable products.

3.7 Road construction and management of peat soils

In a humid climate, as along the coast of Norway and in Ireland, almost all road projects will cross peat areas. These areas offer many challenges including low bearing capacity, restricted drainage capacity, flood risks, and problems related to climate gas emissions when peat material is excavated. There may be conflicts between the required drainage for the road project and the risk of lowering the ground water table in intact peat bogs, which is needed to preserve the bogs both as natural habitat and for carbon storage.

Traditionally, peat material has been removed from the road construction areas and placed at different mass storage sites. In the road project E6 Tiller – Sandmoen, Trondheim, Norway, the amount of surplus peat was estimated to 500 000 m^3, and about half of this amount needed to be placed at a permanent mass storage site (Norwegian Public Roads Administration 2015).

Recent research in Ireland (unpublished) has examined situations where surplus peat from road projects was used to rehabilitate peatland habitats. Successful rehabilitation, with the growth of *Sphagnum sp.*, is feasible if the hydrological conditions are carefully managed. The development of a shallow groundwater table is essential with the use of appropriate bunding and low permeability barriers, used to control the groundwater levels, especially in elevated sites. In addition, it is important to control the depths of surplus peat, the size of the rehabilitated areas and the surface slope. Shallow slopes are essential. If the peat is used to fill deep borrow pits, then successful rehabilitation is unlikely. It is also easier to control groundwater levels in smaller rehabilitation cells using the appropriate low permeability materials (clay) rather than spreading peat over large areas. If the peat is too shallow, then again successful rehabilitation is unlikely. This research is ongoing and more precise methodologies for successful rehabilitation will be developed.

The report on techniques used for peatland restoration in Sweden with focus on regrowth of Sphagnum sp. (Rove and Paulsson 2015) has been more detailed described in subchapter 3.3.

As the peat material is acidic and unstable, permanent mass storage areas with peat materials cause leaching of acidic water containing fine humus particles. In Norway, this has received much attention in areas that impact salmon and seatrout habitat in rivers and creeks.

Based on projects in coastal parts of Norway, Thorsteinsen *et al.* (2020) have developed recommendations for restoring peat soils and other types of soils in coastal areas. Since these areas have very high precipitation, the soil materials are very moist to wet, which presents a challenge in handling them. As shown in Table 2, the difference in bulk density between field conditions and dry bulk density shows the very high moisture content in peat materials. In the H2 material the weight of the water is more than 700 kg m^{-3}, while the weight of the dry matter is only 70 kg m^{-3}. In weakly humified peat materials (H2-4 according to von Post's scale), water can be pressed out or can be drained by gravitation when piled, but in highly humified peat materials (H7-10 according to von Post's scale), most of the water is stored in capillary pores.

Measures for reducing the water content in the peat materials is very important. It has been shown that building up piles with peat and sand, or peat and crushed rock material (0-2 mm), is effective for rapid reduction of the moisture content (Skjærseth *et al.* 2014). The particle size of the mineral soil material needs to be fitted to the properties of the peat material, as the key process is capillary water transport. When highly humified peat materials dry the volume will shrink considerably. This shrinkage is irreversible as the original volume will not reappear after rewetting (Lie 2001). Therefore, it is important to obtain sufficiently dry material so that irreversible shrinkage occurs. If there are too large differences in pore size distribution between the mineral material and the peat material, there will be no capillary water transport. Mixing a coarse sand with highly humified peat will lead to a sticky mass with very low hydraulic conductivity as peat particles will fill the pores between the sand grains. In Figure 10, some of the problems related to wet and unstable peat materials are shown. Water saturated peat materials are very unstable and may slide out when such materials are placed on sloping terrain. In a humid climate with high precipitation (>1500 mm annually), placing a shallow layer of peat above mineral soil or a layer of fine crushed rock material will cause the peat material to be almost permanently water saturated.

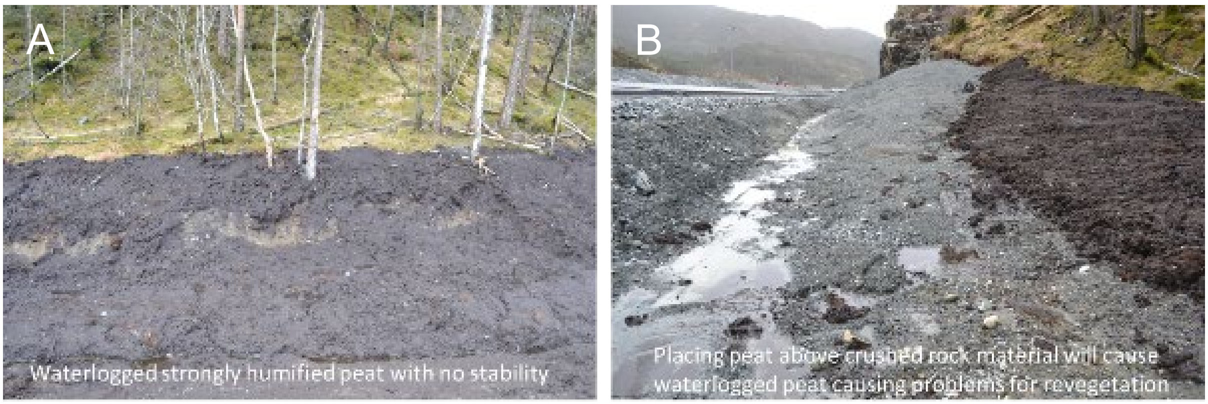


Figure 10. Placing wet highly humified peat material on slopes cause sliding to drainage ditches (A). Placing highly humified peat material above mineral material with higher hydraulic conductivity will not drain the peat material (B). Photo: Trond Knapp Haraldsen.

Table 2. Decomposition of peat according to von Post's scale (H1-10), description of peat material, loss on ignition, and density of peat materials in piles from a road project (Haraldsen 2023).

Von Post's scale	Description	Loss on ignition, % of DM	Density in field, Mg/m^3	Bulk density, dry, Mg/m^3
H2	Weakly humified peat with abundant fine roots	89.3 (82.6-93.0)	0.79	0.07
H3	Weakly humified peat with many fine roots	15.5 (12.3-19.1)	0.73	0.18
H5(H3)	Medium humified peat with lumps of weakly humified peat and some gravel	45.1 (16.7-84.4)	1.14	0.40
H7(H8)	Strongly humified peat with some loamy mineral material	11.0 (8.0-15.3)	1.25	0.62
H9	Strongly humified peat with some gravel and stones	38.2 (36.5-41.0)	1.01	0.25
-	Water saturated gravelly loamy sand	4.6 (4.2-5.2)	1.81	1.35

4 Training soil management at construction sites

4.1 The Swiss system of certified soil protection experts for construction sites

4.1.1 Introducing certified soil protection experts on construction sites

After almost 20 years of utilizing certified soil protection experts at construction sites in Switzerland, the standards of soil management have tremendously improved. In the early stages, however, there was strong resistance among experienced professionals against attaining certification. Members of the Swiss Soil Science Society (SSSS) appraised this resistance as a temporary phenomenon and adopted the certification procedure. During a transition phase of several years, experienced professionals could achieve their certificate without taking the exam. They simply had to prove their professional experience in soil protection on construction sites and provide their credentials to administration and construction management.

4.1.2 Training courses for soil protection experts on construction sites

Candidates must have a graduate degree in geography, environmental, or engineering sciences, or similar disciplines with in-depth studies in soil science. They can attend a specific training course about soil protection issues on construction sites, which is offered by Sanu Future Learning AG, a private company specialised in advanced environmental training courses. These training courses last for 17 days over a period of three months, so that the candidates can attend the course concurrently with their usual jobs. In six teaching units, the candidates learn about the principles and legal basis of soil protection in Switzerland, techniques of soil protection on construction sites, tools and checklists for planning, implementing, and supervising construction processes, as well as communication techniques and practical examples (Sanu Future Learning AG, 2022). The course ends with an exam at which the theoretical knowledge of the candidates is tested. This exam is mandatory for a certificate as soil protection expert on construction sites and can be repeated twice in case of failure (Sanu, 2020). The course can also be attended without taking the exam, however, which has been the choice of soil protection officers in administration or foreign professionals. Since their introduction in 2002, there has been a strong demand for these courses, particularly among young soil experts at the beginning of their professional career.

4.1.3 Certification procedure

The SSSS certifies professionals based on the “regulations for the certification as soil protection expert on construction sites” which were approved at the general assembly of the society in 2005 (Swiss Soil Science Society, 2005). The society’s board appoints the “commission of selection and acknowledgement” who awards the candidates the title of “Soil Protection Expert on Construction Sites of the Swiss Soil Science Society” (SPECS-SSSS). The society’s board also appoints an appeals commission, who is independent of the commission of selection and acknowledgement, for cases of dispute.

Candidates applying for the acknowledgement as SPECS-SSSS do not only have to pass the exam of the training course but must also prove at least two years of professional experience in soil protection on construction sites. In addition, they must provide references from two soil experts, one from a soil protection administration and one from a local construction site manager.

Successful graduates are listed on the SSSS website as certified soil protection experts on construction sites. This is a competitive advantage for certified individuals, as well as for the companies where they work. During the EIA process, the cantonal soil protection offices prescribe the appointment of a soil protection expert at construction sites. Their recommendation is to select a certified expert from the SSSS-list. Conversely, construction contractors are better off in the EIA process, if they hire a certified expert from this list.

4.2 Thematic courses in soil management at construction sites in Norway

There is no systematic education of soil specialists in soil management at construction sites in Norway. The Norwegian University of Life Sciences (NMBU) is the only university in Norway that offers courses in soil sciences at B.Sc., M.Sc., and Ph.D. levels. The soil courses at NMBU are mainly focused on agricultural soils and, to minor degree, on soil management at construction sites. Although NMBU has a post graduate course program in many subjects, courses on soil management and soil protection in planning processes are not offered by the centre for post graduate courses (SEVU-NMBU).

Although the Norwegian Institute for Bioeconomy Research (NIBIO) is not an educational institution, NIBIO has developed a course programme for soil management at construction sites. The course materials are available both in Norwegian and English. The courses consist of four modules:

1. Key factors for successful soil translocation – moving agricultural soil or re-establishing soil? (Haraldsen and Økland 2021).
2. Invasive alien species: a training course (Fløistad 2021).
3. Potato cyst nematodes (PCN) - *Globodera rostochiensis* and *G. pallida* (Holgado 2021).
4. *Phytophthora*. What is *Phytophthora* and where does it come from? (Talgø 2020).

In addition to these courses, NIBIO also offer field training courses for construction companies and construction machine drivers at construction sites, based on PowerPoint presentations. The field training courses include:

- Identification of soil horizons in soil profiles, focusing on colour, structure, moisture, friability, and root depth.
- Use of portable equipment for moisture recording (e.g., Delta T soil moisture kits or similar from other suppliers).
- Demonstration of compacted soil horizons and loosening by excavator.
- Logistics for mass storage and mass transport.

The feedback on the practical courses for construction companies and drivers of construction machines has been very positive, and such courses are very important to ensure that the described procedures are understood and followed.

Based on the experience on practical reconstruction of agricultural soils, as shown in Chapter 3.2 and 3.6, a video has been made as a part of the ROADSOIL project highlighting the procedures. The video is available at VIMEO (https://vimeo.com/829180968/7007adda53).

5 Conclusions

To become a smart, sustainable, and inclusive economy in Europe, increasing the reuse of excavated soil is a necessity. In this report, we point out the obstacles for reusing soils including regulatory, organizational, logistical, economic, and material quality barriers. Through better planning of road construction projects, starting at a regional level, it is possible to find solutions for the better utilization of soil material. Based on experience from both Switzerland and Norway, it is very important that soil experts are included in all parts of the road construction process, from the planning phase through the construction phase, and including following-up monitoring of completed soil restoration projects. The soil experts must also be sufficiently competent, and the system for education of soil experts in construction projects developed in Switzerland should be a template for other European countries.

It is very important to plan areas for processing of soil and stone materials into products that can be used both in the road projects, and as surplus soil which may be manufactured outside the road projects. This will reduce the need for permanent storage of soil and stony materials in landfills.

In this report, many of examples from construction projects are shown, both successful and unsuccessful. Lessons learned from past projects should be applied to future projects, and successful examples should be adapted to the local conditions of road projects in different countries throughout Europe. The principle of reconstruction of soils horizon by horizon and avoiding soil compaction during construction work are the keys for reestablishing fertile agricultural soils, as well as for revegetation of nature areas.

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