

Land use and land development part 1, agricultural engineering

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Publication date:

2008

Permanent link:

<https://doi.org/10.3929/ethz-a-005705685>

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LAND USE AND LAND DEVELOPMENT

Part 1 Agricultural Engineering

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October 2008

IMPRINT

Title: Land use and Land development; Part 1 Agricultural Engineering
Document for the Lecture 103-0435G D-BAUG Course of studies Geomatics and Planning, 5th Sem. BSc ETH Zürich
2nd edition 2005; translation 2008

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1. INTRODUCTION

1.1 *Current tasks of Agricultural Engineering*

The traditional role of Agricultural Engineering was the preparation of the soil for human use. Today, it is increasingly related to preventing the over exploitation of natural resources and to compensate or remediate any caused damage. Since in industrialized countries there is barely any completely unused land, the current task of Agricultural Engineering is rather the restoration of land for a new use. In doing so, the field of action is not limited to individual parcels, but must include the scope of all the affected environmental systems. These tasks correspond to **regional land use management**.

Today it is a matter of the optimal distribution and implementation of land use, so that a sustainable use of resources within a region is possible. There are different **actors** involved, each one with different usage requirements:

- direct land users (e.g. farmers, gravel mining companies)
- indirect beneficiaries (e.g. consumers in regional centers, road users on streets or highways)
- affected neighbors (e.g. residents beside gravel pits, highways).

Through regional land use management, the requirements of the actors as well as of the environment are to be taken into consideration, for these actors are responsible for the implementation of a regional sustainable land use.

1.2 *The Sustainability principle*

In economics, the term “Sustainability“ has a long tradition. The concept of sustainability originated in the forestry sector, where there is a commitment to forest management features, in which the lumbering does not exceed the regenerative ability of the forest, so that a permanent loss of wood resources is avoided. In a further sense, the concept of sustainable harvest is used in the economics of resources for a stock-sustaining use of renewable resources (sustainable yield) (Ewers and Rennings 1996, p. 422). Since the 1970s, this term was also extended to the rest of the sectors of the economy and all the resources of the environment. The first global environmental conference of the United Nations was held in 1972 in Stockholm. At the second international environmental conference of the United Nations in 1992 in Rio de Janeiro, in particular, the concept of sustainable development was defined (Deutsches Institut für Fernstudienforschung Uni Tübingen 1997, S. 425-462).

„**Sustainable** is a development that meets the needs of the present generation without compromising the ability of **future generations** to meet their needs“ (Hauff 1987). This definition of the World Commission on Environment and Development (WCED) in the so-called Brundtland-Report ‘Our Common Future’ from 1987 is probably the most cited. This very general definition, however, has the great weakness, that from it hardly any concrete objectives can be derived. The WCED assumes that without a permanent economic growth, which is usually related with an increase in gross national product (GNP), a sustainable development is not possible.

In Rio in 1992, three key issues were associated to the concept of sustainable development. It combines the following three aspects: the development must be **socially**, **economically** and **environmentally** compatible. This so-called **retinity** of sustainability is the core of the model (see Fig. 1).

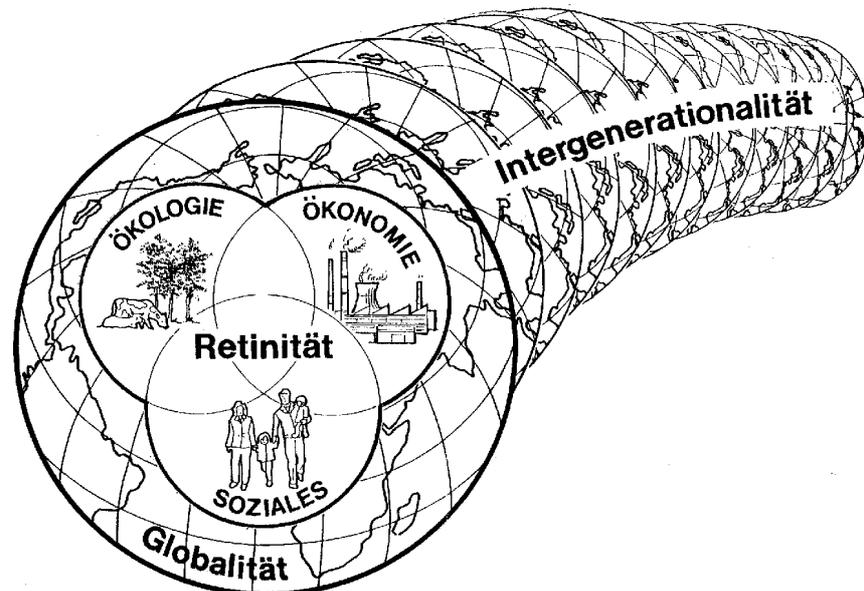


Fig. 1 Ethical dimensions of the model of sustainable development (Deutsches Institut für Fernstudienforschung Uni Tübingen 1997, S. 446)

Sustainability must therefore be very widely understood. Currently, the best known is the environmental component which aims at the prevention of the over-exploitation of natural resources. Also, the economic sustainability is of importance to maintain the economic subsistence of individuals and entire states. Finally, sustainability also has a social component. The desirable condition is in this case, the social justice in the use of resources.

In addition to these three dimensions of sustainability, there are also the dimensions of time and space. The **equitable distribution of resources** and admissible environmental uses are generally considered as an integral part of social tolerance; this both **intragenerational**, i.e. within generations, as well as **intergenerational**, i.e. between generations. The principle of equal distribution has therefore two dimensions. First, every person in this world should be allowed to consume an equal amount of resources, which at the current consumption levels of developed countries would not be environmentally sustainable. On the other hand, future generations should receive a resource capital, with which they can appropriately satisfy their own needs.

The environmental component in the concept of sustainable development has a significant role to play, because the conservation of natural resources is a prerequisite for the survival on our planet. Without sustainability in terms of ensuring the ecological bases for life, and therefore the relative stability of the natural evolution, there is neither social nor economic dimension. Basically, the first priority is for Ecology. However, from case to case, in the short term social or economic needs can prevail over the ecological needs. But in the long-term horizon, the ecological needs must remain as priority (Ruh 1997, p. 14).

Derived from the postulate of global sustainability, the ecologically, economically and socially sustainable use of the land should be guaranteed in the long term within a region, too. The conservation and restoration of multi-functional areas stands in the foreground, which means the highest possible spectrum of (subsequent) use is to be preserved.

As a **precaution**, damages to the environmental systems by land use should be avoided; particularly in sensitive areas, the ways of utilization should be carefully selected. Areas, on

which the multi-functionality is restricted, should be either restored or compensated through **regional land compensation** in the affected functions. That means, in the same region, other areas for the possible uses are no longer available. Already after the postulate of economic sustainability, **fallow** i.e. unused land is to avoid. These are to be restored or be put to another use, which is also possible even at reduced multifunctionality. Moreover sustainable environmental use also means the conservation of biodiversity, of the human health as well as the protection of air, water and soil quality, required to secure the lives and welfare of people as well as animal and plant life in the future.

Cities and municipalities recognize that a city or municipality cannot afford to 'export' problems in the environment or in the future. Therefore, all the problems and imbalances in a city are initially to be cleared internally at a local level, or compensated by an external body on a larger regional or national level.

To conclude, it is a matter of **optimizing land use** in its type and distribution within a region. This optimization in the use of the land must but be appreciated by the participating **actors**; otherwise they will not implement it (cf. section 1.1). The question of the implementation of a sustainable land use in a region is ultimately a **decision-making problem**, as all parties are looking for the maximum benefit for themselves. A regional land use management should serve to develop decision-bases and procedures, and to promote the integral sustainability of land use within a region.

1.3 Natural and anthropogenic factors that determine land use

The natural resources of the environment can be divided into the three elements: soil, water and air (Fig. 2). In every environmental system all three elements are always represented. From the interaction among the elements, result the specific functions of individual environmental systems, which man can use. For example, for agricultural or forestry use of the land an adequate soil water- and air regime is crucial. The scope of this lecture will be limited to the use of the resource soil. We discuss the impact of land use on the following important **soil functions** (Tobias et al. 1999b, S. 2):

- Bioreactor for the decay of organic substances
- Location for the natural vegetation and crops
- Habitat for soil organisms (including gene reservoir)
- Filter and buffer for substances
- Balancing body in the water, air and temperature regime
- Historical archive (soil as an information carrier)
- Supporting ground for buildings and/or roadway for agricultural and forestry vehicles and machines
- Reservoir of raw material
- Sink for waste.

Unlike air and water, the soil is a finite resource. There are no cycles such as the water cycle or the O₂-CO₂-cycle, over which the soil could renew itself within observable periods (Sojka und Upchurch 1999, S. 1041). This also applies for the various resources, which result from the soil, and that can directly be used by man:

- Area
- Landscape
- Raw Materials
- Energy
- Ecosystem
- Basis for the primary production.

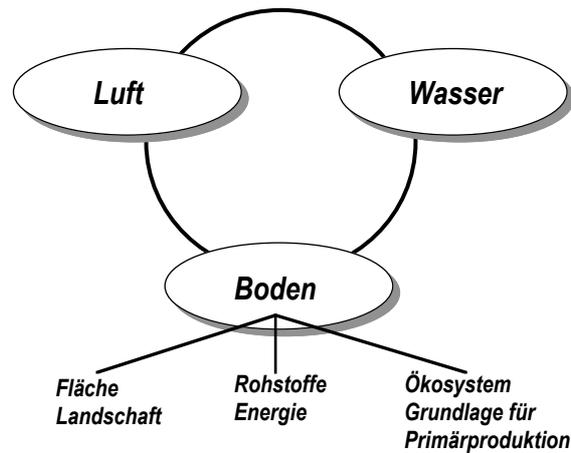


Fig. 2 Our environmental resources

The problem of land scarcity is intensified by the fact that not all areas are equally well suited for human use. Häberli et al. (1991, p. 12ff) noted that the actual economic life of Switzerland is limited to only a third of the country's territory (Fig. 3). This is mainly because of the **topography**. A strong slope can make the use of an area technically impossible. The flat lands, which are suitable for an intensive use, are limited to the Central Plateau and the bottoms of alpine valleys. There, productive agriculture, industry, transport and urban areas are concentrated.

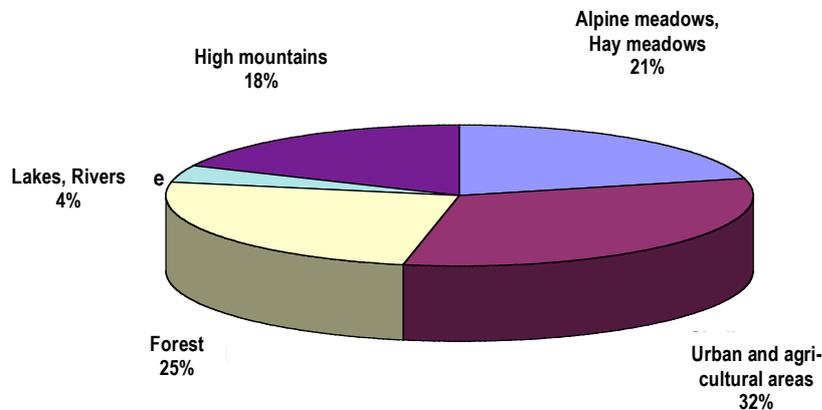


Fig. 3 The land use in Switzerland (Häberli et al. 1991, S. 12)

Another natural location factor which determines land use, is the **potential** of an area. The presence of mineral resources (in Switzerland are gravel, sand and clay), the suitability for agricultural crops, and the exposure and location can predict land use.

Infrastructure facilities represent a key **anthropogenic location factor**, which determines the spatial distribution of commercial land use (Nowotny 1971, S. 18ff). The development of transport networks around economic centers leads, in most cases, to the extension of residential areas in the neighboring communities because more people, who work in the city are drawn to live in the countryside. According to the data from the 2000 census about 74% of the Swiss population live now in urban areas. In some cases, infrastructure investments actually allow the exploitation of the actual surface potential. For instance, the agricultural pro-

ductivity of the peat soils, rich in nutrients, could only be exploited after their drainage. Hence the name "soil improvement" or "melioration" for agricultural engineering measures. Famous examples of large area drainages are the Linth correction (1807-1816), the first Jura water courses correction (1868-1891), the second Jura water courses correction (1962-1973) and the correction of the Alpine Rhine in the Rhine Valley in St. Gallen (late 18th century to present).

An agglomeration effect of economic centers that is crucial for the use of land in a region is the creation of specific **markets**. The urban agriculture produces mostly vegetables and fruit, i.e. fresh products that reach consumers directly, without further processing. Conversely, certain crops are cultivated on a wide territory because of single processing plants of agricultural products. Since the products in general must be processed while fresh (such as canned fruit, sugar beet), the spatial extent of suppliers is primarily restricted by the required transportation time. In the case of Hero Lenzburg AG and Hilcona AG, Schaan (FL), cultivation contracts for fresh products were made with farmers in a radius of 60 to 120 km (Mr. Galmann, purchaser at Hero Lenzburg AG, personal communication of March, 16th 2000).

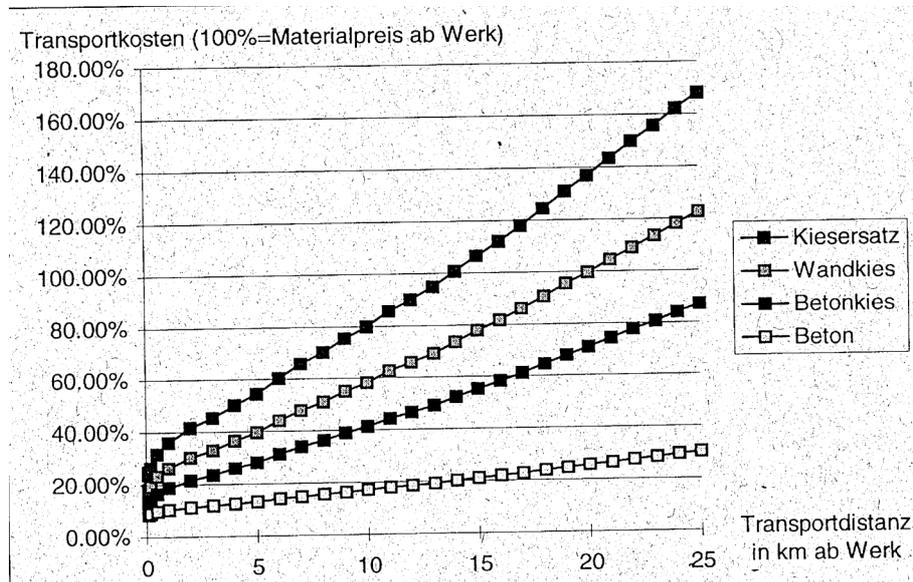


Fig. 4 Impact of transport costs on the material costs of different qualities of gravel depending on the transportation costs (Binswanger und Siegenthaler 1995, p. 424)

Transport costs also limit the sales area in the gravel market (Fig. 4). Consequently, the gravel market has a very important region-specific relevance. The sale prices within a gravel region can be determined regardless of the global market. In addition, there are often cartel-type associations within a region, which determine the price. Because of the distance protection and antitrust agreements, many relatively small and medium-sized enterprises can still be found in the gravel economy (Binswanger und Siegenthaler 1995).

Land use can significantly affect natural resources. It can permanently change the characteristics of the environmental systems. These changes can be evaluated positively or negatively, depending on whether they are considered from the perspective of humans or from the environmental resources point of view. In recent decades however, in many cases it was observed that to a certain extent, positive effects of land use can also turn into negative. Precisely this turn of positives to negatives is to be avoided in the sense of sustainable resource management.

Since the mid-20th Century the negative effects of agglomerations are more significant. Urban agglomerations are characterized by the lack of natural resources, in particular soil space, natural habitats and recreation areas, as well as to some extent (ground) water. Thus,

the land use conflicts within in a region intensify. In addition there is the impact on environmental resources by the different types of land use; on the one hand with waste released into the air, water or soil, on the other hand by the over exploitation.

Although it is undisputed that contrary measures must be taken against the negative urban agglomeration effects, the economic use of resources must be furthermore guaranteed. Thus, the Swiss country prescribes a balanced proportion between the protection and utilization of natural resources (Art. 73 BV). The Federal Act on Agriculture (Landwirtschaftsgesetz) (Art. 1 LWG), the Forest Act (Waldgesetz) (Art. 1 WaG) and Water Protection Act (Gewässerschutzgesetz) (Art. 1 GSchG) highlight in the purpose articles the multi-functionality of the type of use; that means, the **protection of resources** is basically **to be integrated in the use**. Also after the precautionary principle of the Environmental Protection Act (Umweltschutzgesetzes) (Art. 1 Abs. 2 USG) the **prevention** of environmental damage **preceeds** the **restoration**. The statutory assignment for the spatial balance between protection and use of resources is given by the Land Use Planning Act (Raumplanungsgesetz) (Art. 1 RPG).

The implementation of the statutory mandate for the sustainable use of environmental resources in a particular case requires appropriate measures from all disciplines that deal with the various resources, as well as a smooth cooperation at the interfaces (Fig. 5). Thus the **decision-making for the optimal allocation of the land use** is a very complex problem. Within this lecture, the fundamental bases for the decision-making will be discussed.

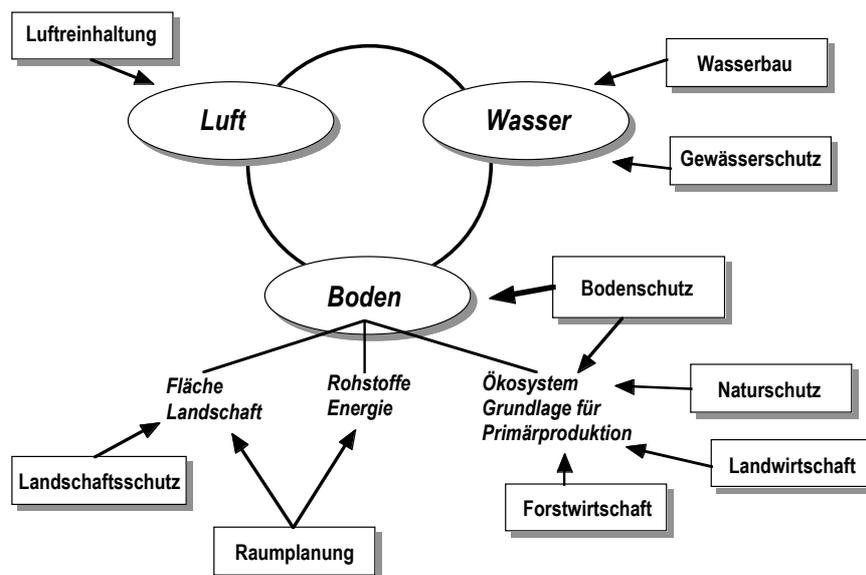


Fig. 5 The various disciplines, that regulate the management of environmental resources

2. INTERVENTION IN THE WATER REGIME OF A TERRITORY

The interventions in the landscape water regime are controversial agricultural measures because they affect in most cases a wide area, that is, they have an impact on hydrological catchment areas. These are the irrigation and drainage of soils, and the regulation of water bodies that serve as collectors of water. In humid climate areas, such as large parts of Central Europe, the irrigation of soils plays a subordinate role, whereas the drainage is a more important issue.

2.1 Soil Drainage

Purpose

The main objectives of soil drainage are **the improvement of the soil, air and water regime**, for the contemplated agricultural crops, particularly the elimination of water logging in the soil. The main effect of drainage is the increase of the distance between soil surface and groundwater, so that the layer of the soil occupied by the roots is not permanently saturated with water. Information on the root depth of different crops, and the optimal distance to groundwater can be found in Muth (1991, p. 58f). Especially in the first half of the 20th Century the conversion of grassland into arable land was one of the main reasons for soil drainage. The lowering of groundwater levels resulted primarily in an improved aeration of the root area, which contributed significantly to the safeguarding and to some extent to the increase in yields. Due to the improvement in air provision, the soil in the root area has a faster and more frequent increase in water potential. This increases the mechanical stability of the soil, which means that over the year, the soil can be more frequently worked on and driven over. Moreover, due to the improved oxygen supply, the biological activity of soil organisms also increases. The increased demand for nutrients is covered by the decomposition of soil humus. Through the decomposition of soil humus the nutrients in the soil are mineralized, which mainly results in a strong increase in the amount of nitrogen available for plants (Blume 1992, p. 229). The higher the content of organic matter in the soil, the more nutrients can be released through drainage. For this reason the peat containing, rich in humus swamp soils were considered as particularly fertile soils, which was the reason to drain large swamps (e.g. Grosses Moos in the Canton of Bern and other examples already mentioned in section 1.3).

The causes of water logging in soils are essential for the choice of suitable drainage procedures. In Central Europe the following water logging causes are known:

- high groundwater level
- compaction
- lateral flow (local sources or inflows)
- residual water.

The goal of classical peat drainage was the lowering of **groundwater levels**. As the peat soils are usually well permeable, the drains were very successful. However, the organic matter decomposes very quickly because of air supply, so those soils can lose up to 2 cm of altitude per year (Kuntze et al. 1994, S. 334, Blume 1992, S. 229). This leads to soil subsidence in large areas. Thus, the drain facilities are located closer to the soil surface, and may be damaged by the plough. Because the thickness of the peat layer is usually not the same over an entire drainage area, there are spatial differences in the subsidence. This may entail counter slope, or even failure of drainage pipes. In these cases the drainage effect, at least locally, no longer exists. Today, the question of restoration arises for many old drainage areas. Preserving the cultivation possibilities of the areas requires the removal of high-

lying pipes and the replacement with new, deeper ones. This process can be repeated until the pipes reach the impervious layer, which actually enabled the formation of the peat bog. After this however, it can be said that the peat bog has, in the truest sense of the word "run down". The humus has been consumed and it will not renew itself even in a geological period. For this reason, the **peat soil management** in Holland, North Germany, as well as by the lakes in Switzerland where they have been wide spread, **cannot** be described as a **sustainable** form of land use.

In addition, the repeated lowering of the drainage facilities entails a deeper channel for the receiving waters to avoid the drainage pipes lying below the water table of the receiving waters. Otherwise, the drainage pipes would be flooded. If the deepening of the channel is no longer possible, the drainage water has to be pumped to the higher water level in the channel.

Compaction can have both natural and anthropogenic causes. The water is accumulated over an impermeable layer and generally has no contact with ground water. Every abrupt change in grain size or soil structure that causes a great difference between the pore diameters of the upper and lower layer acts as an impervious horizon. In nature, clay- or gravel pockets, or structure changes caused by **tillage** and cultivation (see section 3.1), constitute the impervious layers. Water logging can occur very locally, like in a hollow where the soil water of a whole area is collected, or at heavily wheeled places such as field edges and field access roads. In particular, compaction and water logging is the main problem on restored soils (see section 4.2).

Lateral flow is caused by external inflows. In most cases they arise more or less locally at the base of a slope or beside roads, buildings or movements of terrain. In general, this lateral water can be deviated with one or a few **capture drains**, without setting up an extensive installation.

Residual water occurs especially in silty and clay soils. Anthropogenic soil compaction or structure disruption can facilitate residual water. Soils with residual water are very difficult to drain because of their fine grain components and dense stratification. The water is bound with very high capillary forces (water potential).

Technical Requirements

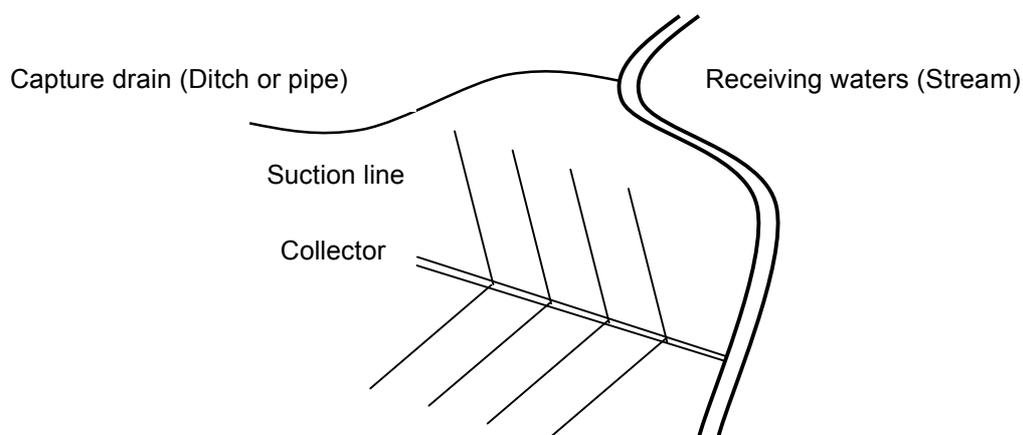


Fig. 6 Schematic representation of a drainage perimeter

A **drainage system** consists of suction lines, collectors and the receiving waters (see Fig. 6). The suction lines take the water from the soil and pass it further into the collectors which lead the flow into the receiving waters. On the edge of a drainage perimeter, capture drains are installed depending on the lateral flow.

Drainage systems work after the gravitational principle. Thus, they can only drain **water, which can move freely** out of the soil, i.e. water that is bound with a capillary suction of less than 6 kPa ($pF = 1.8$) (Fig. 7). In other words, it can only be drained until field capacity. The field capacity is conventionally defined as the water content of a soil two to three days after having reached full saturation. This is the main reason why soils with residual water cannot be drained.

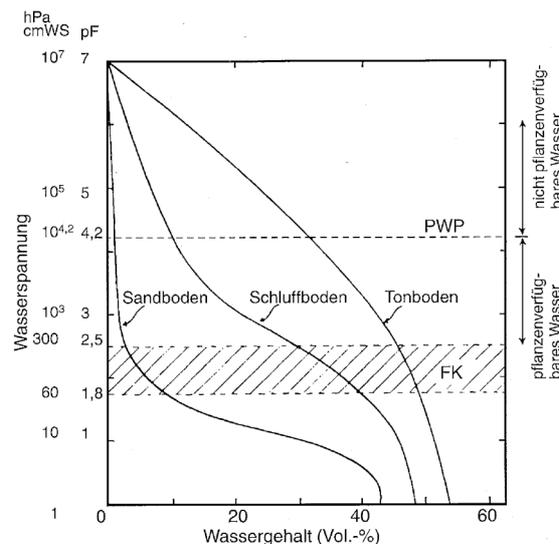


Fig. 7 Water potential curves of different soils (*cmWS* = Centimeter Water column (equivalent to 0.1 kPa); *FK* = Field capacity; *PWP* = Permanent Wilting Point) (Scheffer und Schachtschabel 1998, S.189)

The **technical implementation** of drainage facilities is done either with open drainage ditches or with underground pipes, gravel packs, or so-called earth or mole drains. Rectangular networks with straight **drainage ditches** dominate many landscapes of Switzerland (e.g. the Linth plateau). Since open ditches interfere with the agricultural management, they are usually only laid out in large intervals as receivers for the underground drainage. They must often be deepened in the course of drainage renovations, because the drainage in the surrounding soils is lowered. Earlier, **drainage pipes** were made out of clay tubes placed one after the other with several mm distance between them. Today perforated PVC-tubes are used as a rule. An alternative are **gravel slots**, which are covered with humus. On soil restorations, linear gravel packs are sometimes laid out prior to the filling on the restoration plane (land restoration, see section 4.2).

For **mole drainage** a specially shaped pressing head is pulled through the ground, forming canals in this way. This technique can only be applied in soils containing clay, without coarse stones. Otherwise, the created vault is not stable due to the lack of cohesion. The advantage of the mole drainage is that this technique can be executed by the farmer with his own tractor because of the relatively low tensile force required. For technical details about the installation of drainage facilities refer to Muth (1991, p. 74-79).

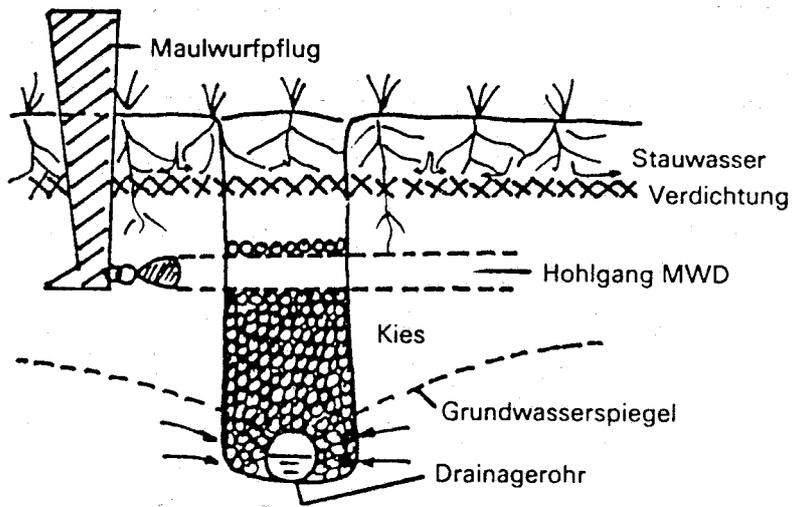


Fig. 8 Combined application of pipe and mole drainage (Müller, 1992)

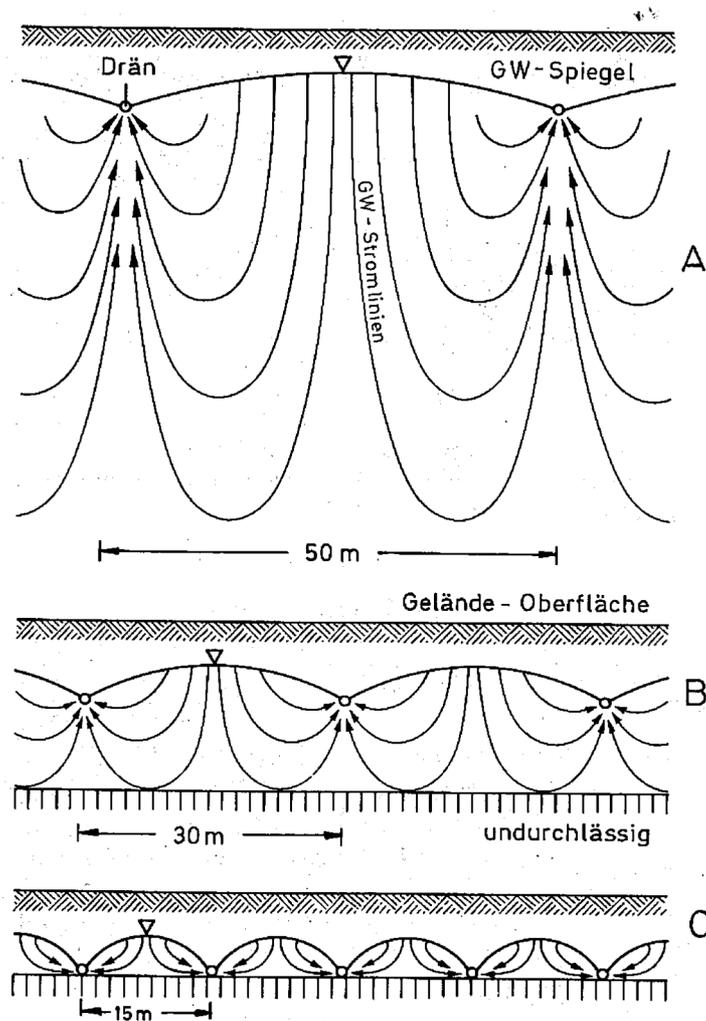


Fig. 9 Flow of water to the drain pipe, depending on the depth of the impermeable layer (A>B>C) (Kuntze et al. 1994, p. 345)

For the **influx** of ground water into the **drainage pipes** as well as for the necessary spacing between drainages, the depth, at which the impervious layer is located, is crucial (see Fig. 9). The nearer the drainage lines are to the impervious layer, the shorter the infiltration ways. This means, the faster drainage is accomplished, but the smaller the spacing between the drainage lines has to be, too.

There are different approaches to calculate the influx to a drain. They are derived and explained in Ritzema (1994, p. 263-304). As example the equation of Hooghoudt is derived below.

Hooghoudt - Equation

Assumptions

- Drain pipes run parallel; (ii) Stationary flow condition (infiltration rates and water contents are constant in time); (iii) two-dimensional water flow in a plane rectangular to the drainage pipes.

Calculation approach

The groundwater flow is formulated through a vertical section at a distance x from a ditch, so we get after the Darcy-law:

$$q_x = Ky(x) \frac{dy}{dx} \quad (1)$$

where: q_x flow rate in x-direction

K Water conductivity

$y(x)$ Groundwater level at location x

$\frac{dy}{dx}$ Hydraulic gradient

From the assumption that a steady flow has developed, follows:

$$q_x = R \left(\frac{1}{2} L - x \right) \quad (2)$$

where: R = Infiltration Rate

L = Drainage distance;

Then (1) is replaced in (2), and follows:

$$Ky(x)dy = R \left(\frac{1}{2} L - x \right) dx \quad (3)$$

The integration of equation (3) with the following conditions:

with $x = 0$; $y = D$

with $x = 0.5L$; $y = H$

Results in the equation (4):

$$q = R = \frac{4K(H^2 - D^2)}{L^2} \quad (4)$$

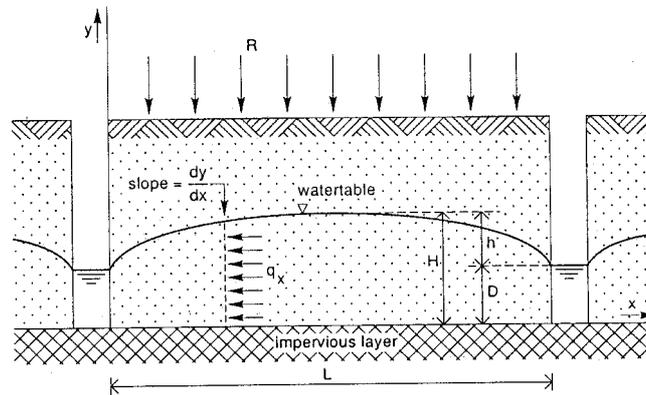


Fig. 10 Horizontal flow conditions in a drainage over an impermeable layer (Ritzema, 1994).

In Fig. 10 it can be seen, that $H-D=h$ and $H+D=2D+h$. The height h in the Fig. represents the difference between the ground water level and the drain water level. Similarly equation (4) can be rewritten to:

$$q = \frac{8KDh + 4Kh^2}{L^2} \quad (5)$$

This equation (5) is known as the Hooghoudt- or the Donnan-equation. If the drainage is directly on the impermeable layer, then $D = 0$, and the equation is reduced to equation (5):

$$q = \frac{4Kh^2}{L^2} \quad (6)$$

In this case, the groundwater flow occurs above the drains into the ditches. In the case $D \gg h$, that is, the impermeable layer is very low, then the second term of (5) can be neglected and the result is:

$$q = \frac{8KDh}{L^2} \quad (7)$$

Here, the greatest part of the water flows to the ditch below the drainage level. In some cases, the drain pipes lie on or near a boundary between two layers of materials with different permeability. This circumstance can be taken into consideration when using the equation (6) and (7). It can accordingly be seen in the Hooghoudt-equation:

$$q = \frac{8K_2Dh + 4K_1h^2}{L^2} \quad (8)$$

In it, K_1 is the conductivity of the upper and K_2 , the conductivity of the lower layer. As Fig. 9 shows, the groundwater inflow into a tube-shaped drainage is not the same as in the case of drainage ditches. In the surroundings of the drainage lines there is a contraction of the stream-lines and a radial deformation of the flow field. Hooghoudt considered these radial flow losses to a drain-pipe in decreasing the layer thickness D . In equation (5), this approach means that instead of D , the reduced value d is used. The distance d is also called equivalent value. Correspondingly, equation (5) is transformed into:

$$q = \frac{8K_2dh + 4K_1h^2}{L^2} \quad (9)$$

The equivalent value d depends on the drainage distance L , the layer thickness D and the radius of the drainage pipe r_0 . Hooghoudt developed several nomograms to

derive the amount of d . In order to apply the approach of Hooghoudt in calculation models, the following function for calculating the equivalent value was developed:

$$d = \frac{\frac{\pi L}{8}}{\ln\left(\frac{L}{\pi v_0}\right) + F(x)} \quad (10)$$

In equation (7) x is defined as follows:

$$x = \frac{2\pi D}{L} \quad (11)$$

as well as:

$$F(x) = \frac{\pi^2}{4x} + \ln\left(\frac{x}{2\pi}\right) \quad \text{for } x \leq 0.5 \quad (12)$$

$$F(x) = \sum_{n=1}^{\infty} \frac{4e^{-2nx}}{n(1 - e^{-2nx})} \quad \text{for } x > 0.5 \text{ and with } n = 1, 3, 5, \dots \quad (13)$$

Restoration of wetlands

For the restoration of **wetland habitats**, large quantities of water must be available throughout the year. Therefore, in the first place it must be ensured that rain water is not removed. Existing drainage systems are to interrupt or flood. For this reason, the renaturation of wetlands is often realized as an alternative to the restoration of deteriorated drainage systems. In rare cases, intact drainage systems are actively flooded (e.g. land improvement Kloten).

In addition, there must be an **impervious layer** available. This can be either the natural retainer which caused the original wetland, or an artificial sealant. The latter can be accomplished, for example, with the deposition of sludge from gravel washing (see section 4.4).

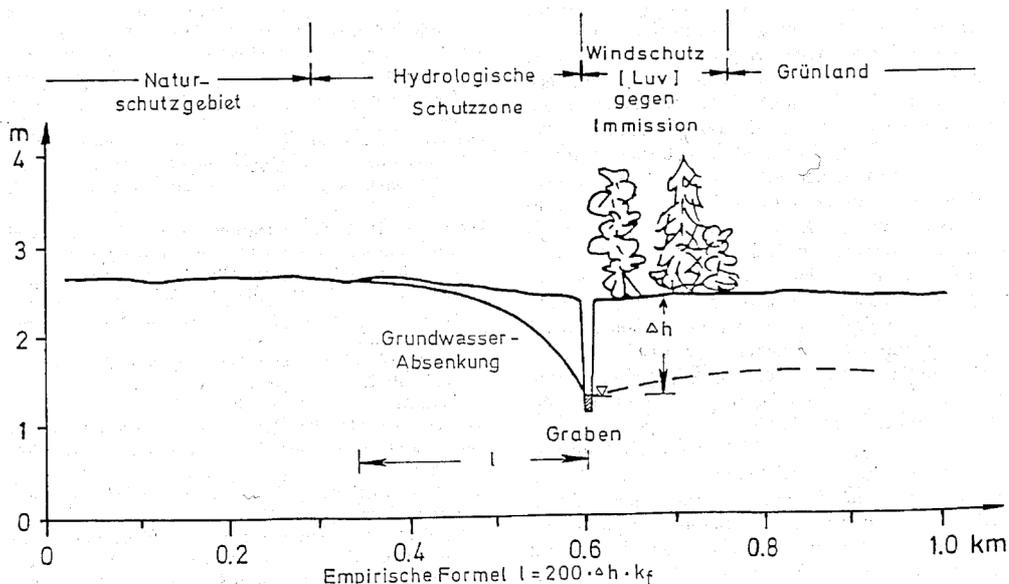


Fig. 11 Establishment of hydrological and immission protection areas around renaturalized wetlands (Blume 1992, S. 691)

Further, the **groundwater levels** in the wetland must be raised again in relation to the surrounding (agriculturally used) area. This entails the need for a **hydrological protection zone** between the actual wetland and the surrounding agricultural zone (see Fig. 11).

Equally important is the **prevention of the entry of nutrients** in renaturalized wetlands. Against pollution from the air, a vegetation windshield is recommended at the weather-side of the main wind direction. If wetlands are fed from the groundwater in the surroundings, stripes of filtering vegetation are to be established to protect the wetland from nutrients in the groundwater (see. section 3.3 Fertilization and pest management). In individual cases, where the required space for the establishment of hydrological (pollution) protection zones is not available, the groundwater regime of the wetland can be isolated using sheet pilings towards the surrounding. The supply of uncontaminated water in the habitat must then also be artificially ensured (for example with pumps).

Basically, it should be noted that a restoration shows success only after a very long time (decades to centuries). The recuperation of peat bogs is only successful in the presence of a peat layer (rescue of the remaining peat layer). The regeneration of the peat will take several thousand years (Klötzli 1991). In severely decomposed peats, the nutrient supply is so high that the original meager state of the habitat can not be reached by a new water logging alone. In practice, in such cases the nutrient-rich topsoil is removed (e.g. peat bog of Steinaur, land improvement in Kloten, both in Canton Zürich). But also in less extreme cases, for example in the conversion of nutrient-rich meadows in less nutrient-rich levels such as arhenaterion (Fromentalwiese), the occurring nutrients must always be removed again (harvested). Nevertheless, even in these cases a conversion requires decades. Considering the fertilizer from the air (see section 3.3) the actual restoration to the original condition is unlikely.

2.2 Irrigation

Objective

In **arid climate areas**, irrigation is often a necessary condition for the cultivation of agricultural crops. In our latitudes, usually irrigation takes place only temporarily **at certain times of the growing season**, which is when the crops need more water for their growth than there is available from the soil water supplies. For this reason, especially sandy soils, which present low water storage capabilities, are often irrigated. This allows, in particular with vegetables, to significantly increase the yields. Another reason for irrigation in areas with humid climate is the **antifreeze irrigation as protection** for flowers or buds against late frosts in the spring (and respectively, to protect the young plants against early frosts in autumn).

Technical Requirements

There are various irrigation techniques; from flood irrigation, and underground water inflow with drain like channels, to aspersion with sprinklers. The procedures are describes in detail by Muth (1991, p. 207-270). In industrialized countries it is mainly irrigated with sprinklers, because this is most similar to the natural rainfall. The antifreeze irrigation in particular, is only possible through sprinkling, so that the water supplied can freeze around the sensitive parts of the plant like an ice mantle. When the water is freezing, condensation heat is released which is enough to prevent the cell liquid to cool down below its freezing point (-0.5°C) (Muth 1991, p. 267). However, it must be irrigated during the entire period of frost (e.g. the whole night until sunrise) so that the heat supply is not interrupted.

Even with a careful implementation of the irrigation, the supplied water is never fully available for the plants. The excess of water must be drained back to prevent damages resulting from water logging. Consequently, **every irrigation needs a drainage system**.

In silty soils, potent sprinkler equipment may cause the **soil sealing** on the soil surface (see also section 3.2 Erosion) (Blume 1992, p. 233). Likewise, barely permeable soils should not be irrigated, as they naturally tend to **water logging**. If the water retention capacity of a soil is extremely small (pure sands), the irrigation can be very **inefficient** (Muth 1991, p. 208).

In arid climates, the **salinisation of the soil** is one of the most important problems caused by irrigation. In dry periods, the salts from the groundwater ascent by capillarity and are transported to higher soil layers, where they crystallize and concentrate. Because the ground water level is increased in many cases due to irrigation, the capillary water rises more frequently up to the root horizon. In particular, a high concentration of sodium ions is problematic, because **sodium ions possess high hydration energy**. Due to the small radius of the ions, the positive charge concentrates on a small surface. The bipolar water molecules are more attracted, so that a water jacket accumulates around the sodium ions. This increases the osmotic potential of the ground water, making it less available for plants, because the water absorption of plants is largely regulated by the osmotic pressure (passive absorption). In addition, soil structure is disturbed. Because the sodium is located between the clay particles, water adsorption leads to swelling, and finally to the dispersion of the clay particles. Salinisation finally results in almost impermeable and mechanically not resistive soils.

3. INTENSIFICATION OF THE AGRICULTURAL LAND USE

In industrialized countries, the primary production, where agriculture and forestry are included, showed a massive decline in the manpower in contrast to the industrial and service sector in the 20th Century. In Switzerland, the number of people employed in agriculture declined from 1950 to 1991 by more than 50% (Häberli et al. 1991, p. 86). In the former Federal Republic of Germany, the permanent manpower employed in agriculture decreased from 5.87 Mio (1949) to 1.308 Mio (1993). In the process, a gradual transformation took place, from full time employment to a part-time occupation and finally to entire retreat from farming. In Switzerland, the number of full-time farmers declined from 177412 to 62804, i.e. by more than half, in the period between 1939 and 1990. The part-time farms developed in the same period from 61069 to 45492, which means they decreased by about 25% (Baur 2000). In the old Federal Republic, between 1979 and 1991, around 11.1% of the farmers switched from full time to part-time work, and during the same period 21.6% of the part-time farmers abandoned the farming activity completely. Conversely, the sizes of the farms increased (Deutsches Institut für Fernstudienforschung Uni Tübingen 1997, p. 204f).

This shift in the employment situation is both a consequence of industrialization (which led to the increase in the proportion of part-time farmers), and of the technological progress in agriculture itself. The latter enables the efficient management of the soil, without which agriculture would no longer be viable. As a result, agriculture increasingly specializes by regions; the soils of each region are progressively used in a one-sided way (Fig. 12)

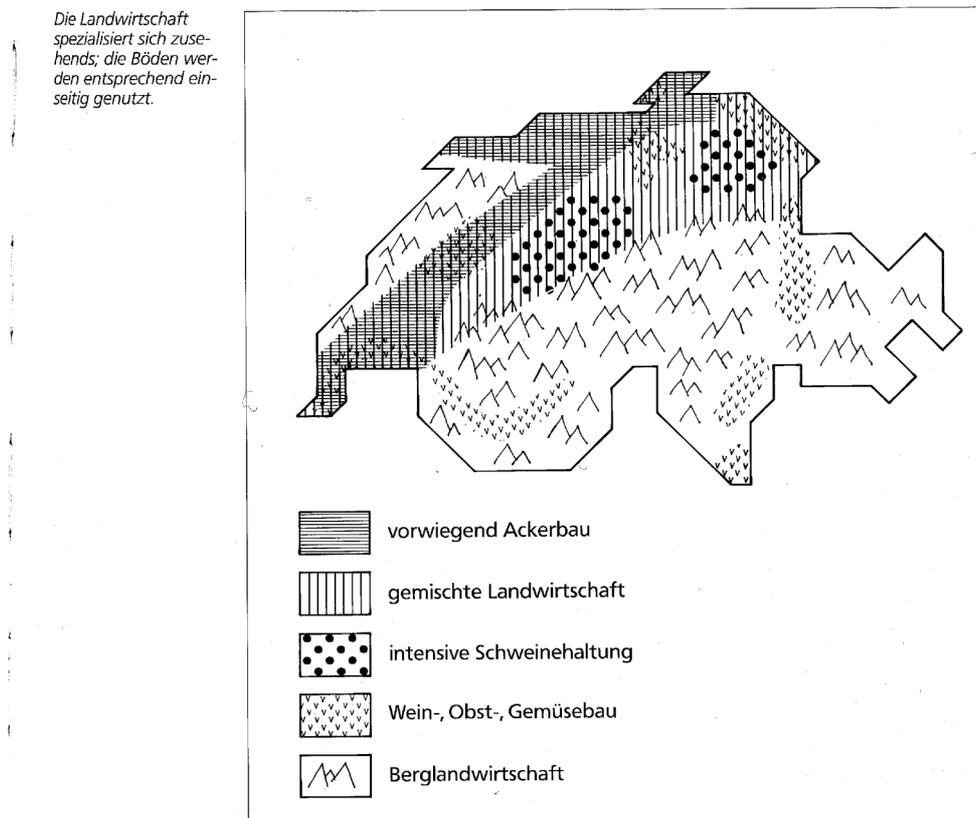


Fig. 12 The specialization of Swiss agriculture in different geographical units (Häberli et al. 1991, p. 89)

3.1 Mechanical Impacts, Soil compaction

Mechanical properties of the soil

Each soil has its own degree of **inherent stability**, which results essentially from the contact between the soil particles. The denser a soil is, that is, the more and the bigger the contact surfaces are with adjacent soil particles, the higher the pressures (or tensions) that must be applied to separate the particles from each other or even to move them closer together. In soil mechanics, the stability of the soil is described with the **shear strength**, and the **pre-compression stress** (more details in Hartge and Horn 1991, p. 55-80, and Kézdi 1969, p. 169-206).

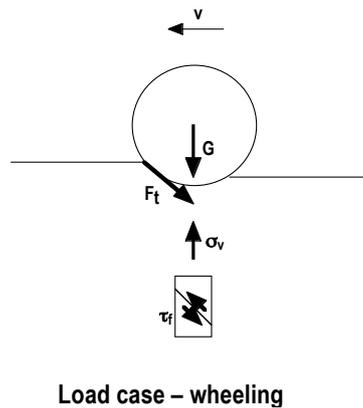


Fig. 13 Schematic representation of the strain condition in the soil with a load passing over. G : Wheel load, σ_v : Precompression stress value, τ_f : Shear strength

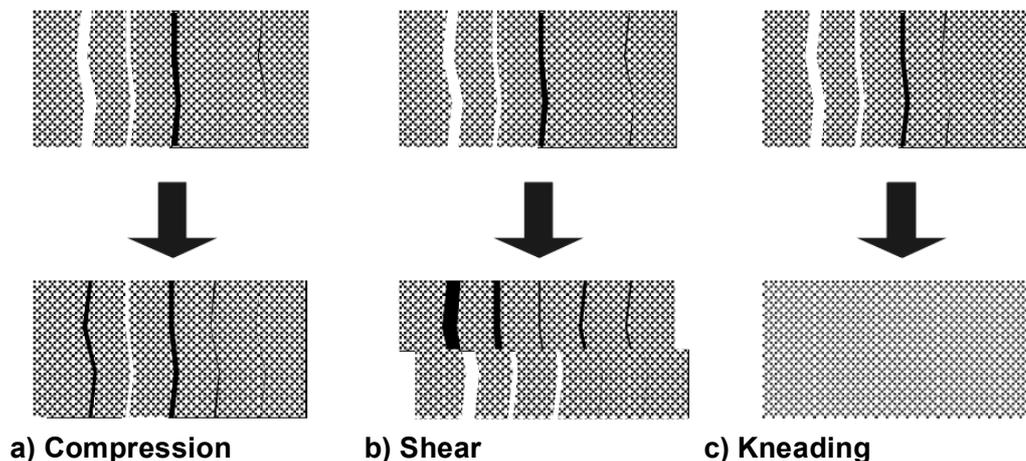


Fig. 14 a) **Compression**: compression leads to the destruction of coarse pores. This decreases the total pore volume; however the relative proportion of medium and fine pores can be increased.
 b) **Shear**: shear does not lead to increased bulk density in every case. The soil pores, however, are sheared off and subsequently no longer continuous.
 c) **Kneading**: Kneading means the destruction of the secondary structure. The transition to coherent or single grain structure (primary structure) is referred to as homogenization.
 (Source: Tobias et al., 1999b, p. 23)

Fig. 13 explains the situation of the loading case in a wheeling. A wheel acts perpendicular to the ground with its wheel load G . A soil particle at a certain depth experiences the (partially decomposed, see below) stresses and acts against them with its own stability. The maximum axial stress that the soil particles can raise corresponds with their precompression stress σ_v . The maximum shear stress, with which it can counteract the strain, corresponds to the shear strength τ_f . If the wheel load exceeds the inherent stability of the soil (σ_v or τ_f), there will be a permanent deformation or failure. The soil is compressed (exceedance of σ_v) or the particles are sheared apart (exceedance of τ_f). Close to the wheel, the soil structure is kneaded, i.e. it is homogenized. The soil aggregates are destroyed, the soil structure becomes single grained or coherent micro-structure. Fig. 14 provides a schematic overview of the different mechanisms.

Compression / precompression stress

If a soil cylinder is compressed, it will deform. If it is not fixed at its sides (as in the so-called simple pressure test) it expands to the sides, without greatly reducing its initial volume. In nature, i.e. in the soil (as in the Oedometer experiment), the lateral expansion of the cylinder considered is impeded. The soil core can only deform in vertical direction, resulting in the reduction of the volume (Fig. 15).

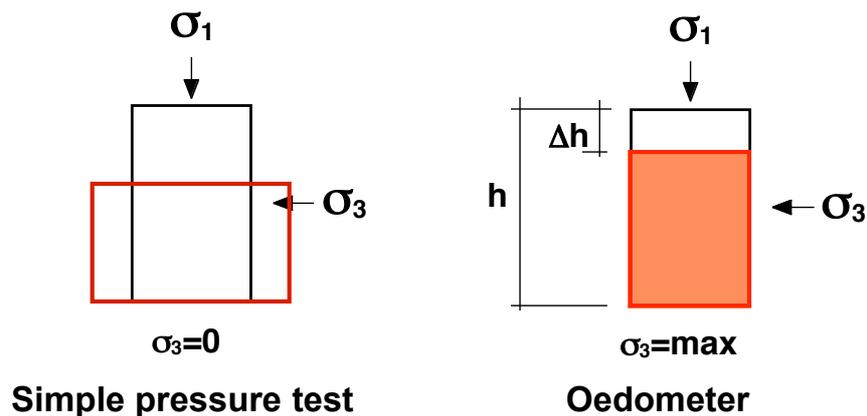


Fig. 15 Compression (Consolidation)

This deformation is elastic, i.e. reversible, as long as the **pre-compression stress** of the soil is not exceeded. Exceeding this pre-compression stress will result in a plastic, permanent deformation. The pre-compression stress is determined from the Oedometer test. The results of the Oedometer test are represented in the consolidation curve, which shows the (linear) volume decrease ε , as a function of the common logarithm (log) of the applied compressive stress (Fig. 16). The half logarithmic representation of the consolidation curve enables the distinction between a stress range of elastic deformation (re-load curve), and a stress range of plastic deformation (virgin compression line). The log of the pre-compression stress corresponds to the value on the x-axis in the strongest curvature of the consolidation curve.

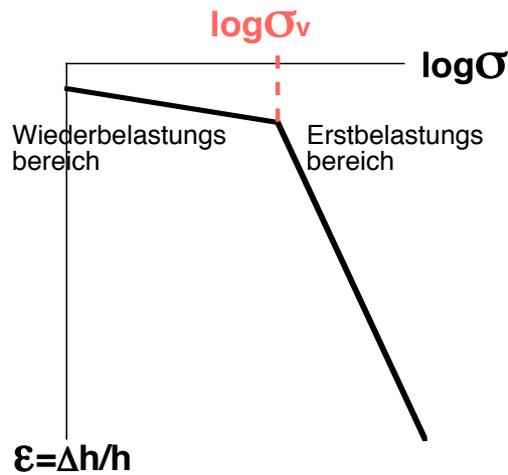


Fig. 16 Consolidation curve

Shear

Shear means the displacement of soil particles against each other. Depending on the arrangement of the soil particles there will be a compaction (volume reduction), or a loosening (volume increase) (Fig. 17). In the process, thrusts are effective, which exceed the shear strength (τ_f) of the soil.

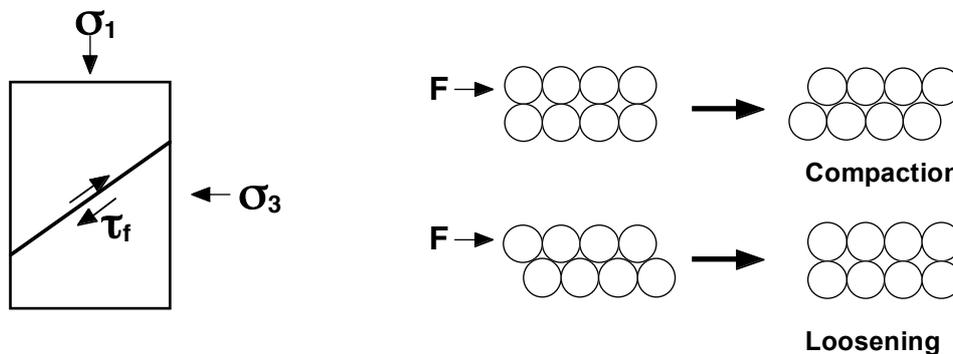


Fig. 17 Shear

The **shear strength** is determined by shear tests (tri-axial or direct shear tests). The stresses in the failure state are represented in the stress-strain diagram of Mohr. Fig. 18 shows various breaking conditions for the same soil. The **shear strength** τ_f is the **maximum value of the thrust** in the failure area. This shear strength is defined by the function of the envelope of all failure circles (called Mohr's failure curve). Within the applicable tension range for the concrete problem, Mohr's failure curve can be approximated with a line. This is known as Coulomb's failure line and is defined by the following equation:

$$\tau_f = c + \sigma \tan \varphi$$

$\sigma \tan \varphi$ is the slope of the failure line and c the ordinate section. φ is usually called **angle of internal friction** and c **cohesion**.

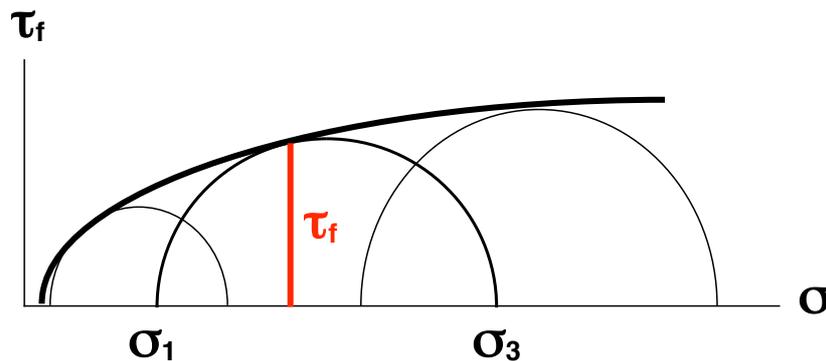


Fig. 18 Mohr's circles, Shear strength value (τ_f)

Pre-compression stress and shear strength values are strongly correlated; therefore, both failure mechanisms occur at the same time, but in locally different zones. Moreover, the two parameters depend strongly on the soil water potential, as the capillary tensions "pull" the particles closer together, resulting in an increase of the number of contact points. Pre-compression stress and shear strength are therefore not constants, but state values, which heavily depend on soil moisture. Basically, the inherent stability of a soil increases as the humidity content decreases.

Causes

The need of the individual steps in agricultural cultivation arises from the choice of crop rotation. Grassland ploughing goes in advance of the cultivation of field crops and is repeated periodically in crop rotations with artificial meadows or green fallow land. Ploughing serves to transport harvest residues or organic fertilizer in the root horizon, on the one hand, and increases the nutrient supply for the subsequent crop. On the other hand, it allows to mechanically combating weeds. The soil structure is brought to a state, which allows the optimal growth of the desired crop. The objectives of the various procedures and the agricultural equipment used for these purposes can be seen in Table 1. Besides the actual soil cultivation, the wheeling of agricultural vehicles, spreading fertilizers or pesticides or collecting the harvest, has an essential impact. In this sense, attention has to be paid on the multiple cuts of grassland within the vegetation period.

The choice of the different **crops** is crucial, because, as already said, this determines the necessary procedures for the crop management, as well as the timing for the cultivation of the soil (Fig. 19). Especially problematic is where farmers commit with processing plants (such as canning factories) through cultivation contracts, which bind them to deliver their harvest in large quantities at certain dates. In case the agreed dates are in a period of bad weather, the farmers have no possibility to delay their harvest due to the reduced bearing capacity of the soil. In addition, due to the mass production the harvest must be accomplished with very powerful machines (see Section 1.3).

Agricultural soil cultivation primarily consists of **loosening** the soil structure by breaking up the aggregate composites (ploughs, cultivators, spade machine), or crushing the aggregates themselves (power driven milling machines and harrows). As a result, the pre-compression stress and the shear strength of the soil are greatly reduced, which means the soil is wheeled in a state with a low bearing capacity. Any further loading supports the homogenization and compaction of the soil structure. Generally, agricultural soils must be compacted artificially with rollers or packers after loosening, because the roots of only very few crops (such as potatoes) can hold in extremely loose substrates.

Tab. 1 Major objectives of various agricultural cultivation measures (Blume 1992, p. 156)

| Maßnahme (Geräte) | Ziele |
|---|--|
| Stoppelbearbeitung: (Schälpflug, Schälgrubber, Kreiselgrubber, Scheibenegge, Spatenrolle, Fräse) | <ul style="list-style-type: none"> - Auflockern oder Wenden der Bodenoberfläche zur Förderung der Infiltration u. Wasserspeicherung und Verminderung des Abflusses, - Verhinderung von Verdunstungsverlusten, - Einmischen von Ernterückständen u. org. Düngern und Förderung ihrer Verrottung, - Vernichtung vorhandener Unkräuter und Schaffung eines Saatbettes für Ausfallgetreide und Unkrautsamen, - Störung bzw. Vernichtung von Wurzelunkräutern. |
| Grundbodenbearbeitung: (Streichblechpflüge ggf. mit Packer, Scheiben-, Kreiselpflug, Spatenmaschine, Schwergrubber) | <ul style="list-style-type: none"> - Tiefgreifende Lockerung bzw. Wendung des Bodens, - Unterbringung von Ernterückständen u. org. Düngern, - Vernichtung vorhandener Unkräuter, insbesondere der Wurzelunkräuter, - Schaffung günstiger Voraussetzungen für garefördernde Frostwirkungen, - Vermeidung von Verschlammungen und Bodenerosion während des Winters. |
| Saatbetherichtung: (Feingrubber, Zinkeneggen, zapfwellengetriebene Eggen, Wälzegen, Walzen, Schleppen) | <ul style="list-style-type: none"> - Homogenisierung und Einebnung der Krume, - Rückverfestigung der Krume unterhalb der Saattiefe zur Sicherung der Keimwasserversorgung bei zu großer Lockerheit, - Auflockerung des Saathorizontes bei zu starker Dichtlagerung und Verschlammung während des Winters, - Krümelung der oberflächennahen Schicht bis zur Saattiefe je nach Anspruch der Folgefrucht. |

Particularly adverse is the impact of wheeling or cultivating **moist and wet soils**. In this state, the soil generally has a low precompression stress and shear strength, which lead to important plastic (irreversible) deformations and kneading during loading and manipulation. For Swiss climate and soil conditions (usually high amount of rainfall and fine-grained soils) the cultivation of root crops (potatoes, corn, sugar beet) is conceivably inappropriate. Because of their long growing season, these require a seed bed preparation in early spring with full soil water storage, and harvest in late fall with increased soil moisture due to lower evapotranspiration. The central point here is to choose a **crop rotation**, which is **appropriate to the local climatic and soil conditions**. But even with cereal dominated crop rotation, the time for land cultivation can still be optimized in regard to soil protection. So it is recommended to accomplish as many working steps as possible in autumn, when the soil water storage is largely consumed.

The biggest problems appear in **soils with a sensitive structure**. The most unstable structure is featured in fine-grained, not cohesive soils (i.e. not containing clay). These show the lowest shear resistance at all moisture contents when compared with differently granulated soils. Silt and fine sand are the most at risk of structural damage. In addition, a surplus of sodium ions compared with calcium ions is very unfavorable. Soils with a high Ca^{++} -content feature a much more stable micro-structure than soils in which Na^+ prevails (see section 2.2).

Therefore, **hazardous soil compaction conditions** appear especially with:

- intense loosening (destroyed micro structure, reduced precompression stress)
- high soil moisture (reduced shear strength)

- fine-grained, not cohesive soils (silt soils: low shear strength due to the lack of genuine cohesion)
- unfavorable cation adsorption of clay minerals (Na-soils instead of higher Ca-saturation).

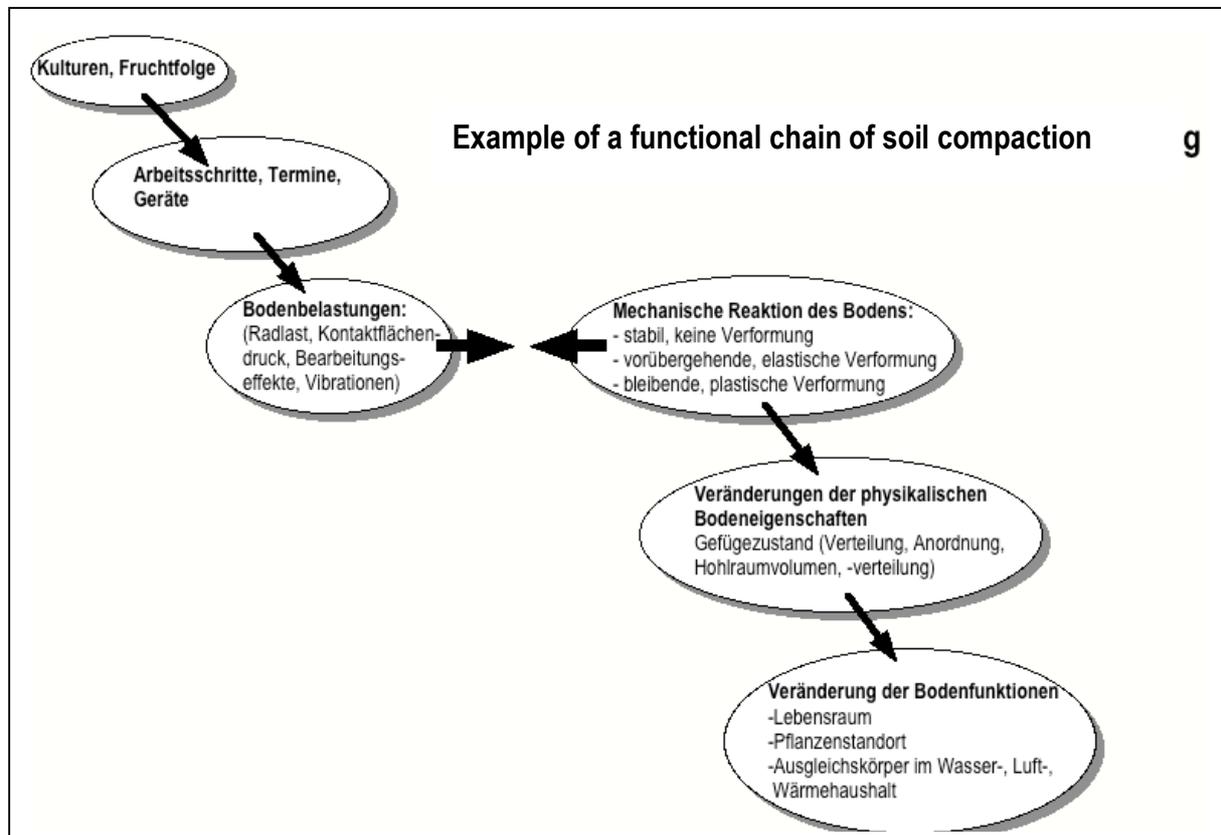


Fig. 19 Example of a functional chain of soil compaction

The extent of soil compaction does not only depend on the structural sensitivity of the soil itself, but also largely on the management technique. A high **contact pressure** at the soil surface leads to high tensions and consequently strong compaction and kneading directly below the contact area. Since 1950, the weight of agricultural vehicles and machinery has massively increased with the increased power (see Fig. 20). The pressure in the contact area of the equipment can be maintained or even partially reduced by increasing the contact areas, for example with twin or extra wide tires. The increase of the contact area, however, leads to deeper compaction, as the **pressure** spreads under the contact surface in a **bulb-shape** (see Fig. 21). The wheeling and cultivation of the soil with heavy machinery lead to compaction of the sub-soil, which is very serious, as the farmer can hardly correct it with his available equipment.

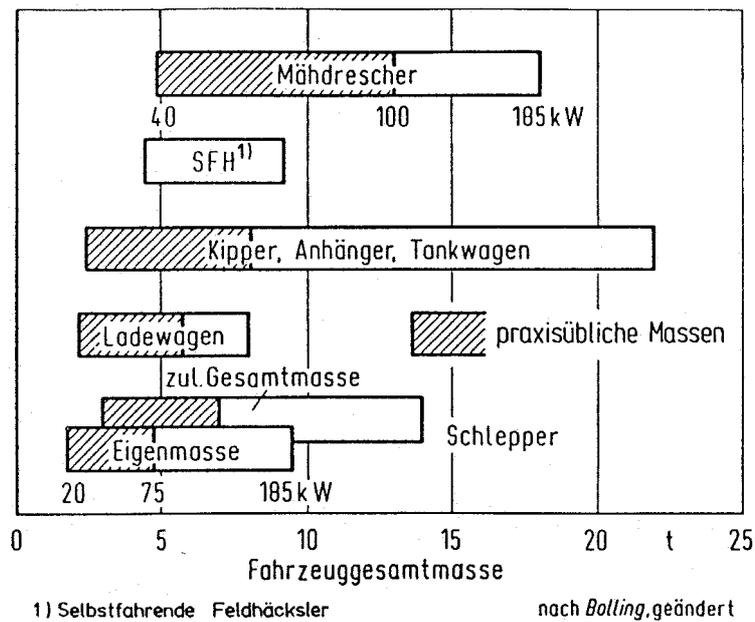


Fig. 20 Bandwidth of the allowed overall mass for agricultural vehicle types offered in the Federal Republic of Germany (Sommer and Hartge 1991, p. 107)

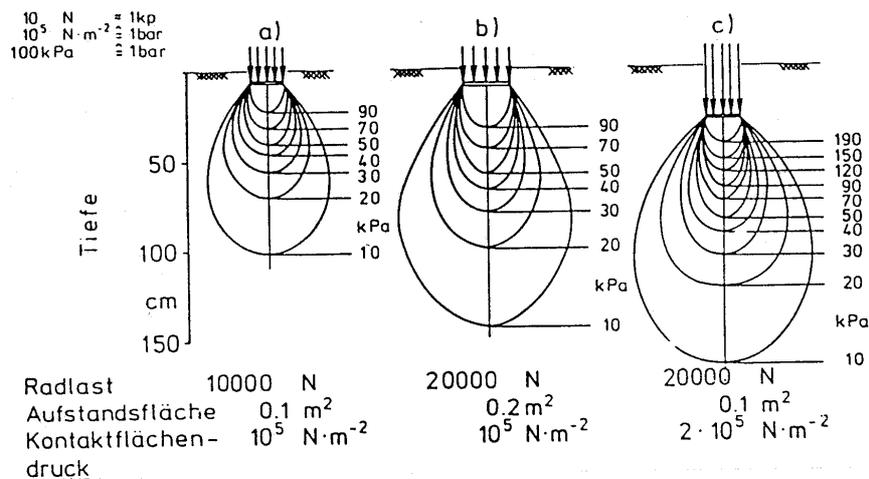


Fig. 21 Pressure bulbs for three different tracks (Sommer and Hartge 1991, p. 108)

The **type and frequency** of the passes also have a large influence on the damage patterns and their extent. Fig. 22 illustrates the effects on the soil when ploughing. While the topsoil is loosened (along with a reduction in pre-compression stress and shear strength), the subsoil is heavily compacted by the tractor wheel traveling along in the plough furrow. This technique leads to the widespread appearance of the **plough sole**. The simplest and most effective measure to prevent the plough sole is the avoidance of driving in the plough furrow. Some farmers already apply so-called Onland- (or offset-) ploughs, which allow the tractor to drive over the unploughed soil with all four wheels (Fig.23).

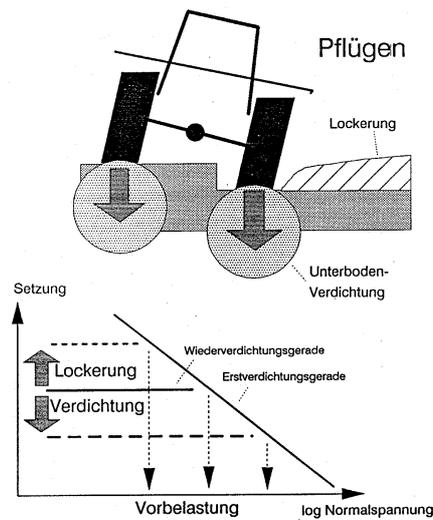


Fig. 22 Change of the pre-compression stress with the ploughing activity (Semmel and Horn 1994, p. 45)

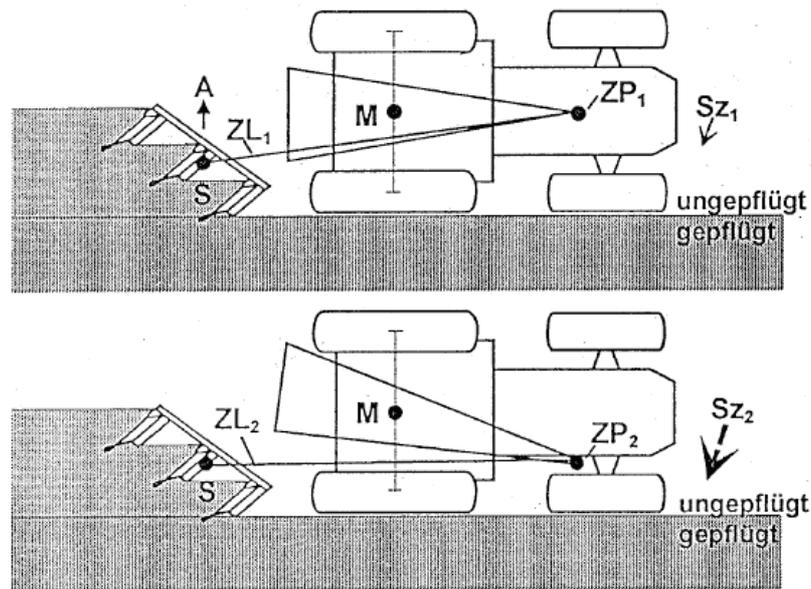


Fig. 23 Location of the charge points of the pulling force with Onland (or offset) ploughs
 Top: "Pulling point in the middle": The pulling point (ZP_1) is centered, the tractor drives with a slight side pull (Sz_1), because the pulling line does not run through the rear axle (M). The inclined pull line (ZL_1) leads to an increased pressure from the plough attachments against the furrow wall (A), which increases the tensile force requirements.
 Below: "Pulling point ploughed": The pulling line (ZL_2) is straight, the required pulling force is therefore reduced. The side pull is greater, because the pull line (ZL_2) runs away further from the middle of the rear axle (M). (Anken 1996, p. 6)

Multiple passes on the same areas lead to the **expansion of compaction zones** in the **depth**. Compacted horizons react to stresses as rigid plates, they handle the tension without significant further reduction in layers, which can absorb the tension while deforming, which means, also being compacted. Finally, the slip of the driving wheels also contributes to damage on the soil structure, because it causes the kneading of the soil. Slip originates in low

tensile force, especially in wet soils. Power driven devices greatly reduce the slip as the energy for manipulating the soil must not originate only in the towing vehicle. However, the power driven machinery destroys the aggregates more, which in turn supports the homogenization of the soil.

Ecological consequences of soil compaction

Soil compaction takes place primarily at the expense of **coarse pores**, where the proportion of fine pores increases. Also, the middle sized pores decrease except for coarse sands. Furthermore, by moving the soil particles against each other, the continuity of the pores is interrupted. Consequently, the water and air balance of the soil changes. The gas exchange with the atmosphere is strongly obstructed, not only in volume due to the loss of coarse pores, but also the diffusion is severely limited due to the lack of pore continuity. Below compacted horizons the oxygen diffusion can decline so much that anaerobe and reducing conditions arise. The **infiltration capacity** of a compacted soil is strongly diminished, resulting in increased surface runoff. At the same time, a compacted soil can drain less rapidly, what entails **water logging**.

Through the loss of air filled pores, the **effective heat capacity and conductivity** increase. Consequently, compacted soils heat up slower and also cool down at a slower pace, so that the loosening effect of frost hardly occurs.

Also the **nutrient balance** is affected. Manganese, iron and sulfur are reduced under anaerobic conditions, and thus less available for plants. Nitrate can be reduced to elemental nitrogen (de-nitrification), which then escapes to the atmosphere.

Compactions restrict the **root space**, as compacted horizons present a much higher penetration resistance for the roots. Dense clods or aggregates are not penetrated by the roots, but surrounded by them. Consequently, in compacted soils the roots grow mainly along cracks. The nutrient and water resources stored in the clods can hardly be accessed. Finally, (sugar) beets change in compacted soils their growth habit. They develop several peaks that break easily at the harvest and lead to yield losses.

Remediation of soil compactions

The remediation of compacted soils involves two aspects: first, the loosening of compacted horizons; second, the stabilization of the loosened micro structure. The actual land improvement interventions are usually of relative short duration compared with the time needed for such a strongly loosened structure to find a new equilibrium with natural consolidation and the re-emerging of biological activity (Horn et al. 1995). For the remediation of soil compaction, the **protective subsequent use** after the technical intervention should also be encountered. That means, agricultural use of the soil is not possible to the usual extent for several years. Soil preparation and driving maneuvers are to be reduced to an absolute minimum (e.g. extensive grassland with a maximum of one cut per year). Grazing is excluded. If afterwards, the loosened soil is not appropriately managed in a careful way, there is a risk of renewed compaction damage, which can have a far greater extent than the original. But the technical remediation measures are very expensive and extensive subsequent use yields only little revenue. Thus, the added value of rehabilitated land remains small over several years. This problem is again to be solved on an agro-political level. From this arises the essential meaning of damage prevention.

Loosening

The restoration by loosening to break up the compacted layers, the loosening depth is usually deeper than that of ordinary agricultural cultivation. There is a distinction between **restorative cultivation** (occasional deep ploughing or loosening under the crumb depth) and **subsoil restoration** (single intervention in a greater depth, that is 50-80 cm). The transitions are, however, continuous.

The subsoil restoration comprises basically two procedures, which principally differ in their impact: **deep loosening** and **deep ploughing** (Fig. 24). In the deep loosening, the stratification of the soil horizons is preserved. This avoids that unfavorable material (too cohesive or acidic soil material, layers rich in coarse material) from deeper layers is mixed with the topsoil. Conversely, deep ploughing breaks up the soil in great depths, and combines the horizons. This is recommended, if the subsoil contains physically and chemically more favorable material. Moreover, impermeable horizons are placed steeper, which increases the water permeability.

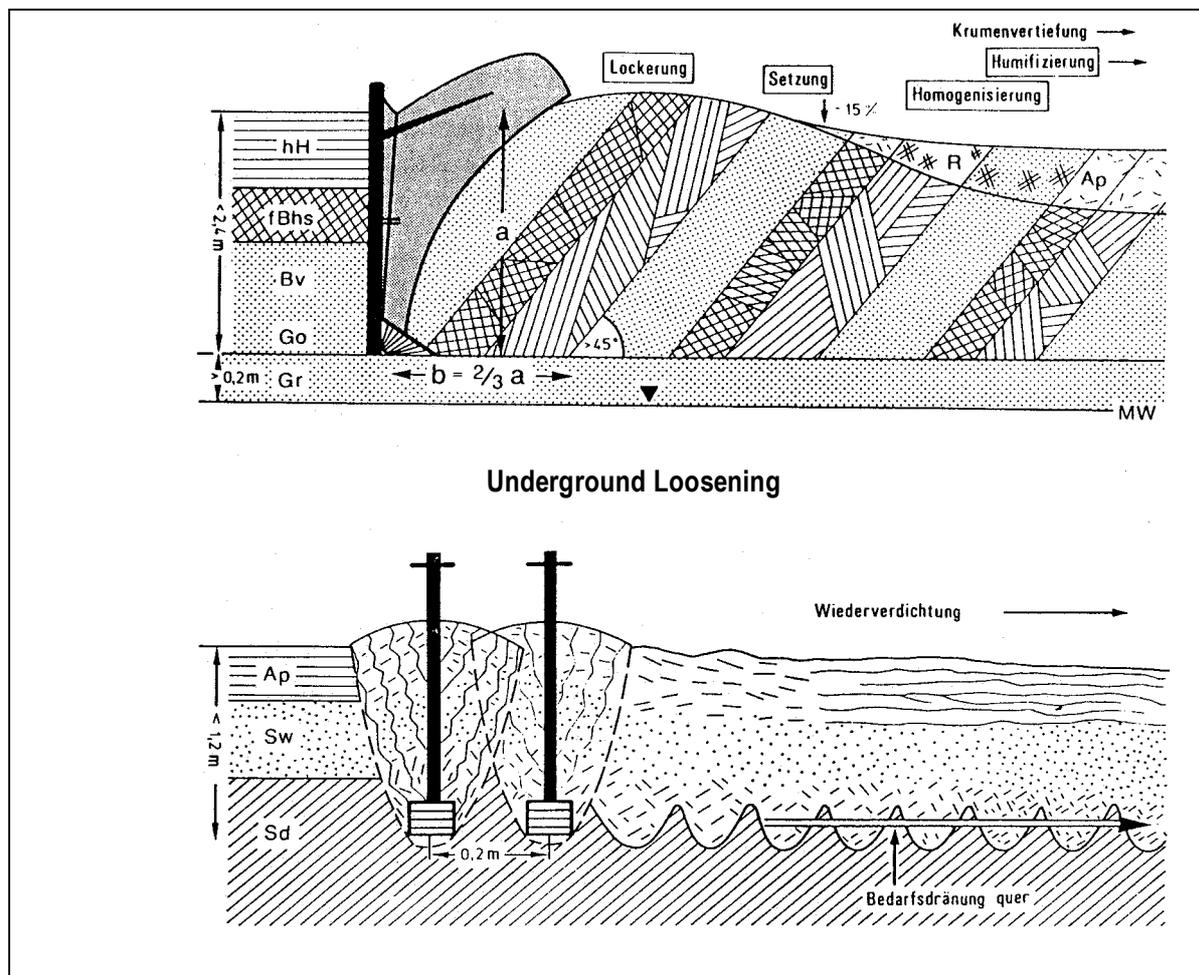


Fig. 24 Combining and loosening subsoil restoration with deep ploughing and deep loosening (Kuntze et al. 1994, p.352)

However, the success of a subsoil restoration also depends largely on the **soils' properties** and conditions. Soils, which tend to have fragile structures, in particular silt soils poor in clay, soils with a low content of organic substance or Na-saturated soils (see Section 2.2 Irrigation), are not suited to get loosened because they tend to sealing and compact even more. In addition, the soil must not be too moist. It must not be plastically deformable, and should break up in loose aggregates. The soil must be dried down to the desired **manipulation depth**. The working principle of different deep scrapers is shown in Fig. 25.

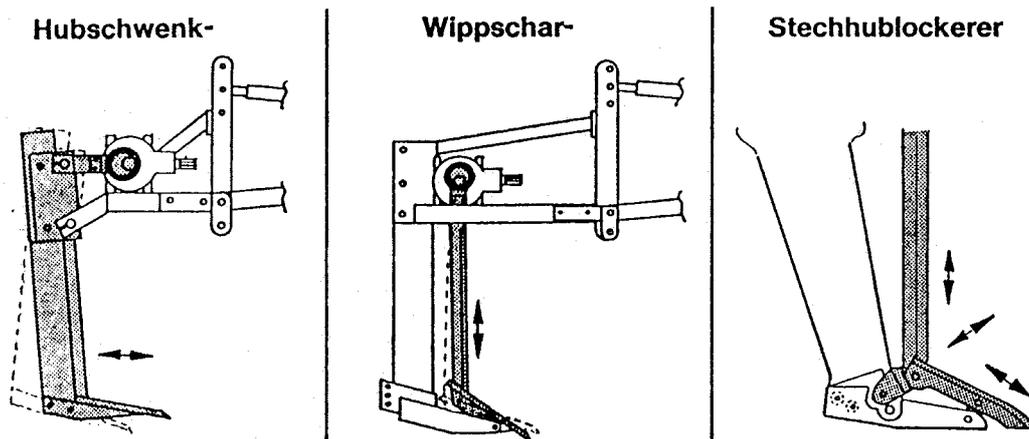


Fig. 25 Working principle of movable subsoil scrapers (Schulte-Karring 1976; in Kuntze et al. 1994, p. 353)

Stabilization

The soil structure artificially is stabilized with biological, mechanical and chemical **additives**, often in connection with a subsoil restoration.

Decomposed **organic matter** acts as a cementing material; it supports the formation of aggregates and provides the soil with additional cohesion, which increases shear strength. Organic fertilizer and vegetation residues are decomposed by soil microorganisms and other animals and accumulate the organic substance in the soil.

On the other hand, organic substances resistant to degradation have hardly any effect on the formation of aggregates. They can only serve as **stabilizers** by filling large empty spaces and increase the proportion of coarse pores locally due to the coarser grain as the soil particles. An example is the addition of plastic particles in subsoil restoration. The addition of sand leads to the same mechanical stabilizer effect, as is done in the land reclamation of peat bogs in northern Germany and Holland (Kuntze et al. 1994, p. 335).

Liming shall primarily adjust the cation occupancy of the clay minerals. The increase of Ca concentration shall promote the aggregation. Moreover, CaCO_3 cements the primary particles. The addition of CaO causes chemical reactions with the silicates. Calcium silicate results, which has such a high bearing capacity that this technique is has been applied in road construction.

Compost from sewage sludge or domestic residues was also used for soil stabilization, especially in the past. However, because of the pollutant content of the waste, this measure entailed a diffused distribution of contaminated agricultural areas (see section 4.3).

3.2 Erosion

Causes

The term Erosion refers to the removal of soil particles by water or wind. Erosion is basically a natural event that can occur on exposed soil. In Central Europe, there are hardly any areas which are naturally exposed or uncovered. Therefore erosion occurs mainly as a result of human actions, namely where the vegetation is temporarily absent or has been reduced. This applies especially in vineyards and arable land. Fig. 26 shows the effects which cause, and are a consequence of erosion.

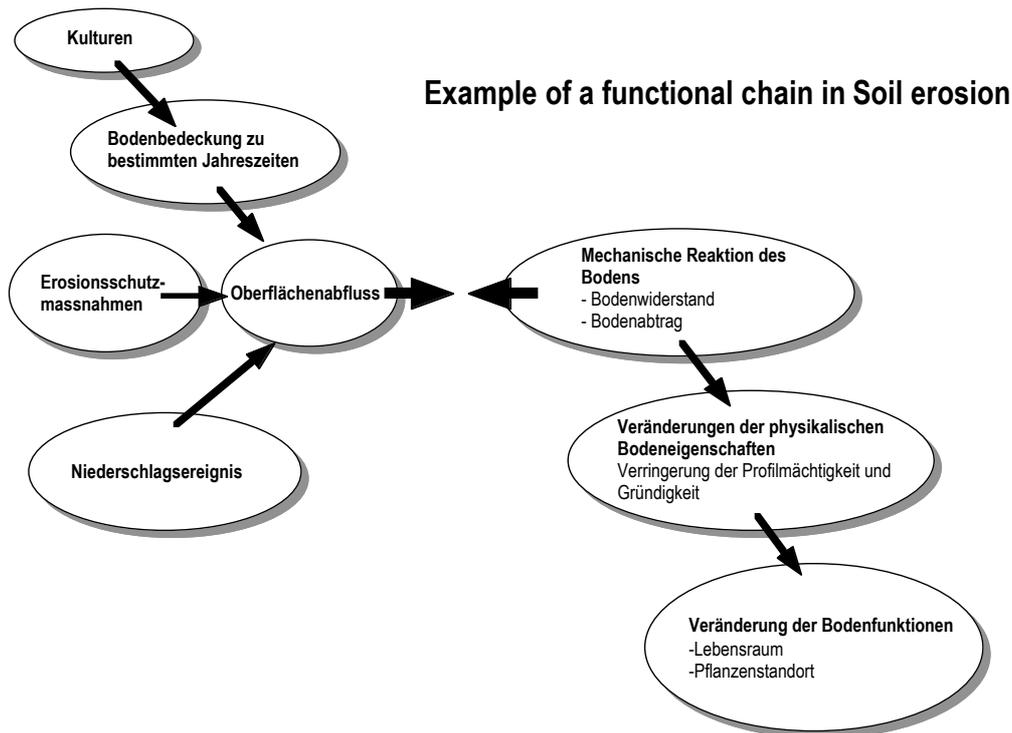


Fig. 26 Example of a functional chain in soil erosion

In regions like ours, **wind erosion** is a secondary problem; **water erosion** however, is of significance in some regions. In general, erosion events are associated with **heavy rainfall**, and due to the impact of raindrops, individual soil particles are dissolved and transported by the infiltrating water under the soil surface. So, the soil particles clog the large and medium-sized pores, which are closer to the soil surface. This results in a **sealing of the soil surface** and a drastic reduction in the soil's infiltration capacity. Water accumulates on the soil surface and additional **surface runoff** occurs on slopes. At high flow velocities, additional soil particles are carried away and relocated due to the friction force of the water.

Surface erosion means that erosion occurs in a uniform way over the soil surface; this phenomenon is characteristic of wind erosion, but it occurs much less frequently with water erosion. More frequent is the **rill** or **gully erosion**, where the water gathers in vertical depressions (tractor tracks, seed grooves) and causes concentrated downhill flows. The progressive deepening of the rills can lead to deep **gullies**.

On the eroded surfaces, **damages due to soil removal** are noticeable. There the loss of soil is evident, but equally serious are the damages by accumulation of removed material in the underlying territories. Trails and roads are covered, canalization and sewer systems clogged, and retention reservoirs and ponds loaded with sediments. Additionally, **pollution** may take

place with materials attached to the soil particles (see section 3.3 fertilization and crop protection).

Today, there are several model approaches to assess the **threat of erosion** and the **potential soil volumes**, which could be removed. One of the best known approaches is the „universal soil loss equation“ (USLE), developed by Wischmeier and Smith (1978) for topographic and climatic conditions in the United States. Schwertmann et al. (1987) adapted this approach for Bavaria. In this form, it found wide dissemination in central Europe under the name of „general soil erosion equation“ (in German: allgemeine Bodenabtragungsgleichung - ABAG).

The USLE or ABAG indicates parameters of the erosion risk based on climate, soil, topography and cultivation characteristics. It gives a long-term average of expected annual soil erosion ratio of a single agricultural parcel, which is homogenous in the parameters mentioned. This erosion risk is determined by multiplying six factors, which have to be calculated in a relatively complex way with the help of tables, nomograms and underlying equations from the individual input variables. The USLE is calculated as follows:

A=RKLSCP

| | | | |
|------|---|---|---|
| with | A | = | long-term, average yearly soil removal [t/ha] |
| | R | = | Precipitation- and superficial drainage factor for the geograph. location |
| | K | = | Soil erodability factor |
| | L | = | Slope length factor |
| | S | = | Slope inclination factor |
| | C | = | Cropping factor |
| | P | = | Erosion protection factor |

Technical requirements for an effective protection against erosion

Just as with soil compaction, **fine-grained, structurally unstable soils** (silt, fine sand) are the most exposed to erosion. In locations with slopes, such soils should be used for the production of green fodder, only. Until recently, the widespread implementation of this postulate was obstructed by the boni for hillside farming and the milk quota system in Switzerland (Tobias et al. 1999a, p.175).

The crushing of the aggregates and **loosening** of the soil during the preparation of the seed bed (see section 3.1) also makes the soil susceptible to erosion and should therefore be avoided. Already today, different farmers use the technique of rill seeding. In this process, a crack is cut in the soil, in which the seeds are inserted. The residues of the previous crop cover the soil permanently. Another possibility of extensive soil covering are **grass nursing crops**, which are now increasingly used in the cultivation of wine and corn.

Since erosion is a problem that extends across regions, the spatial production structures should be designed to work against it. In particular, the arable parcels are to be allocated, so that cultivation parallel to the slope becomes most efficient. Also, the **trail network** must not favor erosion; partial trails oriented towards the falling slope often serve as fast gutters for the water, and at bifurcations, massive erosion damages occur in the field below.

Further **erosion protection measures** are capture dams and retention basins to break the run off. In the case of wind erosion, protective vegetation is planted as countermeasure to protect the soil. Further information on the topic of erosion can be found in Blume (1992, p. 182-224) and Kuntze et al. (1994, p. 359-366). One of the fundamental works on soil erosion in Switzerland was written by Mosimann et al. (1991).

Although protection against erosion is basically effective on a preventive level, often measures for erosion protection are taken only when visible damage has already occurred. Evident erosion damages are land slides and erosion at the banks of water bodies. As long as it is a matter of a **superficial slide**, which means that the sliding surface is not deeper than the main root zone of the local vegetation, restoration with living plants is possible. The control of erosion with living plants is called **soil bio-engineering**. Usually, pioneer plants are used for this purpose, because they are often capable of vegetative reproduction. Pioneer species can settle in these inhospitable places, as the topsoil is often removed. The possibility of vegetative reproduction is a decisive factor for the availability of the living construction material in a sufficient quantity. In the case of steep slopes (due to the lack of space and land use conflicts) constructions with vegetation are often combined with supporting elements made of concrete, iron or wood. On the subject of soil bio-engineering, additional documents are available indicating specific literature (Tobias 2003).

3.3 Fertilization and crop protection

Objective

As a result of harvesting, nutrients are removed from the soil, which must be added back to it in the form of **fertilizers** in order to secure long-term yields. This means basically the supply of plant nutrients like nitrogen, phosphorus and potassium. Traditionally, manure is used for this purpose, that is, droppings and liquid manure. With the intensification of agriculture, mineral fertilizers are increasingly applied. The increase in farmers' income since 1950 is attributed to mineral fertilizers in the order of 40-60% (Deutsches Institut für Fernstudienforschung Uni Tübingen 1997, p. 213). In the contrary to manure, nutrients in mineral fertilizers are accessible to the plants almost directly. When manure is used, the organisms in the soil must first decompose the nutrients before they can be absorbed by the plants.

The large-scale cultivation of single crops, as well as the production of high-performance varieties, made an increment in the use of plant **protection products** necessary for the prevention of epidemic diseases and pest control. In the context of this lecture the effects of these products will not be discussed in detail. For the subject of regional land management basically the transport ways are relevant, because they enable the spatial spread of pesticides or their degradation products. This is essentially the same process that will be explained in the next section using the examples of nitrogen and phosphorus. The following sources provide more detailed information on the environmental impact of crop protection substances: Deutsches Institut für Fernstudienforschung Uni Tübingen 1997, p. 210-213; Blume 1992, p. 325-352; Scheffer and Schachtschabel 1998, p. 3312f.

Technical requirements for effective application of fertilizers

The required nutrient addition can in principle be calculated from the **stock in the soil** and the yields to be achieved. If the plants cannot absorb all the nutrients supplied, e.g. because of weather conditions, there will be a surplus of nutrients in the soil. Nutrient accumulation in the soil can be counteracted with staggered fertilization according to the stage of plant growth, particularly with nitrogen. Nitrates and phosphates can relocate easily, leading to pollution of environmental systems outside the fertilized area.

Because fertilizers are relatively cheap, maximum profit and correspondingly higher yields are achieved with more intensive fertilization. Artificial increase of fertilizer costs with e.g. nitrogen tributes may cause a shift of the maximum profit towards a reduced use of fertilizers.

Häberli et al. (1991, p. 87) estimate that an increase of 50-100% in the cost of fertilizers would be necessary to prompt a more rational use. However, the production surplus of mineral fertilizers could only be constrained with a cost increment of around 400-500%. Fig. 27 illustrates this situation for the example of nitrogen.

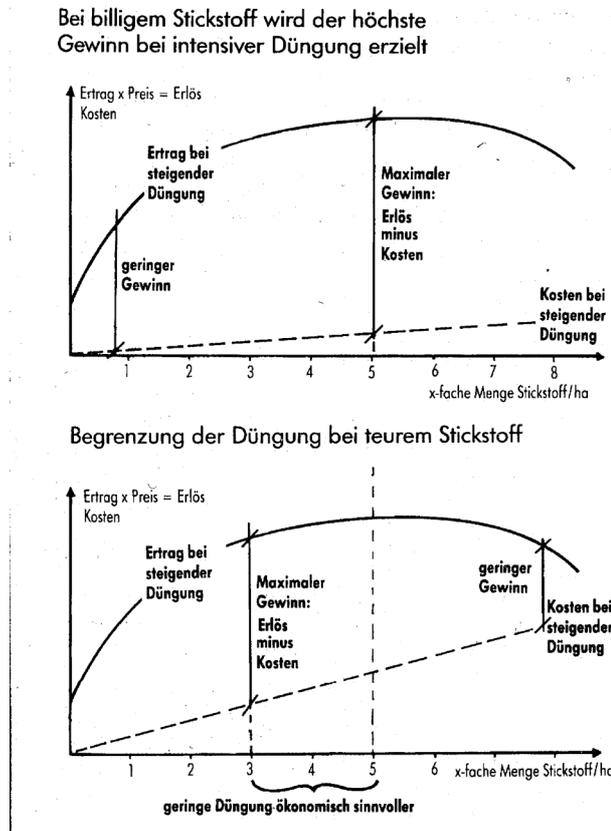


Fig. 27 Expected limitation of fertilization by the introduction of a nitrogen tribute (Deutsches Institut für Fernstudienforschung Uni Tübingen 1997, p. 239)

In most soils **nitrogen** is a limiting factor and because of fear to have lower yields farmers often apply excessive doses of nitrogen to the soil. The unused nitrogen is then dissolved and transported by the soil water as nitrate (NO_3^-) or ammonium (NH_4^+). A transfer into groundwater sources is particularly unfavorable, especially if it concerns drinking water. In the mouth, the micro-organisms convert the nitrates to nitrite. If the nitrite reaches the human blood system, it can oxidize the central atom of hemoglobin, which in such a case loses its ability to transport oxygen. With infants this can lead to death (Blume 1992, p. 250).

In many cases, nitrate reaches **superficial waters** through agricultural **drains** and leads to **eutrophication**. This results in a massive algae bloom in the upper layers of the water, the algae then consume the nutrients and produce oxygen due to assimilation. Dead plant parts sink to deeper layers and are degraded with oxygen consumption. As a result, the nutrients supporting algae growth are released again. In heavily eutrophicated waters, massive fish dying can occur in times of severe oxygen consumption. Eutrophication is favored, if in addition to the nutrients, organic matter reaches the water, which again consumes oxygen in its degradation process. It is particularly problematic in **drained organic soils** (peat soils); through the degradation of organic matter as a result of aeration (see Section 2.1), additional nitrogen is released, which can also be transported with the soil water.

Fig. 28 schematically summarizes the **paths**, through which nitrogen reaches the soil, is transported and finally dispersed. The entry by **rainfall** is not to be underestimated. Greenhouse gases resulting from the burning of fossil fuels often contain the plant nutrients carbon, nitrogen and sulfur in a plant available way. To some extent, they can already be absorbed as gases by the green parts of the plants (CO_2 , NO_2 , NH_3 , SO_2). Otherwise, they are transformed in the soil, so that they can be absorbed by the roots (Scheffer und Schachtschabel 1998, p. 316). This fertilization from the atmosphere leads to a **large-scale pollution of oligotrophic ecosystems**. As a result, the natural plant communities change favoring the strongest, most competitive, nitrogen-avid species (see also section 2.1) (Klötzli 1991, p. 36).

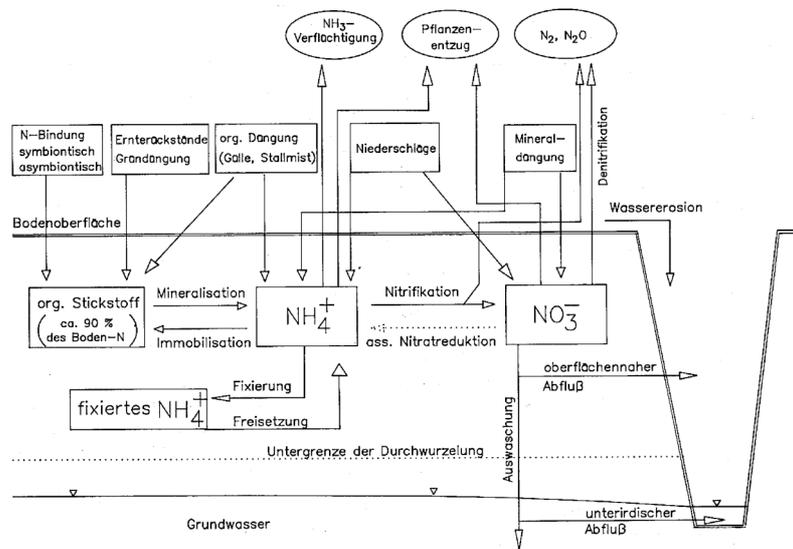


Fig. 28 Paths of the nitrogen transport in the soil (Blume 1992, p. 239)

Phosphorus is bound to soil particles as phosphate. Therefore, only 60% of the dissolved phosphate is available for plants (Deutsches Institut für Fernstudienforschung Uni Tübingen 1997, p. 215). The rest accumulates in the soil. Hence, **soil erosion** can lead to a relocation of phosphate. Since the use of phosphorus-free detergent in the 1980s, soil erosion causes the highest phosphate entries in **open water bodies** (Scheffer und Schachtschabel 1998, p. 311). The consequence is, again, eutrophication (see above). It should be noted that the excess of phosphorus is deposited in the sediments at the ground of the waters. Under reductive conditions (especially by oxygen deficiency) the stored phosphate converts into soluble forms, and is again available as a nutrient. Hence, water bodies subject to excessive fertilization can only recover a long time after the addition of phosphorus has ceased (Scheffer and Schachtschabel 1998, p. 312).

In order to prevent the entry of nutrients in oligotrophic (low in nutrient) ecosystems and water bodies, **vegetation filter strips** are to be provided in adjacent areas (buffer zones). These strips must be several meters wide, and under no circumstances fertilized. Areas, which are set aside from agricultural use, are often used as such filter strips. However, in the filter strips themselves, usually there are nutrient-avid species. Their ecological relevance is therefore due to their function, and not because of the species, which inhabit them.

4. CONSTRUCTION ACTIVITY, EXPLOITATION OF RAW MATERIAL, WASTE

4.1 Soil Sealing

From 1950 to 1990, the overbuilt area in Switzerland has more than doubled (Häberli et al. 1991, p. 14f). Moreover, from 1986 to 1996 the sealed area increased from 168665 ha to 213421 ha, which means to approximately 25% (Bundesamt für Statistik 1986 und 1996). These include residential, commercial and industrial areas as well as transport routes and roads. Because of the sealing, important **ecological regulation functions** of the soil are lost.

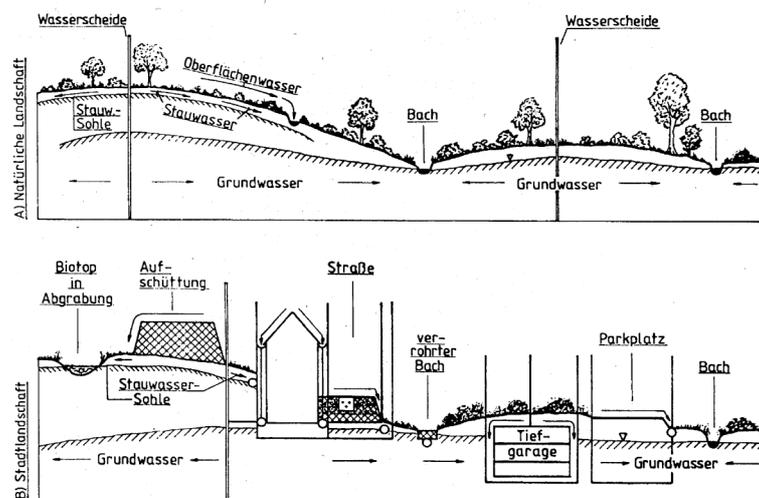


Fig. 29 Changes in the landscape water regime through various forms of soil sealing (Deutsches Institut für Fernstudienforschung an der Universität Tübingen 1997, p. 303)

The ground is no longer (or only partially) available as a **habitat for plants** (for example, as a garden over an underground parking lot). The **landscape water regime** also experiences serious disturbances, as Fig. 29 illustrates. The superficial runoff raises sharply, which in turn increases flooding. The remaining infiltration paths through the soil are drastically shortened. This leads, on the one hand, to increased pollution of the receiving water bodies, and on the other hand, to a sharp reduction of the natural recharging capacity of groundwater.

A target oriented (over-)regional spatial planning should prevent the excessive expansion of the sealed areas. For this purpose, the geographic boundaries of the different land use units should be specifically formulated, at the level of the physical development plan. Otherwise, the physical development plan remains too abstract and will barely be implemented in practice when planning the land use of an area (Häberli et al. 1991, p. 53). For more information, we refer to the lectures on spatial and environmental planning (Institute for Spatial and Landscape Planning, NSL, ETH Zürich).

4.2 Major construction sites and exploitation of raw material

Context of land restoration

Construction sites and the exploitation of resources are temporary land uses. However, they still represent a strong intervention in the soil ecosystem, since they require the removal of

the vital soil layer. In Switzerland, only gravel, sand and clay are exploited in significant quantities as raw materials. This occurs either in surface mining, or in river or lake dredging. Within this lecture, however, the latter is not dealt with. After the temporary uses in construction sites and areas where material was exploited, the original use of the area or other use should be procured. Usually these comprehend agricultural or forestry uses, or the use as natural habitat. For this purpose, usually the removed soil layer must be restored and recultivated. Since the building activity on forest areas is often avoided because of the obligation to compensate with reforestation, there is an increasing pressure on the agricultural areas. The conflict is aggravated because the soil covering exploitable gravel deposits usually also brings high returns for agriculture, and therefore often these areas are favored for crop rotation (RPV 1989) (see e.g. Richtplan des Kantons Zürich; Kanton Zürich 1995).

Extensive construction sites arise in the creation of infrastructure systems, for example, roads and pathways for energy transport. In particular, road construction occupies large areas next to the actual traffic areas, necessary for installations and working space, as well as for possible construction tracks. These areas must be restored after the construction activity has finished. However, the improved integration of transport routes in the landscape involves more extensive soil displacements and therefore, large land restorations (e.g. the A4 through the Knonauer Amt). For example, flattening a slope from 2:3 to 1:10 involves extending backfilling or incisions over an area seven times larger, which must be restored. The construction of open-cast tunnels is also associated with the removal and the continued large-scale dumping of fertile soil. The laying of underground pipes of large diameters (40-90 cm), for example high pressure gas pipes, represents a special case of a linear construction site. The intervention on the soil is limited to a relatively small area (a long, but normally not more than 10 m wide construction strip) and a short time (completion of all work in one place within one to two months). Nevertheless, this intervention represents a strong disturbance of the soil structure and of the cultivation activities. Because such pipelines are laid as straight as possible, the result often is that they are placed without consideration of where the agricultural areas are located, and led across the farmers' fields.

Technical requirements for a successful land restoration

Because of increasing conflicts in the use of land, land restoration has gained more importance due to both environmental and economical reasons, and touches an increasing amount of areas. Depending on the subsequent management planned, there are different requirements on the type and thickness of the restored soil horizons. For areas to be used in agriculture, the usual current practice is a restored soil layer of at least 1 m depth. It should consist of a subsoil layer of about 80 cm (decomposition material, B-horizon) and a topsoil layer of about 30 cm (humus, A-horizon). Forest sites do not need a humus layer, the root area of trees extends to a depth of about 2 m, though. A special case is the restoration to create natural habitats. In the case of creating ruderal habitats or humid biotopes, particularly in gravel pits, soil restoration is often left out.

Fig. 30 schematically shows the **composition of a restored soil**. The restoration plane is either the landfill cover (see Chapter 4.3) or the plane, on which construction vehicles have been driven. In most cases it can be considered impermeable; hence, it should have a smooth surface with a slope of at least 4%, to avoid the creation of local water logging in the restoration layer. On large restoration areas, especially with long fields in the direction of the slope, it is always recommended to install a drainage system. This can be laid out as drainage pipes, linear gravel packs (see Chapter 2.1 Soil drainage) or as laminar gravel cover. The most commonly used for this purpose are also PVC pipes, however, because of fear of

the risk of breakage, often they are incorporated only after the completion of the restoration. Over them lay the actual restoration layer composed of subsoil, and potentially topsoil, depending on the planned management (see above).

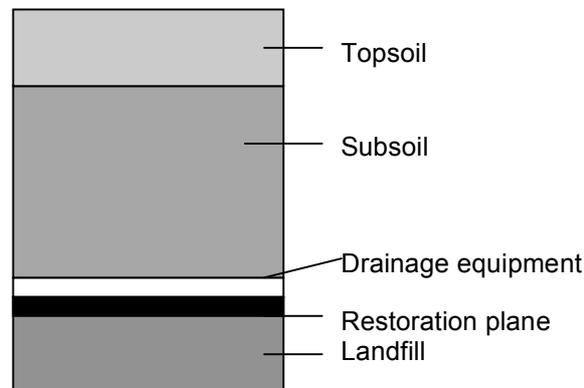


Fig. 30 Soil horizons of agricultural areas after restoration

The **removal** and **heaping** of soil leads to a strong mechanical impact on the secondary soil structure. To avoid the destruction of the individual soil aggregates (especially crumbs), this work must only be carried out with **dry soil**. This also applies to the filling or the removal of intermediate soil deposits (see below). Soil, which has recently been piled up is very loose and therefore should not be driven over. There are two different filling procedures: area extensive or filling in strips, the choice of the method depends mainly on the technical aspects (extension and shape of the restoration area, type and quantity of available filling material, available machinery).

In an **area-extensive filling**, the subsoil is filled up from the restoration plane over the entire restoration area. Then the subsoil is left to consolidate, and 6 to 12 months after, the topsoil is laid on. In order to promote the formation of secondary soil structure and protect the subsoil against erosion, seeds of intermediate-crop plants with deep roots and winter resistant capabilities are spread over it (such as forage rape, colza, yellow mustard). For heaping the topsoil, mostly caterpillar vehicles are used, which apply low ground pressures (e.g. caterpillars for peatbog restoration, <200 kPa). Nevertheless, the high weight of a loaded filling vehicle still leads in many cases to compaction in the top 10 cm of the subsoil. The ejection of the topsoil with excavators, especially with drag lines, avoids passing directly over the subsoil. Because of the limited coverage of the dredgers, this practice is only viable on very small areas.

When a **stripe-filling** takes place, the subsoil and the topsoil are heaped in one working step with excavators, in stripes of approximately 3-5 m width. In this procedure, driving over the subsoil can be avoided; however, the subsoil is burdened with the humus layer immediately after the filling. Additionally, irregular settlements were observed on restored areas using stripe fillings, when compared to area-extensive procedures. In both filling techniques, the topsoil is to be immediately sown with grasses and legumes after heaping.

Basically, after its removal, the soil should be transferred to its final new place as soon as possible to be immediately restored. With this, an **intermediate soil storage location** can be avoided, which on the one hand requires a relative large area, and on the other hand can only be removed under dry conditions. In gravel pits, which are exploited for 20 to 50 years, the mining activity is phased in time and extension; this should largely enable the immediate relocation of the soil from one phase area to another. In temporary construction sites (e.g. installation of gas pipelines), the soil is almost always temporarily stored immediately next to

the excavated trench and then restored to its original location. On road construction sites, where installation spaces are partially laid out for 5 to 10 years, the deposit areas are to be carefully chosen, so that after completion of the construction work there is still enough soil left for restoration. The deposits can be piled up as stock piles, embankments, or extensive areas over arable land (only top soil deposits).

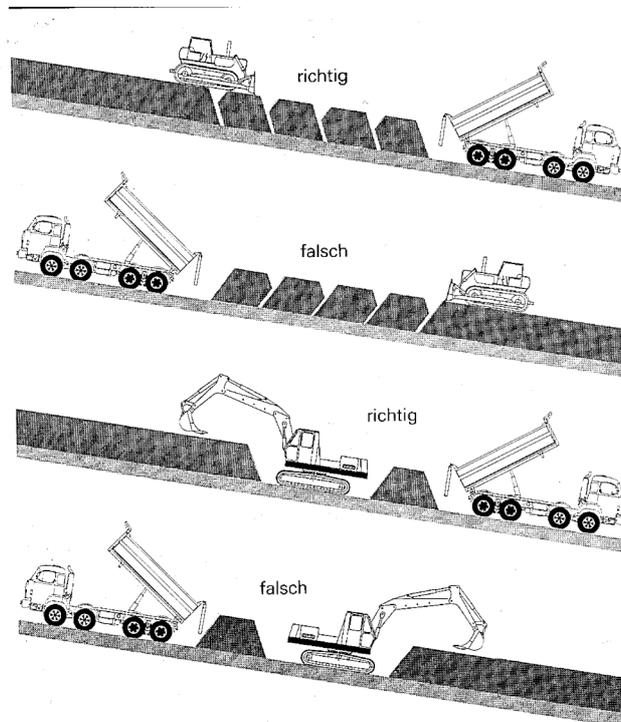


Fig. 31 Heaping of the subsoil (Eidg. Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP Reckenholz und Schweiz. Fachverband für Sand und Kies FSK 1987, p. 18)

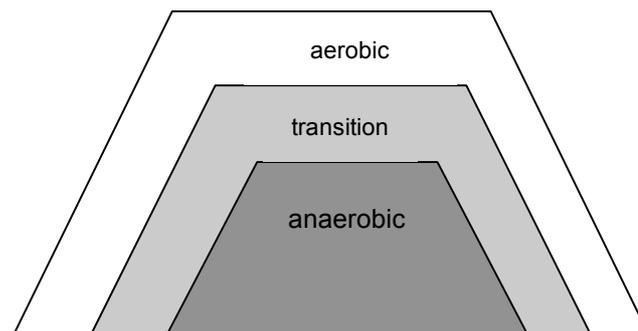


Fig. 32 Aerobic and anaerobic zones in an intermediate soil deposit (according to Harris et al. 1996, p. 71)

The most important issue is the height of the intermediate deposits, because this is crucial to determine the area required. Basically, the soil should not be compressed by its own weight. The finer the grains in the soil, the less ability it has to withstand loads (see section 3.1) and therefore the less high it can be piled up. Harris et al. (1996, p.70f), however, observed anaerobic soil conditions in the core of all soil deposits (Fig. 32). The size of this anaerobic core depends on the grain size of the material and the height at which it is piled (Fig. 33).

For topsoil deposits, heights of 1.5 m to 2.5 m are recommended (FSK 2001). For subsoil deposits heights from 5 to 10 m are recommended, depending on the grain size of the material (Umweltministerium Baden-Württemberg 1991). Extensive topsoil deposits should be so high, so that together with the original topsoil underneath they amount to not more than 50 cm in height, in order to ensure the air circulation in the subsoil below (Salm 1996). These deposits can be cultivated, whereby the utilization restrictions are mitigated. However, it should be limited to an extensive cultivation.

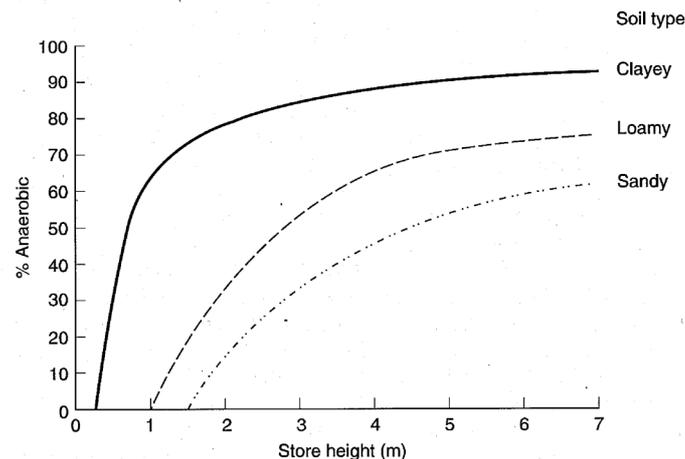


Fig. 33 Percentage of the anaerobic zone within an intermediate soil deposit in relation to the grain size of the material and the piling height (Harris et al. 1996, p. 71)

Currently, for the techniques of reclamation there are different **guidelines** and information sheets that are reviewed on an ongoing basis. The following publications are the most widespread in Switzerland:

FSK-Schweiz. Fachverband für Sand und Kies (Hrsg.), 2001. Kulturland und Kiesabbau. Richtlinie für den fachgerechten Umgang mit Böden. Haller u. Jenzer, Burgdorf, 77 S.

Salm Ch., 1996: Bodenschutz beim Bauen (Handbuch). Bundesamt für Umwelt, Wald und Landschaft BUWAL. Bern

VSBö-Mitteilung Nr. 4, 1993: Verwertung von abgeschältem Oberboden. Bundesamt für Umwelt, Wald und Landschaft BUWAL und Eidg. Forschungsanstalt für Agrikulturchemie und Umwelthygiene IUL (ehem. FAC). Bern und Liebfeld (zur Zeit in Überarbeitung)

Umweltministerium Baden-Württemberg, 1991: Erhaltung fruchtbaren und kulturfähigen Bodens bei Flächeninanspruchnahmen. Luft-Boden-Abfall, Heft 10

Technische Verordnung über Abfälle TVA vom 10. Dez. 1990

Just as important as the restoration of the soil is its adequate **subsequent management**. Today, still very little is known about the evolution of the mechanical bearing capacity in restored soils. In general, it is recommended to restrict the cultivation strongly during the first three to five years (extensive grasslands without grazing). However afterwards, a crop rotation with cereals and (intensive) grassland without root crops is also recommended. In many cases, these recommendations are not followed by the farmers; particularly in relatively short extraordinary uses as for infrastructure construction (roads, railways, pipelines), where the project contractors guarantee a compensation for the loss of agricultural income only for a few years. Until recently compensation payments were higher, the more expensive the harvest could have been sold; for this reason, maize was often cultivated in the first year after the reclamation.

In addition to coarse stones in the topsoil, **water logging** resulting from compaction are the most common problems that farmers complain about after restoration. Because of the overlapping effects in the individual steps of a restoration until the subsequent management, the actual causes of water logging are often difficult to determine. When water logging occurs in the range of the restoration plane, on the subsoil and in the border between the top- and subsoil, mistakes in the restoration itself are to be assumed. Reasons for this could be excessively long parcels without drainage, or bumps in the restoration plane, or the compression of the subsoil due to laminar heaping of the topsoil. By contrast, for compaction at the soil surface, mostly the cultivator is to be held responsible. Heavily compacted parts within the soil horizons emerge from the installation of material, which was too moist, or from intensive mechanical stress, notably at the field margins, where the tractor turns, or in entrances for agricultural or restoration vehicles.

4.3 *Pollutants, Waste*

Pollutants from diffuse sources

Many industrially manufactured products (especially plastic products, mineral fertilizers and fuels) contain **heavy metals** or **organic compounds**, which are released through degradation or incineration of the product; and new compounds (such as dioxins) can then come into play. Pollutants in the **exhaust** of waste incineration plants, chemical or metalworking plants and internal combustion engines are released into the air and with rainfall deposited back into the soil. In the vicinity of **industrial plants** and **roads**, heavy metals or hard-degradable organic compounds deposit partially in the soil in high concentrations. The introduction of flue gas washing bays and catalysts for gasoline engines brought in a strong reduction of emissions into the ground. However, the already existing content of these often toxic substances in soil has not been reduced.

Many pollutants originate from **sewage sludge** spread for the fertilization of agricultural land. The pollutants from waste water concentrate in the sewage sludge, especially problematic are the cases where farmers commit in contracts to accept the sewage sludge. These fields were regularly contaminated and in part present heavy metal concentrations, which make suspect that the long-term fertility of the soil is no longer guaranteed. Due to the high concentrations of pollutants in urban sewage sludge in the past, today farmers refuse, for example in the area of Zurich, to further accept the sludge of the city of Zurich. This represents a disposal problem for the city, as it now has to incinerate the sludge and then dispose the pollutant-containing slag as hazardous waste (NZZ from 19./20.2.2000).

Other sources of pollution are industrial areas, where waste was not sufficiently protected and sealed from the environment; accident locations (accidents involving freight train tanks, leaks in storage facilities); and bullet traps from shooting ranges. Such sites are designated as **contaminated sites**. The pollutant concentrations in contaminated sites are often several orders of magnitude greater than in the diffusely polluted soils of the diffuse areas, which are mentioned above.

Many **heavy metals** are essential elements for life (e.g. Cu, Fe, Mn, Zn); in higher doses, however, they are toxic to most organisms. Other heavy metals fulfill no physiological purpose and are toxic in small quantities (e.g. Cd, Hg, As). Heavy metals in soil cannot be degraded, however, to a certain extent they are adsorbed through the mechanism of the **cation exchange** (Fig. 34) and consequently bound in the soil. The ion exchangers are negatively loaded soil particles, that is, especially clay particles and humic substances.

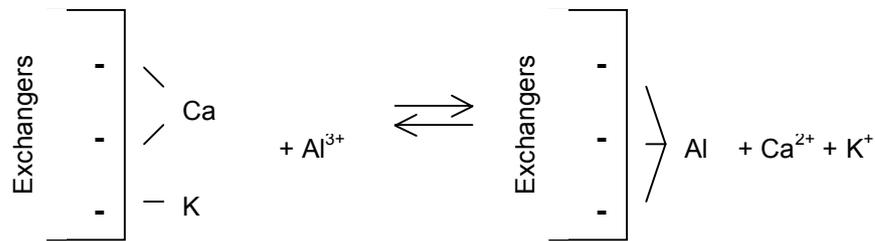


Fig. 34 Principle of the cation exchange in the soil (according to Scheffer and Schachtschabel 1998, p. 93)

The proportion of adsorbed heavy metals depends on the **cation exchange capacity** (CEC). This is defined as the sum of all exchangeable Ca, Mg, Na, K-ions (details on the cation exchange can be found in Scheffer and Schachtschabel 1998, p. 100-103). The cation exchange capacity depends on the pH value of the soil; and at pH 7 reaches its maximum; this is referred to as the potential cation exchange capacity (CEC_{pot}) of a soil. The effective cation exchange capacity (CEC_{eff}) decreases with a lower pH value (Fig. 35). It corresponds to the CEC for the current pH of a soil and is therefore an indicative of the actually occurring processes.

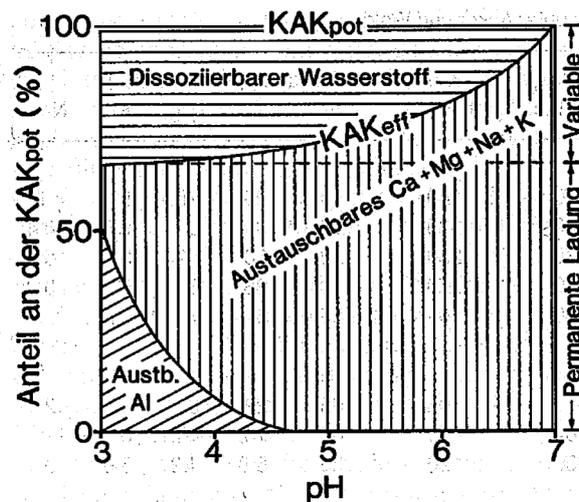


Fig. 35 Schematic diagram of the dependence from CEC_{eff} and cations covering (in % of CEC_{pot}) on pH-value in a soil (in German Kationenaustauschkapazität - KAK) (Scheffer and Schachtschabel 1998, p. 102)

In this way, the soil acts as a **buffer** and reduces the proportion of heavy metals in the soil solution. Dissolved heavy metals can be absorbed by plants and thus enter the food chain. The ratio of dissolved to adsorbed ions can be described using adsorption isotherms (see Fig. 36).

Therefore, in the assessment of the heavy metal pollution in soils there is a difference between the **total content** of heavy metals and the **content of dissolved parts**. The total content is equivalent to the sum of the dissolved and adsorbed shares. The dissolved heavy metals represent an acute danger, because they are directly accessible for plants. However, the adsorbed heavy metals are a latent danger because by a decreasing pH as a result of lack of exchangeable Ca, Mg, Na and K, elements such as Al can migrate into the solution

(Fig. 35), whereby also Al is toxic for plants. This situation is of great importance, since with the emission of SO₂ and NO_x (as well as ammonium in areas with high concentrations of animals) strong acids are incorporated into the soil.

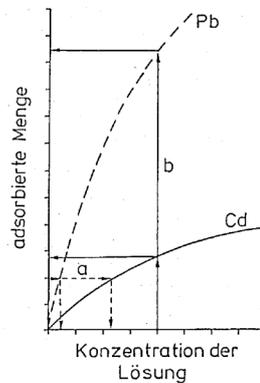


Fig. 36 Schematic representation of adsorption isotherms for Cd and Pb (Blume 1992, p. 296)

The complex building of the metals with **soluble organic substances** in the soil also has a big influence on the plant availability. Dissolved organic substances set free not only heavy metals, but also organic pollutants which are hard to dissolve such as polycyclic aromatic hydrocarbons, or rests of plant protection products. For details on the behavior of substances in the soil solution refer to Scheffer and Schachtschabel 1998, p. 123-133.

The adsorption of organic pollutants in the soil is done mainly by organic ligands. In the framework of this lecture the behavior of organic pollutants in the soil will no longer be discussed. Interested readers are referred to Blume 1992, p. 263-431.

Disposal sites

Areas, where raw materials were once exploited, must generally be refilled; therefore, together with natural troughs in the terrain, they are preferred locations for the dumping of garbage, mining waste and excavation residues. The technical ordinance on waste (in German Technische Verordnung über Abfälle - TVA 1990) distinguishes three **types of disposal sites** according to the chemical ingredients' ability to react:

- *Inert material disposal sites* may include only rock and soil debris type of materials that produce no chemical reactions whatsoever. In this category, mainly gravel pits are included.
- On *waste material deposit sites* substances may be deposited, to the extent that they are chemically inert or decomposed, so that no pollutants are mobilized and can therefore be introduced into the environment.
- Finally, *reactor landfills* contain waste in which decomposition is still ongoing, and thus pollutants resulting from chemical reactions can be released (household waste, slag and filtered ash from refuse incineration plants, building waste). This category is similar to the former "multi-component landfills".

Exploited clay- and loam pits often offer good conditions for waste material or even reactor landfills (with a dense underground to prevent groundwater contamination). Garbage landfills had already been covered in the past for hygienic reasons. Annex 2 of the TVA now stipulates land restoration after the replenishment of the landfill. It is to be designed in a natural way so that it can be used for agriculture or forestry, or alternatively, as natural habitat and

recreational space. Immission-generating landfills have to be sealed against the rise of capillary water and the penetration of roots. The Canton of Zurich stipulates, as a general rule, a higher restoration layer than the root horizon. In fact, studies on a (unsealed) landfill with radioactive waste in south-east Idaho (USA) have shown that with a soil coverage of 60 cm, digging mammals brought 173 g/m² ground material from the subsoil to the surface. With a covering layer of 180 cm, only 1.4 g/m² of subsoil material was brought to the surface. The concentration of radionuclides in the deposited soil was significantly higher than in the original surface of the coverage (Arthur and Markham 1983 in Forrer 1993). Similarly, a massive restoration layer protects mineral sealings from drying and cracking. On the landfill Georgswerder near Hamburg, just three years after the laying of a merely 60 cm thick layer of restoration, shrinkage cracks in the mineral sealing of up to 30 cm deep were observed. In the fissures, there was also strong root growth up to this depth (Dr. S. Melchior, Institute of Soil Science, University of Hamburg, oral communication in 15. Jan. 1996).

Back fillings for the disposal of excavations

While the previously mentioned types of land fills usually require a permit and are consequently able to be monitored officially, small-scale **agricultural land fills** for melioration purposes or wild deposits are usually difficult to list or count. Back fillings in trough locations for the correction of water logging are often performed in association with the discarding of relatively small quantities (a few truck-loads) of construction waste. Such agricultural back fillings are very numerous in the Canton of Zurich and distributed diffusely throughout the Canton area. In many cases, they result in improper land restorations. Often, only the humus layer was removed and the construction waste was deposited on the sub-soil. Some construction waste also contains pollutants, which can be mobilized (see above). In addition, with the application of additional humus on water logged locations, not the cause but the symptom is fought.

In the development of areas used for agricultural purposes, large quantities of arable soil are removed in the construction area and because of lack of space this soil will not, or only to a short extent, be brought back to the same parcels. The soil is removed and used elsewhere for restoration purposes. At this point there is a **risk of pollutant transfer** from more contaminated to less contaminated soils, especially in construction sites nearby pollutant producers (industrial facilities, refuse incineration plants, roads). If suspicion of contamination exists, the pollutant content of the soil is to be investigated at the stage of the building permit application, or alternatively by means of an environmental impact study (VSBo Mitt. 4, currently under revision). For contaminated soils, a disposal site, which displays the same or higher pollutant levels, has to be shown. Within the building permit application, the pollutant content at the disposal site is therefore to be assessed.

Soil remediation

Soil remediation is understood on the one hand as the **elimination** of pollutants, on the other, it refers to the **immobilization** of these pollutants or their conversion into harmless derivatives. As part of this lecture, only a broad overview of the principles of different soil cleaning procedures is presented. Interested readers are referred to the extensive literature available in the topic (e.g. Blume 1992, p. 697-726; Stegmann 1996; Terratech magazine).

The remediation process can be distinguished by the nature of the procedure, or by the location where the remediation takes place. There are mechanical, chemical, biological and thermal remediation procedures, certain procedures can decontaminate the soil on site and in its natural form (in situ methods); for others the soil must be excavated (ex situ process).

Ex situ methods can sometimes be accomplished on location (on site), however, often the soil must be transported into special cleaning facilities (off-site procedures).

Volatile substances can be eliminated from the **soil via air suction**; water soluble substances through the extraction of the water in the soil and subsequent cleaning of the water. **Mechanical** methods, such as soil washing and magnetic separation are suitable only for mineral components in the soil, and even then only for coarser fractions than silt and clay. In **thermal** processes, the pollutants are burned (organic pollutants) or immobilized using very high temperatures („vitrification“). After the heating phase, the soil is sterilized, which means that the organisms in the soil have been killed. Consequently, these procedures are not adequate for the layer hosting the plants' roots. When **chemical** processes are used, the addition of reagents should lead either to the immobilization of pollutants in the soil, or to the increase of their solubility to make an extraction with ground water possible. However, these methods are often associated with a strong increase in soil temperature and/or shift in the pH-value, so that the soil fertility is affected through the procedure itself. Among the **biological** processes, the use of micro-organisms to reduce organic pollutants is the most developed. In most of the cases, the living conditions of the micro-organisms must be improved through ventilation or with the addition of nutrients, in order to ensure the effectiveness of the procedures. In some cases, specialized organisms are inoculated. Currently, research work is being done on the breeding of hyper accumulating plants for the extraction of heavy metals from the soil (Neubauer et al. 1999). An overview of the various procedures and their side effects is shown in Table 2.

Tab. 2 Procedures for the restoration and safeguarding of contaminated soils, including side effects (Blume 1992, p. 697f)

| Verfahren | Nebenwirkungen |
|---|--|
| Sanierungsmaßnahmen Einsatz: <i>ex situ</i> | |
| mechanische Verfahren – Absiebung – magnetische Abtrennung – Dichte-Klassierung – Hochdruckwäsche | Veränderung des Gefüges Zerstörung des Gefüges, Veränderung der Lagerungsdichte u. der Bodenbiologie, Schluff- u. Tongehalt wird entfernt, pH-Wert-Verschiebung |
| chemische Verfahren – Wäsche in Reaktoren mit Lösemitteln/Tensiden | Zerstörung des Gefüges, Schluff- u. Tongehalt werden entfernt, pH-Wert-Verschiebung |
| thermische Verfahren – Pyrolyse (Verschmelzung ohne sauerstoffhaltige Atmosphäre) – Verbrennung (mit sauerstoffhaltiger Atmosphäre) | Sterilisierung und damit Einschränkung der Multifunktionalität des Bodens |
| Einsatz: <i>ex situ und in situ</i> | |
| chemische Verfahren – Immobilisierung durch Verfestigung, z.B. Vermörtelung, Vitrifikation, Verdichtung – Immobilisierung/pH-Wert-Verschiebung, z.B. durch Kalkung | Zeitliche Verlagerung der Problemlösung, Behinderung späterer Sanierung Gefahr der Überschuldung, Nitratmobilisierung, ständiger Wiederholungsbedarf |

Sanierung und Sicherung kontaminierter Böden und Substrate

5.7

Fortsetzung Tab. 5.7/1

| Verfahren | Nebenwirkungen |
|--|--|
| biologische Verfahren – mikrobieller Umbau/Abbau – Entzug durch Pflanzen | verstärkter Humusabbau, Erhöhung der Bodentemperatur und der Nährstoffgehalte, Gefährdung durch Abbauprodukte, Geruchsbelästigung bei ex situ Anwendung Thermische Nachbehandlung u. Deponiebedarf für Biomasse |
| Einsatz: <i>in situ</i> (stets on site) | |
| mechanische Verfahren – Bodenluftabsaugung/Zwangsentgasung – in situ-Strippen – Auslaugung durch Grundwasserentnahme/-reinfiltration – Verdünnung durch Verteilung/Vermischung, Pflügen – Hochdruckwäsche mit und ohne Hüllrohr – Spaltenbildung durch Hochdruckflüssigkeitsinjektion | Bodenschumpfungen/-setzungen durch Austrocknung Bodensetzungen, Trockenschäden an Pflanzen, Verockerung durch Reinfiltration Nur anwendbar wenn unkritische Restgehalte erreicht werden Zerstörung des Gefüges, Veränderung der Lagerungsdichte u. der Bodenbiologie, Erschütterungen durch Ein- u. Ausbau des Hüllrohres Veränderung des Gas- u. Wasserhaushaltes |
| chemische Verfahren – Elektrolyse – Auslaugung durch Grundwasserentnahme und Reinfiltration unter Zugabe von Reagentien – Oxidation durch Sauerstoffinjektion | Erhöhung der Temperatur u. der Durchlässigkeit des Bodens Bodensetzungen, Trockenschäden an Pflanzen, Verockerung des Bodens durch Reinfiltration Verockerung im wassergesättigten Boden |
| Sicherungsmaßnahmen (stets in situ und on site) | |
| Einsatz: <i>Sicherung gegen äußere Einflüsse</i> | |
| – Oberflächenabdichtung mit und ohne Bepflanzung – Sohlabdichtung – Vertikalabdichtung – Fassung und Ableitung/Umleitung von Wasser (Oberflächen- und/oder Grundwasser) | Häufig Gasfassung u. -behandlung erforderlich, Störung der mikrobiellen Aktivität Nur sinnvoll in Kombination mit Vertikalabdichtung, Dichtmaterial kann auslaugen, Dichtigkeit nicht prüfbar Ständige Wasserhaltung u. -aufbereitung erforderlich, ständige Betriebskosten Gefahr von Bodensetzungen, ständige Betriebskosten |
| Einsatz: <i>Sicherung gegen Schadstoffausbreitung</i> | |
| – Fassung und Ableitung von Schichtwasser/Sickerwasser – Fassung und Ableitung von Bodenluft/Deponiegas – Verfestigung – Immobilisierung durch chemische Behandlung | Wasseraufbereitung erforderlich, ständige Betriebskosten, Gefahr von Bodensetzungen Gasaufbereitung erforderlich, ständige Betriebskosten, Setzungen durch Austrocknung Behinderung späterer Sanierung Gefahr der Überschuldosierung, pH-Wertverschiebung, Störung der Bodenbiologie |

4.4 Land use change and spatial compensation

The intensification of land use has led, as described in chapter 2.2, to a fragmented and cleared out landscape as well as to a large change in the water regime of the areas involved. As a result, the habitat of many sensitive plant and animal species has been reduced to a few islands, to the extent that today they are threatened with extinction (species in the so-called "Red List"). In order to counteract against this development, today, an increasing number of natural habitats are being restored, that is, big areas are being re-naturalized. In most cases it concerns the restoration of extreme locations (extremely dry or humid) however, such areas are also not adequate for agricultural or forestry use. Often, conflict situations arise with the owners of the concerned land, for example in areas previously used for gravel mining, this is why many re-naturalization projects take place only after a land allocation, where public authorities (cantons or municipalities) or NGOs have acquired the land concerned.

Open gravel pits are **ruderal habitats** characterized by coarse soils (C-horizon) and mostly extreme drought. These are typical sites of pioneering eco-systems, and therefore valuable refuges for low competitive species. Pioneering eco-systems show, however, a high dynamic as they are replaced within a few decades by succeeding plant and animal societies. The absolute pioneer ecosystems cannot be preserved. Therefore, it is useful to establish so-called "migrant biotopes" (spatially displacing habitats). This can be achieved, for example, through targeted planning of the stages in the gravel mining activity. To some extent, original ruderal biotopes must be supported even in their succession stages, especially in the case where a few highly competitive species dominate. The idea is essentially to prevent the vegetation encroachment, or the control of alien species, which do not have any natural enemies at the site. (e.g. *Solidago altissima*).

The residual mud from gravel washing can be used to build an impermeable layer for wetland habitats. In this way, open gravel pits can be redesigned and transformed into versatile natural habitats, which is why environmental protection organizations often struggle to avoid the back-filling and restoration of such pits. Albeit wetlands in the gravel pits are also often in the early pioneer stages and can only be maintained as migrant habitats in the long-term.

Today, land use change is increasingly considered for areas, which are loaded with pollutants and requiring restoration, since a change in land use usually saves the expense of a total de-contamination. On contaminated sites, isolating the contaminated soil is often enough to avoid endangering the environment. Currently, the redevelopment of **industrial sites** is discussed, especially as the freedom in the choice of subsequent land use depends on the local planning rules and regulations of each municipality. In these cases it has to do largely with the saving of clean-up costs. A conversion contemplating the **averting of a danger** involves the change from a sensitive land use type (e.g. family garden) to a less sensitive one (e.g. parking lot).

Extensions in **agriculture** can also be described as a conversion. The inundation of former drainage areas, for example, represents the shift from an intensive agricultural use to a use closer in touch with nature.

Changes in land use and re-naturalization of biotopes are often implemented in the sense of a **spatial compensation** of intensively used land. The focus is given to maintaining the total area, on which the multi-functionality of the soil is (to a large extent) guaranteed (**Land protection**). Not only ecological compensation areas in agriculture serve as spatial compensation, but also in the expansion of infrastructure facilities such opportunities are used increasingly; especially in projects involving the construction or expansion of roads, often streams in pipes are opened and wetlands are restored. In some cases, old road sections which have

been replaced by new routes have been dismantled and renaturalized into ruderal habitats (e.g. A4 Hettlingen, Canton Zurich).

Such spatial compensation measures are very welcome to maintain the balance between natural and more or less non-natural areas within a region. However, the **connection** of natural areas is as important as their extent. Spatial compensation measures should not only represent quantitative land compensation, but also have to be allocated in a useful manner to ensure that the environmental quality of a region is promoted. The **landscape development concepts** (in german Landschaftsentwicklungskonzepte - LEK) and ecological connectivity projects after the eco-quality ordinance (in german Ökoqualitätsverordnung - ÖQV) represent practical instruments for the sensible management of different forms of land use -and intensities. Since the landscape development concept, in contrast to the ecological connectivity projects, are not supported on a legal basis, they have only a recommending character for now and their concrete implementation depends heavily on the attitudes of the respective owners or managers of the corresponding areas. Extensification takes place, as explained above, often only on land belonging to public entities.

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