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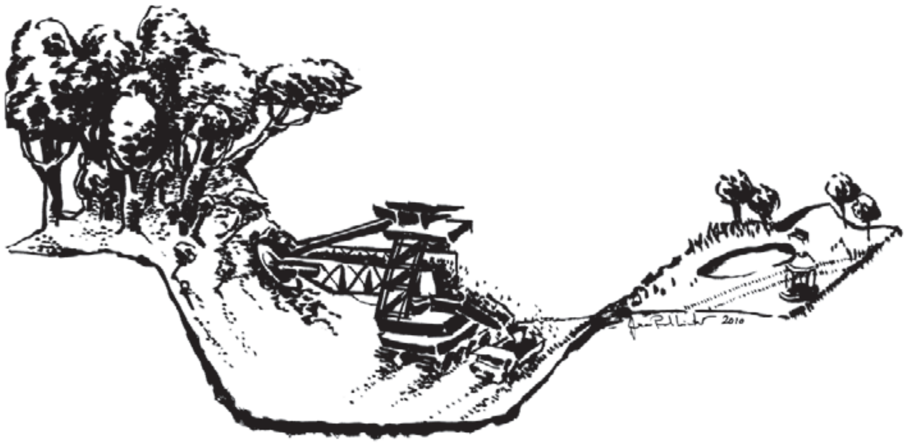
LANCA®
Land Use Indicator Value Calculation in Life Cycle Assessment



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Chair of Building Physics (LBP)
Life Cycle Engineering (GaBi)

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Prefaces

Within a few decades, the most important question on the future in politics, economics and science has become the problem of how to manage the reasonable use of available natural resources. Forced by global trends such as climate change, rising energy demand, urbanization and globalization it has become urgent to find answers to this question. Furthermore, this urgency clearly showed us the gaps in our knowledge on numerous facets of our living environment.

The soil, where humans have built housing for thousands of years, which they use for food production, and life on earth would be impossible without its biodiversity, is one of our most important natural resources. To assess the variety of land use from the cultivation of foodstuffs or plants for energy production to the construction of buildings from an objective point of view seems to be obvious and follows other assessment criteria for the representation of sustainability. There is, for example, a certification system for planning and assessing sustainable buildings.

The Fraunhofer Institute for Building Physics developed a method allowing the quantification of various possibilities of land use within the context of life cycle assessment (LCA), or in other words: We are able to assess changes of natural soils and compare them with values indicating the intensity of present or future impacts. Therefore it is possible to take measures in time to minimize or compensate, for example, local damage to groundwater replenishment.

LANCA® is a practical tool to protect our living environment by objectifying the discussion on land use options, and by offering the opportunity to take a further step towards a sustainable economy.

Prof. Dr. Ulrich Buller
Senior Vice President Research Planning
Fraunhofer-Gesellschaft

SCA owns 2.6 million hectares of forest, making it the largest private forest owner in Europe, and the company's forest management is certified in accordance with the Forest Stewardship Council (FSC). The growth in SCA's forests is more than 20% higher than felling, which entails an annual net absorption of carbon dioxide of 2.6 million tonnes. About two million hectares are used for active forestry, with more than 5 000 fellings per year. Of this actively managed forest, SCA's ecological landscape plans exclude more than 5% from felling. In addition, more than 5% of the forest, in the form of trees, groups of trees and edge zones, is left untouched during felling to preserve the necessary conditions for biodiversity. Approximately 600 000 hectares of SCA's land is not actively used. This is land not utilised due to poor growth levels or other reasons, but the land provides vital habitats for a large number of species.

SCA has a long tradition of working with environmental improvements for its processes and products. The different products have a high content of wood raw materials, and to evaluate the environmental performance of the products SCA is working with Life Cycle Assessment (LCA). For the hygiene products the company has been working with LCA since the early 90's. By the systematic use of LCA it helps SCA to:

- Actively select environmentally sound suppliers
- Identify environmental improvement areas in the total product life cycle
- Support development of sustainable products and services

With a foreseen need to expand the impact assessment in LCA with land use, SCA entered in 2008 a land use project in partnership with Tetra Pak, and the Department Life Cycle Engineering, University of Stuttgart, Chair for Building Physics and Fraunhofer Institute for Building Physics. In the course of this project, the current method report has been elaborated.

SCA IN SHORT

SCA is a global hygiene and paper company that develops and produces personal care products, tissue, packaging solutions, publication papers and solid-wood products. Sales are conducted in some 100 countries. SCA has many well-known brands, including the global brands Tena and Tork. In 2009 sales amounted to EUR 10.5 billion and the company had about 50 000 employees.

Ellen Riise
Senior Scientist
Environment & Product Safety
SCA Global Hygiene Category
Research & Innovation Support

Some three quarters of all the material we purchase for use in the products we sell is paperboard. Forestry and use of land for forestry are therefore important, perhaps even defining, characteristics of the life cycle of the products we sell. Of course then we, and our suppliers, have tools and measures for examining and improving the management of the forests and land from which the material we purchase is sourced. Rich and varied forest ecosystems may be affected positively or negatively by varied management practices and regimes; so our approach, and that of our suppliers, matters.

However, when we turn to LCA, a tool we have used for many years and value highly, land use and associated factors such as ecosystem services and biodiversity are likely either not to be addressed or captured only by a crude measure of area. A forthcoming paper in the International Journal of LCA reports some measure of land use being used in just eight out of twenty-one recent LCAs of beverage cartons. Even when considered, these crude measures of area typically reported provide no practical help in our environmental management efforts; nothing that usefully informs choices and decisions in product development or supply chain management. From our point of view at least, this leaves a gaping hole in the supposedly holistic picture provided by a life cycle approach.

We therefore welcome methodological development that contributes to the ongoing dialogue that will help us all make better choices for the future.

ABOUT TETRA PAK

Tetra Pak is the world's leading food processing and packaging solutions company. Working closely with our customers and suppliers, we provide safe, innovative and environmentally sound products that each day meet the needs of hundreds of millions of people in more than 170 countries around the world. With almost 22 000 employees based in over 85 countries, we believe in responsible industry leadership and a sustainable approach to business. Our motto, “PROTECTS WHAT’S GOOD™," reflects our vision to make food safe and available, everywhere. More information about Tetra Pak is available at www.tetrapak.com.

David F. Cockburn
Director Environmental Technologies
Tetra Pak

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1 Background and Introduction

Land is a limited resource. Especially increasing prices for food and a growing demand for biofuels foster the competition between different uses of land. This competition on the one hand concerns the sheer availability of open spaces. On the other hand, different types of land use have a strong bearing on the quality of the land. Therefore, the interest of addressing the subject of land use is of major concern in politics as well as in science and industrial practice.

Land use appeared as a further important LCA impact in 1996. That time building materials were firstly assessed over the total life cycle in a consistent way, using the brand new ISO 14040 standard series. The comparison of renewable material (e.g. wood) with mineral material (e.g. limestone) pinpointed information on land use. This led to a scientific working group on land use within the Society for Environmental Toxicology and Chemistry (SETAC) in the years 1998-2001, which discussed and compiled the most important basic methodological information on land use.

Of all land use-related issues, soils have been identified as a central subject (KREIßIG 1997; BAITZ 1997; MATTSON 2000): They fulfil main regulatory needs of terrestrial and benthic ecosystems, and they are connected to the biosphere, the hydrosphere, the atmosphere and the lithosphere through material and energy cycles. Many functions and potentials of soils such as erosion resistance, filtering and buffering, vegetation, runoff properties and groundwater regeneration are crucial for ecosystems and humans, and are directly or indirectly influenced by land use activities.

Land use as an environmental issue constantly gains attention in the Life Cycle Assessment (LCA) community (LINDEIJER 2000; MILÀ I CANALS ET AL. 2007).

Many approaches exist, providing suggestions for indicators, which are suitable to model land use impacts in LCA, but few of them provide detailed instructions on how to calculate quantified indicators. Since the beginning of the land use quantification only two principal approaches survived: Land use quantification using biodiversity and land use quantification using soil functionality, both with individual strength and weaknesses. Biodiversity is easy to communicate (one indicator; more is better), but needs a rather extensive data collection and still extensive assumptions. Land functionality is simpler in data collection and needs fewer assumptions, but is not as easy to communicate (more than one midpoint indicator).

For the time being the functionality approach seems to show more promising links towards an application in practice. However, biodiversity within land use is an important issue and may be either a part of the functionality approach as biodiversity function or an own impact besides soil functionality, if the data and model uncertainties are solved.

At LBP-GaBi, a set of approaches to quantify land use implications of industrial processes has been developed by BAITZ (2002). It is based on the concept of land functions, and provides a framework and calculation instructions for different land use indicators. Of these, the approaches dealing with the indicators of Erosion Resistance, Filtering and Buffering and Groundwater Replenishment are described in chapter 2 of this document, as they form the conceptual background for the LANCA® calculation tool, which is explained here.

To make them applicable in a broader sense, the methods developed by BAITZ (2002) have been transformed into an operational calculation tool (Land Use Indicator Calculation Tool, LANCA®). In addition, they have been adapted to the framework on land use impact assessment set up by MILÀ I CANALS ET AL. (2007). For this purpose, in some points, the underlying method according to BAITZ (2002) had to be slightly altered. The resulting approaches applied in the calculation tool are presented in chapter 4 of this report.

Using LANCA®, land use indicator values have been calculated for different mining and agricultural processes. These indicator values have been included into the GaBi database. A detailed description of sources and assumptions of this can be found in BOS (2010).

Considering that consistent land use quantification in LCA is still in its methodological infancy, the following pages are an important step towards a common understanding of the important implications towards a successful application of the land use as impact in LCA practise. The flexible nature of the discussed method like scalability, extendibility, reducibility eases the pathway towards a successful application: Finding the optimal trade-off between precision and complexity.

2 Conceptual Background according to BAITZ (2002)

In chapter 2 a summarization of the conceptual background on how to quantify land quality changes caused by industrial processes based on ecosystem functions as developed by BAITZ (2002) is brought out. For the indicators developed, describing important ecosystem functions, quantification procedures are presented. Although the background approach and document is quite comprehensive, only the subjects further used in the calculation tool (LANCA®, see chapter 4) are described here. A complete description including all indicators, derivations and special cases can be found in BAITZ (2002).

2.1 General structure

The general objective of the approach is the quantification of the effects of different land uses on land functions for an application within Life Cycle Assessment. For this purpose, the area, the duration and the quality progression of the land use are considered and related to the functional unit of the LCA study. According to BAITZ (2002), the indicator values are then characterized with characterization factors of 1 or -1 (see Table 2-9)[1] and treated as inventory flows (see chapter 3).

Land quality is specified using the landscape ecology related works of Marks et al. (MARKS 1989, MARKS 1979, MARKS 1992), which are based on the consideration of land or landscape potentials and functions. These potentials and functions again are strongly dependent on local conditions concerning for example soil and climate.

To calculate the quality of the land in different time steps (see Figure 2-1), input parameters representing site-specific conditions before, during and after the land use are required.

As shown in Figure 2-1, the terms of quality alteration, occupation and transformation of land are introduced. Quality alteration [different units] is defined to be the change in quantifiable land characteristics. Occupation

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[1] A further characterization including site-specific considerations would increase the expressiveness of the values. Respective work is currently being carried out at LBP-GaBi (see chapter 5).

[m²*a] is defined as the occupation of an area during the time of its use. Transformation [m²] is the irreversibly affected area of a land use.

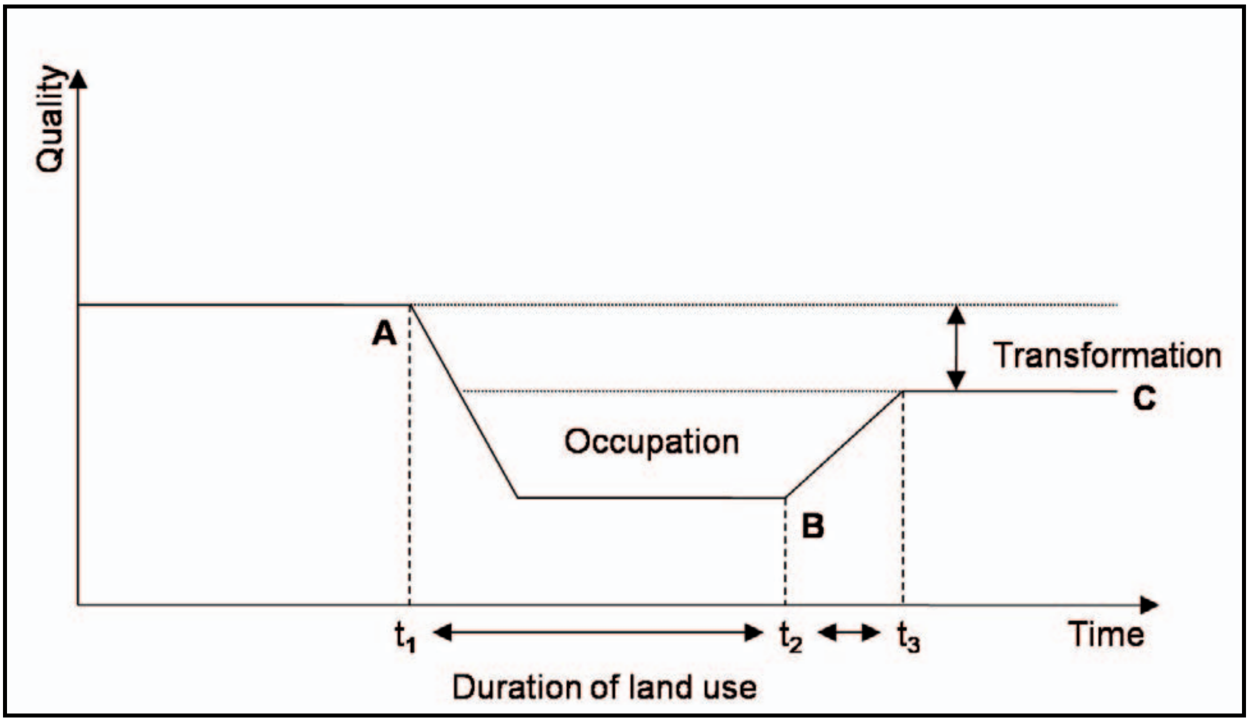

Figure 2-1 **Land Occupation and Transformation (1) (Baitz 2002: Fig. 3.1; see Lindeijer 2001, Baitz 1997, Baitz 2001)**

Figure 2-1 shows a possible quality alteration due to a defined land use: Starting at a quality A in t_1, a hypothetic land use (change) leads to a quality deterioration represented by the situation B (t_2). During use, it is assumed, that the quality is constant. After the end of the use, the land quality can recover until reaching the situation C in t_3.

It can be seen, that the occupation is displayed by the area between the quality alteration over time (A-B-C) from the beginning of the land use (t_1) to the end (t_2) and the parallel to the abscissa crossing C. This parallel illustrates the regeneration potential of the area after the end of the considered land use: After the use the land is able to increase its quality via renaturation or succession from B to C. Accordingly C displays the land quality after regeneration and is thus the reference situation for the calculation of occupation[2]. Transformation is the quality difference of the land after the use (C) and before the use (A).

2.2 Ecosystem functions

Soils have been identified as a central land use related issue (KREIßIG 1997, BAITZ 1997, MATTSON 2000): They fulfil the main regulatory needs of terrestric and benthic ecosystems and they are connected to the biosphere, the hydrosphere, the atmosphere and the lithosphere through material and energy cycles. Thus many functions and potentials such as erosion resistance, filtering and buffering, vegetation, runoff properties, transformation, and groundwater replenishment are directly or indirectly dependent on the kind and type of soil concerned.

In the following chapter, the calculation of respective site-specific ecosystem services or functions[3] according to BAITZ (2002) is shown. Ecosystem functions discussed here are erosion resistance, filtering, buffering and transformation, and groundwater replenishment.

Correlations and functional dependencies of the different parameters are based on technical literature (MARKS 1989, SCHACHTSCHABEL 1992, UMWELTMINISTERIUM 1995, SCHRÖDER 1992, MAYER 1984, SCHMIDT 1979, MÜCKENHAUSEN 1985, WISCHMEIER 1978, SCHWERTMANN 1987, BÖCKER 1997).

2.2.1 Erosion Resistance

According to Marks et al. a land unit can resist to wind and water erosion to a certain degree. The ecosystem function "Erosion Resistance" thus specifies the ability of the land to resist to erosion that exceeds the naturally occurring soil erosion. A change of the Erosion Resistance results in a change in soil erosion. So the Erosion Resistance here is displayed by this change of the soil erosion.

Erosion Resistance considerations are of importance for example regarding open pit mining or the production of renewable resources in large

---

[2] BAITZ (2002) chooses C, the land quality after regeneration, to be the reference situation but states that the setting of the reference is mainly a convention and can thus also be chosen differently.

[3] Wording according to BAITZ (2002)

monoculture plantations. Soil erosion can have a negative influence on the biotic production potential and can lead to the complete devastation of arable land.

Erosion Resistance primarily is dependent on declination, soil texture and type of use (BASTIAN 1994), whereas the humus and skeleton content as well as the water balance have minor but still considerable effects. The model used here is based on the universal soil loss equation (WISCHMEIER 1978) and respective specifications (SCHWERTMANN 1987, UMWELTMINISTERIUM 1995). The universal soil loss equation calculates the mean annual water erosion by multiplying different factors representing precipitation, runoff, soil, length and slope, surface cover, land use and erosion protection. These factors are considered, displayed and combined in the calculations as follows:

The soil texture of the land considered is the basic parameter for the soil type specific erosion resistance classification presented in Table 2-1.

Table 2-1 Soil type specific Erosion Resistance Classes (based on BAITZ 2002: Table 4.2; see Arbeitsgruppe Bodenkunde 1982)

Soil type specific Erosion Resistance Class		
Class		**Soil types**
1.0	Extremely high	Coarse sand, medium sand, weakly clay sand, clay
2.1	Very high	Weakly loamy sand, medium clay sand, weakly sandy clay, medium sandy clay
2.2	High	Fine sand, loamy sand, strongly loamy sand, strongly sandy loam, clay loam, sandy clay loam, strongly sandy clay, loamy clay
3.1	Medium	Silty sand, sandy loam, weakly clay loam, silty clay loam, silty clay
3.2	Moderate	Strongly silty sand, silty loamy sand, weakly sandy loam, strongly silty clay
4.1	Low	Sandy loamy silt, strongly loamy silt, strongly clay silt, silty loam
4.2	Very low	Sandy silt, loamy silt, clay silt
5.1	Extremely low	Very fine sand, silt

Both the skeleton and the humus content of the soil affect the Erosion Resistance: Higher humus content indicates higher root penetration leading to higher Erosion Resistance in the higher Erosion Resistance classes; a higher share of skeleton content also increases the Erosion Resistance. The correction of the soil texture based Erosion Resistance based on the skeleton and humus content of the soil is shown in Table 2-2.

Table 2-2 Soil type specific Erosion Resistance and its modification according to humus and skeleton content (Baitz 2002: Table A2; simplified Marks 1989, Arbeitsgruppe Bodenkunde 1982).

Soil type specific Erosion Resistance – correction by skeleton- and humus content					
Class	**Humus content [%]**	**Skeleton content [Vol. %]**			
		<=10%	**11-30%**	**31-75%**	**>75%**
		Corrected soil type specific erosion resistance class			
1.0	<2%	1.0			
	2-4%	1.0			
	>4%	1.0			
2.1	<2%	2.1	1.0		
	2-4%	2.1	1.0		
	>4%	2.1	1.0		
2.2	<2%	2.2	2.1	1.0	
	2-4%	2.2	2.1	1.0	
	>4%	2.1/2.2	2.1	1.0	
3.1	<2%	3.1/3.2	2.2	2.1	1.0
	2-4%	3.1	2.2	1.0	1.0
	>4%	2.2/3.1	2.1	1.0	1.0
3.2	<2%	3.2/4.1	3.1	2.1	1.0
	2-4%	3.2	2.2	2.1	1.0
	>4%	3.1	2.2	2.1	1.0
4.1	<2%	4.1/4.2	3.1	2.1	1.0
	2-4%	4.1	3.1	2.1	1.0
	>4%	3.2	2.2	2.1	1.0
4.2	<2%	5.1	3.2	2.2	1.0
	2-4%	4.2	3.1/3.2	2.1	1.0
	>4%	3.2/4.1	2.2/3.1	2.1	1.0
5.1	<2%	5.2	4.1	2.2	1.0
	2-4%	5.1	3.2	2.2	1.0

Soil type specific Erosion Resistance – correction by skeleton- and humus content					
	>4%	4.1	3.1	2.1	1.0

In the next step the average natural soil erosion is determined following Table 2-3, taking into account declination and summer precipitation.

Table 2-3 Average natural soil erosion (Baitz 2002: Table A3, see Schmidt 1979 and Schmidt 1988 in Forschungszentrum Karlsruhe 2000)

Average natural soil erosion [t/(ha*a)]							
Corrected soil type specific erosion resistance class	**Mean summer precipitation [mm]**	**Declination [°]**					
		<2°	**2-4°**	**4-7°**	**7-11°**	**11-15**	**>15°**
1.0	<300[4]	0,1	0,2	0,5	1,2	2,2	2,8
	410-480	0,1	0,3	0,7	1,8	3,3	4,2
	>540	0,1	0,4	0,9	2,4	4,4	5,6
2.1	<300	0,2	0,5	1,4	3,5	6,6	8,4
	410-480	0,3	0,8	2,1	5,3	9,8	12,6
	>540	0,4	1,1	2,8	7,1	13,1	16,8
2.2	<300	0,3	0,9	2,4	5,9	10,9	14,0
	410-480	0,5	1,3	3,5	8,9	16,4	20,9
	>540	0,6	1,8	4,7	11,8	21,8	27,9
3.1	<300	0,4	1,2	3,3	8,3	15,3	19,5
	410-480	0,7	1,8	4,9	12,4	22,9	29,3
	>540	0,9	2,5	6,6	16,5	30,6	39,1
3.2	<300	0,6	1,6	4,2	10,6	19,7	25,1
	410-480	0,9	2,4	6,3	15,9	29,5	37,7
	>540	1,2	3,2	8,5	21,2	39,6	50,3
4.1	<300	0,7	1,9	5,2	13,0	24,0	30,7
	410-480	1,1	2,9	7,8	19,5	36,0	46,1
	>540	1,4	3,9	10,3	26	48,0	61,4
4.2	<300	0,8	2,3	6,1	15,8	28,4	36,3
	410-480	1,2	3,4	9,2	23,0	42,6	54,4
	>540	1,7	4,6	12,2	30,7	56,8	72,6
5.1	<300	1	2,6	7,1	17,7	32,8	41,9
	410-480	1,4	4	10,6	26,6	49,1	62,8
	>540	1,9	5,3	14,1	35,4	65,5	83,8

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[4] Within the calculation tool, the data ranges have been altered to <400mm, 400-500mm, >500mm

As the erosion is strongly dependent on the type of land use, the natural soil erosion is corrected by a corresponding erosion correction factor k_{use} as presented in Table 2-4, allocating a correction factor of 0,5 to land use types showing complete surface vegetation, whereas land use types that potentially decrease the surface resistance of an area due to non-enclosed surface vegetation are assigned correction factors of 3,6 or 10. Highest values are considered for fallow grounds without surface vegetation.

Table 2-4 Erosion correction factor k_{use} depending on different types of land use (BAITZ 2002: Table 4.3; extended BASTIAN 1994)

Type of use	k_{use}
Wood, forest, grassland, meadow	0,5
Fallow ground, moorland, lawn	1
Farmland (no complete surface vegetation)	3
Permanent crops (field, little surface vegetation)	6
Fallow ground (no surface vegetation)	10

The resulting usage-dependent erosion B_{use} [t_{Soil}/(ha*a)] is the performance parameter specifying the function "Erosion Resistance" of the regarded land.

2.2.2 Filtering, buffering and transformation

Within an ecosystem, soils form a natural "cleaning system" being able to absorb, bind and – depending on pollutants and attributes of the soil – remove emitted pollutants (SCHACHTSCHABEL 1992).

Again, these functions are especially important regarding different mining processes because here the surface area is removed and so the filtering, buffering and transformation capacity of the soil is strongly influenced.

The model developed is based on a system developed by the "Niedersächsisches Landesamt für Bodenforschung"[5] to evaluate landfill locations (MÜLLER 1975).

Here, five functions and parameters to measure them are distinguished:

1. Mechanical Filtration Capacity measured based on soil permeability/porosity: k_f [cm/d],
2. Physicochemical Filtration Capacity measured based on the Effective Cation Exchange Capacity CEC_{eff} [$mmol_c/kg_{soil}$],
3. Heavy Metal Filtration Capacity measured by potential absorbable heavy metals F_{hm} [$mmol_c/kg_{soil}$],
4. Nitrate Retention measured by nitrogen eluviation: N [kg/(ha*a)],
5. Organic Pollutants Transformation Capacity measured by potential microbial biomass $BM_{pot.mic}$ [$mgC/100g_{Dry\ matter}$].

The items 3 to 5 are dependent on emissions and thus covered by the emission based impact categories of a LCA[6]. They are not considered again in the land use impact assessment.

Mechanical Filtration Capacity

The term Mechanical Filtration Capacity stands for the capacity of the soil to mechanically clarify a suspension (MARKS 1989). In the filtration process, suspended dirt and pollutant particles are mechanically fixed to the soil. For this indicator, the Filtration Capacity of a soil is characterized by the amount of water being able to pass the respective soil in a given time unit (SCHACHTSCHABEL 1992). The higher the Filtration Capacity is, the more water can pass (Filtration Capacity = amount of water passed / time unit). Thus the residence time of the water is shorter, the higher the Filtration Capacity is.

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[5] Agency for soil research of the state of Lower Saxony, Germany

[6] Emission based impact categories are the „classical" impact categories such as Global Warming, Acidification, Eutrophication, Ozone Depletion etc. They are distincted from resource-related impact categories such as Primary Energy Demand and Abiotic Resource Depletion. Also land use related impacts are classified as resource-related impacts.

Filtration Capacity is measured by the k_f-value, which on the other hand is mainly dependent on soil texture and soil texture classification or the clay content of the soil: Soils with a high share of sand and gravel generally have a high Filtration Capacity, whereas soils with a high share of clay and silt have a low one.

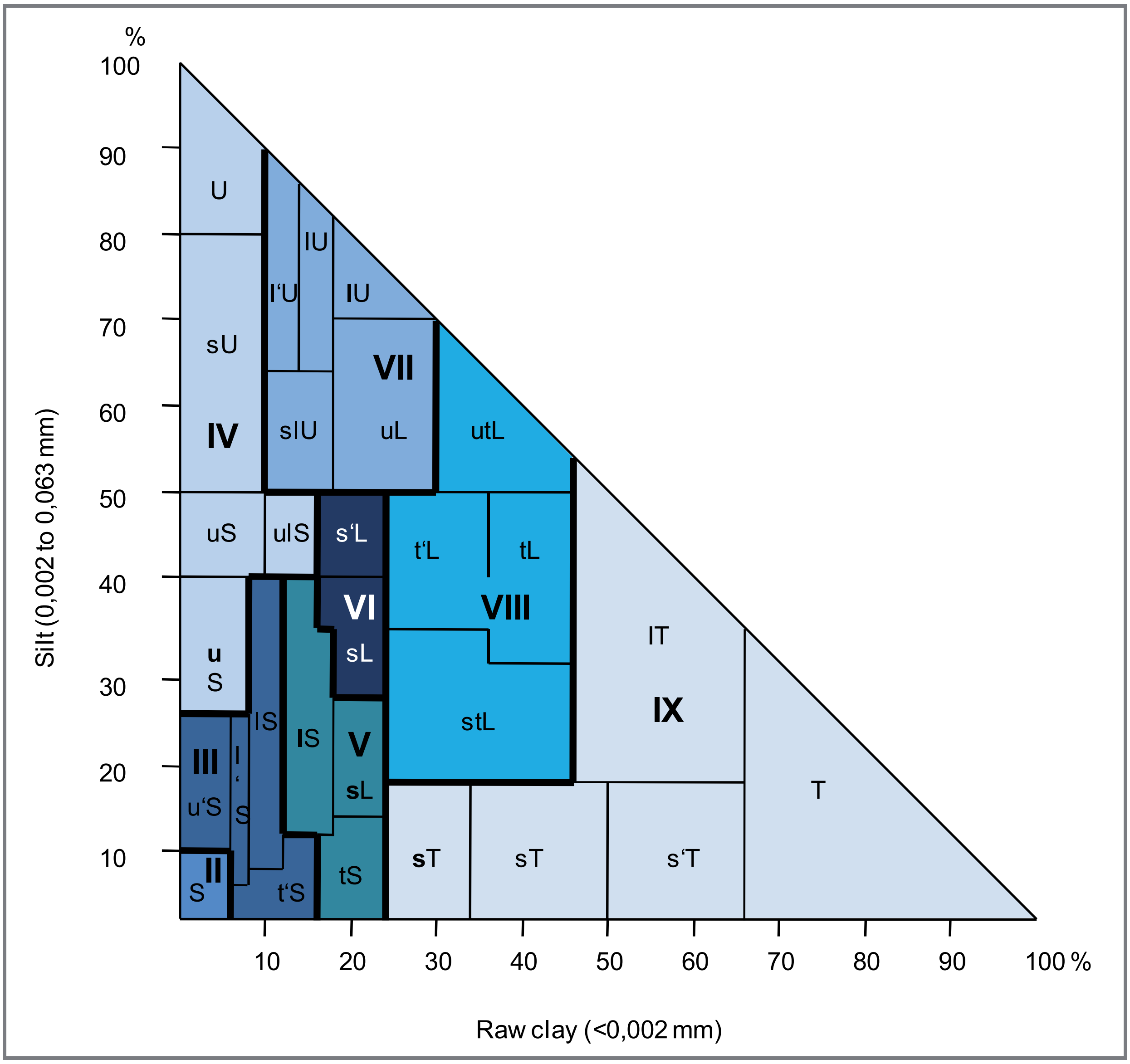

Figure 2-2 **Determination of soil texture classes II-IX from soil textures (Baitz 2002: Fig. 4.12; see Bastian 1994, Annex)[7]**

Figure 2-2, shows a soil classification based on the respective shares of raw clay and silt of the soil. Based on soil texture classes chosen according to Figure 2-2, the k_{f}-value of a soil can be determined as shown in Table 2-5.

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[7] Translations of the soil textures can be found in the Annex

Soil texture class I represents bigger textures such as gravel; X stands for peatlands. Here the k_{f}-value is dependent on the grade of decomposing and eventually has to be calculated separately.

Table 2-5 shows the classification of permeability groups respectively filtration capacity depending on soil texture classes based on Leser (1988). Values in Table 2-5 are valid for a filtration distance of 0,8-10 m. If the distance is less than 0,8 m, the permeability group has to be downsized by one. If the distance is 10-30 m or more than 30 m, the value increases by one respectively two. Influences of climatic water balance surplus are neglected.

Table 2-5 **k_f –values of soil texture classes (BAITZ 2002: Table 4.4; expanded LESER 1988)**

Soil texture class	k_{f}-value representing water permeability/filtration capacity	Permeability group
I	>100 cm/d	5
II	>100 cm/d	5
III	>40-100 cm/d	4
IV	>10-100 cm/d	3-4
V	>10-100 cm/d	3-4
VI	>10-40 cm/d	3
VII	>10-40 cm/d	3
VIII	1-10 cm/d	2
IX	<1 cm/d	1

Soil texture class	k_f-value representing water permeability/filtration capacity	Permeability group
X[8]	<1- >100 cm/d	1-5

The k_f-value [cm/d] according to Table 2-5 is the performance parameter specifying the function “Mechanical Filtration Capacity” of the regarded land.

Physicochemical Filtration Capacity

The Physicochemical Filtration Capacity specifies the ability of the soil to absorb diluted substances from the soil solution and to exchange adsorbed ions: Soil particles with high specific surfaces are able to reversibly absorb ions. Particles smaller than 2 µm can serve as catalysts in order to exchange bound ions. The Physicochemical Filtration Capacity is measured by the effective cation exchange capacity [$\text{mmol}_c/\text{kg}_{\text{Soil}}$], which is dependent on the soil texture (BASTIAN 1994, UMWELTMINISTERIUM 1995) and on the pH-value of a soil[9]. To determine the CEC_{pot} the clay content of a soil is identified according to Figure 2-2.

The dependency of the CEC_{pot} against clay (T) and humus (H) content [%] can be approximately described by a regression equation using values measured in (BASTIAN 1994, MÜCKENHAUSEN 1985, UMWELTMINISTERIUM 1995).

Equation 1 (BAITZ 2002: Equation 22)

$$CEC_{pot}\left[\frac{mmol_c}{kg_{soil}}\right] = 46 + 3{,}4 * T[\%] + 8{,}6 * H[\%]$$

---

[8] The soil texture class X displays peatlands. The k_f value of peatlands is dependent on the degree of decomposition and has to be determined specifically. Therefore this class has not been included into LANCA®.

[9] The Effective Cation Exchange Capacity describes the actual free cation absorbing spaces whereas the Potential Cation Exchange Capacity displays the amount of exchange spaces at neutral pH conditions.

BAITZ (2002) suggests then to calculate the effective cation exchange capacity CEC_{eff} due to the dependency of the relation CEC_{eff}/CEC_{pot} of the pH of the soil:

Equation 2 **(BAITZ 2002: Equation 23)**

$$\frac{CEC_{eff}}{CEC_{pot}} = f(pH)$$

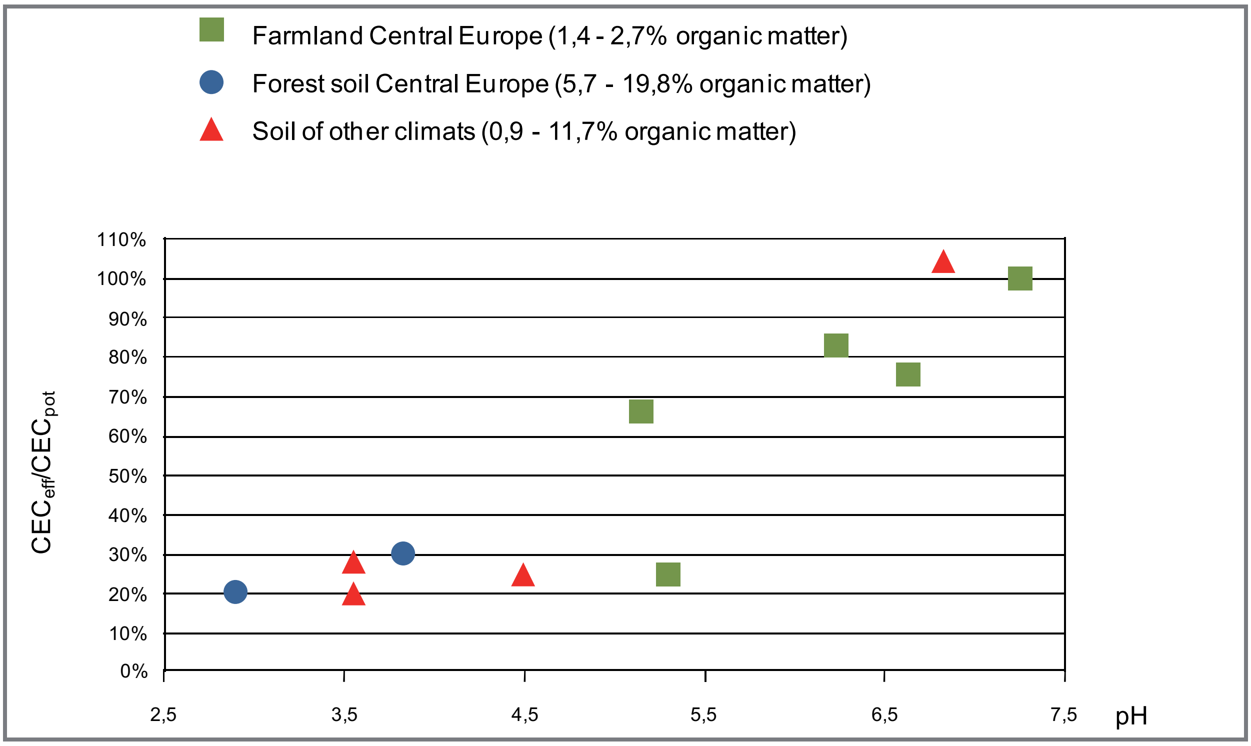

Figure 2-3 **Dependency of CEC_{eff}/CEC_{pot} on pH (values from SCHACHTSCHABEL 1992)**

Figure 2-3 shows a respective diagram containing values from SCHACHTSCHABEL (1992); as the correlation was too weak, no function is provided.

As the highest share of the variable charge comes from the humic substances, in this context the humus content is a very important factor. So for example the CEC_{eff} of an acid humus sandy soil is much lower than the CEC_{pot}. Following these dependencies the CEC_{eff} can be determined regarding local use and conditions of the soils.

CEC_{eff} [$mmol_c/kg_{soil}$] is the performance parameter specifying the Physicochemical Filtration function.

2.2.3 Groundwater function

The Groundwater function describes the ability of the land to replenish groundwater resources due to the structure of vegetation, climatic conditions and permeable layers. To account for the quality of the regenerated groundwater (usable groundwater), filter, buffer and transformation potentials are not sufficient, although there are causal correlations. Another important parameter is the distance between surface and groundwater, as the time delay between the discharge of the pollutants and the entry into the groundwater should also be regarded (MARKS 1989).

Effects on the Groundwater function are mainly important for industrial processes associated to sealing (=decreasing the groundwater inflow), surface degradation (decreasing of capacity for groundwater protection) and exposition of groundwater layers.

Following BAITZ (2002), the Groundwater function can be split into the sub-functions of Groundwater Replenishment and Groundwater Protection. As only Groundwater Replenishment is implemented into the calculation tool, this is the only groundwater related function described in the following.

Groundwater Replenishment

Groundwater Replenishment (V) [mm/a] can be measured directly using lysimeters, tracers, suction power or moisture measurement devices. These means of measurement are very precise for the direct location analyzed, but the problem of transferring this point values to areas remains unsolved (BASTIAN 1994); so these methods are not appropriate for the application in terms of LCAs. Thus another approach is presented here based on annual precipitation (NS) [mm/a], available field capacity (nFK) [mm] and evaporation according to Haude (EH) [mm] and calculated according to Renger (1980) and Marks (1989):

Equation 3 (BAITZ 2002: Equation 24); Farmland

$$V = 0{,}58 * NS - 220{,}3 * \log(nFK) - 0{,}2 * EH + 400$$

Equation 4 (BAITZ 2002: Equation 25); Grassland

$$V = 0{,}54 * NS - 130{,}4 * \log(nFK) - 0{,}341 * EH + 310{,}7$$

Equation 5 (BAITZ 2002: Equation 26); Coniferous woodland

$$V = 0{,}21 * NS + 0{,}00042 * N^2 - 325{,}3 * \log(nFK) - 0{,}666 * EH + 1187{,}3$$

Equation 6 (BAITZ 2002: Equation 27); Deciduous woodland

$$V = 0{,}953 * NS - 0{,}02 * EH + 430{,}1$$

It has to be noted that Equation 3 to Equation 6 are only applicable in the ranges presented in Table 2-6.

Table 2-6 Extents of validity of used equations (BAITZ 2002: Table 4.5; cp RENGER 1980)

Extent of validity of equations 24-27			
Equation	**Precipitation [mm/a]**	**nFK [mm]**	**EH [mm/a]**
Equation 3 (BAITZ 2002: Equation 24); Farmland	400-800	70-230	500-750
Equation 4 (BAITZ 2002: Equation 25); Grassland	500-800	60-180	550-750
Equation 5 (BAITZ 2002: Equation 26); Coniferous woodland	500-1300	100-240	380-750
Equation 6 (BAITZ 2002: Equation 27); Deciduous woodland	700-1300	200	380-500

The data this approach is based on is for example available in Bundesministerium für Umwelt (2000), or can be determined by combining information on available field capacity nFK as provided in Figure 2-4 and a classification of nFK as provided by Table 2-7.

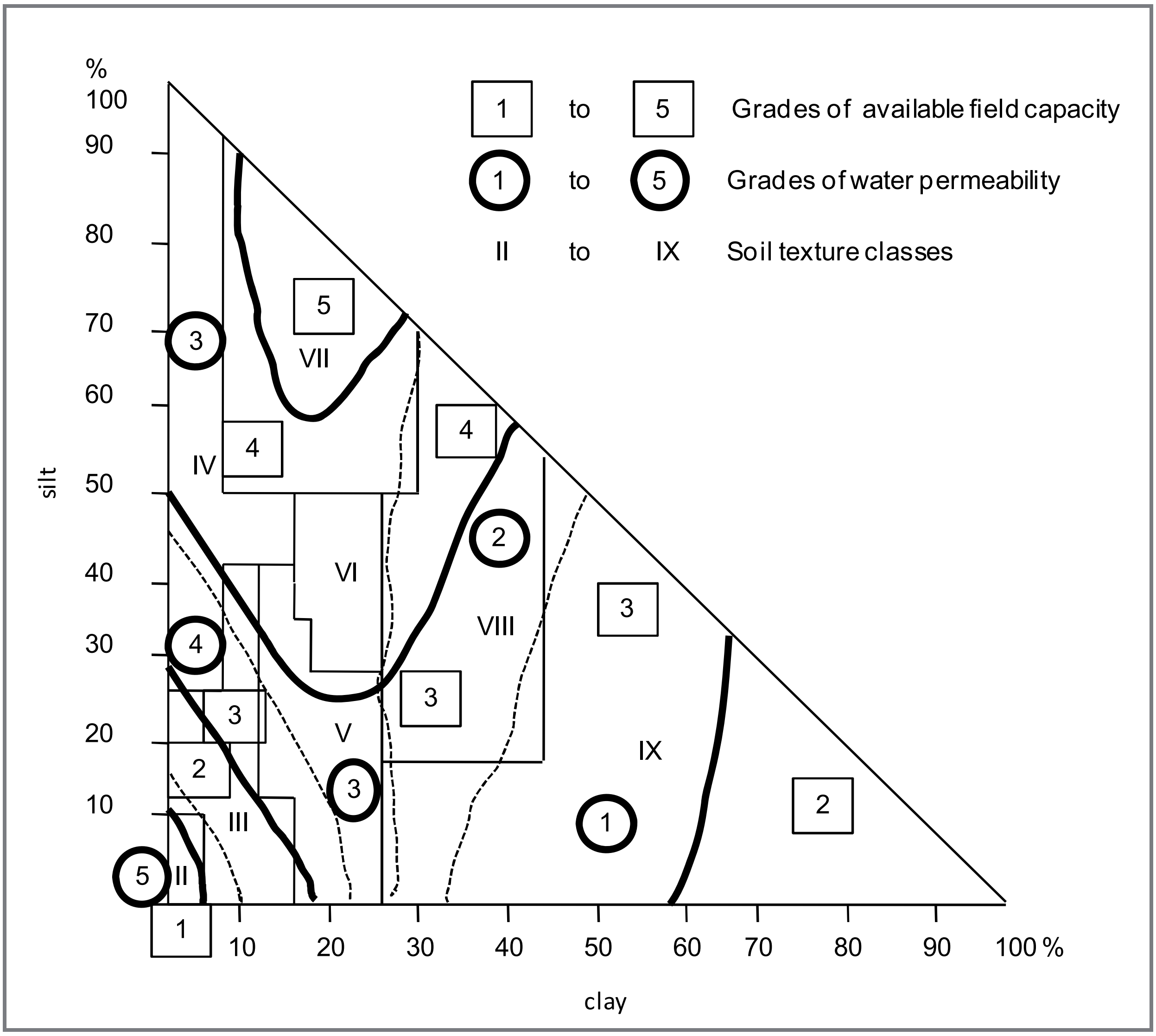

Figure 2-4 **Soil-water-triangle (BAITZ 2002: Fig. A6; according to Zepp modified by Sandner and Kiessling in LESER 1988)**[10]

Both, water permeability and available field capacity are dependent on the soil texture, but whereas the water permeability displays how much water can pass through a soil (the more, the bigger the pore volume is), the available field capacity shows how much water can be retained in the soil against gravity and so available field capacity for example is very low in sand soils, because they have a high water permeability and big pores.

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[10] In Figure 2-4, the rectangular lines mark the borders of the soil texture classes indicated in roman numerals. The thick black lines show the borders of the grades of available field capacity indicated in rectangular boxes. The dashed lines mark the borders of the grades of water permeability indicated in black circles.

Table 2-7 Grades of available field capacity nFK (BAITZ 2002: Table A5; according to ARBEITSGRUPPE BODENKUNDE 1982)

Classes of available field capacity nFK		
Class	**nFK [mm]**	**Description**
1	>50	Very low
2	50-90	Low
3	90-140	Average
4	140-200	High
5	>200	Very high

As Equation 3 to Equation 6 do not consider surface runoff, the groundwater replenishment rate V [mm/a] is divided by the quotient total runoff/groundwater runoff A/A_u to correct V by the surface runoff (see Equation 7). The quotient A/A_u can be determined according to Table 2-8.

Equation 7 (BAITZ 2002: Equation 29)

$$GWN_{ab} = V * \left(A / A_u\right)^{-1}$$

The resulting runoff corrected groundwater replenishment rate GWN_{ab} [mm/a] is the performance parameter specifying the Groundwater Replenishment function.

Table 2-8 **Determination quotient total runoff/groundwater runoff A/Au; (BAITZ 2002: Table A7; see BASTIAN 1994, derived from DÖRHÖFER 1980)**

Determination of quotient total runoff/groundwater runoff A/A_u								
			Declination [°]					
Soil type	**Mean distance surface to groundwater [m]**	**Hydromorphology group**	**0-0,5**	**>0,5-3**	**>3-7**	**>7-12**	**>12-25**	**>25**
Ranker, Rendzina, Braunerde, Parabraunerde, Fahlerde, Rosterde, Podsol, Schwarzerde, Griserde	>1,5	terrestrial	1,0	1,2	1,5	1,7	2,0	2,3
Braunstaugley, Braungley, (Vega)	0,8 – 1,5	semi hydromorph	2,0	2,0	2,0	2,0	2,3	2,3
Gleye, Staugleye, Amphigleye, Anmoore, Moore	<0,8	Hydro-morph	2,5	2,5	2,5	2,5	2,5	2,5

2.3 Conclusion

To summarize, the following parameters representing land quality and their calculation according to BAITZ (2002) were presented:

- Erosion Resistance B_{use} [t_{Soil}/(ha*a)]
- Mechanical Filtration: k_f-value [cm/d]
- Physicochemical Filtration CEC_{eff} [$mmol_c/kg_{soil}$]
- Groundwater Replenishment GWN_{ab} [mm/a]

For each process regarded, these parameters n are used to calculate the approximate change in the land quality ΔQ^*_n due to the regarded land use according to Equation 8 and as illustrated in Figure 2-5.

Equation 8 (BAITZ 2002: Equation 13)

$$\Delta Q_n^* = q_{(ref),n} * (t_e - t_a) - \sum_{c=1}^{h} (t_{c+1} - t_c) * \left(q_{n,t_{c+1}} + 0{,}5 * \left(q_{n,t_c} - q_{n,t_{c+1}}\right)\right)$$

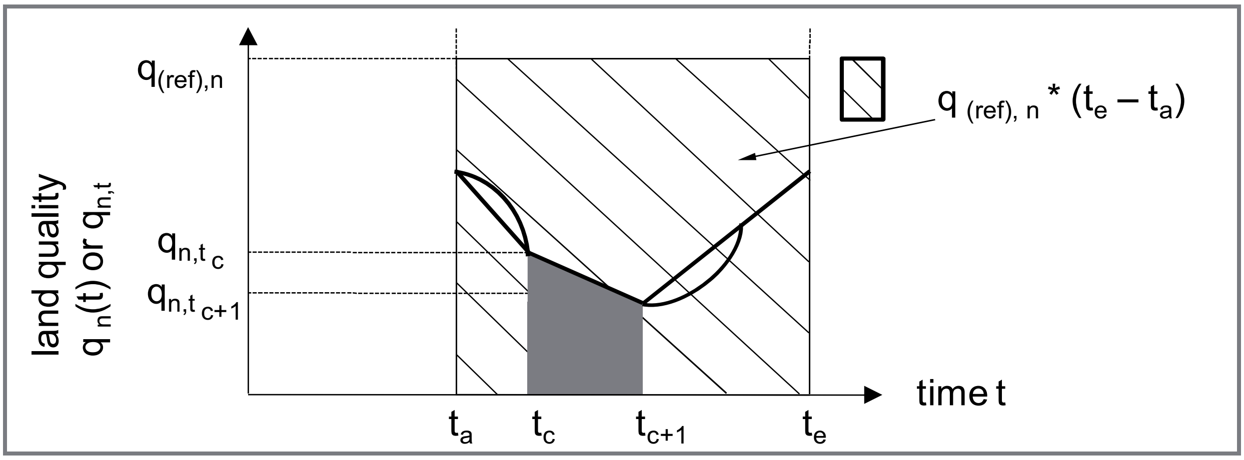

Figure 2-5 Illustration of land quality calculation

In the following BAITZ (2002) proposes to use these ΔQ values as inventory flows for the Life Cycle Assessment that can be aggregated following the life cycle of a product.

To characterize the inventory flows and to adapt them to the characterization of emission-based impact categories, their absolute values are multiplied by the characterization factor $c_{j,w}$=1 respectively -1 accordingly to display the difference between negative and positive effects of the increase of the land quality parameter values[11]: An increase of B_{use} stands for an increased erosion. As in emission-based impact categories increasing values mean an increased negative impact, $|B_{use}|$ is multiplied by 1. In contrast, an increase of the CEC_{eff}-value means an improved Physicochemical Filtration capacity. Thus, $|CEC_{eff}|$ is multiplied by -1.

Table 2-9 Choice of characterization factors (BAITZ 2002: Tab.4.8)

Function	Quality parameter	$\Delta Q_n < 0$ $c_{j,w}$	$\Delta Q_n > 0$ $c_{j,w}$
Erosion Resistance	B_{use}	1	-1
Mechanical Filtration	k_f-value	-1	1
Chemical Filtration	CEC_{eff}	-1	1
Groundwater Replenishment	GWN_{ab}	-1	1
Biotic Production	BM_{spez}	-1	1

If required the characterized impacts can be normalized or weighted.

As a conclusion, the method according to BAITZ (2002) provides an approach to integrate land use aspects of processes into LCA. To identify land use impacts, changes of different aspects of land quality are described using the influence of the land use on different ecosystem functions. Furthermore a characterization method allows for the comparison of results to other emission-based impacts of processes and life cycles.

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[11] According to BAITZ (2002), $c_{j,w}$ is the characterization factor for the flow j and the function w.

3 Requirements for Operationalization

The methods described in this report are supposed to be used in product LCAs. Therefore they need to fit into the framework set by established LCA methodology and software to be widely applicable. In the following chapter, background information on the different requirements is given and requirements are listed. The approach followed by IBP-GaBi is presented and compared to the framework developed recently by the LCA community and introduced by MILÀ I CANALS ET AL. (2007).

3.1 Foreground and background systems

Currently, one of the most widespread LCA software and database in industry is GaBi 4. In GaBi 4, resource and emission flows are modelled for each process, which are then summarized to be displayed in balances. In each inventory flow, all impact categories, to which this flow can contribute, are listed. So in the balance view, the user can choose between viewing the inventory balance and viewing balances of different impact categories.

In GaBi, as in all LCA databases, two sorts of data exist: On the one hand, foreground processes and systems can be modelled by users themselves, thus generating both, inventory flows and impact data.

The other possibility is to use aggregated database data: For example to represent the power grid mix of a country, a complex model is set up by the database provider, taking into account the country-specific shares of different power sources. For all the power sources occurring, the complete production is modelled, starting at raw material extraction. When the model is finalized, all occurring input and output data is summarized and the complex model is transformed into a black box aggregated process (for example power grid mix Germany), that contains all in- and outputs but does not allow to look at the model behind or to change the underlying inventory modelling[12]. These aggregated processes can be used to build up a (foreground) model. In the balance view, again, the user can either view the

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[12] This is important as the GaBi database mainly consists of high quality industry data

inventory balance or choose between different impact categories and analyze the balance.

To include land use data into the GaBi database, background data was intended to be calculated and implemented for example for different mining and agricultural processes. Consequently, due to the aggregation of data, land use data is present in nearly all aggregated processes. Regarding this, an implementation solution had to be found to provide land use data in a way, which would not considerably enlarge the size of the GaBi database.

So, to conclude, for being able to use land use methods in the GaBi software and database, an approach had to be found that fits all these conditions:

- Foreground and background data have to be modelled consistently
- The user has to be able to include foreground data
- The implementation of land use data should not exponentiate the amount of data needed in the database
- Data has to be aggregable and interpretable in balances.

3.2 Implementation approach as followed by IBP-GaBi

To meet the requirements discussed in 3.1, the following approach has been developed:

When modelling processes, indicator values (= impacts) for transformation and occupation are calculated site-specifically outside the LCA software[13] based on "inventory data" such as land use type, climatic zone, area, time, and others (see 4). These data are then included into the software in the technical form of inventory flows, which have to be rather interpreted as "indicator value flows" These flows currently cannot be characterized further[14], but they can be summarized over process chains, displayed in the balance view and evaluated in the same manner as other impact categories.

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[13] For this calculation, LANCA® is used.

[14] Approaches for a further characterization are currently being developed

For aggregated processes, such flows have been calculated based on existing knowledge of different production locations and are provided by the database provider. For foreground processes, the flows can be calculated by users, applying the LANCA® methodology described below.

3.3 Methodological framework

In the framework of an UNEP-SETAC project group dealing with the integration of land use into LCA (LULCIA 2008-2010), a framework document has been elaborated for the integration of land use into LCA (see MILÀ I CANALS ET AL. 2007). In this framework document, the following set of requirements is provided: It is stated, that for each land use regarded, both for occupation and transformation, there should be inventory flows containing information about the type (and intensity) of land use, bio-geographical conditions, area used and time (Example: Inventory Flow Transformation from forest to farmland, cool temperate climate, 1 ha, 1 year). For each possible combination of land use and climatic zones, generic characterization factors have to be provided on different geographical scales.

So, the inventory flows chosen by the user could be summarized in the inventory balance and characterized by applying one of these factors. Within this approach, regarding the GaBi software, only inventory flows representing exactly the same conditions and therefore named identically could be summarized, and thus most of the land use flows would be displayed separately in the inventory balance; which would significantly complicate their assessment and interpretation. In addition, the high amount of flows and characterization factors would strongly inflate the size of the database. Another reason for not implementing generic respectively site-dependent characterization factors is that this deprives the user of the possibility to calculate indicator values site-specifically for foreground processes, which is an important feature for example for comparing different agricultural sites, and which is possible by using LANCA® and the land use implementation method applied by IBP-GaBi.

Regarding the indicators to be assessed, based on the concept of Ecosystem Services, LULCIA (2008-2010) suggests to develop indicators for Biotic Production, Carbon Sequestration, Fresh Water Regulation including

Groundwater Replenishment, Erosion Regulation and Water Purification. Comparing these recommendations with the LANCA® indicators described in chapter 4, a strong correlation can be found, strengthening the relevance and importance of the indicators chosen and calculated by IBP-GaBi.

To summarize, the calculation methods developed by the Department for Life Cycle Engineering generally are in line with the framework provided by MILÀ I CANALS ET AL. (2007)[15]. Operationalization, however, is different, as no generic characterization factors are used, but indicator values are calculated outside the LCA software site-specifically and then included into the LCA software in form of indicator value flows for practical reasons.

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[15] In fact, LANCA® can be used to calculate on the one hand generic characterization factors, on the other hand, site-specific indicator values for the implementation in GaBi.

4 Operationalization: The LANCA® tool

Following the method of Baitz (2002), at the Department for Life Cycle Engineering, a tool (LANCA®) has been developed to calculate land use indicator values based on ecosystem functions. To make the tool applicable, the underlying methods have been customized; in addition, the framework methodology has been adapted to the framework on land use impact assessment set up by Milà i Canals et al. (2007). The resulting approaches applied by LANCA® are presented in the following chapter.

4.1 General structure

LANCA® calculations follow the structure shown in Figure 4-2 based on the theory illustrated in Figure 4-1. Similar to Figure 2-1, Figure 4-1 shows a possible quality alteration due to a defined land use: Starting at a quality $q(t_1)$, which represents the situation of the land before the start of the regarded land use, a hypothetic land use (change) leads to a rapid quality deterioration represented by the situation $q(t_2)$[16].

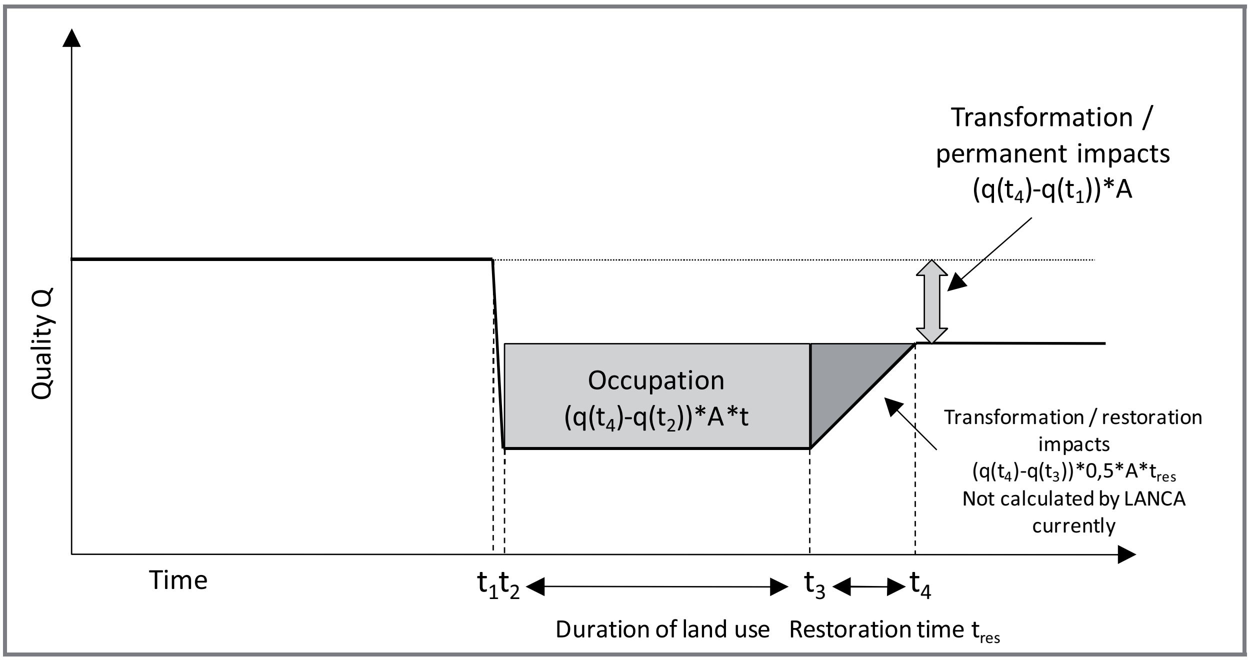

Figure 4-1 **Quality development and calculation of indicator values**

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[16] As the quality deterioration from t_1 to t_2 is supposed to happen in a narrow time frame, respective occupation impacts are assumed to be negligible.

During use, it is assumed, that the quality is constant. After the end of the use, the land quality can recover until reaching situation $q(t_4)$.

The user is requested to provide input data concerning site-specific conditions for soil and climate for the different time steps regarded (t_1-t_4).

In addition, land use types occurring in the different time steps, the time of use and the area needed to produce one functional unit have to be provided. If site-specific input data cannot be provided by the user, there is the possibility to use the data provided in the tool database on country-level. The input data is forwarded to the quality calculation sheets for the different indicators. Respective input data and calculation rules for the indicator qualities are described in chapter 4.2. Qualities are calculated for the time steps t_1-t_4. They are then used in the indicator value calculation as shown in Equation 9 and Equation 10.

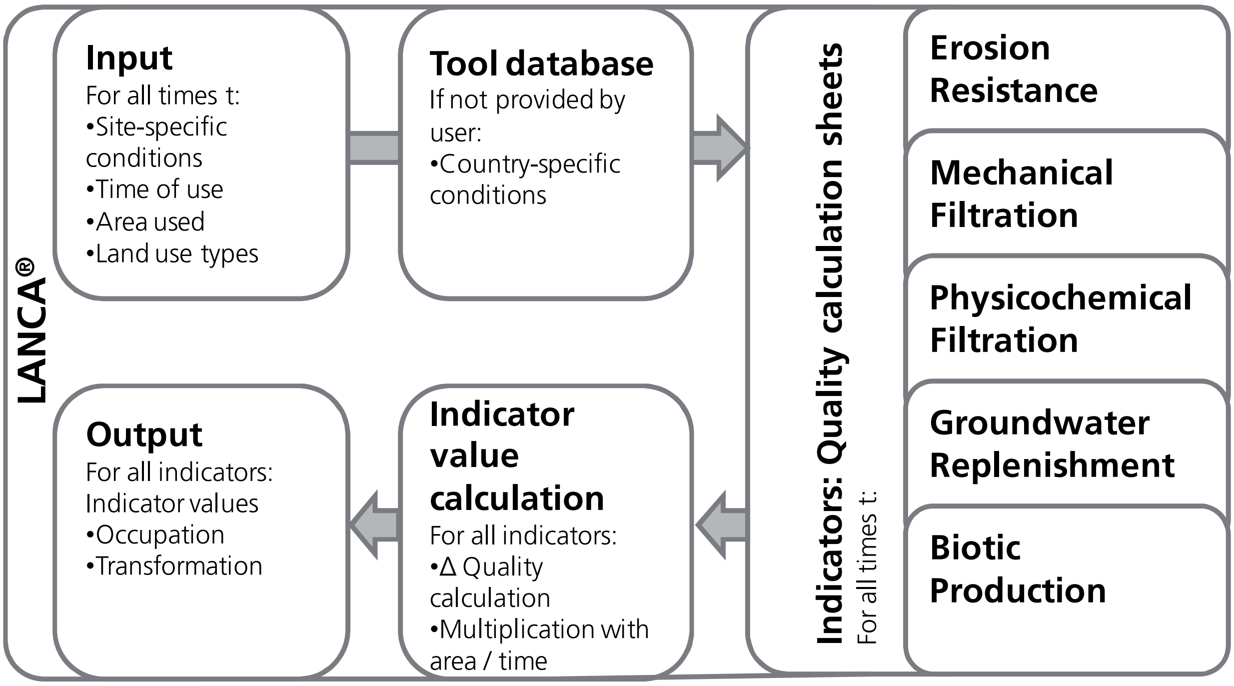

Figure 4-2 LANCA® structure

In contrast to Baitz (2002) (see Figure 2-5 and Equation 8) and following the framework developed in Milà i Canals et al (2007), the indicator values are calculated separately for occupation and transformation (see Reference states, Transformation Calculation).

So the tool uses inventory data as requested by Milà i Canals et al. (2007); indicator values calculated and presented to the users in the output section of the tool can be interpreted as a kind of "midpoints"[17]. They can be included into LCA software such as GaBi in the technical form of "inventory flows", allowing for an aggregation of data in the balance view without further possibilities of characterization at present.

The potential effects of anthropogenic land use are accounted for as the change of the land quality during the time of occupation. The general calculation steps are as follows:

1. For each indicator n: calculation of quality parameters q_n,

- for transformation (permanent impacts) representing land conditions in t_1 and t_4
- for occupation representing land conditions in t_2, t_3 and in the reference situation.

2. Calculation of the differences ΔQ and of indicator flows $I_{trans,\ occ}$ according to Equation 9 and Equation 10. Table 2-9 is then used to adapt algebraic signs of the indicator values for occupation. Accordingly, a respective table, which was developed in the LANCA® development process (Table 4-1), is used for transformation.

Table 4-1 Choice of "characterization" factors[18] (Transformation)

Function	Quality parameter	$\Delta Q_n < 0$ $c_{j,w}$	$\Delta Q_n > 0$ $c_{j,w}$
Erosion Resistance	B_{use}	-1	1
Mechanical Filtration	k_f-value	1	-1
Chemical Filtration	CEC_{eff}	1	-1
Groundwater Replenishment	GWN_{ab}	1	-1
Biotic Production	BM_{spez}	1	-1

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[17] At present, the indicators just reflect the delta of the land qualities before, during and after use, which are caused by the land use regarded. To obtain information on the severeness of these deltas, it is necessary to relate them to region-specific mean values. A respective method is currently being developed at IBP-GaBi.

[18] Wording according to BAITZ (2002)

Equation 9

$$I_{trans,n} = \left|\Delta Q_{trans,n}\right| * c = \left|q_n(t_4) - q_n(t_1)\right| * A * c$$

Equation 10

$$I_{occ,n} = \left|\Delta Q_{occ,n}\right| * c = (\left|q_n(ref) - q_n(t_2)\right| * t_{use} * A) * c$$ [19]

These calculated indicator values $I_{trans,\ occ}$ can then be used in the technical form of inventory flows in the GaBi software.

The quality parameters are generally calculated according to BAITZ (2002). In some points, modifications have been made to be able to implement the method adequately. The tool described in the following is supposed to allow a global calculation of the respective impacts. For being able to use the approaches used in BAITZ (2002), which were mostly developed on a small scale in Germany, it must be assumed that they are also globally valid and applicable.

The applications of Equation 9 and Equation 10 and the units of the indicator qualities as described in this chapter lead to units for the different indicators as shown in Table 4-2.

Table 4-2 Units of indicators

Indicator	Quality unit	Occupation indicator unit	Transformation indicator unit
Erosion Resistance	[t/(ha*a)]	[t]	[t/a]
Mechanical Filtration	[cm/d]	[cm*m²]	[cm*m²/d]
Physicochemical Filtration	[cmol/kg$_{soil}$]	[cmol*m²*a/kg$_{soil}$]	[cmol*m²/kg$_{soil}$]
Groundwater Replenishment	[mm/a]	[mm*m²]	[(mm*m²)/a]
Biotic Production	[g[20]/(m²*a)]	[g]	[g/a]

Positive occupation indicator values can be interpreted as follows:

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[19] At IBP-GaBi, always $q(t_4)$ was used as the reference q(ref) for the occupation calculation.

[20] g Dry mass

- Erosion Resistance (expressed by tons of erosion): tons of soil eroded in addition to naturally occurring soil erosion (this state is displayed by the quality of Erosion Resistance in t_4) due to the functional unit regarded during the time of use.
- Mechanical Filtration: amount of water that could not be filtered due to the functional unit regarded during the time of use.
- Physicochemical Filtration: cations that could not be fixed to the soil due to the functional unit regarded during the time of use.
- Groundwater Replenishment: amount of groundwater, which could not be replenished due to the functional unit regarded during the time of use.
- Biotic Production: amount of biomass not produced due to the functional unit regarded.

Positive transformation indicator values (permanent impacts) can be interpreted as follows:

- Erosion Resistance: tons of soil eroded in addition to naturally occurring soil erosion per year in the time following the regarded land use on the used land due to permanent transformation impacts of the functional unit regarded.
- Mechanical Filtration: amount of water that cannot be filtered in the time following the regarded land use per day on the used land due to permanent transformation impacts of the functional unit regarded.
- Physicochemical Filtration: cations that cannot be fixed to the soil in the time following the regarded land use per day on the used land, due to permanent transformation impacts of the functional unit regarded.
- Groundwater Replenishment: amount of groundwater that cannot be replenished in the time following the regarded land per year on the used land, due to permanent transformation impacts of the functional unit regarded.

- Biotic Production: amount of biomass that is not produced in the time following the regarded land per year on the used land, due to permanent transformation impacts of the functional unit regarded.

Negative indicator values show the respective positive impacts.

Reference States, Transformation Calculation

Concerning Transformation Calculation, as mentioned by VAN DER VOET (2001), in general two schools exist:

The first one regards transformation as the change of a situation to another one. Following this school transformation impacts can be generally calculated in the same way as occupation impacts taking into consideration the regeneration time t_{regen} and the slope of the quality curve (see KÖLLNER 2007). If only this kind of transformation is regarded, usually t_4 is supposed to be equal to t_1. Transformation and occupation impacts have the same units and recovery is assumed to be complete, i.e. that there are no irreversible impacts (see Figure 4-1, transformation / restoration impacts).

The second school according to VAN DER VOET (2001) refers to transformation impacts as the lasting impacts of the change, i.e. the irreversible damages caused by the land use. They can also be named permanent impacts and are calculated and displayed without taking into account the recovery time of the land (see WEIDEMA & LINDEIJER 2001; Figure 4-1, transformation / permanent impacts).

The calculations in the tool follow the second school by calculating the permanent impacts of a land use without taking into consideration the recovery time. Recovery times of ecosystems are very difficult to define and to determine (see VAN DER VOET 2001), and the assumption of total recovery is not generally applicable. As the tool was developed and used to calculate land use impacts of rather coarse land interventions such as open-pit mining, where total recovery is not even possible, this seems to be the more suitable approach. Another argument is that double counting of impacts is avoided by calculating occupation impacts as the delta between $q(t_4)$ and $q(t_2)$ and transformation impacts as the difference between $q(t_4)$ and $q(t_1)$.

Furthermore, restoration times are defined to be negligible and the state $q(t_4)$ is set to a score that can be reached by natural relaxation.

Reference systems are required for calculating land use impacts. The corresponding reference values have to be set for every single parameter, and are area-specific. Concerning reference situations different approaches also exist.

Occupation impacts are generally calculated as $(q(t_4)-q(t_2))*A*t$. So $q(t_4)$, the state of the land after regeneration is the reference situation for the occupation calculation.

Regarding transformation, as stated before, different approaches exist (see Figure 4-1). The first one defines $q(t_4) = q(t_1)$, i.e. the land is able to recover until the state before the land use change is reached, and no permanent impacts occur. The second one states that $q(t_4)$ can also be higher or lower than $q(t_1)$ leading to permanent impacts or improvement potentials (see for example WEIDEMA & LINDEIJER 2001, KÖLLNER 2007). At IBP-GaBi the second approach is followed, stating that permanent impacts do occur and should be accounted for. Thus $q(t_4)$ is different from $q(t_1)$ and represents the actual relaxation potential of the land after the use, identified by expert judgment.

According to school 2, to calculate transformation, $q(t_4)$ is compared to $q(t_1)$. In the majority of cases it is assumed that $q(t_1)$ represents a natural situation, for example the potential natural vegetation (PNV) currently discussed by LULCIA (2008-2010). In some cases this cannot be assumed; in Europe, for example, there are almost no natural situations anymore. Using this approach, the issue how to deal with such situations is not yet solved in a satisfying manner. Related to this, another issue not yet solved within this approach is how to allocate transformation impacts that have been imposed by for example a transformation from forest to agricultural land a long time ago to functional units.

In the application of LANCA®, t_4 has been defined to be equal to t_{ref} i.e. that the state after recovery is the reference for the calculation of occupation and transformation impacts. Nevertheless, the user of the tool can define reference states $q(t_1)$ and $q(t_{ref})$ by entering respective input data.

Applying LANCA® at IBP-GaBi, $q(t_4)$ is usually set to the natural relaxation potential of an area, whereas $q(t_1)$ represents the state of the land before the regarded use.

Due to unsolved allocation issues (transformation of natural land to agricultural land might have occurred hundreds of years ago) transformation impacts for agriculture in Europe are not calculated yet. Regarding reference situations, the tool provides the possibility to calculate the land quality q_n for the time steps t_1, t_2, t_3 and t_4 and leaves the possibility to define and calculate $q(t_{ref})$ separately.

4.2 Indicators

The indicators addressed in the tool in general are closely related to the indicators as developed by BAITZ (2002) and described in chapter 2. In some cases, simplifications or adoptions had to be made.

For being able to calculate indicator values as described in Equation 9 and Equation 10, for each indicator presented, qualities have to be calculated for t_1, t_2, t_3 and $t_4 = t_{ref}$.

For each indicator, an exemplary calculation for one time step is carried out at the end of the respective chapter. The example used assumes a transformation from coniferous forest (t_1) to an open pit lignite mining area (t_2 and t_3) and a restoration to fallow with vegetation ($t_4=t_{ref}$). For the exemplary calculation, the calculation steps only necessary for the tool (for example transformation to number codes) are not regarded. Input data used represents country-specific values for France derived from the tool database.

Please note that, to calculate the whole example, all indicator qualities would have to be calculated for all time steps t_1-t_4. Respective results are shown in Table 4-12*.*

4.2.1 Erosion Resistance

For the LANCA® calculation of the Erosion Resistance qualities, the following input data is needed:

- Soil texture

- Declination [°]
- Summer precipitation [mm/a]
- Type of land use
- Skeletal content [% volume]
- Humus content [% weight]
- Kind of surface

The Erosion Resistance is then calculated according to BAITZ (2002) in 6 steps

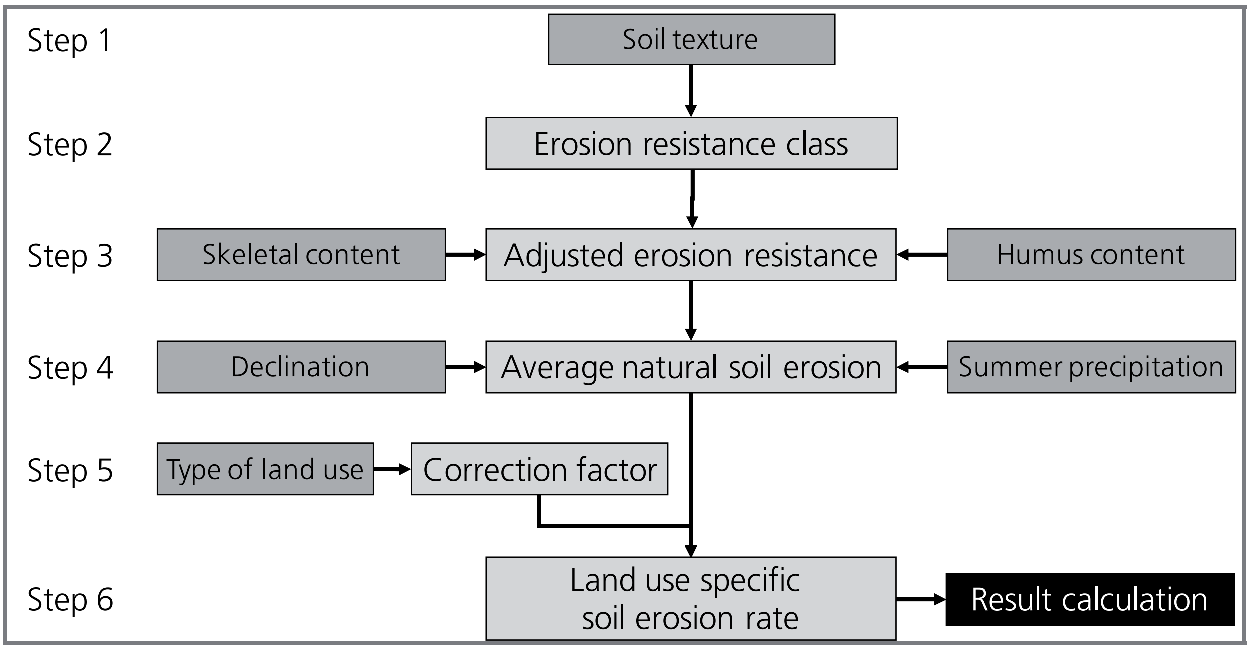

Figure 4-3 **Calculation steps for Erosion Resistance**

1. Definition of the soil texture at the studied location and its input in the calculation tool using a dropdown menu (see Table 4-3).
2. Determination of a soil texture related erosion resistance class according to Bastian (1999): According to Table 4-3 a soil texture code is assigned to the soil texture chosen[21] and the erosion resistance class based on the

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[21] For being able to calculate and perform assignments, all input data has to be transformed into codes readable by the tool.

soil texture is assigned as shown in Table 4-3 based on the suggestions shown in Table 2-1[22].

Table 4-3 Assignment of soil texture and soil texture class

Soil texture	Soil texture class	Texture code	Erosion resistance class
No soil cover (rocks, open water)	0	0	0
Silt	4	1	5.1
Weakly loamy silt	7	2	
Medium clay silt	7	3	4.2
Medium silty loam	7	4	
Medium sandy silt	4	5	
Strongly loamy silt	7	6	4.1
Sandy loamy silt	7	7	
Strongly clay silt	7	8	
Silty loam	7	12	
Weakly sandy loam	6	9	3.2
Silty loamy sand	4	10	
Strongly silty sand	4	11	
Silty clay loam	8	13	
Weakly clay loam	8	14	3.1
Medium sandy loam silty sandy loam	6	15	
Medium silty sand	4	16	
Silty clay	8	17	
Fine sand	2	18	
Medium clay loam	8	19	2.2
Medium loamy clay	9	20	
Sandy clay loam	8	21	
Strongly sandy loam	5	22	
Strongly sandy clay	9	23	

---

[22] Table 4-3 has been compiled from Table 2-1 and Figure 2-2 and extended by expert judgement based on the soil texture classifications given in Leser 1988, Bastian 1994 and DIN 4220 (2008).

Soil texture	Soil texture class	Texture code	Erosion resistance class
Strongly loamy sand	5	24	
Medium loamy sand	3	25	
Weakly silty sand	3	26	
Weakly sandy clay	9	27	
Medium sandy clay	9	28	2.1
Medium clay sand	5	29	
Weakly loamy sand	3	30	
Cobble	1	31	
Gravel	1	32	1.0
Coarse gravel	1	33	
Medium gravel	1	34	
Fine gravel	1	35	
Sand	2	36	
Clay (max)	9	37	
Clay	9	38	
Medium sand	2	39	
Weakly clay sand	3	40	
Coarse sand	2	41	

3. Adjustment of the erosion resistance class, considering specific skeleton and humus shares in the soil at the studied location: Via a dropdown menu skeleton and humus content of the considered land has to be fed into the tool. If this data is not available, country specific data is provided by a database included in the tool[23]. Both, for skeletal and humus content a code is assigned. In the following, the adjusted erosion resistance class is assigned according to Table 2-2[24].

---

[23] Humus content data is taken from ISRIC WISE 1.1 Soil Data – ORGC, Skeletal content data is taken from ISRIC WISE1.1 Soil Data – GRAVEL. If no generic data exists for a country, "less than 1%" is chosen for humus content and "less than 10%" for skeletal content.

[24] In cases where two different classes are possible, in the tool the worst case is assumed. If no allocation is possible due to missing records in Table 2-2, 1.0 is assumed.

4. Determination of the average naturally occurring soil erosion [t/(ha*a)] depending on summer precipitation[25] and declination (slope) at the studied location: Using dropdown menus, the mean summer precipitation and the slope of the considered land have to be provided[26]. For the summer precipitation, again a country specific database is provided in the tool and country specific values are taken, if no data is provided by the user[27]. In the tool, codes are assigned to the input data. Subsequently, the average natural soil erosion is assigned based on Table 2-3[28].

5. Determination of a correction factor considering land occupancy at the studied location: As the erosion is strongly dependent on the type of land use, the average natural soil erosion must be corrected accordingly. In the LANCA® input field, a land use type has to be chosen for t_1-t_4, which is again transformed into a code by the tool (see Table 4-4). This land use type is then assigned to a correction factor between 0,5 and 10 according to Table 4-4, which is based on Table 2-4. For land that has already been sealed, maximal erosion (83,3t/(ha*a)) is assigned: although no erosion is possible from sealed land, the ecosystem function Erosion Resistance is permanently affected here.

6. Calculation of a land use specific soil erosion rate related to land occupancy from the results from steps 4 and 5: The average naturally occurring soil erosion [t/(ha*a)] is multiplied by the correction factor.

Reference state for the occupation calculation is the average natural soil erosion without any sealing.

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[25] Summer is defined to be March through August in the Northern Hemisphere and September to February in the Southern Hemisphere. The summer average of precipitation is calculated using ecological assessment procedures figured out by e.g. MARKS (1989), MARKS (1992) for average precipitation in Germany assuming the applicability of this procedure for other countries.

[26] If this data is not available for the user, an assumption for the declination is made taking 0-0,5°.

[27] Summer precipitation data is taken from the AQUASTAT (2003) database. If no country-specific data is available, "less than 400 mm" is chosen.

[28] In the tool, the classification categories of summer precipitation were slightly changed from BAITZ (2002), because here the scale was not continuous. New classification categories: <400mm → 1; 400-500mm→2; >500mm→3.

If the soil is completely or partly removed leaving the layer beneath blank in the soil texture dropdown menu "no soil cover" has to be chosen. In this case, no values are calculated for Erosion Resistance, Mechanical Filtration and Groundwater Replenishment.

Example

The quality is calculated for t_4 = Fallow with vegetation.

Input data: Humus content: 3 %, Skeletal content: 11 %; Soil texture: Weakly sandy loam; Summer Precipitation: 403 mm; Declination: 0,5° (default); Land use type = Fallow with vegetation.

Step 1: Soil texture = Weakly sandy loam. Step 2: Table 4-3*: Erosion resistance class = 3.2. Step 3: Skeletal content = 11 %; Humus content = 3 %; Table 2-2 → adjusted erosion resistance class = 2.2. Step 4: Declination = 0,5°; Summer Precipitation = 403 mm → Table 2-3 : Average natural soil erosion = 0,5 t/(ha*a). Step 5: Land use type = Fallow with vegetation; Table 4-4 → Correction factor = 1. Step 6: Multiplication of Average natural soil erosion by Correction factor → Erosion Resistance quality in t_4 = Fallow with vegetation = 0,5 t/(ha*a), meaning that in this example after the regeneration of the land an Erosion of 0,5 t/(ha*a) is present.*

4.2.2 Physicochemical Filtration

Within LANCA®, the Physicochemical Filtration, represented by the effective cation exchange capacity CEC_{eff}, is not calculated according to BAITZ (2002), as no functional dependency between CEC_{eff} and the potential cation exchange capacity CEC_{pot} is given there. Rather the local effective cation exchange capacity CEC_{eff} has to be provided by the user or can be taken from a country specific database and is corrected by the degree of sealing of the considered land thereafter.

For the calculation of the Physicochemical Filtration, the following input data is needed:

- Effective cation exchange capacity CEC_{eff} [cmol/kg_{soil}]
- Type of land use

The calculation for the qualities $q(t_1)$-$q(t_4)$ are then carried out in two steps:

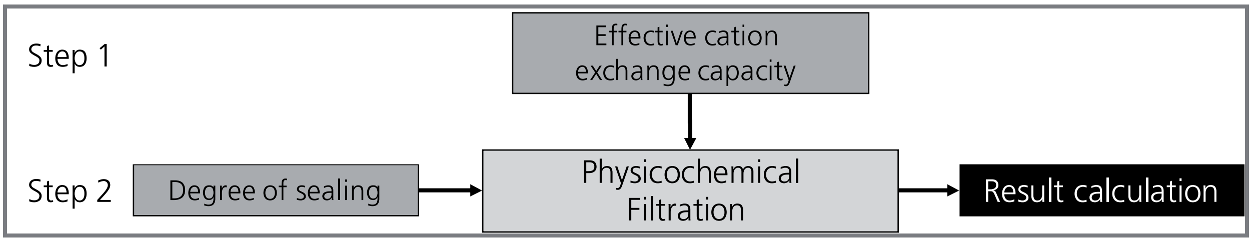

Figure 4-4 **Calculation steps for Physicochemical Filtration**

1. Entering of the site-specific Effective Cation Exchange Capacity (CEC_{eff}). If this data is not available to the user, LANCA® provides country specific data taken from the ISRIC database [ISRIC WISE (2002)]. PH-conditions, which are very important for the determination of CEC_{eff} are already considered in the values taken from the ISRIC database.
2. Calculation of the Physicochemical Filtration considering a correction factor that is based on the degree of anthropogenic sealing at the studied location: After entering the type of land use in the input sheet of the tool, a sealing code is assigned to the chosen value according to Table 4-4 and Table 4-5.

Table 4-4 **Allocation of sealing codes and correction factors**

Type of land use	LUC-Type[29]	Correction factor Land Use Type k_{use}	Sealing code
Grassland, meadow	1	0,5	6
Wood[30]: Coniferous woodlands	2	0,5	6
Wood: Deciduous woodlands, unspecific	3	0,5	6
Wood: Deciduous woodlands, summer green	4	0,5	6
Wood: (Sub-) tropical Rainforest	5	0,5	6
Wood: Monsoon woodlands	6	0,5	6
Wood: Temperate zone Rainforest	7	0,5	6
Wood: Mixed tree woodlands	8	0,5	6

---

[29] Land use / Land cover type; codes used by LANCA®

[30] "Wood" here is defined to be natural, non processed and naturally grown woodland

Type of land use	LUC-Type[29]	Correction factor Land Use Type k_{use}	Sealing code
Forest[31]: Coniferous forest	9	0,5	5
Forest: Deciduous forest	10	0,5	5
Forest: Mixed tree forest	11	0,5	5
Moorland, lawn or fallow with vegetation	12	1	6
Permanent crops (field, little surface vegetation)	13	6	5
Farmland (no complete surface vegetation)	14	3	5
Fallow ground (no surface vegetation)	15	10	6
Continuous urban influenced area[32]	16	Max	1
Non continuous urban influenced area	17	Max	1
Industrial real estate	18	Max	1
Road network	19	Max	1
Railway system	20	Max	1
Traffic infrastructure area (ports, airports, garages, etc.)	21	Max	1
Mining area	22	Max	1
Landfill	23	Max	1
Artificial, not farmed grassland	24	3	4
Freshwater	25	0	6
Swamp area	26	1	6
Ocean	27	0	6
Riff	28	0	6
Estuary	29	0	6
Forest steppe	30	1	6
Tropical savannah	31	1	6

---

[31] "Forest" here is defined to be artificially planted wood deemed to be processed artificially.

[32] For the land use types 16 to 23, very high sealing grades occur and thus erosion is avoided. Nevertheless, the long term erosion resistance of the soil is permanently decreased. To solve this methodological problem, a maximum erosion of 83,3t/(ha*a) is assigned to display these permanent impacts (see BAITZ 2002).

Type of land use	LUC-Type[29]	Correction factor Land Use Type k_{use}	Sealing code
Temperate savannahs	32	1	6
Semi-desert	33	1	6
Desert, glacier	34	0	6
Tundra	35	1	6
Alpine area	36	1	6

In the next step a mean value [%] used as a correction factor is assigned to the sealing code based on Table 4-5.

Table 4-5 **Assignment of mean value of sealing used as correction factor**

Grade of Sealing	Sealing code	Mean value [%] used as correction factor k_{seal}
Sealed completely (90-100%): e.g. Asphalt, streets, building areas	1	95
Mainly sealed (50-90%): e.g. Spaces with gravel on the surface	2	70
Partly sealed (30-50%): e.g. Farm tracks	3	40
Hardly sealed (10-30%): e.g. Public parks	4	20
Non sealed (0-10%): e.g. Grass land, lawn, wood, fields	5	5
Non sealed (0%): e.g. Fallow grounds	6	0

Finally the CEC_{eff} is corrected by the correction factor as follows:

Equation 11

$$CEC_{eff,corr} = CEC_{eff} * (1 - correction\ factor)$$

If no other value is specified, the reference value for the occupation calculation is a country-specific CEC_{eff}-value taken from the data base. Also the correction factor is chosen according to the land use type specified for the reference situation t_{ref}.

Example

The quality is calculated for t_1 = Coniferous Forest.

Input data: Effective Cation Exchange Capacity = 13 cmol/kg_{soil}; Land use type = Coniferous forest.

Step 1: Effective Cation Exchange Capacity = 13 cmol/kg_{soil}; Step 2: Land use type = Coniferous forest; Table 4-4 → *Sealing code = 5;* Table 4-5 → *Correction factor = 0,05 → Physicochemical Filtration quality of the land in t_1 = Coniferous forest = 12,35 cmol/kg_{soil}, meaning that 12,35 cmol of polluting cations could be fixed per kg of soil in this time step.*

4.2.3 Mechanical Filtration

The Mechanical Filtration function describing the amount of water being able to pass per time (hydraulic conductivity as velocity through soil) k_f [cm/d][33] is again calculated very closely to Groundwater Protection as suggested by BAITZ (2002). Input data required is

- Soil texture,
- Distance surface to groundwater [m],
- Type of land use.

The following calculation steps are performed for the qualities $q(t_1)$-$q(t_4)$ by the tool:

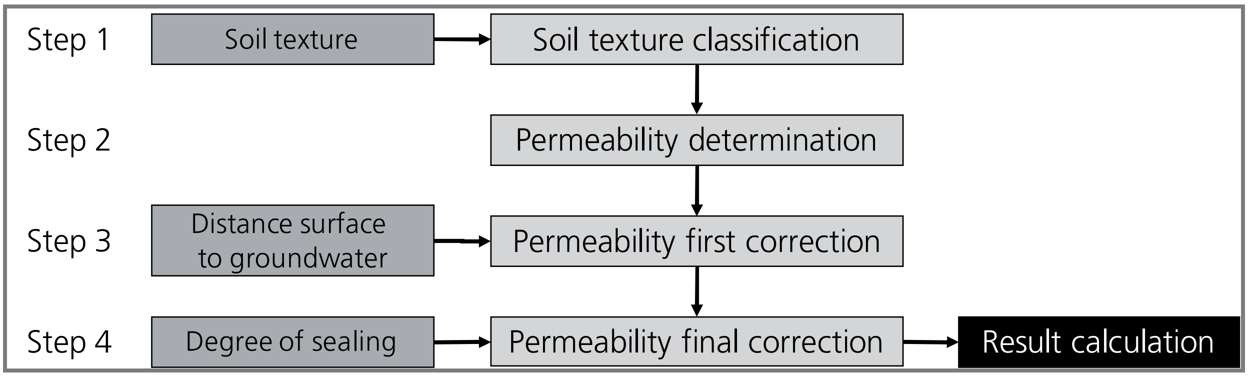

Figure 4-5 Calculation steps for Mechanical Filtration

1. Determination of the soil texture: As in Erosion Resistance, the soil texture has to be provided. Subsequently, a soil texture code and a soil

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[33] Usually k_f is valid for homogeneous and isotropic media. Here it is assumed to be valid for all soils.

texture class are assigned according to Table 4-3, to which minimal and maximal k_f-values can be assigned as shown in Table 2-5.

2. Determination of the water permeability k_f of the soil: A water permeability group value is assigned based on the soil texture classes according to Table 2-5.
3. Adjusting the permeability, considering the distance between surface and groundwater layer: It is assumed that Mechanical Filtration Capacity is higher, the longer the filtering distance is. So the distance between surface and groundwater must be entered into the input sheet[34]. In the following it is converted to a code according to Table 4-6 and the water permeability group is corrected also according to Table 4-6 using an if-function.

Table 4-6 **Allocation of distance code and correction of water permeability group[35]**

Distance surface to groundwater	Distance code	Water permeability group correction
<0,8 m	1	-1
0,8-1,5 m	2	valid
0,8-10 m	3	valid
10-30 m	4	+1
>30 m	5	+2

After this correction of the distance surface to groundwater, the permeability groups have to be reclassified according to Table 4-7 and the corrected water permeability group is reassigned to the respective mean of the corrected permeability [cm/d] according to Table 4-8[36].

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[34] If this data is not available to the user, a distance of 0,8-10 m is assumed and the respective code is assigned.

[35] This table is compiled from two sources: BASTIAN (1994), p. 213, and BASTIAN (1994), p. 250. In the tool, for Mechanical Filtration, the Distance codes Distance codes 2 and 3 are treated equally, for Groundwater Replenishment, only the distance codes 1-3 are applicable.

[36] Table 4-6 and Table 4-7 are an operationalization of BASTIAN (1994), p. 213.

Table 4-7 **Adjustment of corrected water permeability group**

Corrected Water permeability group	Corrected and adjusted water permeability group
2,5	2
4,5	5
5,5	5
6	5
7	5

Table 4-8 **Reassignment of corrected mean permeability**

Soil texture class	Water permeability group	Minimal water permeability [cm/d]	Maximal water permeability [cm/d]	Mean value water permeability [cm/d]
1	5	100	600	350
2	5	100	600	350
3	4	40	100	70
4	3,5	10	100	55
5	3,5	10	100	55
6	3	10	40	25
7	3	10	40	25
8	2	1	10	5,5
9	1	0	1	0,5
10	1-5	0	600	300

4. In addition to the BAITZ (2002) method, a further correction of the permeability by considering the degree of anthropogenic sealing at the studied location is carried out: The user has to enter the type of land use into the tool. According to Table 4-4 a sealing code is assigned to each land use type.

   Subsequently, correction factors for the water permeability are assigned to the sealing codes as shown in Table 4-5 and the corrected permeability is multiplied by this factor (see Equation 11).

The result is the water permeability [cm/d] corrected by the distance surface to groundwater and by the degree of surface sealing.

Example

The quality is calculated for t_1 = Coniferous Forest.

Input data: Soil texture = Weakly sandy loam; Distance surface to groundwater = 0,8-10 m (default); Land use type = Coniferous forest.

Step 1: Soil texture = Weakly sandy loam; Table 4-3 → Soil texture class 6. Step 2: Table 2-5 → Permeability group 3. Step 3: Distance surface to groundwater: 0,8-10 m; Table 4-6 → Distance code 3; water permeability group valid → Table 4-8 → mean water permeability = 25 cm/d. Step 4: Land use type = Coniferous Forest → Table 4-4: Sealing code = 5 → Table 4-5: Sealing factor = 0,05 → Mechanical Filtration quality in t1 = Coniferous forest is = 23,75 cm/d, meaning that the water permeability in this time step is 23,75 cm/d.

4.2.4 Biotic Production

The main ecological function of the biotic production potential of an ecosystem is the provision of biomass for the first heterotrophic level of the ecosystem.

This function can be approximately described by the term "Net Primary Production", i.e. the total (=gross) primary productivity of the ecosystem minus the autotrophic respiration. It can be expressed in units of energy (J/m²), carbon (g C/m²) or dry organic matter (e.g. t/ha).

BAITZ (2002) suggests determining the Biotic Production based on different ecosystem ranges, and specify them, depending on declination, soil texture, skeleton content, nutrient supply, water supply, mean annual temperature or erosion sensibility.

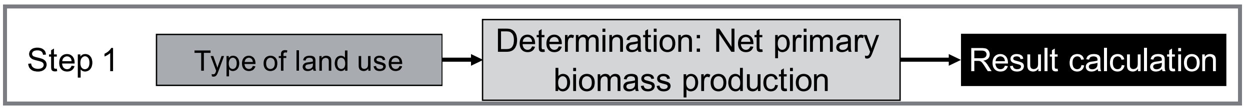

Figure 4-6 **Calculation steps for Biotic Production**

Due to the data situation this approach is not followed in the tool. Instead, as an approximation, for the different types of land use selectable in the tool net primary production factors [g/(m^2*a)] have been determined based on different sources (e.g. LIETH 1975, SCHULTZ 1988, KALUSCHE 1996, BICK 1989, GLCC-EROS 1998). In some cases the factors were corrected depending on the type of use and the degree of sealing. The resulting net biomass production values for the different types of land use as used in the tool are listed in Table 4-9; so the qualities $q(t_1)$-$q(t_4)$ regarding Biotic Production are directly picked from Table 4-9.

Table 4-9 Biotic production

Type of land use	NPP [g/(m²*a)]
Grassland, meadow	500
Wood: Coniferous woodlands	800
Wood: Deciduous woodlands, unspecific	average = 1575
Wood: Deciduous woodlands, summer green	1200
Wood: (Sub-) tropical Rainforest	2200
Wood: Monsoon woodlands	1600
Wood: Temperate zone Rainforest	1300
Wood: Mixed tree woodlands	1420
Forest: Coniferous forest	650
Forest: Deciduous forest	650
Forest: Mixed tree forest	650
Moorland, lawn or fallow with vegetation	500
Permanent crops (field, little surface vegetation)	650
Farmland (no complete surface vegetation)	650
Fallow ground (no surface vegetation)	130
Continuous urban influenced area	0
Non continuous urban influenced area	150
Industrial real estate	0
Road network	0
Railway system	40
Traffic infrastructure area (ports, airports, garages, etc.)	80
Mining area	40

Type of land use	NPP [g/(m²*a)]
Landfill	0
Artificial, not farmed grassland	620
Freshwater	500
Swamp area	2000
Ocean	125
Riff	2500
Estuary	1500
Forest steppe	700
Tropical savannah	700
Temperate savannah	600
Semi-desert	93
Desert, glacier	3
Tundra	140
Alpine area	140

Example

The quality is calculated for t_2 *= Mining area*

Input data: Land use type = Mining area

*Step 1: Table 4-9 → Biotic production quality = 40 g/(m²*a); meaning that in* t_2 *= Mining area, a Biotic Production of 40 g/(m²*a) is present.*

4.2.5 Groundwater Replenishment

The Groundwater Replenishment qualities for t_1-t_4 are calculated according to BAITZ (2002). In addition, a correction dependent on the degree of sealing is carried out.

Input data required is

- Soil texture
- Type of land use

- Precipitation
- Evapotranspiration
- Distance surface to groundwater
- Declination

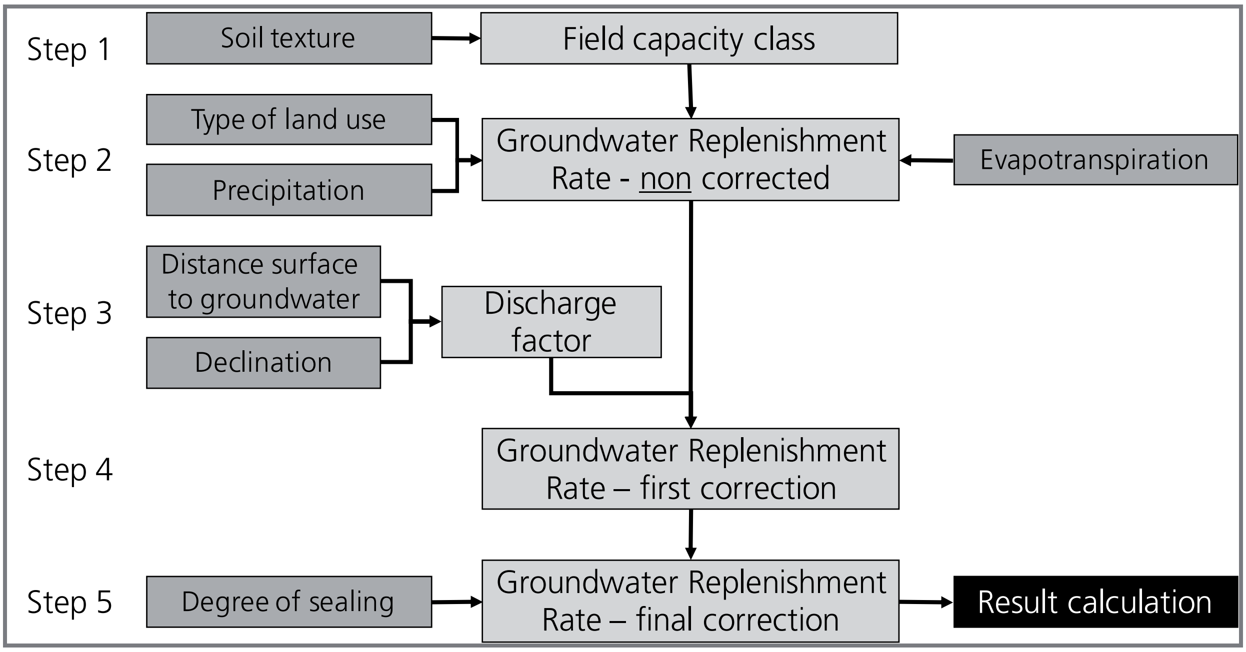

Figure 4-7 **Calculation steps for Groundwater Replenishment**

1. Determination of the field capacity class, considering the soil texture: As in the Erosion Resistance calculation the soil texture has to be entered into the tool and a soil texture code is assigned to the soil texture selected according to Table 4-3. Afterwards the available field capacity class is assigned based on Figure 2-4 as shown in Table 4-10. Field capacity classes are then transformed into the available field capacity nFK [mm] following average values derived from Table 2-7 as suggested by BAITZ (2002).

Table 4-10 **Soil codes and field capacity classes in the tool**

Soil texture	Soil code in the tool	Field capacity class	Soil texture	Soil code in the tool	Field capacity class
No soil cover (rocks, open water)	0	0	Sandy clay loam	21	3
Silt	1	4	Strongly sandy loam	22	4

Soil texture	Soil code in the tool	Field capacity class	Soil texture	Soil code in the tool	Field capacity class
Weakly loamy silt	2	5	Strongly sandy clay	23	3
Medium clay silt	3	5	Strongly loamy sand	24	3
Medium silty loam	4	4	Medium loamy sand	25	3
Medium sandy silt	5	4	Weakly silty sand	26	3
Strongly loamy silt	6	5	Weakly sandy clay	27	3
Sandy loamy silt	7	4	Medium sandy clay	28	3
Strongly clay silt	8	4	Medium clay sand	29	3
Weakly sandy loam	9	4	Weakly loamy sand	30	2
Silty loamy sand	10	4	Cobble	31	1
Strongly silty sand	11	3	Gravel	32	1
Silty loam	12	4	Coarse gravel	33	1
Silty clay loam	13	4	Medium gravel	34	1
Weakly clay loam	14	4	Fine gravel	35	1
Medium sandy loam Silty sandy loam	15	4	Sand	36	1
Medium silty sand	16	3	Clay (max)	37	2
Silty clay	17	3	Clay	38	3
Fine sand	18	1	Medium sand	39	1
Medium clay loam	19	3	Weakly clay sand	40	2
Medium loamy clay	20	3	Coarse sand	41	1

2. Calculation of a non-corrected Groundwater Replenishment Rate, considering precipitation, evapotranspiration, land use type (see Table 4-4) and the determined field capacity class: The user has to enter site-specific mean annual precipitation data [mm/a] and mean annual evapotranspiration [mm/a]. If no value is entered, country-specific data from the tool data base is inserted[37]. Then data is checked regarding its

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[37] Precipitation data is taken from ISRIC WISE 1.1 soil data – ORGC; if no data is available there: assumption 700 mm/a. Evapotranspiration data is taken from AQUASTAT 2003; if no data is available there: 1000 mm/a

suitability for the application of Equation 3 to Equation 6 according to Table 2-6[38].

If the data fits, the groundwater replenishment rate [mm/a] is calculated applying one of these equations. If the data is not within the ranges given in Table 2-6, the groundwater replenishment rate is approximately calculated as the difference between precipitation and evapotranspiration.

3. Evaluation of a discharge factor, considering the distance between surface and groundwater layer and the declination/slope[39] of the studied location: The distance surface to groundwater and the respective code are determined as already shown in step 3 of the Mechanical Filtration calculation. In addition, according to Table 4-11, hydromorphology is determined and hydromorphology classes are assigned to the distance codes in LANCA®.

Table 4-11 Assignment of hydromorphology classes

Distance surface to groundwater	Distance code	Hydromorphology	Hydromorphology class
<0,8 m	1	hydromorph	1
0,8-1,5 m	2	half hydromorph	2
0,8 (1,5)-10 m[40]	3	terrestrial	3
10-30 m	4	terrestrial	3
>30 m	5	terrestrial	3

Furthermore, declination is required. Then the discharge factor DF (A/A_u) is determined combining the hydromorphology class and the declination according to Table 2-8.

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[38] Additionally to Table 2-6, Equation 3 is valid for the Land Use Codes 13,14,15; Equation 4 for the codes 11,12 and 24; Equation 5 for the codes 2,8,9 and 11 and Equation 6 for the codes 3,4,5,6,7 and 10.

[39] If the user does not provide declination data, country-specific generic data from the ISRIC WISE database is used. If for the country no generic data is provided, 0-0,5° are assumed.

[40] Due to the use of two classification systems, the classification applied in the tool here is 0,8-10 m (following BASTIAN 1994, S. 213). So it is up to the user to choose the correct classification: Distance code 3 should only be applied, if the real distance to groundwater is between 1,5 and 10 m.

4. Calculation of a groundwater replenishment rate, being corrected by the discharge (GWR_{dc}): the non-corrected Groundwater Replenishment Rate (GWR_{nc}) calculated in step 2 is corrected by the discharge factor (DF) by division resulting in the Groundwater Replenishment Rate corrected by the discharge:

Equation 12

$$GWR_{dc} = GWR_{nc} / DF$$

5. Correction of the groundwater replenishment rate by considering the degree of anthropogenic sealing: The sealing code as described in step 2 of the Physicochemical Filtration is transformed into a correction factor following Table 4-5.

   In the last step the groundwater replenishment rate is finally calculated by multiplying the Groundwater Replenishment Rate corrected by the discharge with (1-correction factor, see Equation 11).

Example

The quality is calculated for t_4 = Fallow with vegetation

Input data: Soil texture = Weakly sandy loam; Precipitation = 867 mm/a; Evapotranspiration = 840 mm/a; Distance surface to groundwater = 0,8-10 m (default); Declination = 0,5 ° (default); *Land use type = Fallow with vegetation.*

Step 1: Soil texture = Weakly sandy loam; Table 4-10→ *Field capacity class = 4;* Table 2-7→ *nFK = 140-200 mm. Step 2: Land use type = Fallow with vegetation; Precipitation = 867 mm/a; evapotranspiration = 840 mm/a;* Table 2-6*:* Equation 3 - Equation 6 *are not applicable → approximation: Groundwater Replenishment Rate non corrected = 27 mm/a. Step 3: Distance surface to groundwater = 0,8-10 m; Table 4-11→ Hydromorphology class = 3 (terrestrial); declination = 0,5°; Table 2-8→ quotient total runoff / groundwater runoff = 1,0. Step 4: Equation 12→ discharge corrected Groundwater Replenishment Rate: 27 mm/a. Step 5: Land use type = Fallow with vegetation; Table 4-4→ Sealing code 6; Table 4-5→ correction factor = 0; finally corrected Groundwater*

*Replenishment Rate = (1-0)*27 = 27* mm/a. So in *t_4 = Fallow with vegetation, the Groundwater Replenishment is 27 mm/a.*

Completion of exemplary indicator value calculation

For each indicator, in the exemplary calculations, the determination of one of the 4 qualities needed to calculate occupation and transformation indicator values is shown. The other qualities are calculated accordingly. If changes in input data needed are known, they can be accounted for (e.g. change of humus content or evapotranspiration due to land use). Otherwise, only the land use types are changed, leading to different correction factors for land use and sealing (see Table 4-4 and Table 4-5).

Table 4-12 shows the respective qualities.

Table 4-12 Example qualities (rounded)

	Unit	*Q(t_1)*	*Q(t_2)*	*Q(t_3)*	*Q(t_4)*
Erosion Resistance	*[t/(ha*a)]*	2,50E-01	8,38E+01	8,38E+01	5,00E-01
Mechanical Filtration	*[cm/d]*	2,38E+01	1,25E+00	1,25E+00	2,50E+01
Physicochemical Filtration	*[cmol/kg$_{soil}$]*	1,24E+01	6,50E-01	6,50E-01	1,30E+01
Groundwater Replenishment	*[mm/a]*	2,60E+01	1,00E+00	1,00E+00	2,70E+01
Biotic Production	*[g[41]/(m²*a)]*	6,50E+02	4,00E+01	4,00E+01	5,00E+02

For the calculation of indicator values, a land productivity of 1,50E-04m²/a is assumed to produce 1 kg of product. Indicator values for occupation and transformation are calculated according to Equation 9 and Equation 10. Results are shown in Table 4-13.

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[41] g dry mass

Table 4-13 Example indicators not adapted

	Occupation	Unit	Transformation	Unit
Erosion Resistance	-1,25E-06	[t]	3,75E-09	[t/a]
Mechanical Filtration	1,30E+00	[cm*m^2]	1,88E-04	[cm*m^2/d]
Physicochemical Filtration	1,85E-03	[cmol*m^2*a/kg$_{soil}$]	9,75E-05	[cmol*m^2/kg$_{soil}$]
Groundwater Replenishment	3,90E-03	[mm*m^2]	1,50E-04	[(mm*m^2)/a]
Biotic Production	6,90E-02	[g]	-2,25E-02	[g/a]

To follow the general impact theory, positive values should stand for negative impacts. To achieve this, Table 2-9 has to be applied for occupation and Table 4-1 for transformation. Final results are presented in Table 4-14.

Table 4-14 Example indicator results adapted

	Occupation	Unit	Transformation	Unit
Erosion Resistance	1,25E-06	[t]	3,75E-09	[t/a]
Mechanical Filtration	1,30E+00	[cm*m^2]	-1,88E-04	[cm*m^2/d]
Physicochemical Filtration	1,85E-03	[cmol*m^2*a/kg$_{soil}$]	-9,75E-05	[cmol*m^2/kg$_{soil}$]
Groundwater Replenishment	3,90E-03	[mm*m^2]	-1,50E-04	[(mm*m^2)/a]
Biotic Production	6,90E-02	[g]	2,25E-02	[g/a]

The indicator values as shown in Table 4-14 *can then be integrated into the GaBi software or any other LCA software in the technical form of an inventory flow. These flows can be aggregated over process chains and viewed in the balance view.*

5 Conclusions and Outlook

Using the methods described in this report, land use indicator values can be calculated, allowing for an analysis of implications of anthropogenic land use in industrial process chains. Several important land functions respectively Ecosystem Services are regarded to determine the potential impacts on the ecological quality of land. The method is applicable for different processes in a process chain and allows for the aggregation of data along the chains. Site-specific data can be used as well as country-specific data. Applications including sensitivity analyses show that the calculation methods are able to display different on-site conditions.

Same as in all LCIA methods, simplifications of established methods had to be made for being able to adapt them to LCA requirements. Subtle differentiations between land use types such as conventional and organic farming are not possible yet.

One improvement that is currently being worked out is the amelioration of the data basis of the tool: Using freely available GIS data, site-specific input values for LANCA® can be determined at a very detailed geographic scale. Also, high quality average values for any areas of interest can be determined.

Both, methodology and indicators are subject to continuous improvement processes, thus assuring the currentness of the method and the reliability of results.

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Annex

Table 0-1 Translation of soil textures (see Figure 2-2)

Abbreviation	German	English
T	Ton	clay
s‘T	Schwach sandiger Ton	weakly sandy clay
lT	Mittel lehmiger Ton	medium loamy clay
sT	Mittel sandiger Ton	medium sandy clay
sT	Stark sandiger Ton	strongly sandy clay
stL	Schwach sandiger toniger Lehm	weakly sandy clay loam
t’L	Schwach toniger Lehm	weakly clay loam
tL	Mittel toniger Lehm	medium clay loam
utL	Schluffig toniger Lehm	silty clay loam
U	Schluff	silt
l’U	Schwach lehmiger Schluff	weakly loamy silt
lU	Stark lehmiger Schluff	strongly loamy silt
lU	Mittel lehmiger Schluff	medium loamy silt
sU	Mittel sandiger Schluff	medium sandy silt
slU	Sandig lehmiger Schluff	sandy loamy silt
uL	Mittel schluffiger Lehm	medium silty loam
uS	Mittel schluffiger Sand	medium silty sand
ulS	Schluffig lehmiger Sand	silty loamy sand
s‘L	Schwach sandiger Lehm	weakly sandy loam

Abbreviation	German	English
tS	Stark toniger Sand	strongly clay sand
sL	Stark sandiger Lehm	strongly sandy loam
sL	Mittel sandiger Lehm/Schluffig sandiger Lehm	medium sandy loam/silty sandy loam
lS	Stark lehmiger Sand	strongly loamy sand
lS	Mittel lehmiger Sand	medium loamy sand
t'S	Schwach toniger Sand	weakly clay sand
S	Sand	sand
u'S	Schwach schluffiger Sand	weakly silty sand
uS	Stark schluffiger Sand	strongly silty sand
l'S	Schwach lehmiger Sand	weakly loamy sand

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