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A Simple Code of Practice for the Assessment of Surface Runoff Coefficients for Alpine Soil-/Vegetation Units in Torrential Rain (Version 2.0)

In the frame of

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Water Supply Management Measures

Act 7.1

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Preface

The first simple "Code of Practice for assessment of surface runoff coefficients in convective torrential rain (version 1.0)" was presented in 2004. It was based on the results of rain simulation experiments utilising a transportable spray irrigation installation for the assessment of runoff behaviour on typical runoff contributing areas in alpine catchments. These experiments had been carried out at the Department of Natural Hazards of the BFW in Austria and the LfU in Bavaria for more than three decades. These investigations usually have been combined with investigations on site characteristics, e.g. information on vegetation and soil. Data from more than 700 single rain simulation experiments have been stored in a joint database and analysed in detail.

The version 1 of the Code of Practice has evolved into a basic means for the derivation of surface runoff coefficient maps, which are needed to calculate peak runoff and runoff amount in torrent catchment areas in case of extreme precipitation, e.g. the recurrent design event.

Within the last eight years target-oriented spray irrigation experiments have been continued and new insights into runoff development have been gained:

- The Federal Ministery of Agriculture and Forestry, Environment and Water Management funded a project on investigations about runoff development in long duration rain events (Nachtnebel et al. 2005).
- The Austrian Academy of Sciences (ÖAW), Commission of Hydrology, has granted money for research dealing with the theme "Assessment of bandwidths of shallow interflow velocities in alpine catchments".
- Additional results from simulations of torrential rain have been earned in work for BFW-projects and in the frame of orders by the Austrian Avalanche and Torrent Control Service (WLV).

This information and data have been combined with the results of the investigations in the CC-WaterS-Project in Waidhofen a.d. Ybbs and been incorporated into the present version of the "Code of Practice (Version 2.0)".

The authors gratefully acknowledge the help of the institutions mentioned above.

Innsbruck, Munich and Vienna December 2011

LIST OF ABBREVIATIONS

Abbreviation	Explanation	Dimension
AK, AK_{ges}, C, c, ψ, ψ_{tot}	Runoff coefficient = ratio between total runoff and total precipitation	
AK_{const}, ψ_{const}	Runoff coefficient at the point in time when runoff is constant	
AKl	Runoff coefficient class	
BMLFUW	Federal Ministry of Agriculture and Forestry, Environment and Water Management	
BFW	Federal Forest Research Centre - BFW	
Bu	Beech	
GBA	Geological Survey of Austria, Vienna	
DB	Database	
DG	Dominance of vegetation	
dr	Dry	
f	Fresh	
ff	Very fresh - humid	
FBVA	Federal Forest Research Station (= former name of BFW)	
Fi	Spruce	
GVE	Livestock unit	
i_N, i_T	Intensity of precipitation	mm h^{-1}
IWHW-BOKU	Institute for Water Management, Hydrology and Hydraulic Engineering, University of Applied Life Sciences (BOKU), Vienna	
K_S	Saturated hydraulic conductivity	m sec^{-1}, cm h^{-1}
Lä	Larch	
LfU	Bavarian Environment Agency	
mf	Moderately fresh	
n	Wet	
n	Number of samples	
N	Precipitation	mm
ÖAW	Austrian Academy of Sciences	
Q	Runoff	mm, Lt*m^{-2}
RCL	Runoff Coefficient Class	
SR	Surface runoff	
STO	Site(s)	
Ta	Fir	
ÜG	Canopy cover	
ZA	Interflow	
Zi	Cembran pine	
∅	Diameter	
∞	Infinite	

A Simple Code of Practice for the Assessment of Surface Runoff Coefficients for Alpine Soil-/Vegetation Units in Torrential Rain (Version 2.0)

Kurzfassung

Vor über 3 Jahrzehnten wurde am Institut für Naturgefahren des Bundesforschungszentrums für Wald in Innsbruck und Wien und am Bayerischen Landesamt für Umwelt in München mit der Durchführung von Starkregensimulationen und begleitenden Untersuchungen, wie der Erhebung boden- und vegetationskundlicher Kennwerte zur Charakterisierung des Abflussverhaltens beitragender Flächen in Wildbacheinzugsgebieten begonnen. Die Ergebnisse von über 700 Einzelberegnungen wurden in einer gemeinsamen Datenbank zusammengeführt und ausgewertet.

Ein erstes Produkt dieser Auswertungen war die 2004 erschienene „Geländeanleitung zur Abschätzung des Oberflächenabflussbeiwertes bei konvektiven Starkregen (Version 1.0). Sie ist die Basis für die Erstellung von Abflussbeiwertkarten zur Berechnung von Abflussspitze und Abflussfracht beim Bemessungsereignis in Wildbacheinzugsgebieten.

In den letzten acht Jahren wurden am BFW die Beregnungen gezielt weitergeführt und neue Erkenntnisse zum Abflussverhalten erarbeitet. Diese Informationen und einige Anregungen von Anwendern in der Praxis fließen in die vorliegende Version 2.0 der „Provisorischen Geländeanleitung“ ein.

Die gegenständliche Anleitung enthält Hinweise für die quantitative und qualitative Abschätzung des Oberflächenabflussbeiwertes bei Abflusskonstanz, einen Ansatz zur Anschätzung der Rauigkeit der Oberfläche und eine Funktion zur Abschätzung der Initialabstraktion auf beitragenden Flächen in Wildbacheinzugsgebieten. Erste Angaben zu Fließgeschwindigkeiten des Zwischenabflusses und Bildbeispiele zur Beurteilung von Geländesituationen runden die Anleitung ab.

Schlüsselwörter: Abflussbeiwert, Abflussbeiwertkarte, Anlaufzeit, beitragende Fläche, Nutzung, Oberflächenabfluss, oberflächennaher Zwischenabfluss, Oberflächenrauigkeit, Starkregensimulation,

Abstract

Rain simulation experiments utilising a transportable spray irrigation installation for the assessment of runoff behaviour on typical runoff contributing areas in alpine catchments have been carried out at the Department of Natural Hazards of the BFW in Austria and the LfU for more than three decades. These investigations usually have been combined with investigations on site characteristics, e.g. information on vegetation and soil. Data from more than 700 single rain simulation experiments have been stored in a joint database and analysed in detail.

The first product emerging from these analyses has been the simple “Code of Practice for assessment of surface runoff coefficients in convective torrential rain (version 1.0)” - presented in 2004. It has evolved into a basic means for the derivation of surface runoff coefficient maps, which are needed to calculate peak runoff and runoff amount in torrent catchment areas in case of extreme precipitation, e.g. the recurrent design event.
Within the last eight years target-oriented spray irrigation experiments have been continued and new insights into runoff development have been gained. This information and suggestions from practitioners have been incorporated into this present version of the “code of practice (version 2.0)”.
This manual comprises advice for the assessment of surface runoff coefficients and surface roughness as well as a function for the calculation of initial abstraction on runoff contributing areas in alpine catchments. A short list of data on velocities of shallow interflow in Central European geological substrates and pictures illustrating typical field situations bring the manual down to a round figure.

Key words: Cultivation, runoff coefficient, runoff coefficient map, runoff contributing area, runoff delay, shallow interflow, simulation of torrential rain, surface roughness, surface runoff

Contents of this „Code of Practice“

This Manual contains approaches for

- Assessment of surface runoff coefficients when runoff is constant (ψ_{const}) on runoff contributing areas in a qualitative and quantitative manner.
- An approach to assess surface roughness of the hydrological vegetation unit concerned.
- Advice for preparing the mapping of surface runoff coefficients in the field and the set up of the necessary database .
- Advice / references for application of the parameters derived by use of the „„Code of Practice““ in hydrological models.

The BFW and its partners (IWHW-BOKU and GBA) have investigated the question of “runoff behaviour of alpine catchments in persistent rain” in a study financed by BMLFUW (Nachtnebel et al. 2005) and two research projects funded by the ÖAW (Austrian Academy of Sciences, Commission of Hydrology) (Markart et al. 2008, 2010). So this report comprises first results of these investigations in form of

- A diagram to assess surface runoff coefficients in torrential rain and
- A table with examples of bandwidths of shallow interflow in Central European substrates. This table will be amended by results of a literature review and additional day-to-day investigations in the field.

1. Surface runoff in torrential rain

Introduction

When rain intensities increase, surface runoff gets more important (Kirnbauer et al. 2009). Calculation or assessment of runoff coefficients or runoff from runoff contributing areas is often conducted by the use of imprecise data or non site-specific information from literature (e.g. Zeller 1974, 1981; Kölla 1986 or numerous empirical formula).
As a basis for the improvement of knowledge on runoff development, simulations of torrential rain are developed by the Department of Natural Hazards at the Federal Research Centre for Forests in Austria and by the LfU on different alpine soil/vegetation units for more than three decades. The mode of operation of the employed spray irrigation installation is delineated by Karl und Toldrian (1973), Lang (1995), Markart und Kohl (1995).

Runoff-relevant parameters derived from more than 700 rain simulation experiments and accompanying information on soil, vegetation, type and intensity of land use have been calibrated, merged in a database and evaluated for version 1.0 of this "Code of Practice" presented by Markart et al. (2004). Besides the immense effort provided by BFW and LfU, this work has been funded by the Jubilee Fund of the Austrian National Bank (Project No. 7607) and the BMLFUW in the frame of the module MU2 (alpine Valleys – protective function, PIRKL et al. 2000) and a project funded by the BMLFUW (Dept. IV/4). Reports have been presented by Markart et al. 2001, Sotier et al. 2000, 2001, Markart and Sotier 2011)

For the version 2.0 of the „Code of Practice" in hand the BFW-data pool has been augmented with approximately 100 rain simulations (torrential rain and persistent rain) and the results of the corresponding investigations in the field. At the moment the data pool is based on results from more than 40 catchments and regions in the Eastern Alps

The data have been seriously tested by use of statistical analysis to allow the deduction of interrelationships generally valid, e.g. basic conditions favouring development of runoff, like high antecedent soil moisture content for cohesive soils or a high fraction of plants indicating humidity.
Despite the standardized experimental setup of the spray irrigation treatments, every experiment forms a singular event. Therefore an empirical analysis also became necessary, focusing on the target to develop a manual for the assessment of the surface runoff characteristics of the most important hydrological vegetation units of the Eastern Alps – **suitable for practitioners**. First steps to such a „Code of Practice" have been presented by Rickli und Forster (1997), Löhmannsröben et al. (2000), Markart et al. (1999, 2000).

Analyses of data in the database, indicate that many regions of the Eastern Alps are underrepresented, meaning that by far not all runoff-relevant hydrological vegetation units are included in the data pool (Fig. 1).

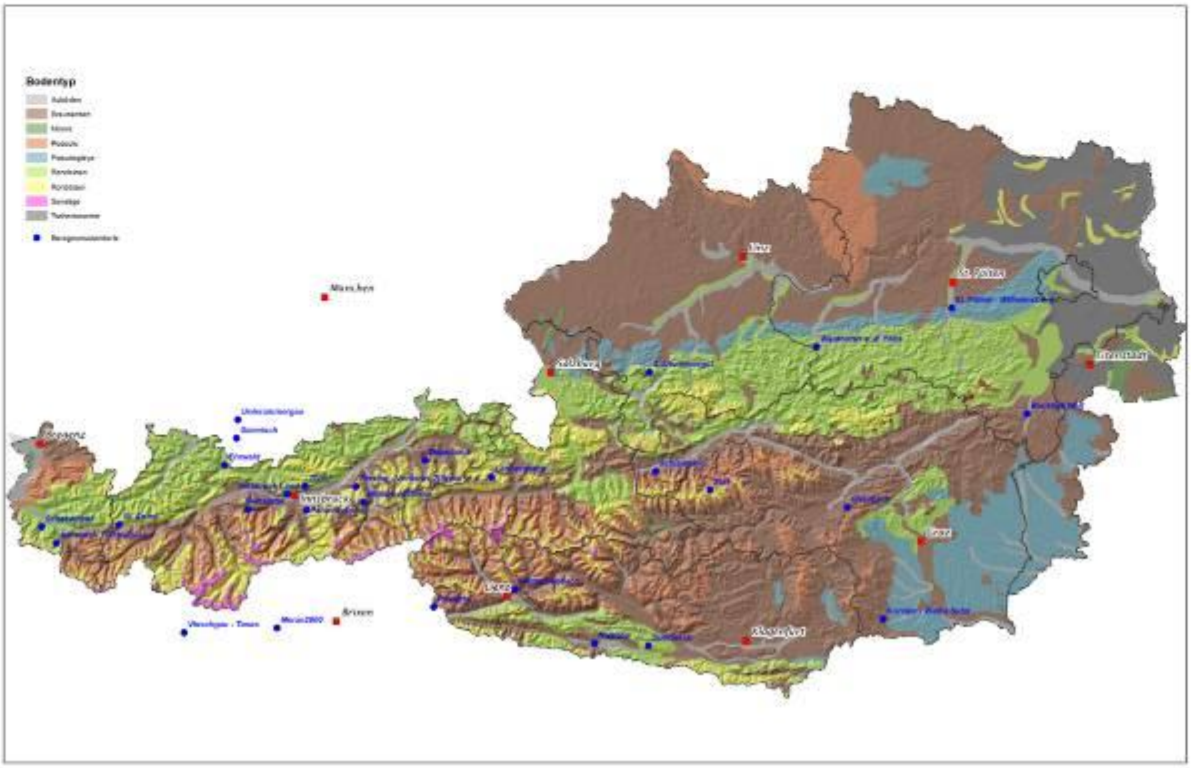


Fig. 1: Catchment areas and regions from where results of rain simulations (torrential rain or persistent rain) are available at BFW.

Future investigations by the Department of Natural Hazards at the BFW will focus on a better coverage of these “white patches”. Therefore also the version 2.0 of the “Code of Practice” in hand must be seen as a provisional solution. It will be optimized further on in dependence of the results of further field investigations, new scientific findings and feedback from the practitioners.

Contents of the manual:

- Chapter 2 comprises terminology and a basic explanation of the “Code of Practice” .
- Chapter 3 outlines the scope of application (which types of precipitation, which type of runoff coefficient, ancillary conditions).
- The most important site conditions influencing runoff behaviour (vegetation, soil, type and intensity of land use, site specific characteristics, etc.) are described in Chapter 4.
- Examples for the choice of the correct hydrological vegetation unit and attribution of surface runoff coefficients on runoff contributing areas (also with heterogeneous vegetation cover) can be found in Chapter 5.

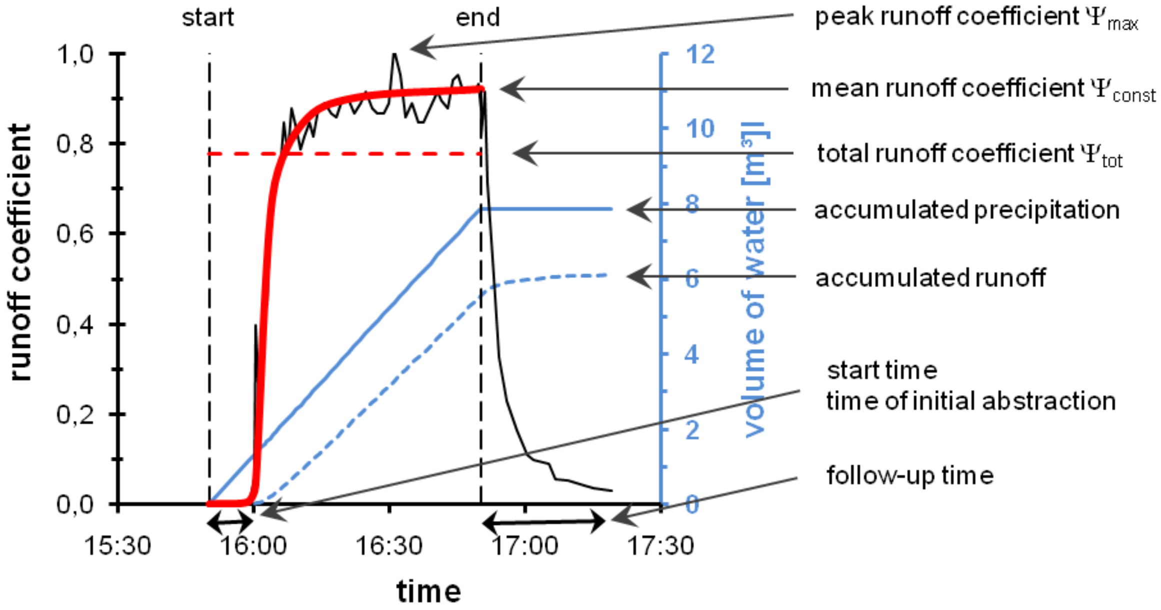
- Hints for the assessment of initial abstraction (delay of runoff formation at the beginning of a precipitation event) and a diagram which can be used for assessment of surface roughness – this factor decisively determines velocity of surface runoff – are described in Chapters 6 and 7.
- The „Code of Practice“ in fact is built-up in the form of tables and offers examples for typical hydrological vegetation units in the Eastern Alps (Annex 1).
- In addition a series of photos of typical sites including information on surface runoff coefficient classes and surface roughness coefficient classes can be found in Annex 2.
- Annex 3 comprises photographs and a list of plants indicating specific runoff characteristics.
- In the last pages of the manual (Annex 4) a standard form for the assessment of runoff characteristics in the field is presented.

2. Definitions

The calculation of design events and concentration times, development of hazard maps and definition of hazard zones in torrent catchment areas are bound to the knowledge of runoff from runoff contributing areas. For an objective characterization of catchment runoff, the following parameters must be known besides topographic information and site characteristics:

- Initial abstraction (runoff delay at the beginning of a precipitation event)
- Surface roughness (for the assessment of flow velocity at the surface)
- Surface runoff coefficient when runoff is constant (ψ_{const})

The following chapters are based on the definitions given by Kohl and Markart (2002) (see Fig. 2.1).



* ψ_{tot}= Total runoff coefficient = relation of total runoff versus fallen precipitation
** ψ_{max} = Peak runoff coefficient = maximum observed surface runoff coefficient
*** ψ_{const} = mean runoff coefficient, when runoff is constant
Start time: Time period between the beginning of the precipitation event and the occurrence of the surface runoff at the measuring point.
Follow-up time = Time period between the end of the precipitation event and the cessation of runoff at the measuring point.

Fig. 2.1: Runoff parameters – Definitions following Kohl and Markart (2002)

3. Design rainfall and application range of the „Code of Practice“

The code is based on results derived from rain simulation experiments on 50-100 m² large plots and rain intensities between 75 and 100 mm h^{-1}. According to investigations conducted by Kainz et al. (1992), a minimum plot size is needed for the simulation of torrential rain events, in order to reach runoff coefficients representing wider parts of a whole catchment area. Therefore only relative values can be achieved by the use of spray irrigation with a plot size of ≤ 10 m², as an extrapolation of such values to similar units in the catchment is extremely limited.

Due to varying ancillary conditions during the field experiments (e.g. changes or limitations of water supply) maintenance of the threshold of 100 or 75 mm h^{-1} was not always possible. Variations and differences of the applied precipitation values have been corrected following the criteria of Kohl et al. (2003) by extrapolating the runoff coefficients derived during the experiment to the threshold intensity of 100 mm h^{-1}. Calculations based on rain simulation experiments using rainfall intensities between 27 and 120 mm h-1 on 26 plots done by Kohl and Markart (2002) show that an increase of i_N from 30 to 100 mm h^{-1} only results in an runoff coefficient increase of 6% (standard deviation = ± 9%). The „Code of Practice“ therefore can be used for the assessment of runoff coefficients for i_N from 30 to 120 mm h^{-1} without any surcharge or deduction.

Which type of runoff coefficient do we assess?

Total surface runoff coefficient during a precipitation event is strongly influenced by the antecedent site conditions (inter alia antecedent moisture content, degree of free micro retention space or hydrophobic effects). Thus start-up time and consequently ψ_{tot} may seriously vary in dependence of the pre-conditions of a precipitation event.

Therefore this „Code of Practice“ is based on the assessment of the runoff coefficient when runoff is constant (Ψ_{const}). In contrast to Ψ_{tot}, Ψ_{const} is less dependent on pre-conditions.
The BFW-spray irrigation experiments show that on surface runoff producing plots Ψ_{const} normally keeps the level achieved during the precedent irrigation in case of a repetition of the experiment and also under different antecedent conditions. Recent experiments indicate that repeated irrigation esp. on cohesive soils with short breaks between the irrigations (15-30 min) only led to a significant increase of Ψ_{const} in the 2nd irrigation phase. Reasons for this effect are under investigation.

Missing branches of the runoff hydrograph (initial abstraction and increase of the hydrograph – a function of surface roughness) are calculated separately (see Chapters 6 an 7)

Which site conditions?

The „Code of Practice“ has been designed for the assessment of potential surface runoff on typical hydrological vegetation units (soil/vegetation complexes). Thus a realistic BAD-CASE-SCENARIO for the catchment under investigation must be assumed, e.g.:

- Heavy rain in midsummer and high antecedent soil water content, e.g. caused by:
    - Heavy thunderstorms following-up a short intermediate dry spell and a preceeding steady rain.
    - Heavy rain on soils with high soil moisture content in spring (after snowmelt)
- Reduced plant coverage (reduced plant dominance) on alpine pastures in mid and late summer.
- Seasonally higher content of hydrophobic organic matter or litter.
- Reduced plant coverage (reduced plant dominance) and increased water repellence on meadows after mowing.

It is the duty of the mapper or the person in charge to clarify under which realistic bad ancillary conditions a precipitation event can occur in the concerned catchment.

4. Structure of the „Code of Practice“

4.1 Hydrological vegetation units

The sites in question are mapped by use of the standard form (listed in Annex 4) and assigned to one of the following units. The definition of the listed vegetation units follows the structure given by Hartl et al. (2001):

- Pioneer vegetation – immature soils
- Grass vegetation, grasslands – meadows
- Dwarf shrub heaths
- Bush associations
- Tall forb associations
- Forests
- Graded and sealed areas

These units are sub-divided into typical hydrological vegetation units of the Eastern Alps:

Pioneer vegetation - immature soils

Grass vegetation, grasslands – meadows

- grasslands (without *Nardus stricta*)
- *Nardus stricta* grasslands
- Meadows
- Marsh areas and low moors (fens)

Dwarf shrub heaths

- Alpenrose and blueberry heath
- Scotch heather (*Erika* sp.)

Bush associations

- Green alder and willow bushes
- Gray alder and willow bushes
- Mountain pine, krummholz

Tall forb associations

Forests

- Coniferous forests
    - Spruce forest, more than 50% spruce (no or sparse ground cover – *Piceetum nudum*)
    - Spruce forest, more than 50% spruce (with herbal layer)
    - “Larch meadows” (canopy cover < 0,3)

- Forests rich in larch (> 50% larch)
- Forests rich in *Pinus cembra* (Cembran pine)
- Pinewood

- Deciduous forests and mixed forests (deciduous and coniferous trees)

Graded and sealed areas

Surfaces changed by mechanical impact like roads, embankments, parking lots, ski pistes, urban areas, etc.

By use of the schemes in Annex 1 the correct runoff coefficient class can be attributed to a hydrological unit in dependence of the soil characteristics, land use, sites specifics and indicative function of the vegetation (e.g. humidity value).

An example showing the structure of such a classification scheme is given in Table 4.1.1.

The runoff behaviour of every hydrological vegetation unit is determined by the following parameters:

- **Soil**
- **Land use / site characteristics (particularities)**
- **Vegetation**

On loose soil with a high content in soil skeleton, high pore volume and combined with plants indicating very good site conditions (good aeration, low humidity value), a low surface runoff coefficient is to be expected.

Conversely, on sites with cohesive, dense soils, a high degree of anthropogenic disruption (e.g. intensive land use) and negative plant indicators (bad aeration, high humidity), high runoff coefficients must be expected.

Table 4.1.1: Scheme to assess the „correct“ surface runoff coefficient. The mean runoff coefficient may be used for rough calculations.

Vegetation-unit	Soil	Land use / specific characteristics	Plant inicator value	RCL	Ψ_{const}
Hydrological vegetation unit (dwarf shrub heath, forest, grasslands…)	Coarse soil, loose	No land use – mechanical impact / no additional load, no soil wetness, no network of small channels	dr - mf	**0**	0
				1	0,05
	↓	↓	↓	**2**	0,2
				3	0,4
	Fine soil, cohesive, dense	Intensive load, intensive pasturing, accumulation of von depression lines, …	w	**4**	0,625
				5	0,875
	dense	bare sheet of water, asphalt, concrete, rock, …	w	**6**	1

The indicative function of soils, type and intensity of land use, site specific characteristics and vegetation are discussed in more detail in the following chapters.

4.2 Indicative function of soils

Systematic description of soils in this work follows the classification system of the “Identification of Austrian Soils” by Kilian et al. (2002) or the Austrian Soil Classification System (Nestroy et al. 2000).

In alpine catchments localised holes in the ground or outcrops are rare. In addition the time for gathering pedological information (e.g. by retrieving soil samples, digging profiles, etc.) is limited in practice. Thus, the only soil information, which can be easily gathered in the field, e.g. information from open embankments of forest roads, eroded parts of slopes, etc. shall be integrated in the site analysis. However, such openings must be prepared before doing an interpretation of soils physical aspects: For instance, it makes sense to make a small test pit by using a small spade at an open road embankment or an outcrop. Only by doing so, naturally layered soil can be reached and soil physical characteristics (e.g. texture by use of the “finger test” – see Blum et al. 2001) can be assessed in the correct manner.

Infiltration of precipitation into the soil is primarily governed by macro pores (Burch et al. 1989). The depth of penetration is mainly influenced by the soil structure, i.e. whether soil is densely or loosely layered (Czell 1972). For this reason the „Code of Practice“ is substantially based on following pedological features:

- Content of coarse soil and fine soil: The higher the content of parts with a diameter >2 mm, the faster the infiltration process. The higher the volume of fine particles – especially silt (0,063 mm - 0,002 mm ∅) and clay (< 0,002 mm ∅) – the slower the infiltration process into the soil matrix. It is important to note, whether the soil is supported by the soil skeleton or the soil matrix (Fig. 4.2)?
    - Supported by soil matrix: Coarse components are „swimming“ within the fines. This composition influences soil characteristics directly. Such a soil is mostly compact and dense. Packed in a silty or clayey matrix, coarse components cannot adopt the function of the soil skeleton, the coarse components do not have any infiltration-elevating effect.
    - Supported by soil skeleton: The soil is reinforced by coarse components (> 2 mm diameter), the coarse elements form a skeleton by holding up each other. Generally drain pore volume is much higher in soil supported by soil skeleton.

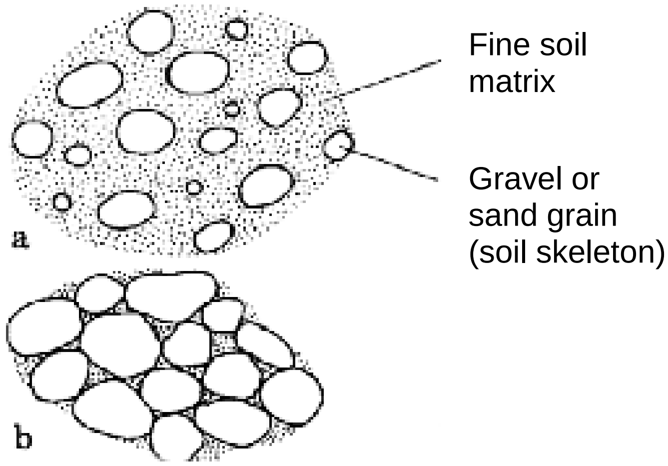


Fig. 4.2: Examples of soil structure: a) soil supported by soil matrix, b) soil supported by soil skeleton or grains

- Stratification of soil: Loose bedding allows easy infiltration into deeper soil horizons. With increasing bulk density the content of drain pores decreases, infiltration is limited.
- Deepness of soil: Especially on (very) shallow soils on steep slopes with a solid rock base quite close to the surface, infiltration of precipitation is often limited and water frequently comes back to the surface after a short passage along the impermeable soil–solid rock -layer in the form of a concentrated return flow and makes a significant contribution to direct linear surface runoff (Mendel 2000). For information on the classification of soil deepness see Tab. 4.2.2.

The simple soil-classification-scheme in Tab. 4.2.1 focuses on the parameters fines / coarse fraction and soil bedding / density. The classification has been derived from the American Society for Testing Materials (1966), DIN 18196 (1988), Schriftleitner und Smoltczyk (1990) und Prinz (1991) and in addition is based on the results of numerous soil analyses done at the lab of the BFW in Innsbruck.

Note:
Users of version 1 of this „Code of Practice“ repeatedly requested to be able to assign a definite bandwidth of K_S-values to each soil class in tab. 4.2.1. This wish cannot be fulfilled, because there is a big discrepancy between K_S-values measured in the lab and effective hydraulic conductivity in the field. In addition the analysed soil physical data show high values of statistical variance. Corresponding to Renger et al. (2008) the evaluation of soil physical data would additionally require the integration of information about the basic substrate and genetic characteristics of the soil in question. Therefore a high analytical effort would be necessary to assign K_S-values to each of the five soil classes, therefore the accuracy of these values would be very low.

Tab. 4.2.1: Rough soil-classification by dependence on infiltration behaviour.

Pos.	Soil	Description	Example
1	**Coarse soils loose**	**Coarse grained soils, rich in coarse fraction (sand, gravel, stones),** **supported by soil skeleton** **Hydraulic conductivity: Very high**	
2	**Coarse grained soils, rich in skeleton with fines, loose**	**Rich in skeleton, coarse grained to mixed grained soils,** rich in coarse fraction (sand, gravel, stones), content of clay and fine silt: <20% At least partly **supported by soil skeleton** **Hydraulic conductivity: Very high to -medium**	
3	**Fine soils** with small content of coarse fraction **loose**	**Mixed grained to fine grained soils** Content of silt and clay up to 40% **Supported by soil matrix, only partly supported by soil skeleton** **Hydraulic conductivity: Very high to medium**	

4	**Fine grained soils - cohesive**	These mixed grained to fine grained soils show higher content of silt and clay (> 40%), they are cohesive - ductile The coarse fraction present in the soil is only hydrologically relevant during dry periods (shrinkage cracks) **Supported by soil matrix Hydraulic conductivity: Medium to low,** bonding capacity for water is significant to high. Ductile properties vary in dependence of water content.	
5	**Fine grained soils, compacted, dense**	**Infiltration behaviour** of coarse grained soils with fines and the characteristics of fine grained soils is **reduced by mechanical impact** (passing over with heavy machines, levelled areas, pastures,…) **Supported by soil matrix** If fine grained loose soils are levelled and compacted they should be assigned to this class	

Tab. 4.2.2: Depth of forest soils (after Blum et al. 1996):

Soil depth (class)	**Soil depth** (cm)
Very shallow	< 15
Shallow	15-30
Medium depth	30-60
Deep	60-120
Very deep	> 120

4.3 Land use and special site characteristics - Indicators

4.3.1 Effects of mechanical impact and technical measures

Examples of different types of land use and their effects on infiltration characteristics in dependence of soil properties (coarse fraction / fines and stratification) are given in Table 4.3.1. This information is based upon statistical and empirical analyses (inter alia Markart et al. 2001, Sotier et al. 2002, Markart und Kohl 2003, Markart et al. 2006).

Type and intensity of land use and cultivation affect infiltration characteristics in a specific manner. Most anthropogenic exploitation methods (levelling, passing over, pasture – compaction by livestock, soil damages during harvesting, etc.) present a mechanic soil load and mostly result in a decrease in infiltration capacity of alpine soils during torrential rain (inter alia Schiechtl 1954, Müller 1988, Schauer 1988, Bunza und Schauer 1989, Schreiber 1997, Markart et al. 2000, Markart und Kohl 2000, 2003; Markart et al. 2006).
On levelled areas moderate runoff coefficients are only achieved on coarsely textured parental material (Hagen et al. 1993). However, due to“landscape-cosmetic” reasons a lot of effort is invested in greening such sites (application of natural topsoil, grass-seeds,…). Under mechanical impact, i.e. pasturing or passing over with heavy machines, the topsoil applied to these greened areas is compacted within a short time span. This consequently results in a drastic increase of surface runoff during torrential rain, despite the extremely permeable substratum (Markart und Kohl 2003, Schauer 1988).

Table .4.3.1: Effects of different types of land use, impacts and measures on surface runoff in torrential rain in dependence of the underlying substratum.

Type of land use / impact	Effect on surface runoff in dependence of soil conditions			
	Coarse soil, rich in soil skeleton, loose	Coarse soil, rich in soil skeleton with fines, loose	Fine soil, loose	Fine soil cohesive
Grading / levelling	+/-	-	--	--
Extensive pasturing	+/-	+/-	--	--
Intensive pasturing	-	--	---	--
Extensive passing over	+/-	-	--	-
Intensive passing over	-	--	--	--
Levelling + additional loading (pasturing, passing over, grooming of ski pistes)	+/-	--	---	--
Utilization of wood	(+/-)	(+/-)	(+/-)(-)	(-)/(--)
Drainage	+/-	+/-	+	++
Manuring	+/-	+/-	++	+
Bioengineering measures (covered seed measures…)	+/-	+	+++	++

Legend of symbols:

+/-	indifferent, marginal degradation	(-)
-	significant degradation	
--	severe degradation	
---	extreme degradation	
()	temporary, reversible	
+/-	indifferent, marginal improvement	(+)
+	significant improvement	
++	severe improvement	
+++	extreme improvement	

Pasturing

Pasturing is one of the most common land use types in alpine catchments. Pasturing intensity varies seasonally, effects on runoff development can generally only be assessed due to visible traces in the field.

In the course of the analysis of the results of the heavy rain simulations at BFW, different intensities of pasturing have been discerned (see Table 4.3.2). By the term “intensity” we mean the effect upon the soil/vegetation complex, i.e. the same number of livestock units (GVE) has different effects on fine grained soils and steep slopes or on coarse grained planar soils .

Thus conclusions from the number of GVE regarding the effects of pasturing on runoff development are of limited explanatory power. The factor GVE only gives

limited information about the seasonal and spatial distribution of livestock on alpine pastures.
Numerous plants give us hints to the pasturing intensity of a site:

- There are indicator species for severe compaction, e.g. as a consequence of too high pasturing intensities. Among these are: *Juncus effusus*, *Juncus articulatus*, *Deschampsia cespitosa* – also indicating water-logging).
- Many pasturing-indicators are cultivated by negative selection. Livestock do not like these species, which increases the progeny of these plants: gentian sp. (because of bitterness), *Nardus stricta* and thistles, like C*arlina acaulis* Ci*rsium spinosissimum*. Additional pasturing indicators, i.e. species quite common to alpine pastures are: *Poa supina*, *Poa alpina*, *Cynosurus cristatus*, *Phleum alpinum*, *Trifolium repens*, *Ranunculus repens*, *Rumex obtusifolius* and *Rumex alpinus*, *Senecio alpinus*, *Plantago lanceolata*, *Plantago alpina* and *Plantago atrata*, *Crepis aurea*.

Further information about indicator species see Schauer and Caspari (2001, 2008), Schmeil - Fitschen (1982).

Table 4.3.2: Characteristics allowing the assessment of pasturing intensity and pasturing effects.

Pasturing intensity	**Characteristics**
None	
Marginal/moderate	Traces of single steps of livestock, pasturing rather linear – e.g. connection / track between two pastures; sporadic traces of dung. Additionally in forests: Damaged tree-roots lugs (sporadic)
Medium	Significant traces of livestock steps, but nowhere reduction of plant dominance below 0,7. Short-time pasturing on meadows in autumn (one to two weeks intensively grazed): This type of land use is very badly visible esp. in early summer when the grass is high. Pasturing indicators visible. In forests: Damaged tree-roots, traces of damages on young trees caused by livestock.
Intensive	Intensive soil damages (animal steps), Numerous pasturing-indicators – plants indicating pasturing and soil compaction, e.g. *Juncus sp., Ranunculus repens, Deschampsia cespitosa, Mentha longifolia*). Accumulation of plants indicating rest-places of livestock (e.g. *rumex* sp.) Esp. on steep slopes (coarse soils with fines): Fine grained soils and cohesive soils show a significant reduction of visible plant dominance (< 0,7) esp. during and after humid periods. Development of livestock tracks, partially bare und eroded. In planar position (esp. on fine grained and cohesive soils): Very

	extensive loss of plant cover due to livestock steps, accumulation of steps by livestock, visible compaction of topsoil (e.g. impact by horses) Accumulation of excrement (dung). Only visible at ground openings: Layered topsoil In forests: Accumulation of damaged tree-roots, damages by livestock steps, numerous damaged young trees.
Former pasturing	On steep slopes: Livestock tracks (coadunate) and / or vivid micro-relief (coadunate livestock steps). At the soil profile: More compacted soil layers (in 5-10 cm soil depth) – in coarse grained soils with high content of fines, fine grained soils and cohesive / dense soils.

Without additional information (GVE, date of bringing cattle up to the alpine pastures, duration of pasturing, knowledge of plant indicators,…) only the three pasturing intensities:

No pasturing
Marginal/moderate pasturing
Intensive pasturing.

can be distinguished.

Effects of pasturing are visible in the landscape from spring to autumn (steps, dung). Best visibility is possible in late summer.

4.3.2 Irrigation and drainage

Irrigation and drainage systems increase base flow, thereby free soil water storage volume and retention capacity of the soils are increased.

Fig. 4.3.2**:** Small channel irrigation system (Waal) in the Brixenbach Valley (Tyrol / Austria).
Such systems require accurate maintenance. Lacking maintenance increases the soil moisture content of the slope, thereby the retention capacity of the soils is reduced. The stability of slopes rich in fines is also reduced.

In the direct zone of influence of the drainage systems a more rapid runoff reaction to precipitation must be expected. Additionally irrigation along small channel systems (so-called “Waale”) are quite common in the Alps (Fig. 4.3.2).

Lacking maintenance of such systems often results in water-logging and a destabilization of whole slopes. Such “secondary” soil wetness often is the consequence of unregulated extensification. On such sites unregulated pasturing will be followed by a direct and rapid formation of runoff in heavy rain (Markart et al. 1996).

Security offered by uncontrolled shrub encroachment or reforestation respectively may be tricky, because even shrubs and / or tree vegetation are not able to buffer the total increase of surface water and interflow. During the persistent rain events on 22nd/23rd August 2005 in the Bregenzerwald (Vorarlberg / Austria) landslides in forested areas have preferentially been observed in forests becoming overgrown in an unregulated manner (former alpine pastures - Markart et al. 2007). Changes in land use may alter the frequency of landslides (Caviezel et al. 2011).

4.3.3 Influence of dominance (DG) of plant cover

Spray irrigation experiments done by Markart and Kohl (1995) in the Löhnersbach catchment (Salzburg / Austria), Markart et al. (2000) in Meran 2000 (South Tyrol / Italia) und Kohl et al. (2002) in the Größsölk Valley (Styria / Austria) resulted in significantly lower runoff volume on bare loose soil in relation to fully vegetated plots at the beginning of the experiment. During the first phase of the precipitation event soil aggregates are smashed by the high kinetic energy of the raindrops, the ejected drops take fines with them, which are washed in at other points and seal the soil surface (Ghadiri und Payne 1988). In a second step the formation of surface runoff begins, runoff after few decimeters to meters concentrates in deep lines (linear runoff and linear erosion). Due to the rapid moisture penetration of the topsoil the material turns into papescent-liquid, the coefficient of friction is exceeded. Consequently gullies, shallow landslides and other forms of erosion appear (see Fig. 4.3.3.1 - from Markart et al. 2011).

Fig. 4.3.3.1: Simulation of torrential rain on a fine grained soil (with no coarse material embedded in the matrix) without vegetation. A few minutes after the start of the experiment, the moisture has penetrated and sealed the topsoil, linear erosion begins (pictures from Markart et al. 2011).

With convenient spray irrigation installations for large plots it is only possible to reproduce the intensity of torrential rain events in a realistic manner but not the kinetic energy and the drop size.
In case of decreasing dominance of ground cover (increase of runoff and erosion potential below a DG of 70% - Dadkhah and Gifford 1980) the erosive force of natural heavy rain is dramatically underestimated by artificial spray irrigation experiments.
Thus, to attribute the correct runoff coefficients, the dominance of ground cover (DG) always has to be taken into account. This is especially valid for land cover units where the DG varies seasonally, e.g. due to grazing or mowing (Fig. 4.3.3.2).

Fig. 4.3.3.2: Reduced dominance on grassland after mowing
Left picture – DG = 50%
Right picture – DG = 30%

4.3.4 Effects of slope inclination

Available results from heavy rain simulations done by the BFW and LfU do not show a direct relationship between slope inclination and surface runoff in heavy rain. The effect of slope gradient often is overlaid by a combination of other factors:

- braking effect of ground cover / vegetation = effect of surface roughness.
- retention and breaking effect by micro relief or stones on the soil surface

With decreasing dominance of the vegetation the effect of slope gradient increases (critical value of ground cover: 70%)

Increase of pore water pressure may lead to “slope explosions” especially at flat slope sections, below sections of slope increase and subsequently concentrated linear runoff from these eroded areas (Andrecs et al. 2002).
Generally sheet flow takes place only over short distances. Especially on steep (grassy) slopes runoff immediately concentrates after short distances (few meters) in deep lines. This fine perennial channel network can be easily reproduced with the

help of plant indicator values (Fig. 4.3.4.1). The deep lines / vegetation covered perennial channel network shows a higher content of humidity-indicating plants than the surrounding parts of the slope (Fig. 4.3.4.2).

Fig. 4.3.4.1: Even on plots appearing quite homogenous to the human eye, surface flow concentrates within a short distance in deep lines. On sloped ground sheet flow changes to linear flow after a few meters.

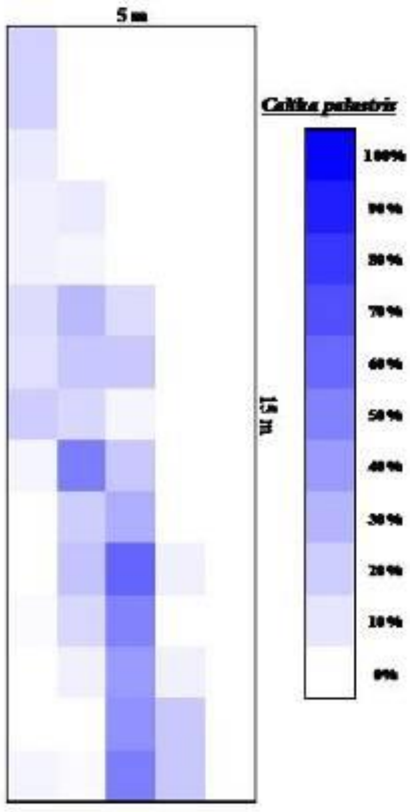


Fig. 4.3.4.2: Preferential surface runoff path indicated by *caltha palustris*.

4.3.5 Bioturbation in the soil

Intensive grubbing e.g. by mice, moles, etc. increases infiltration on alpine grassland (even on pastures and ski pistes). The percentage of shallow interflow and near surface interflow increases, as does the the probability of return flow (resurgence of already infiltrated water), e.g. near slope sides. Often high activity of rodents on alpine pastures and ski pistes can be seen as an indicator of good maintenance (e.g. periodical manuring with barn manure)

4.3.6 Effects of forest vegetation

The effects of stem number and tree utilization on catchment runoff have been discussed in numerous papers. Roughly simplified the following rules concerning the effect of forest management on runoff development can be stated:

- The more biomass is taken out from the forest, the higher the runoff increase.
- Increase of runoff is highest directly after tree utilization and decreases in the years after the usage following a logarithmic function.
- The higher the reduction of the stem number is at the beginning, the longer tree utilization effects are visible.
- Runoff increase after tree utilization can be measured mainly during half tide water and flood water

Canopy cover

Besides substratum, combination of species and possible additional types of utilization forest canopy cover (CC) is of great importance.

For optimal buffering of the kinetic energy of precipitation, the CC should have values between 0,7 and 0,9. On stands with CC-values lower than 0,7, dominated by conifers und incomplete ground cover (< 70% coverage) medium to high disposition for the development of surface runoff must be expected, except on sites rich in coarse grained substratum.

Fig. 4.3.6:
A spruce stand with too high stand density without understory and marginal ground cover. The runoff disposition is higher than in a well structured spruce stand.

CC values below 0,5: Runoff behaviour is increasingly determined by ground cover and soil conditions - forest-effects (interception, breaking of kinetic energy of the raindrops) decrease. In beech stands a significant increase of catchment runoff can only be observed when the stand density is reduced significantly below the natural critical stand density value (Führer 1988).

Stands with a too high density must be seen critically (Fig. 4.3.6).
The stability of the stand decreases due to high H/D-values and weak / one-sided crowns on the one hand while on the other, due to the darkness in the stand, ground cover is missing. In such (coniferous) stands hydrophobic substances are often formed in the organic layer and at the top of the mineral soil (i.e. *Piceetum nudum*, Fig. 4.3.6), therefore a significant increase of surface runoff often is the consequence (e.g. Doerr et al. 2003, see also Chapter 4.3.7).

4.3.7 Hydrophobic effects due to dryness – thatched roof effect

During the vegetation period runoff conditions vary in many cases (Kohl und Markart 2002). Esp. on alpine pastures soil cover is reduced by the pasturing activity (damages by livestock steps), plant growth decreases in midsummer, content of dead organic matter and hydrophobic substances in the organic layer and the mineral topsoil increases. Plants like *Nardus stricta* (matgrass) or different *Festuca*-species accumulate dead biomass and form a dense net of roots in the topsoil. Decomposition of their decay products takes a long time, they become hydrophobic and the dead leaf sheaths act like a “thatched roof” (Markart und Kohl 1995, Markart et al. 1996 a, b; Markart et al. 1997, Markart et al. 2000).
On intensively used pastures with *Nardus stricta,* but also on fine grained levelled areas, periodical application of stall manure stimulates bioturbation and decay of the dead biomass; in doing so the surface runoff coefficient can be lowered by about one runoff coefficient class (Markart et al. 1999, see also classification scheme for matgrass – *Nardus stricta* in Annex 3). By high mechanical load, e.g. during intensive pasturing or passing over with heavy machines esp. under humid conditions the positive effects of manuring are often nullified within a short period.

In dense spruce stands (e.g. thickets, ploe stage – not thinned for a long time) without understory, humic layers may act hydrophobic during and after dry periods (Markart und Kohl 2003). Greiffenhagen (2005) proved hydrophobic effects take place under pine throughout the whole year. However, hydrophobic effects were especially high in periods of dryness. Such effects favour – in combination with a smooth relief – formation of surface runoff (Fig. 4.3.6).
Hydrophobic effects can also be observed on loosely structured dwarf shrubs on dry sites with moor as an organic layer and/or fine grained topsoil (e.g. *Erica* sp. at sun exposed ridges): However, such areas are normally of less importance in torrent catchments.

4.3.8 Effects of antecedent moisture content

Antecedent moisture content / antecedent precipitation events determine available free storage in the soil.

When runoff is constant, the runoff coefficient (Ψ_{const}) varies only to a slight extent in dependence of antecedent moisture content – as shown by the results of Kohl und Markart (2003). However, high antecedent soil moisture expresses itself in a significant reduction of runoff start time. This is proved by analyses of numerous heavy rain simulations with measurements of soil moisture in different soil depths (e.g. Kohl 2004, Markart und Kohl 2003). Stochastic sensitivity analyses of precipitation /runoff simulations for convective events with low frequency in three small catchments by Castillo et al. (2003) showed the same results.

High discharge rates and rapid reaction must be expected on humid and wet areas (low moors / fens, marsh areas, secondary wet areas – e.g. alpine pastures without managed water channel systems). Such areas are water-logged to a high extent except in longer dry periods.

Greenlands and re-vegetated / greened / levelled areas react very sensitively to high antecedent moisture content with rapid runoff formation. Forest sites reflect this effect on a significantly lower level.

Soils under dwarf shrub heath (Alpenrose, blueberry,…) generally show a well balanced soil humidity and high retention capacity, also due to the organic layer (moor - raw humus).

Despite of this fact, assignment of runoff coefficients to some types of dwarf shrubs must be carefully examined. Alpenrose (*Rhododendron ferrugineum*) is often native to fresh sites as well as areas with permanently high water content. Thus Alpenrose-heath locations must be checked for humidity indicators (e.g. plants like *Sphagnum sp.*) or other indicators (e.g. accumulation of small watercourses, dense small channel network).

Spray irrigation of a wet slope with *Rhododendron ferrugineum* and *Sphagnum sp*. showed better precipitation buffer effects in relation to a wet alpine pasture in the same area. Under identical soil moisture the runoff coefficient of the Alpenrose heath was significantly lower (ψ_{const} = 0,8) than that of the pasture ((ψ_{const} = 1,0). Furthermore the time of initial abstraction of the Alpenrose heath is much longer due to its multilayer structure, in relation to sites with a similar moisture content.

4.3.9 Density of channel network, slope water

Channel network density is an expression of the geological characteristics. Soils developed from weathering of marl or similar rocks like phyillites, mica shist, etc. limit water percolation and are prone to erosion. Surface runoff easily changes to linear erosion (gully erosion).

Relief formation often gives significant hints to runoff formation at a site. The slopes of the Pfannhorn near Toblach (South Tyrol / Italy) impressively show that surface runoff on the loosened substrate increases in dependence of decreasing vegetation cover and increasing slope inclination (Fig. 4.3.1 - between gully no. 10 und gully no. 5). The channel network of the less steep slopes adjacent to gully no. 5 are intensively covered by Alpenrose heath is less distinctive.

An accumulation of small channel networks and gullies can also be observed

- Below steep rock formations and flanks of gravel
- In fold flanks with intensive slope water movement
- In marsh areas and moors of greater extension

Generally high surface runoff discharge rates must be expected (RCl **5, 6**) from such areas see Fig.4.3.2.

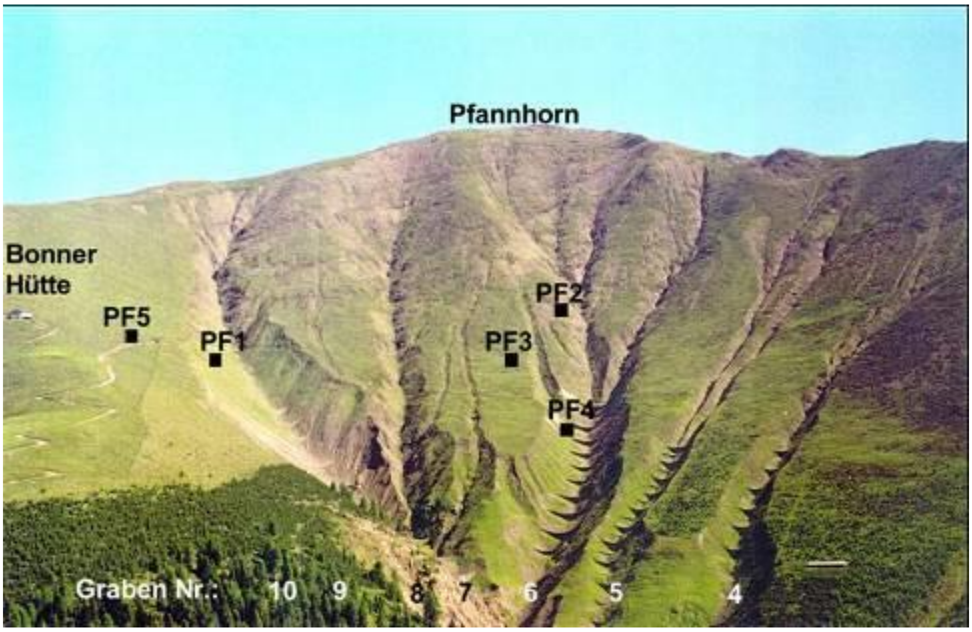


Fig.4.3.1: System of gullies and deep lines at the slopes of the Pfannhorn near Toblach in the Pustertal (South Tyrol / Italy). The steeper the slope and the lower ground cover (e.g. by dwarf shrub heath or forest vegetation), the more intensive the channel network and the rift system.

Photo: W. Gallmetzer

Fig. 4.3.2: Riederbach catchment (right sided contributory brook to the Gerlosbach, Ziller Valley, Tyrol, Austria): Dense channel network at the slopes with high water supply all year round serve as indicators for high surface runoff.

Photo: H. Pirkl

4.4 Indicative function of the vegetation, humidity indicator values

Vegetation units and vegetation forms indicate site conditions, especially the predominant humidity conditions. This allows conclusions about potential runoff behaviour (Schauer 1992, Kohl 2000). The knowledge of common plants in the Alps allows a good characterization of the runoff situation at a site in question. Pictures of some important indicator-plants are enclosed in Annex 3

The indicator values derived from single plants, e.g. after Ellenberg (1986), Ellenberg et al. (1991) or Landolt (1977) are too broad for the direct application in practice (attribution of a runoff coefficient) as indicated by the analyses of the results of the spray irrigation simulations at LfU following vegetation criteria (Schauer 2002).
Schauer's analyses gave no differences for the humidity classes **dr** (dry) to **mf** (moderately fresh). For the assessment of runoff characteristics using indicator plants, a concentrated classification system can be utilised (Table 4.4):

Table 4.4: Indicator values of the ground vegetation (after Schauer 2002)

mf	dry – moderately fresh
f	fresh
ff	very fresh - humid
n	very humid - wet

4.5 Runoff coefficient classes

Runoff behaviour varies in dependence of different ancillary conditions (seasonal fluctuation of soil moisture, intensity of bioturbation, development of vegetation, type and intensity of land use, etc.). Thus the assessment of surface runoff coefficients is meaningful only in the frame of bandwidths. The present „Code of Practice" is grouped as a system with 7 runoff coefficient classes (RCL - Table. 4.5).

- Runoff coefficient class **0** comprises areas which will not produce surface runoff in any case, e.g. (coarse) blocky rock fans.
- Sites with dwarf shrub heath like Alpenrose, blueberry or forests with a dense understory of dwarf shrubs on loose soil and without permanent high moisture content, have a very low disposition for formation of surface runoff . Such units can normally be classified as RCL **1**. The reaction of such units can be classified very precisely, therefore the bandwidth of this class is narrow (only 10% of a torrential rain event will contribute to surface runoff).
- With increasing runoff disposition, the discretisation of the different units gets more difficult. For instance: Well managed meadows (no pasturing) can be assigned to RCL **2**. However, already a small additional utilization or load – often not distinguishable for the mapper in the field – like short time grazing in

autumn or temporary passing over with technical equipment, results in an increase of runoff potential (RCL **3**).

- With an increasing degree of land use (levelled areas, ski pistes, pastures, grazed meadows, pastured forests, etc.) and generally on cohesive soils, runoff disposition is higher. However, classification of these units is more difficult - therefore the runoff classes **4** and **5** are broader in relation to RCL **1-3**.
- (Nearly) 100% runoff must be expected from stagnant water bodies, saturated areas (e.g. low moors / fens), plane rock or sealed, dense sites (RCL **6**).

Table 4.5: Runoff coefficient classes (RCL) – the colouring follows the concept of a traffic light: **green** = positive runoff characteristics, **red** = danger, therefore: **Dark green** = best runoff characteristics, **light green** = moderate SR, **yellow** characterises medium runoff characteristics, **red** = sites with a high surface runoff disposition, **blue** = wet or non-receptible areas.

Runoff coefficient class (RCL)	**Surface runoff in % of precipitation**
0	0
1	> 0 - 10
2	11 - 30
3	31 - 50
4	51 - 75
5	> 75
6	1,0 (wet, sealed areas)

4.6 Attribution of runoff coefficients

Runoff coefficients can be assigned to different types of land cover or hydrological vegetation units (Chapter 4.1) by evaluating the site characteristics in Chapters 4.2-4.4. Assignment of runoff coefficients follows the principle given to the scheme in Table 4.6.

Table.4.6: Assignment of surface runoff coefficients to hydrological vegetation units in dependence of soil conditions (see Chapter 4.2), land use and site-specific characteristics (see Chapter 4.3), as well as humidity class (see. Chapter 4.4). Example: Spruce forest without understory and only marginal ground cover.

Vegetation-unit	Soil	Land use; spec. site characteristics	Indicator values Humidity	Runoff coefficient class
Spruce forest, > 50% spruce no or little ground cover - nudum)	**Coarse grained soil,** also with fines, loose		mf-f	1
	Coarse grained soil with fines/ fine grained soil	Moor layer - dry		2
		Moderate pasturing; moor layer - dry		3
	Fine grained soil, dense	Slope water, intensive pasturing	mf-ff	4
	Fine grained soil, cohesive, dense	Soil wetness, cumulation of depth contours	ff-n	5

4.7 Runoff behaviour during precipitation events with hail and on snow covered surfaces

Hail

The effect of hail on surface runoff formation has not be simulated during the rain simulation experiments by the BFW und LfU. Concerning the reports of eye witnesses who observed torrential rainfall events with hail in the Wildschönau (Tyrol / Austria, 1994) or at the Zettersfeld near Lienz (Eastern Tyrol / Austria, 1997) and other events, the hail grains prevent surface runoff like a dam. However, after some time this dam breaks, the hail grains and the water begin to move (cylindric); on alpine grasslands and pastures surface runoff immediately concentrates linearly in deep lines.

Therefore, in catchments with frequent events of torrential rain combined with hail esp. for grasslands, pastures, open soils with a high content of fine grained soil and acres with poor soil cover, e.g. maize) instead of using the surface runoff coefficient determined by the use the „Code of Practice" for the respective hydrological vegetation class, Ψ_{const} of the next higher class should be utilised. For runoff coefficient class 5 the value of the upper class border (Ψ_{const} = 1,0) should be utilised.

Snow-covered surfaces

Concerning the results achieved by Fuchs et al. (2000) and Kohl et al. (2001), the effects of heavy rain on snow-covered surfaces can be described in the following way:

- Snow depth and the delay of runoff are directly correlated, i.e. the deeper the snow cover and the lower the content of free water and the higher the runoff delay. Every increase of snow cover deepness by 10 cm gives an additional delay of a initial abstraction of 3,6 min as shown by results of heavy rain simulations with i_N = 100 mm h^{-1}.

- Immediate runoff and high runoff coefficients must be expected from shallow and completely wetted snow covers (snowmelt!) or from frozen soil.

5. Instructions for the use in practice

5.1 Examples of the use of the „Code of Practice“ for the assessment of the surface runoff coefficient

The user chooses a hydrological vegetation unit from the examples in Annex 1, which matches the unit he identifies in the field.

Now it is possible to limit the hydrological characteristics of the area in question by use of the site characteristics in columns 2-4 (soil, land use and site characteristics, plant indicators / humidity) and to assign a surface runoff coefficient.

5.1.1 Example 1: Pure spruce-stand (*Piceetum nudum*), pastured

Assumptions concerning the stand

Pure spruce stand without understory and ground cover (*Piceetum nudum*) with the following site characteristics (see also Fig. 5.1.1 and Annex 2, point 2.6 - forests):

- Infiltration characteristicsof the soil are determined by the content of fine soil (grain size < 2 mm diameter), the soil is not cohesive and not dense.

Fig. 5.1.1: Pure Spruce stand without understory and ground cover (*Piceetum nudum*)

- The site is charactericed by a small humic layer, consisting of spruce needles (low degree of decomposition) and a poor ground cover, mainly by *oxalis acetosella*
- Single steps from cattle and single excrements indicate effects of moderate current pasturing
- Vegetation indicates moderately fresh site conditions.

Annex 1 gives information about following hydrological vegetation units:

1 Pioneer vegetation – immature soils
2 Grass vegetation, grasslands – meadows
3 Dwarf shrub heaths
4 Bush associations
5 Tall forb associations
6 Forests
7 Graded and sealed areas

The table including the potential runoff coefficients of pure spruce stands are provided in Annex 1, point 6 (**forests**). For the current example the table leads us over 6.2, to **coniferous forests**, and here in the first table to:

Spruce forests > 50% spruce (no or marginal ground cover – nudum, see Table 5.1.1.1)

For the unit in our example, the attribution of the runoff coefficient is done according to Table 5.1.1.2:

(1) The soil is not coarse, not cohesive and dense, therefore in column 2 (soil) only lines 2 and 3 remain.

Table 5.1.1.1: *Piceetum nudum* - Scheme for the estimation of the runoff coefficient class

	Vegetation-unit	Soil	Land use; spec. site characteristics	Indicator values Humidity	Runoff coefficient class	Lines
	Spruce forest, > 50% spruce no or few ground cover - nudum)	**Coarse grained soil,** also with fines,		mf-f	1	1
		Coarse grained soil with fines/ fine grained soil	Moor layer - dry		2	2
			Moderate pasturing; moor layer - dry		3	3
		Fine grained soil, dense	Slope water, intensive pasturing	mf-ff	4	4
		Fine grained soil,	Soil wetness, cumulation of deep gullies	ff-n	5	5
Columns	1	2	3	4	5	

(1) Land use and special site characteristics (litter cover from spruce needles – humus form: moor) only allow the choice of lines 2 and 3, however, the choice is narrowed down to line 3 due to pasturing influence.

(2) Plant indicator values (column 4) only offer an indifferent distinguishing feature for this example, they at least indicate that runoff coefficient classes 4 and 5 are not appropriate. Thus runoff coefficient class **3** can be assigned.

Table. 5.1.1.2: Attribution of runoff coefficient class for the example *Piceetum nudum*, pastured.

	Vegetation-unit	Soil	Land use; spec. site characteristics	Indicator values Humidity	Runoff coefficient class	Lines
	Spruce forest, > 50% spruce no or few ground cover - nudum)	**Coarse soil, some fines,** loose		mf-f	1	1
		Coarse grained soil with fines/ fine grained soil	Moor layer - dry		2	2
			Moderate pasturing; moor layer - dry		3	3
		Fine grained soil, dense	Slope water, intensive pasturing	mf-ff	4	4
		Fine grained soil,	Soil wetness, cumulation of deep gullies	ff-n	5	5
Spalten	1	2	3	4	5	

5.1.2 Example 2: A slope covered by dwarf shrub heath (*Alpenrose, blueberries*)

Assumptions concerning the site (see. Fig. 5.1.2)

- The soil is rich in coarse grained material, loose, shows a mighty humic layer (raw humus).
- No visible traces of pasturing, Alpenrose does not show damages by livestock steps, no visible traces of human impact.
- No signs indicating serious dryness or wetness, the plants indicate moderately fresh to fresh site conditions.

Fig. 5.1.2: Dwarf shrub heath (*Alpenrose, blueberries*)

Assignment of runoff coefficient class:

(1) Choice of the grouping unit: ***Dwarf shrub heath***
(2) Choice of the hydrological vegetation unit: ***Alpenrose and Blueberry heath***
(3) According to the soil characteristics stated above only lines 1 and 2 are valid: **Coarse grained soil, loose**, soil can also contain **fines**.
(4) No additional land use and specific site conditions visible (e.g. steps from livestock, erosion,…), therefore in column 3 only line 1 is remaining.
(5) Vegetation does not give any specific hints with respect to extreme dryness or wetness (Lines 1-3 in columns 4 are possible).
(6) Due to missing land use influences for coarse (blocky) substratum RCL **0**, for higher content of fines (coarse grained soil containing fines) RCL **1** can be assigned (see also Annex 2, Chapter 3 – first picture)

Table. 5.1.2: Example for the assessment of runoff characteristics on a site covered by *Alpenrose* (substratum permeable, no additional land use impact).

	Vegetation-unit	Soil	Land use; spec. site characteristics	Indicator values Humidity	Runoff coefficient class	
	Alpenrose und / or blueberry heath	**Coarse grained soil,** also with fines, loose	None	mf-f	0/1	1
			On small areas steps from livestock /or erosion damages up to 25% of the		2	2
		Fine grained soil, locally dense	Grassy areas up to 25%, steps from livestock, or erosion damages (on max. 25% of the area)	mf-f	3	3
		Fine soil - cohesive	Humid areas with pronounced channel network	f-ff	4	4
			Water-logged, dense channel network	n Sphagnum	5	5
Spalten	1	2	3	4	5	

5.1.3 Example 3: *Nardus stricta*-grassland

Assumptions concerning the site (Fig. 5.1.3)

- No or only marginal coarse material (soil skeleton) detectable at the soil surface, high content of fines.
- Marginal damages by livestock steps (extensive pasturing).
- Vegetation cover and topsiol are dense (high pressure needed when trying to penetrate the vegetation cover with shoe, penetration of the topsoil- root felt even difficult when using a knife).
- High content of dead biomass (litter, adhesive dead leaf sheaths).
- No hints regarding water-logging (no slope water, no fine channel network, no plants indicating humidity).

Nardus stricta grasslands generally show a high surface runoff potential. No units belonging to RCL 1 and RCL 2 have been observed during the heavy rain simulations done by the BFW. *Nardus stricta* litter is difficult to decompose, therefore dead leaf sheaths and litter are accumulated. Precipitation is discharged at the surface like from a thatched roof (Cernusca und Seeber 1989, Klug-Pümpel 1994, Markart und Kohl 1995, Markart et al. 2000, Markart et al. 2007). In addition they form a dense root felt, which decreases infiltration potential too. Possible good drainage characteristics of the mineral soil do not take effect.

Fig. 5.1.3: In the front and the middle section of the picture: *Nardus stricta* grassland

Table 5.1.3: Example for the assessment of the surface runoff coefficient class on a site with *Nardus stricta* (fine grained soil, extensive pasturing).

	Vegetation-unit	Soil	Land use; spec. site characteristics	Indicator values Humidity	Runoff coefficient class	Lines
	Nardus-stricta grassland	**Coarse grained soil,** loose; partailly in-situ soil skeleton with open cracks	No pasturing	mf-f	3	1
		Fine soil, dense (root felt)	Pastured or no without pasturing, dwarf shrub cover up to 25%		4	2
			Pasturing / extensive	mf-ff	5	3
		Rock, very shallow soil	Grassland alternating with rock and dense open talus; a lot of gullies, mostly steep, no or only few dwarf shrubs	mf-f	5	4
Columns	1	2	3	4	5	

Assignment of runoff coefficient class (see Table 5.1.3)

(1) Choice of the grouping unit **grassland vegetation, grasslands – meadows**.
(2) Choiceof the hydrological unit ***Nardus stricta* grassland**.
(3) The soil conditions (column 2) only allow the use of the lines 2 and 3: **Fine soil dense, root felt**.
(4) The site is extensively grazed, no dwarf shrubs are existing, therefor choice in column 3 is narrowed to line 3 (**pastured / grazed, extensified**).
(5) 4th column: Humidity conditions of the site can be described by use of indicator plantts if these can be found besides *Nardus stricta*. *Nardus stricta* or matgrass itself is an „ubiquist", it can be found on a wide range of areas form carbonate to silicate ground, from dry to wet sites.
(6) According to the information from columns 2 and 3 RCL **5** must be assigned to the site (see also tab. 5.1.3, picture in Annex 3, Chapter 2).

5.1.4 Example 4: Site with Alpenrose and *Nardus stricta*-grassland

Assumptions concerning the site:

- The site conditions from example 2 are valid for *Alpenrose* and from example 3 for *Nardus stricta*- grassland.
- Both vegetation units cover the site to an extent of approx. 50% (the percentage of area covered by the different vegetation units in practice should be assessed in 10%-classes).
- *Alpenrose* is distributed within the *Nardus stricta* like a mosaic.
- Assignment of runoff coefficients should be done for precipitation events with and without hail.

Assignment of runoff coefficient class

(1) Determination of runoff coefficient class for each vegetation unit separately following example 2 (Chapter 5.1.2) und example 3 (Chapter 5.1.3).
(2) For the *Nardus stricta*-grassland RCL **5** must be used.
    - Average of the runoff coefficient class – 87,5% of the precipitation in case of pure rain
    - Upper limit of the class (100%) of a precipitation event in combination with hail, due to the effect of hail (see Chapter 4.7).
(3) The mosaic-like distribution of Alpenrose is less effective in buffering surface flow in a belt-like fashion. To be on the safe side, the upper limit of RCL **1** (10%) should be used. With respect to the existing observations, hail has no negative effect on the runoff behaviour of Alpenrose.
(4) The runoff coefficient can be calculated as the arithmetic mean of the runoff coefficient classes derived for the two vegetation units:

Rain without hail:

(Mean of RCL **5** + upper limit of RCL **1**) / 2
= (87,5% +10%) / 2 = 48,75% ⇒ upper limit of RCL **3**

Precipitation with hail:

(upper limit of RCL **5** + upper limit of RCL **1**)/ 2
= (100% + 10%) / 2 = 55% ⇒ lower range of RCL **4**

Restrictions: Units which feature good infiltration characteristics like Alpenrose heath or well structured forests must have a minimal extension on a site to be able to develop hydrological positive effects. Critical value: 25 % cover of the area.
Below this ground cover percentage no arithmetic mean must be calculated. In this case the RCL of the worse unit should be taken (in this example: *Nardus stricta*-grassland) and the calculations should be done with the runoff coefficients from the lower limit of the RCL (in this case Ψ_{const} = 0,75-0,8).

6. Calculation of initial abstraction

6.1 Basics

The initial abstraction (abstraction time) characterises the time period from the beginning of the precipitation event until the formation of surface flow.

Thus these losses at the beginning form the amount of precipitation which is necessary to produce direct runoff. The initial abstraction enfolds all the water losses, which must be considered for the calculation of extreme floods.

Adhesive water in the soil and vegetation (interception), transpiration from the soil and vegetation surface (evaporation), active water use by plants (transpiration), water retention in terrain depressions (cavity storage), active infiltration into the soil and consequently runoff into the substratum (interflow deep seepage) can be summarized under the synonym initial abstraction.

It is difficult to quantify the specified losses, as they strongly depend on the duration of the precipitation event. Thus these losses are recognized only in a generalized form in the literature.

6.2 Initial abstraction in relation to the runoff coefficient

Mean values of abstraction time versus corresponding runoff coefficient classes are shown in Fig. 6.1 by example of the analysis of approx. 200 simulations of heavy rain on 128 sites.

The assessment of runoff coefficients has been outlined in Chapter 4.5. In those units summarized in RCL **0**, the system is capable of absorbing 100% of the precipitation. Thus the initial abstraction can be assumed to be equal to the precipitation time.

During „standard“ spray irrigations precipitation i_N = 100 mm h^{-1} is applied for about 60 minutes. On 16 of the total 128 analyzed sites, no surface runoff has been registered. This can be seen as a proof that infiltration rates of 100 mm h^{-1} are not that unlikely, as described by Zeller (1981).

6.3 System conditions – extreme scenarios

The range of measured values is wide, due to the heterogeneous complex of factors, which influence the initial abstraction. On average a significant dependence of duration of initial abstraction from the value of the measured runoff coefficient has been observed.

On the one hand in extreme cases even on sites with RCL 1 very short abstraction times have been observed. Such extreme cases have been simulated in the field when one heavy rain simulation followed the other on the same site with only a short break in-between the two experiments. In reality such scenarios can be neglected because these cases can only be observed very rarely.(= unrealistic worst case scenario).

On the other hand the spray irrigation data pool also contains experiments treated under „best-case“-conditions (extreme positive antecedent system conditions), e.g.

extremely high free soil water storage after long dry periods, desiccation cracks, full micro retention capacity, etc.). Even sites belonging to RCL 6 with 100% surface runoff show an initial abstraction of at least 5 minutes, the maximum abstraction time observed for an RCL 6 stand was 17 minutes.

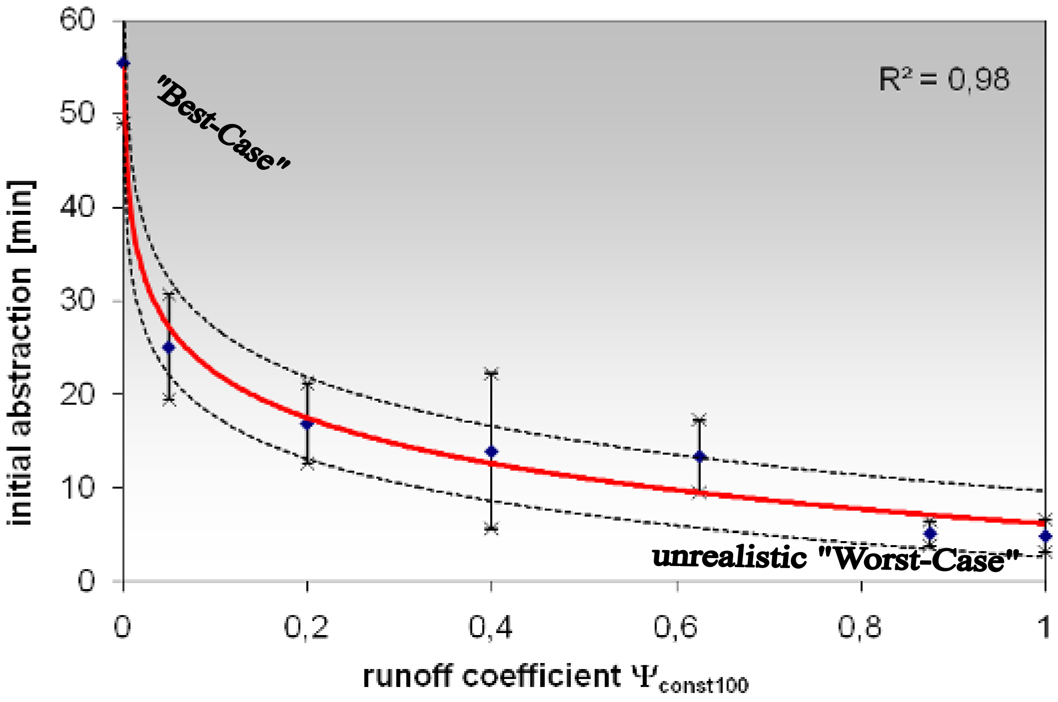


Fig.6.1: Correlation of initial abstraction and runoff coefficient, where Ψ_{const} is within a confidence interval of ± 95 %.

6.4 Calculation of initial abstraction for the „realistic bad-case-scenario"

Calculations of floodwaters or runoff design events should focus on a **„realistic bad-case-scenario"** of the investigated catchment (see Chapter 3).

The data pool of the BFW spray irrigation experiments scatters – as described above – between "unrealistic bad case" and "best case"-conditions. Therefore simplifying average values can be used for the assessment of the realistic bad-case-scenarios. Hence the initial abstraction of runoff contributing areas can be calculated after assigning the respective runoff coefficient class according to the function presented in Fig 6.1.

An average value of initial abstraction can be calculated for each RCL based on the function in Fig. 6.1 (see Table 6.1). Naturally no initial abstraction values can be calculated for RCL 0. Even on areas with high surface runoff potential (RCL **5** and **6**) runoff is delayed for 7 or 5 minutes respectively.

Table 6.1: Mean value of initial abstraction based on the function in Fig. 6.1 for the different surface runoff coefficient classes.

Initial abstraction (min)	**Roughness coefficient class (RCL)**
∞	**0**
28	**1**
20	**2**
15	**3**
11	**4**
7	**5**
5	**6**

7. Assessment of surface roughness

7.1 Basics

„A runoff coefficient has been introduced, which characterises runoff features of the soil surface, comparable with the k-value in the Strickler-equation for the calculation of channel runoff". Using this method, Zeller (1981) describes a parameter in his runtime method, named "water runoff coefficient ***c***". This parameter antagonizes slope inclination and flow depth (the latter in form of the effective precipitation $C*i_T$), both increase runoff velocity at the soil surface. The coefficient ***c*** can be seen as an analogon to Strickler's energy loss coefficient (= roughness coefficient), but ***c*** is dimensionless.

According to Zeller, the k-value for steep, uneven and extremely rough channels, like alpine brooks and rivers, ranges from 5 to 20 $m^{1/3}$ sec^{-1}respectively. For non–channel runoff Petraschek (1973) calculated a k-value of about 4 $m^{1/3}$ sec^{-1} based on spray irrigation experiments. For the Manning-coefficient ***n*** (much in use in the anglophone space), tables are available characterising surface runoff or "sheet flow" (inter alia Chow 1959, Arcement 1984, Engman 1986, Thomsen 1991, Weltz 1992). However, such tables give only a rough overview of possible roughness values, therefore its use in alpine regions is limited.

Velocities of surface flow have been measured during spray irrigation experiments by applying salt and dye tracers (Kohl 2003). The registered velocities were recalculated by using the parameters flow length and start-up time t_{OB} of the hydrograph from the rain simulation experiment – a very good fit between measured and calculated values has been achieved.
As t_{OB} derived from the rain simulations produced reasonable flow velocity values, it made sense to recalculate approx. 200 rain simulation experiments (128 plots) from

the BFW data pool to get the water runoff coefficient ***c*** for these plots. By conversion of the flow formula developed by IZZARD-equation (1) based on the known parameters flow length on the surface (L_{OB}), slope inclination (J) and the effective precipitation (= runoff coefficient C * i_N), the velocity of surface runoff can be calculated as follows:

$$v = \frac{L_{OB}}{t_{OB}} = \frac{L_{OB}^{\frac{2}{3}} \cdot J^{\frac{1}{3}} \cdot (C \cdot i_T)^{\frac{2}{3}}}{527 \cdot c} \qquad (1)$$

Similar to the estimation of surface runoff coefficients, the assessment of surface roughness is also based on a rough classification of vegetation types. Effective classification of surface roughness finally is dependent on the type and quality of vegetal cover.
To simplify the assessment, surface roughness is assumed to be constant for the duration of a precipitation event. Changes of environmental condition during the precipitation event, e.g. decrease of roughness due to hail, diminution of hydrophobic effects with increasing duration of precipitation, etc. are neglected.

7.2 Seasonal differences in surface roughness

Plant cover shows seasonal differences. Meadows are fairly smooth directly after snowmelt; from the beginning of grass-growth, until mowing, the roughness increases, after swath or in case of subsequent grazing, surface roughness will decrease again.
For the calculation of the **realistic bad-case-scenario,** potential seasonal changes must be taken into account and the roughness class corresponding to the bad case conditions should be assumed.

7.3 Assessment of surface roughness

Attribution of surface roughness classes to different land cover types and vegetation units (see also Fig. 7.1):

Asphalt, concrete, rock, ice

Zeller (1981) specifies a ***c***-value of 0,007 for smooth asphalt coating. Only few data are available from extremely smooth surfaces like asphalt coatings in the BFW data base. The mean value of the class should not fall below 0,01, otherwise the velocity calculation will deliver unrealistically high velocities.

Immature soils, open fallows

These units comprise the classes “very smooth” and “fairly smooth”. The degree of succession, i.e. the plant cover, is a good indicator. Simplified sites with a plant cover exceeding 10% can be assigned to roughness class 2 (fairly smooth).

Grassland, meadows

Grassland and meadows cover a wide roughness spectrum. Contrary to widespread bibliographic references, numerous grassland sites irrigated by the BFW belong to roughness class 1 (very smooth). Especially on *Nardus stricta*-meadows, they visually make the impression of a rather rough structure, however, heavy rains result in high and rapid runoff due to hydrophobic effects or “thatched roof effect” by litter and dead leaf sheaths. Pasturing increases runoff too. Highly compacted ski pistes (e.g. due to pasturing or other mechanical load) often must be assigned to roughness class 1 too.
Intensive management and tendance from the start of the construction of the ski run (sites specific re-vegetation, no pasturing, prevention of mechanical load, mowing with light equipment, mulching), increase surface roughness up to class 3.
Surface roughness of meadows likewise depends on the degree of maintenance. The roughness coefficient ranges from class 3 – slightly smooth (high grass cover) to class 2 (e.g. after mowing).

Humid and wet areas

Under the term „humid and wet areas” we understand waterlogged grasslands and meadows. These areas are discussed separately because they show relatively high surface roughness (unsteady micro-relief), despite high runoff coefficients. Humid grasslands with high content of mosses are slightly more rough (roughness class 4). Flow velocities on these areas are mostly lower than on non-waterlogged grasslands and meadows.

Dwarf shrub heath

Dwarf shrubs communities often show high surface roughness, dependent on the dominant dwarf shrub species.

- *Calluna vulgaris*, often associated with *Nardus stricta* can be attributed to the slightly more smooth units (roughness class 3).
- Stands with alder and birch vary in surface roughness, they cover the roughness classes 3-4.
- Blueberries, cranberries and other *Vaccinium* sp. form fairly rough stands (roughness class 5). Extensive stands of Alpenrose belong to those units most

effectively opposing the flowing water (class 6) – even if they are waterlogged and associated with humidity indicators like *Sphagnum* sp.

Forest sites

Besides the dwarf shrubs, the forest vegetation is of special importance in minimizing the kinetic energy of heavy rain. When precipitation has penetrated canopy cover, only the roughness of the underlying layers (ground cover, humus layer, form of micro relief) has decelerating effects on the runoff.

Because of the precipitation retarding effect of the canopy cover roughness, class 1 is generally not assigned to forest stands. The precipitation buffering effect of forests must not be overestimated (about 4-6 mm per precipitation event in coniferous stands - Markart 2000), especially in treeless plots within the stand, precipitation reaches the soil within a short time span.
The roughness coefficient is assigned depending on the understory, ground cover and micro relief (smooth area – enhancing runoff; many small cavities – runoff delay) in 5 classes beginning with runoff coefficient class 2 (e.g. 0,02 for *Piceetum nudum*).

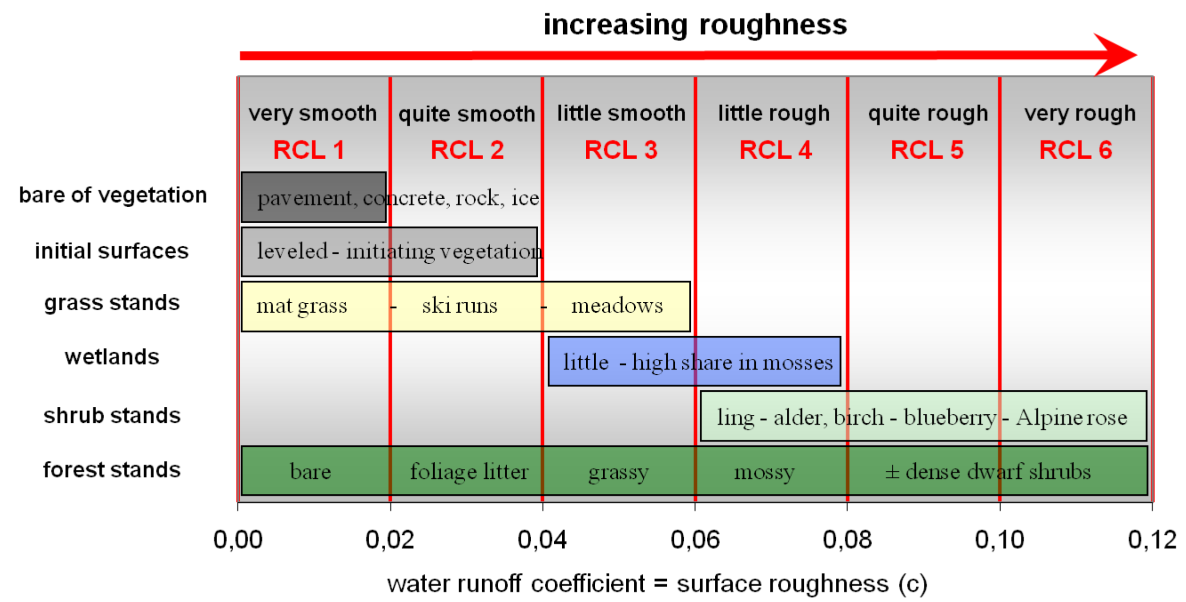


Fig. 7.1: Roughness classification for different vegetation units;
Sealed areas - dark grey; immature soils - light grey; grassland and meadows - yellow; humid and wet areas - blue; dwarf shrub heaths – bright green; forest sites – dark green.

Effect of spatial distribution

To include the surface roughness correctly, the spatial distribution of the different units must also be considered.
Example: In the pastured Alpenrose-belt often a mosaic-like disaggregation of Alpenrose heath can be observed. The areas in-between often are covered by *Nardus stricta*, on such livestock paths velocity of flowing water increases, limiting the effect of the Alpenrose.

When a distribution of Alpenrose (50% - roughness class **6**) and *Nardus stricta* (50% - roughness class **1**) is assumed, the areal distribution of these units is essential. In case of belt-like array of Alpenrose heath, the buffering effects are higher (roughness class 4). Insular or mosaic-like array weakens the dwarf shrubs. *Rhododendron* moves back onto small elevations, the runoff retarding effect is weaker (roughness class 3).

8. Form for mapping in the field

The form in Annex 4 has been developed for documentation of runoff assessment on the detailed scale (M ≤ 1 : 5000).

To maintain the reproducibility of the runoff coefficients mapped in the field on the detailed scale, most important features of the different hydrological units should be noted. In addition, each separate unit should be sufficiently documented with photographs.

Such a documentation makes

a) Decision in the field for a definite surface roughness coefficient class and roughness class easier
b) An essential contribution to objectivation in disputed cases, e.g. in the frame of the revision of hazard maps after disasters - the daily work of specialists and (legal) experts.

9. Field work and hydrological modelling – basics and workflow

The „Code of Practice“ is a tool for field investigations on the medium (1:10.000) or the detailed scale (≥ 1:5.000). For more detailed analyses, the handbooks of the ETALP-project are recommended for the corresponding scales (ETALP project team 2004).

The basics and workflow, from the preparation of the field work, over mapping in the field, to the hydrological modelling / precipitation / runoff-modelling have been summarized in Fig. 9.1.
The extent of the investigations depends on the assignment (requested degree of detail of the results).

Some of the aspects listed in Table 9.1 are shortly discussed below. These hints should be taken into account while preparing the field work. Diligent preparation can simplify the subsequent workflow significantly (mapping in the field, processing of data, hydrological modelling). Further information beyond the aspect of surface runoff coefficient mapping are discussed by Kohl (2011, 2012) for Austria and by Hemund et al. (2011) for Switzerland.

9.1 Pre-differentiation (classification of areas) on the orthophoto

This work comprises the pre-classification of areas and units with different runoff disposition by use of orthophotos (manually or via computer using GIS-software). Areas / polygons, which show obvious differences in runoff behaviour or/and surface roughness are delineated and runoff coefficients can be pre-assigned (e.g. by roughly sketching or encircling the polygon using the respective colour of the appropriate RCL).

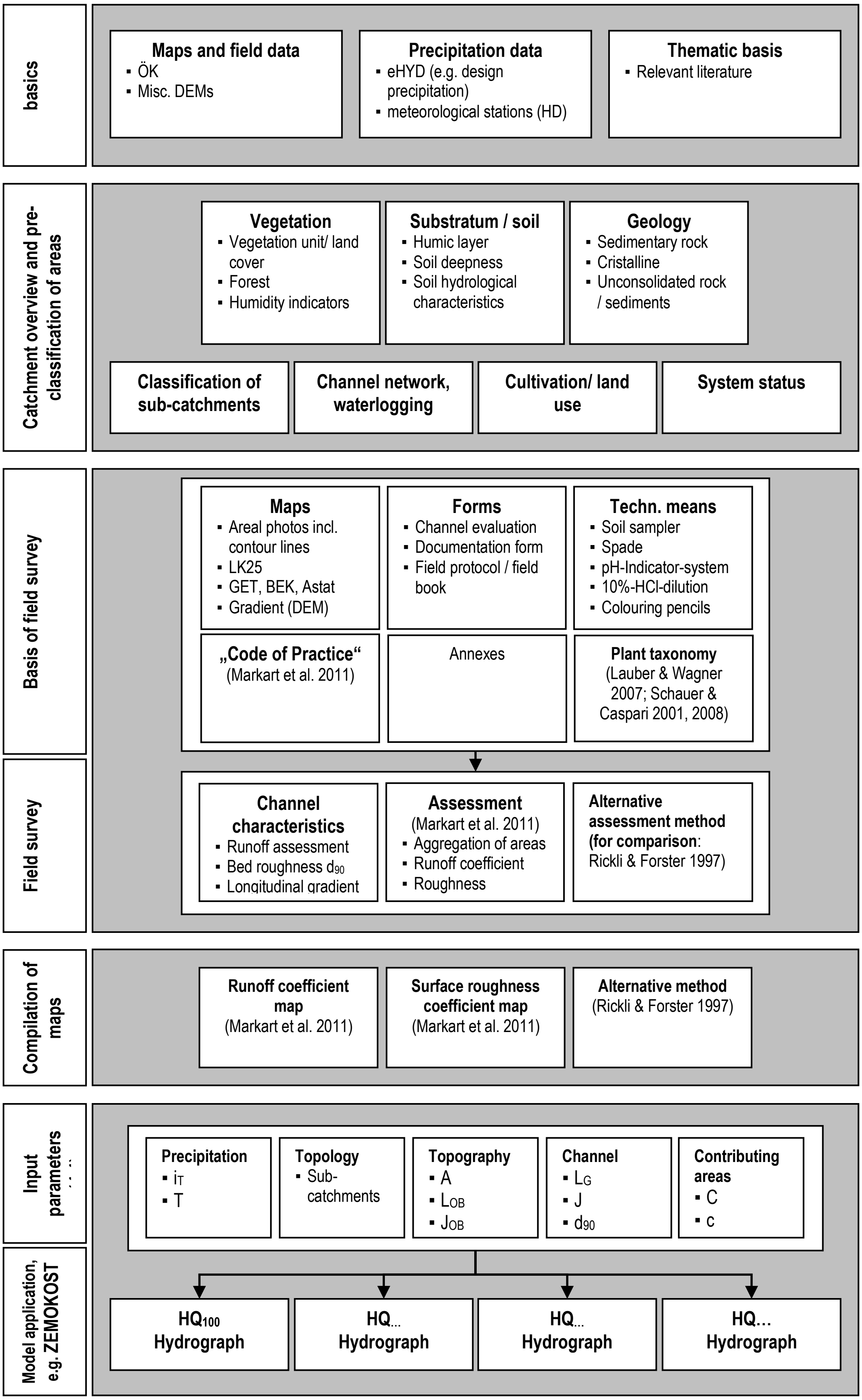


Fig. 9.1 – Schematic workflow: Application of the „Code of Practice“ and hydrological models like ZEMOKOST – after Hemund et al. 2011 (modified). For details concerning the aspects not included in the assessment of the runoff coefficients, see Kohl (2011, 2012) and Hemund et al. (2011).

Easy delineation on an orthophoto or aerial photograph is inter alia possible for:

- Rocky outcrops
- Open gravel fans
- Forests
- Dwarf shrub heath
- Pastures, grazed grasslands
- Meadows
- Acres
- Levelled areas
- Units with dense channel network
- Sealed areas

Accurate delineation of such areas / units, results in a high number of polygons (see Fig. 9.1) – only marginal further sub-categorisation is necessary in the field (degree of detail depends on the scale and assignment). The time and effort for the finalisation of surface roughness maps and roughness maps on the PC is much lower too.

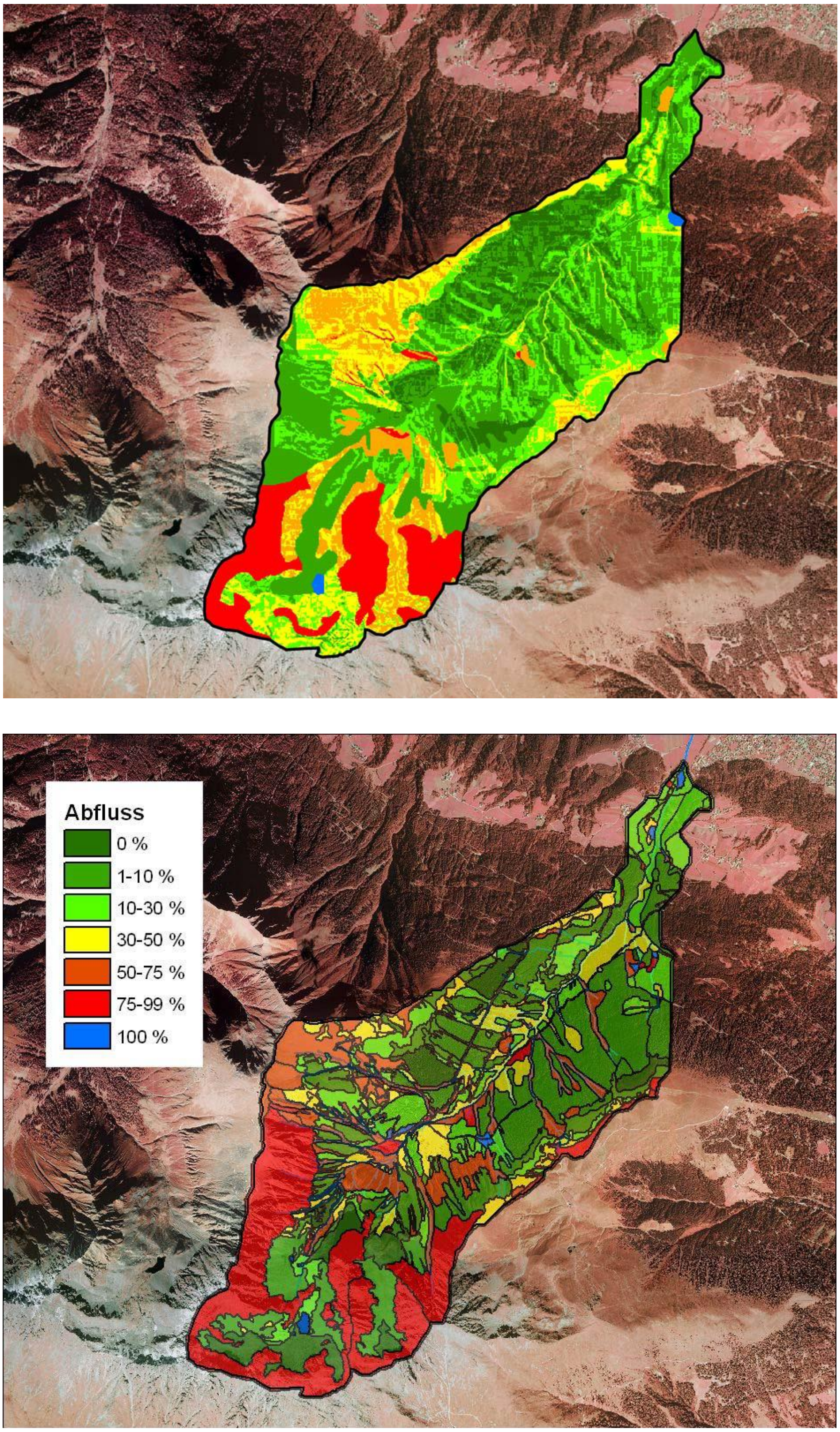


Fig. 9.1 – upper picture: An example of a runoff coefficient map delineated on basis of an orthophoto using a PC.
Lower picture: The final runoff coefficient map falsified and further refined by field survey. Location: Enterbach catchment, near Inzing (Tyrol, Austria).
Source: Kohl et al. (2005)

9.2 Information facilitating the delineation of contributing areas

The delineation of runoff contributing areas is facilitated by the use of the following maps (mostly available in digital form, examples for Austria):

- Geological maps of the Republic of Austria (GBA – Geological Survey of Austria)
- eBOD – digital map of agricultural soils (BFW – Federal Forest Research Centre)
- Biotope inventories of the Austrian districts
- Land use types defined and published by Seger (2001)
- Information concerning types of agricultural land use (AMA 2007)
- Austrian forest map (Bauerhansl 2007)

Some of these maps are not available for all parts of Austria (e.g. geological maps) or their acquisition is limited (e.g. due to legal or data protection reasons).

Digital orthophotos with pre-delineated contributing areas should also comprise contour lines (equidistance e.g. 20 m) and be printed in an outdoor-suitable format (e.g. folded to DIN A4 or DIN A3).
Important: The plausibility of the runoff contributing areas delineated at the „green desk“ must be falsified in the field!

9.3 Use of parameters estimated on basis of the „Code of Practice“ in hydrological models

The data collected by using the „Code of Practice“ can be directly implemented in hydrological models (see Table 9.1). The hydrological model ZEMOKOST – the runtime method developed by **ZE**ller (1981) **MO**dified by **KO**hl and **ST**epanek (Stepanek et al. 2004, Kohl 2011) has been specifically developed for the use of parameters gathered by implementing the „Code of Practice“.

Runoff coefficients and surface roughness coefficients may also serve as input data for several other precipitation / runoff models (P/R-models), which are based on established velocity formulas with roughness coefficients and runoff coefficients (e.g. HEC-1 or HEC-HMS – USACE 1998). The use of these models combined with the SCS-approach does not make sense for the Alps. The approach has been developed to perform well under conditions found in the US (Merz and Blöschl 2000). Investigations and calculations done by Kuntner and Burlando (2003) and Kohl (2011) show that the SCS-method does not deliver reproducible results for 1/3 of the Alpine area. However, HEC-HMS can also be „fed“ with runoff coefficients derived with the „Code of Practice“ as done in the BUWELA-study by Klebinder et al. (2009).

P/R-calculation makes a detailed description of catchment characteristics necessary. Besides the runoff characteristics of the contributing areas, information on channel properties for optimal characterization of linear flow velocity are desired. Concerning the requirements of the investigation and quality of these additional parameters we point to following standard reports:

- The methods presented in the frame of the project ETALP (holistic survey and evaluation of erosion and transport processes in torrent catchment areas; see ETALP project team 2004) funded by the BMLFUW – contains an approach on how channel characteristics should be described in Austria.
- In the PhD thesis and the report by Kohl (2011, 2012) the hydrological model ZEMOKOST and the input-parameters necessary for the calculation are described in detail.
- „Code of Practice“ and ZEMOKOST have been tested by Hemund et al. (2011, 2010) in six and later in four additional Swiss catchments. Additionally ZEMOKOST and the parameters needed for hydrological modelling are presented in detail in the paper of Hemund et al. (2010).

10. Assessment of surface runoff and interflow in persistent rain

Since the end of the 20^{th} century numerous disastrous persistent rain events have taken place in Central Europe (e.g. the floods at Whitsun in 1999 in Western Austria and Bavaria, the 2002-floods Eastern Austria and the dramatic floods in Western Austria on $22^{nd}/23^{rd}$ August 2005). In torrential rain mainly surface runoff processes contribute to catchment runoff. During long-lasting rainfall, near-surface interflow and deep-seated interflow processes gain in importance in relation to direct runoff at the soil surface. However, knowledge about these interflow runoff processes is still inadequate (Kendall et al. 2001, Kienzler and Naef 2008b, Sarkar and Dutta 2009).
In hydrological practice (e.g. civil engineering, water management, torrent control) often very simple hydrological approaches are used. Many of the methods used are not capable of reproducing interflow processes with sufficient accuracy and in a process-oriented manner.

10.1 Surface runoff in persistent rain

The dependence of surface the runoff coefficient on precipitation intensity has been investigated on 37 sites with intensities ranging between 30 and 100 mm h^{-1} with a rain simulator for large plots. Following the results achieved by Nachtnebel et al. (2005) and with the rain simulation experiments conducted in the frame of the project „shallow interflow“ funded by the Austrian Academy of Science (ÖAW), Commission of Hydrology, aggregated in Fig. 1, the relation between precipitation intensity and runoff coefficient can be described by function (2):

$$\varnothing \Psi_{NS}=(0{,}3\cdot \Psi_{100}^2+0{,}7\cdot \Psi_{100})\cdot(1-EXP(-0{,}03\cdot EXP((0{,}1\cdot EXP(3{,}3\cdot \Psi_{100}))\cdot i_T \verb|^|(-0{,}7\cdot \Psi_{100}+1)))+(-0{,}0035\cdot \Psi_{100}+0{,}0035)\cdot i_T) \quad (2)$$

Based on the relationships shown in Fig. 10.1, the following deductions can be made for persistent rain events with i_N < 10mm h^{-1}.

- Sealed or waterlogged areas: Such sites yield a very high runoff also in case of long-lasting rain events with intensities <10mm h^{-1} (after a short abstraction time) an must be assigned to RCL **6**.
- Humid and wet areas or sites with cohesive or dense topsoil will deliver high surface runoff but acceleration time will be longer than in torrential rain (surface roughness and relief storage are more effective): RCL **3-4** (0,31 < ψ_{const} < 0,75).
- On sites with RCL 4 (0,51 < ψ_{const} < 0,75) a lower level must be expected in torrential rain in case of persistent rain surface runoff (RCL **1-2**: ψ_{const} < 0,30).
- Areas producing low to medium surface runoff during a convective rainfall event (RCL 1-3) will deliver negligible runoff in persistent rain (RCL **1**: ψ_{const} < 0,10).
- On sites with no or negligible runoff in torrential rain (RCL 0, 1), no or negligible surface runoff must be expected during long duration rainfall events (RCL **0, 1**).

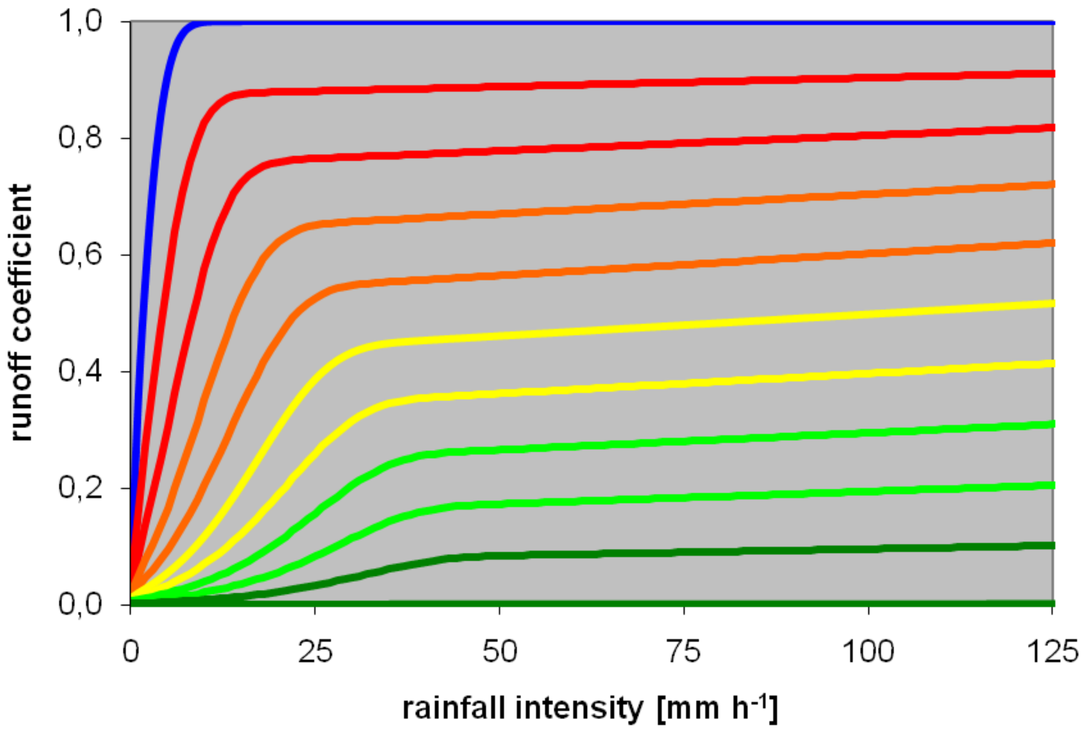


Fig. 10.1: Relation between precipitation intensity and runoff coefficient for rain simulation experiments with different precipitation intensities.

It must be taken into account that near surface interflow (runoff profile type 2 after Pirkl et al. 2000) and return flow (runoff in the soil, which returns to the surface) in strips near to the brooks and receiving water courses, will increase surface runoff. The extent of such surface runoff producing areas varies in dependence of the duration and intensity of the precipitation event and conductivity of the substratum.

10.2 Bandwidths of interflow on different substrata in persistent rain

Recently a lot of effort- and time-consuming process-studies on the plot have been conducted or are still in progress (e.g. Scherrer 1997, Kienzler 2007, Laule 2007, Tromp-van Meerveld and Weiler 2008) to get more information on the genesis of interflow; how such processes run and how to integrate the results into hydrological models using corresponding algorithms. Such field studies inherit the problem of the limited and unclear transferability of results from the plot scale to larger scales (Cerdan et al 2004).

Due to the fact that many hydrological models are not capable of reproducing interflow runoff in a process-oriented manner, the GBA and BFW have launched field investigation to assess bandwidths of flow velocities of the near surface interflow (down to 10 m depth) of typical substrata in the Eastern Alps (funded by ÖAW), accompanied by intensive literature research.

The search shows that data concerning flow velocities of interflow are only rarely published in Europe. Most data is included in unpublished project reports (so called “grey” literature), i.e. sources with limited access contain such information. First results of the literature search and field experiments are listed in Table 10.2.

By using this information, runoff volume from interflow of contributing areas can be assessed. Therefore realistic velocities for interflow can be implemented in hydrological modelling. This list will be amended, depending on new results from field research and literature search.

In forest soils rich in large pores or macro pores, or in soils with pipes (mice holes, root channels, (shrinkage) cracks,…) near surface interflow velocities of about 500 m d^{-1} must be expected (< 850 m d^{-1} - Mosley 1982, < 500 m d^{-1} in Schwarz 1984, 432 m d^{-1} - Weinmeister 1991). Thus the runoff contributing zone of 100 m around the receiving water courses mentioned by Kölla (1986) must be significantly enlarged in persistent rain, especially in forested catchments. The latitude of this strip varies in dependence of precipitation intensity and duration.

Tab. 10.2: Flow velocities bandwidths of near-surface interflow for various Central European substrates

Location	**Substratum**	**Velocity (m/h)**	**Author (year)**	**Specifics of the experiment**
Zastlertal, Südschwarzwald (D)	perigacial surface layer (clayey, silty, gravelly)	1-5	Laule (2007)	Fastest percolation through a clayey layer with 1,39 m/h, through a gravelly layer 1,5 m/h; the assessment of the maximum flow velocities based on texture information in the single periglacial surface layers is not possible
Heumöser slope, Ebnit, Vorarlberg (A)	Fine textured loamy soil with high content of fissures and scondary pores	2,1-2,7 4,2-9,5	Wienhöfer et al. (2009), Markart et al. (2010)	1. value: mean flow velocity Fließgeschw.; 2. value: peak velocity measured by use of NaCl as a tracer. Results achieved by Wienhöfer et al. during simulations of persitant rain have been confirmed by Markart et al. (2010)
Kangaslampi (Eastern Finland)	postglacial moraine, sandy-silty Podzols with high content of coarse material (up to 30 Vol%)	2-6	Laine-Kaulio (2008)	No homogenous irrigation of the investigated plot (only small area was irrigated, velocity of interflow decreases with distance to the oirrigated plot), interflow velocities were measured with tracer NaCl
Limberg Alp, Löhnersbach near Saalbach, Salzburg (A)	Blocky debris	3,6	Tilch et al. (2006), Kirnbauer et al. (2009)	Insertion of fluorescence-tracer in hillside debris; simulation of persistent rain over 36 h with spray installation on an area of 400 m², detection at a gauging station situatet downwards the hillside
Limberg Alp, Löhnersbach near Saalbach, Salzburg (A)	Blocky debris, supported by soil matrix	0,36	Tilch et al. (2006), Kirnbauer et al. (2009)	deeper groundwater aquifer with delayed reaction; simulation of persistent rain over 36 h with spray installation on an area of 400 m², fluorescence-tracer, detection at a gauging station situatet downwards the hillside
Rotherdbach catchment, Erzgebirge(D)	Rhyolith-Podzols over Altenberger Quarzporphyr, skeleton content between 30 and 70%, fine soil: 10% clay, 43% silt, 47% sand	0,5	Didszun (2004)	Insertion of the tracer sodium-bromide along the interface humus layer / mineral soil over a 10 cm deep soil slot; distance to the receiving water course: 4,5 m
Rotherdbach catchment, Erzgebirge (D)		4	Didszun (2004)	Drainage along a large macro pore direct into the receiving water course; insertion of the tracer eosin in 30 cm soil depth, distance to the receiving water course: 4 m
Wattener Lizum - Lizumer Boden, Tyrol (A)	Cambisol on moraine, pastured	2	Markart et a. (2008)	Rain simulation on a 100 m² large plot, salt tracer inserted by irrigation of the whole plot; vertical and lateral movement of soil water with identical velocity
Wattener Lizum - Lizumer Boden, Slopes at the Tarntaler, Tyrol (A)	Carbonate debris	25	Markart et a. (2008)	Punktual insertion of the tracer NaCl in hillside debris, registration of conductivity changes in in the springs at the base of the hillside
Bromberg, Bucklige Welt, Lower Austria(A)	Pasture; phyllitic mica-shist and phyllites; Loose rock layer, partially loamy	0,3-0,75	Markart et a. (2010)	Precipitation on 100 m² plot, insertion of the salt tracer along a soil slot; tracer was washed in for several hours by irrigation of the whole plot
Möls Niederleger, Wattental, Tyrol (A)	Pasture on podzolic Cambisol; substratum: blocky talus cone	0,4	Markart et a. (2010)	Precipitation on 100 m² plot, insertion of the salt tracer along a soil slot; tracer was washed in for several hours by irrigation of the whole plot

11. References

AMA (2007): Daten Mehrfachantrag (MFA) 2007. Agrarmarkt Austria.

American Society For Testing Materials (1966): Classification for engineering purposes. ASTM – Destination 2487 – 66 T.

Andrecs P., G. Markart, E. Lang, K. Hagen, B. Kohl und W. Bauer (2002): Untersuchung der Rutschprozesse vom Mai 1999 im Laternsertal (Vorarlberg). In: Beiträge zur Wildbachforschung, BFW-Bericht Nr. 127, 55-87.

Arcement, J.Jr. and Schneider V. R. (1984): Guide for selecting Manning's roughness coefficients for natural channels and flood plains. Springfield (VA): U.S. Department of Transportation and the National technical Information Service. 62 p.

Bauerhansl, C., T. Koukal und K. Schadauer (2007): Erste österreichweite Waldkarte. Österr. Forstzeitung 12.

BFW (2011): Elektronische Bodenkarte – eBOD (http://bfw.ac.at/rz/bfwcms.web?dok=7066)

Blum, W.E.H., H. Spiegel und W.W. Wenzel (1996): Bodenzustandsinventur, Konzeption, Durchführung und Bewertung, Empfehlungen zu einer Vorgangsweise in Österreich. Arbeitskreis Bodenzustandsinventur der ÖBG. Bundesministerium f. Land- und Forstwirtschaft, 2. Auflage, 1-47.

Breitsameter, J. (1996): Untersuchungen zum Feststoffaustrag aus unterschiedlich dicht bewaldeten Kleineinzugsgebieten im Flysch und in den Kalkalpen der Tegernseer Berge; Forstliche Forschungsberichte München – Schriftenreihe der Forstwissenschaftlichen Fakultät der Universität München und der Bayer. Landesanstalt für Wald und Forstwirtschaft, Bd. 154.

Bunza, G. (1989): Oberflächenabfluss und Bodenabtrag in der Alpinen Grasheide der Hohen Tauern an der Grossglockner-Hochalpenstraße". - Österr. Akademie der Wiss., Veröff. des österr. MaB-Programms, Bd. 13, S. 155 - 200, Universitätsverlag Wagner - Innsbruck 1989.

Bunza, G. und Schauer, Th. (1989): Der Einfluss von Vegetation, Geologie und Nutzung auf den Oberflächenabfluss bei künstlichen Starkregen in Wildbachgebieten der Bayerischen Alpen. Informationsber. 2/89 d. Bayer. Landesamtes f. Wasserwirtschaft, München.

Burch, G.J., I.D. Moore and J. Burns (1989): Soil hydrophobic effects on infiltration and catchment runoff, Hydrol. Processes, 3: 211-222.

Castillo, V.M., A. Gomez-Plaza and M. Martinezmena (2003): The role of antecedent soil water content in the runoff response of semiarid catchments: a simulation approach. J. Hydrol., 284, Issue 1-4, 114-130.

Caviezel, C., N. J. Kuhn and K. Meusburger (2011): Applicability of Alp Inspection Reports for the Reconstruction of Land-Use and Mass Wasting History in the Ursern Valley, Switzerland. Die Erde 141, landscape Ecology and beyond, 301-319.

Cerdan, O., Y. Le Bissonais, G. Govers, V. Lecomte, K. van Oost, A. Couturier, C. King and N. Dubreuil (2004): Scale effect on runoff from experimental plots to catchments in agricultural areas in Normandy. J. Hydrol., 299, 4-14.

Cernusca, A. und M.C. Seeber (1989): Phytomasse, Bestandesstruktur und Mikroklima von Grasland-Ökosystemen zwischen 1612 und 2300 m in den Alpen. In: Cernusca, A. (Ed.): Veröff. Österr. MaB-Programmes 13, 420-461.

Chow, V.T. (1959): Open–channel hydraulics. McGraw-Hill, New York. 680 p.

Czell, A. (1972): Wasserhaushaltsmessungen in subalpinen Böden. Mitt. Forstl. Bundesversuchsanstalt, Bd. 98.

Dadkah, M., and G.F. Gifford (1980): Influence of vegetation, rock cover and trampling on infiltration rates and sediment production. Water Resources Bulletin, 16, 979-986.

DIN 18196 (1988): Erd- und Grundbau. Bodenklassifikation für bautechnische Zwecke.

Doerr, S.H., A.J.D. Ferreira, R.P.D. Walsh, R.A. Shakesby, G. Leighton-Boyce and C.O.A. Coelho (2003): Soil water repellency as a potential parameter in rainfall-runoff modelling: experimental evidence at point to catchment scales from Portugal. Hydrol. Process. 17, 363-377.

Ellenberg H. (1986): Vegetation Mitteleuropas mit den Alpen in ökologischer Sicht. 4., verb. Aufl., Ulmer - Verlag, Stuttgart.

Ellenberg H., E. Weber, R. Düll, V. Wirth, W. Werner und D. Paulissen, (1991): Zeigerwerte von Pflanzen in Mitteleuropa. Verlag Erich Goltze KG, Göttingen.

Engman, E. T. (1986): Roughness coefficients for routing surface runoff. Journal of Irrigation and Drainage Engineering. ASCE 112 (1), 39-53.

Frehner, M; Wasser, B; Schwitter, R. (2005): Nachhaltigkeit und Erfolgskontrolle im Schutzwald. Wegleitung für Pflegemassnahmen in Wäldern mit Schutzfunktion. Vollzug Umwelt. Bundesamt für Umwelt, Wald und Landschaft, Bern, 564 S.

Fuchs, M., H.P. Nachtnebel, B. Kohl, G. Markart und G. Patzelt (2000): Entwicklung eines Hangmodells zur Simulation der hydrologischen Prozesse bei Starkregenereignissen auf Schnee. Österreichische Wasser- und Abfallwirtschaft, Jg. 52, Heft 7/8, 181 – 194.

Greiffenhagen, A. (2005): Einfluss der Humusauflage auf das Benetzungsverhalten und den Wasserhaushalt von Kiefernstandorten. Dissertation TU-Berlin, Fakultät VII – Architektur, Umwelt, Gesellschaft, 132 Seiten.

Hagen, G., E. Nieszlein und U. Schapeit (1993): Das Wasserabflussverhalten auf den Schipisten der Idalpe. Wildbach- und Lawinenverbau, 57. Jg., Heft 124, 229-234.

Hager, H. (1988): Stammzahlreduktion – Die Auswirkungen auf Wasser-, Energie- und Nährstoffhaushalt von Fichtenjungwüchsen. Forstliche Schriftenreihe, Universität für Bodenkultur, Wien, 189 Seiten.

Hartl, H., R. Stern und M. Seger (2001): Karte der aktuellen Vegetation von Kärnten (M 1 : 50.000). Naturwissenschaftlicher Verein für Kärnten.

Hemund, C., R. Weingartner, J. Dobmann, G. Markart and B. Kohl (2010): Flood assessment in small catchments - Evaluating an Austrian method in Switzerland. Hydrologie und Wasserbewirtschaftung, 54. Jg., Heft 3, 156-168.

Hemund, C., G. Markart, B. Kohl, J. Dobmann und R. Weingartner (2011): Abschätzung von Oberflächenabflussbeiwerten bei konvektiven Starkregen – Evaluation der Geländeanleitung von Markart et al. (2004) für Schweizerische Einzugsgebiete. BFW-Dokumentation 12/2011.

Hibbert, A.R. (1967): Forest treatment effect on water yield. In: Sopper W.E. und H.W. Lull (Hsg.): Int. Symp. On For. Hydr., Penn. State. Univ., Aug 29-Sept. 10, 1965, Pergamon Press, N.Y., 527-543.

Kainz, M., K. Auerswald and R. Vöhringer (1992): Comparison of german and swiss rainfall Simulators - utility, labour demands and costs.; Z. Pflanzenernähr. Bodenk. 155, 7-11.

Karl, J. und H. Toldrian (1973): Eine transportable Beregnungsanlage für die Messung von Oberflächenabfluss und Bodenabtrag; Wasser und Boden, 25. Jg., Heft 3; 63 – 65.

Kendall, C., J. J. McDonnell and W. Gu (2001): A look inside „black box“ hydrograph separation models: a study at the Hydrohill catchment. Hydrol. Process. 15, 1877-1902.

Kienzler, P.M. (2007): Experimental study of subsurface stormflow formation - Combining tracer, hydrometric and geophysical techniques. Dissertation, ETH Zürich Nr. 17330.

Kienzler, P.M. and F. Naef (2008): Subsurface storm flow formation at different hillslopes and implications for the „old water paradox“. Hydrol. Processes, 22, 1, 104-116.

Kilian, W. M. Englisch, E. Herzberger, O. Nestroy, S. Huber, A. Pehamberger, J. Wagner, P. Nelhiebel, E. Pecina und W. Schneider (2002): Schlüssel zur Bestimmung der Böden Österreichs. Mitt. Österr. Bodenkundl. Ges., Heft 67.

Kirnbauer R., B. Kohl und G. Markart (2009): Hochwasserauslösende Prozesse. Wiener Mitteilungen, 216: Hochwässer: Bemessung, Risikoanalyse und Vorhersage, 21-44.

Klebinder, K., B. Kohl, G. Markart und B. Sotier (2009): Bucklige Welt – Wechselland, Hydrologische Studie Schopfgraben – Modellrechnung HEC-HMS, Bericht im Auftrag des Forsttechnischen Dienstes für Wildbach– und Lawinenverbauung, Gebietsbauleitung Südliches Niederösterreich und Burgenland.

Klug-Pümpel, B., B. Burgstaller und R. Schiffer (1994): Borstgrasweiden im Schattberggebiet (Land Salzburg): Artengarnitur und Phytomasse. Die Bodenkultur, Journal für landwirtschaftliche Forschung, Bd. 54, Heft 2, 99-111.

Koella, E. (1986): Zur Abschätzung von Hochwässern in Fließgewässern an Stellen ohne Direktmessung. Eine Untersuchung über Zusammenhänge zwischen Gebietsparametern und Spitzenabflüssen kleiner Einzugsgebiete. Mitt. VAW-ETH Zürich, Nr.87.

Kohl B. (2000): Vegetation als Indikator für die Abflussbildung. Internationales Symposion INTERPRAEVENT 2000 – Villach / Österreich, Tagungspublikation, Band 2, 41-51.

Kohl, B., K. Kohl and G. Markart (2005): Endbericht Mittlere und Detailebene -Themenkomplex Boden, Vegetation und Landnutzung. Interreg IIIb-Projekt :nab (Naturpotenziale alpiner Berggebiete), Modul 1, Naturgefahrenbewertung – Evaluierung ETALp.

Kohl, B. (2011): Das Niederschlags-/Abflussmodell ZEMOKOST - Entwicklung eines praktikablen Modells zur Ermittlung von Hochwasserabflüssen in Wildbacheinzugsgebieten unter Einbeziehung verbesserter Felddaten. Dissertation, Fakultät für Geo- und Atmosphärenwissenschaften, Universität Innsbruck.

Kohl, B. (2012): Das Niederschlags-/Abflussmodell ZEMOKOST - Entwicklung eines praktikablen Modells zur Ermittlung von Hochwasserabflüssen in Wildbacheinzugsgebieten unter Einbeziehung verbesserter Felddaten. BFW-Dokumentation, in Vorbereitung.

Kohl B., M. Fuchs, G. Markart and G. Patzelt (2000): Heavy rain on snow cover. Annals of Glaciology 32, 33-38.

Kohl, B. and G. Markart (2002): Dependence of surface runoff on rain intensity – Results of rain simulation experiments. In: International Commission for the Hydrology of the Rhine basin: Proceedings of the International Conference on Flood Estimation, March 6-8, Berne, Switzerland, 139-146.

Kohl B., G. Markart und W. Bauer (2002): Abflussmenge und Sedimentfracht auf unterschiedlich genutzten Boden-/Vegetationskomplexen bei Starkregen im Sölktal/Steiermark. BFW-Bericht Nr. 127, 5-30.

Kohl, B. and Markart G. (2003): Surface roughness and its influence on overland flow. Proceedings: International Workshop on Mountain Hydrology, April 2-4, 2003, Einsiedeln, Switzerland, S. 13.

Kohl, B. und G. Markart (2009): Von der Starkregensimulation zur Abschätzung von Hochwasserabflüssen kleiner Einzugsgebiete. Forum für Hydrologie und Wasserbewirtschaftung, Heft 28.10, 157-170.

Kuntner, R. and P. Burlando (2003): Parsimonious and Spatially Distributed Modelling of Runoff Generation in Mesoscale Prealpine and Alpine Catchments. In: Proc. of the "International Conference on Flood Estimation", Bern, Switzerland, 6-8 March 2002, CHR-KHR rep. n° II-17, 407-418.

Lang, E. (1995): Starkregensimulation - Ein Beitrag zur Erforschung von Hochwasserereignissen; Berichte der Forstlichen Bundesversuchsanstalt Wien, Bd. 90.

Landolt, E. (1977): Ökologische Zeigerwerte zur Schweizer Flora. Veröff. Geobot. Inst. ETH, Stiftung Rübel, Zürich.

Lauber K. und G. Wagner (2001): Flora Helvetica. Farbfotos von 3000 Blüten- und Farnpflanzen der Schweiz, Artbeschreibungen und Bestimmungsschlüssel. 3. Auflage. Verlag Paul Haupt, Bern. ISDN 3-258-06313-3.

Laule, J. (2007): Experimentelle Untersuchungen zum Interflow in periglazialen Decksedimenten. Diplomarbeit, Universität Freiburg i. Br., 138 S.

Lee, R. (1979): Radiative indexes to deforestation effects on water yield. Univ. München, Met. Inst. Wiss. Mitt. Nr. 35, 72-75

Löhmanssröben, R., O. Altfeld, G. Bunza, M. Eidt, A. Fischer, P. Jürging, T. Schauer und R. Ziegler (2000): Geländeanleitung zur Abschätzung des Abfluss- und Abtragsgeschehens in Wildbacheinzugsgebieten. Bayerisches Landesamt für Wasserwirtschaft, Materialien Nr. 87.

Lorenz, P. und Skoda G. (2000): Bemessungsniederschläge kurzer Dauerstufen (D □ 12 Stunden) mit inadäquaten Daten. Mitt. Hydr. Dienst in Österr., Nr.80, 1-24.

Markart, G. (2000): Zum Wasserhaushalt von Hochlagenaufforstungen – am Beispiel der Aufforstung von Haggen bei St. Sigmund im Sellrain. FBVA-Bericht, Nr. 117.

Markart, G. und B. Kohl (1995): Starkregensimulation und bodenphysikalische Kennwerte als Grundlage der Abschätzung von Abfluss- und Infiltrationseigenschaften alpiner Boden-/Vegetationseinheiten. Ergebnisse der Beregnungsversuche im Mustereinzugsgebiet Löhnersbach bei Saalbach in Salzburg. FBVA-Bericht 89, 38 Seiten.

Markart, G., B. Kohl, K. Kohl und P. Zanetti (1996a): Integralmelioration “Vorderes Zillertal” - Einfluss von Boden, Vegetation und rezenter Bewirtschaftung auf den Abfluss bei Starkregen. Unveröffentlichter Bericht der Forstlichen Bundesversuchsanstalt, Wien, 131 Seiten.

Markart, G., B. Kohl und P. Zanetti (1996b): Einfluss von Bewirtschaftung, Vegetation und Boden auf das Abflussverhalten von Wildbacheinzugsgebieten - Ergebnisse von Abflussmessungen in ausgewählten Teileinzugsgebieten des Finsingtales (Zillertal/Tirol). Beitrag Symposium INTERPRAEVENT, Garmisch-Partenkirchen, Juni 1996, Tagungsband 1, 135-144.

Markart, G., B. Kohl und P. Zanetti (1997): Oberflächenabfluss bei Starkregen - Abflussbildung auf Wald-, Weide- und Feuchtflächen (am Beispiel des oberen Einzugsgebietes der Schesa - Bürserberg, Vorarlberg), Cblt. ges. Forstwesen, 114. Jg., Heft 2/3, 123-144.

Markart G., Kohl B., Poscher G., Wanker W. and Schnetzer I. (1999): Assessment of runoff charakteristics in a torrent catchment area. Proceedings of the XXVIII IAHR Congress, 22-27. August, Graz

Markart, G., B. Kohl, W. Gallmetzer und A. Pramstraller (2000): Wirkungen von Begrünungen auf das Abflussverhalten in Wildbacheinzugsgebieten bei Starkregen. Internationales Symposion INTERPRAEVENT 2000 – Villach / Österreich, Tagungspublikation, Band 2, 53-64.

Markart, G. und B. Kohl (2004): Abflussverhalten in Wildbacheinzugsgebieten bei unterschiedlicher Landnutzung. Wildbach- und Lawinenverbau, Heft 149, 9-20.

Markart, G., B. Kohl, R. Kirnbauer, H. Pirkl, H. Bertle, R. Stern, A. Reiterer and P. Zanetti (2006): Surface runoff in a torrent catchment in Middle Europe and its prevention. Geological and Geotechnical Engineering, 24, 1403-1424.

Markart, G., B. Kohl und F. Perzl (2007): Der Bergwald und seine hydrologische Wirkung - eine unterschätzte Größe? LWF-Wissen Nr. 55, Berichte der Bayerischen Landesanstalt für Wald und Forstwirtschaft, 34-43.

Markart, G., F. Perzl, B. Kohl, R. Luzian, K. Kleemayr, B. Ess und J. Mayerl (2007): Schadereignisse 22./23. August 2005 - Ereignisdokumentation und -analyse in ausgewählten Gemeinden Vorarlbergs. BFW-Dokumentation No. 5.

Markart, G., B. Kohl, G. Bieber, A. Römer, A. Ita, K. Klebinder, S. Pfeiler, K. Suntinger, W. Bauer, H. Pausch, M. Strasser (2008): Beitrag des oberflächennahen Zwischenabflusses zum Gesamtabfluss in einem alpinen Kleinsteinzugsgebiet bei Dauerregen. Endbericht zu einer Pilotstudie an die Österreichische Akademie der Wissenschaften, Kommission für Hydrologie. 89 Seiten.

Markart G., G. Bieber, A. Römer, A. Ita, B. Jochum, K. Klebinder, B. Kohl, H. Pausch, B. Sotier, M. Strasser, K. Suntinger (2010): Abschätzung der Bandbreite von Fließgeschwindigkeiten des oberflächennahen Zwischenabflusses in alpinen Einzugsgebieten. Endbericht zum 1. Projektjahr. Österr. Akademie der Wissenschaften, Kommission für Hydrologie.

Markart, G. and B. Sotier (2011): META-Information on assessment of surface runoff characteristics / infiltration characteristics in different regions of the Eastern Alps. Compiled results of rain simulation experiments. BFW-report in the frame of the INTERREG SEE-Project CCWaterS, WP7, 12 p.

Markart, G., K. Klebinder, B. Kohl and B. Sotier (2011): Niederschlagsretention und Abflussbildung in alpinen Einzugsgebieten. Ingenieurbiologie, in press.

Mendel, H.G. (2000): Elemente des Wasserkreislaufs: Eine kommentierte Bibliographie zur Abflussbildung. Hsg.: Bundesanstalt für Gewässerkunde, Koblenz. 1. Aufl. Berlin, Analytica.

Merz, R. und G. Blöschl (2002): Marktüberblick und Beispiele – Software für die N/A-Modellierung. Wiener Mitteilungen, Bd. 164, 223-242.

Mosley, M.P. (1982): Subsurface flow velocities through selected forested soils, South Island, New Zealand, J. Hydrol., 55, 65-92.

Müller, T. (1988): Bodenphysikalische und bodenmechanische Informationen der forstlichen Standortskarte. Forstw. Cbl. 107, 104-111.

Nachtnebel, H.P., K. Leroch, J. Fürst, H. Holzmann, G. Markart, B. Kohl, W. Bauer, H. Pirkl, R. Kirnbauer und P. Ramspacher (2005): Endbericht zum Projekt „Abflussverhalten von „Einzugsgebieten verschiedener Größe bei Dauerregen“. GZ 5811-VC7/2000 im Auftrag des Bundesministeriums für Land- und Forstwirtschaft, Umwelt- und Wasserwirtschaft, unveröffentlicht.

Nestroy, O., O.H. Danneberg, M. Englisch, A. Gessl, H. Hager, E. Herzberger, W. Kilian, P. Nelhiebel, E. Pecina, A. Pehamberger, W. Schneider und J. Wagner (2000): Systematische Gliederung der Böden Österreichs (Österreichische Bodensystematik 2000). Mitt. Österr. Bodenkundl. Ges., Heft 60.

Pirkl, H., G. Markart und B. Kohl (2000): Von Fachkartierungen zu flächenhaften Prozessdarstellungen – Aggregierungsschritte als Weg. Internationales Symposion INTERPRAEVENT, Villach, Juni 2000, Tagungspublikation, Band 3, 259 – 270.

Prinz, H. (1991): Abriss der Ingenieurgeologie. 2. neu bearbeitete und erweiterte Auflage. Ferdinand Enke Verlag, Stuttgart.

Projektteam ETALp (Hsg. - 2004): ETALP – Erosion, Transport in Alpinen Systemen – Gesamtheitliche Erfassung und Bewertung von Erosions- und Transportvorgängen in Wildbacheinzugsgebieten. Lebensministerium, Abteilung IV/5.

Renger, M., K. Bohne, M. Facklam, T. Harrach, W. Riek und W. Schäfer, G. Wessolek und S. Zacharias unter Mitarbeit von: J. Bachmann, U. Dehner, W. Duijnisveld, W. Eckelmann, K.-H. Hartge, V. Hennings, S. Knoblauch, L. Müller, U. Müller, R. Plagge, U. Schindler, K. Schwärzel, H. Sponagel, T. Vorderbrügge (2008): Ergebnisse und Vorschläge der DBG-

Arbeitsgruppe „Kennwerte des Bodengefüges“ zur Schätzung bodenphysikalischer Kennwerte (http://www.boden.tu-berlin.de/fileadmin/fg77/_pdf/publikationen/bodenphysikalischeKennwerte.pdf).

Rickli, C. und F. Forster (1997): Einfluss verschiedener Standortseigenschaften auf die Schätzung von Hochwasserabflüssen in kleinen Einzugsgebieten. Schweiz. Zeitschr. f. Forstwesen.

Sarkar, R. and S. Dutta (2009): An experimental and modeling investigation of macropore dominated subsurface stormflow in vegetated hillslopes of northeast India. New Approaches to Hydrological Prediction in Data-sparse regions (proc of Symposium HS.2 at the Joint IAHS IAH Convention, Hyderabad, India, September 2009). IAHS Publ. 333, 145-152.

Schauer, T. (1988): Zur Problematik der Schipistenbegrünung. Rasen, Turf, Gazon; Heft 1 (Intern. Zeitschrift f. Vegetationstechnik für Forschung und Praxis).

Schauer, T. (1992): Der Beitrag der Vegetationskartierung für die Abschätzung und Prognose des Abflusses, des Abtrags und der Belastung bei spezifischen Nutzungen in alpinen Wildbacheinzugsgebieten. Internationales Symposium INTERPRAEVENT, Bern.

Schauer, T. (2000): Der Einfluss der Schafbeweidung auf das Abfluss- und Abtragsgeschehen Internationales Symposion INTERPRAEVENT 2000 – Villach / Österreich, Tagungspublikation, Band 2, 65-74.

Schauer, T. und C. Caspari (2001): Der große BLV-Pflanzenführer – über 1500 Blütenpflanzen Mitteleuropas. Achte überarbeitete Auflage (Neuausgabe), München 2001, ISBN 3-405-16014-5, BLV-Verlagsgesellschaft mbH, München.

Schauer, T. und C. Caspari (2008): Der BLV-Pflanzenführer für unterwegs. 1150 Blumen, Gräser, Bäume und Sträucher. Zweite durchgesehene Auflage, ISBN 3-405-16014-5, BLV-Buchverlag GmbH Co. KG, München.

Schauer, T. (2002 – schriftliche Mitteilung): Pflanzen als Abflusszeiger – Auswertungen von Beregnungsversuchen. Bayerisches Landesamt für Wasserwirtschaft München.

Scherrer, S. (1997): Abflussbildung bei Starkniederschlägen. VAW-Mitteilungen, Nr. 147.

Schiechtl, H. M. (1954): Die Folgen der Entwaldung am Beispiel des Finsingtales in Nordtirol. Zentralblatt für das ges. Forstwesen, Wien, Heft 1/2: 13-28.

Schmeil - Fitschen (1982). Flora von Deutschland. Verlag Quelle und Meyer.

Schreiber, P. (1997): Geländeauffüllungen: Probleme mit der Qualität der geschütteten Böden. Umweltpraxis Nr. 13, Feb. 1997. 67-70.

Schriftleitner, U. und U. Smoltczyk (1990 – Hsg.): Grundbau-Taschenbuch. 4. Auflage, Teil 1, Verlag Ernst Sohn, Berlin.

Schwarz, O. (1984): Der Wald als Hochwasserschutz. Neue Ergebnisse über die Wasserschutzfunktion der Wälder. Mitt. Forstl. Vers-. u. Forschungsanstalt Baden-Württemberg, 189-194.

Seger, M. (2001): Rauminformationssystem Österreich - ein digitaler thematischer Datensatz des Staatsgebietes. Österreichische Zeitschrift für Vermessung und Geoinformation; Nr. 89.

Stepanek, L., B. Kohl, und G. Markart (2004): Von der Starkregensimulation zum Spitzenabfluss. In: Conference Proceedings - Internationales Symposion Interpraevent 2004, Riva, (II). 101-112.

Swank, W.T., L.W. Swift, Jr. and J.E. Douglass (1988): Streamflow changes associated with forest cutting, species conversions and natural disturbances. In W.T. Swank and D.A. Crossley, Jr. (eds.): Forest Hydrology and Ecology at Coweeta. Ecological Studies – Analysis and Synthesis, Vol. 66, Springer Verlag, New York, 297-312.

Sotier B., G. Markart, B. Kohl, T. Schauer und J. Stötter (2000): Objektivierung der Untersuchungen zur Hochwassergenese als Grundlage der Gefahrenzonenplanung - Zusammenführung von

Daten aus Beregnungsversuchen und bodenkundlichen Begleituntersuchungen. Bericht an die Österreichische Nationalbank.

Sotier, B., G. Markart und T. Schauer (2001): Datenbankgestützte Auswertung und Interpretation von Daten aus Beregnungsversuchen, boden- und vegetationskundlichen Begleituntersuchungen, Unveröffentlichter Zwischenbericht an das BMLFUW, 02/2001.

Stepanek, L., B. Kohl und G. Markart (2004): Von der Starkregensimulation zum Spitzenabfluss. Internationales Symposion INTERPRAEVENT 2004 – Garda / Italien, Tagungspublikation, Bd. 1, Thema II / 101-112.

Thomsen, B. W. and Hjalmarson H. W. (1991): Estimated Manning's roughness coefficients for stream channels and flood plains in Maricopa County, Arizona. Phoenix, Arizona: Flood Control District of Maricopa County.

Tromp-van Meerveld I. and M. Weiler (2008): Hillslope dynamics modeled with increasing complexity. J. Hydrol., 361, 24-40.

Weinmeister, H.W. (1991): Die Bedeutung der flächenwirtschaftlichen Maßnahmen für die Wildbach- und Lawinenverbauung. In. Waldsanierung, Ideen-Vorschläge-Lösungen. Beiträge zur Hochschultagung, Wien / Österreich, Oktober 23-24, Univ. f. Bodenkultur, 1-12.

Weltz, M. A., A. B. Awadis and L.J. Lane (1992): Hydraulic roughness coefficients for native rangelands. Journal of Irrigation and Drainage Engineering. ASCE 118 (5), 776-790.

Zeller, J. (1974, 1981): Starkniederschläge und ihr Einfluss auf Hochwasserereignisse. Eidgen. Anst. Forstl. Versuchsw., Bericht Nr. 126., 1. und 2. Auflage.

Internet:

Geotip: http://geotip.igt.ethz.ch/index.php?&gfield=knowledge&gmenuleft=blocs&gblocid=21&PHPSESSID=r969q13rlrkpgov72r6ookupc5

Annex 1 – Code of Practice

1.1 Additional remarks for the use of the Code of Practice

The table listed in the chapters 1.2 to 1.8 allow the attribution of runoff coefficient classes to typical „hydrological vegetation units in the Eastern Alps in dependency of:

- Soil conditions
- Way and intensity of land use
- Plant species (hydrological indicator function)

The order of the columns 2-4 (Soil, land use / site conditions, plant indicator values) gives no hierarchical information about site information, in addition no quality rating can be derived from the order.

For an experienced soil scientist it will be possible to specify runoff and infiltration conditions only on basis of the soil information more precisely.
Specialists with good knowledge of plant species can limit the bandwidth of possible surface runoff based on the indicator function of plants common or abundant in that area in torrential rain. Geomorphological indicators (e.g. network of small channels) as well as way and intensity of land use allow specification of runoff behavior on its own.

The code available forms a manual for practitioners. Therefore the user shall have the opportunity to assess runoff behavior by the choice out of several features which can be easily derived in the field.

Column 3 (land use / specific site conditions) often contains examples of several different characteristics. At least on feature must be fulfilled to assess the convenient runoff coefficient class. Several clearly visible simplify assignment of runoff coefficients and make it more precise.

1.2 Pioneer vegetation – immature soils

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient Class
Vegetation-free or initial phase of vegetation development	**Blocky debris**, coarse soil, loose	No gullies at the underlying slope	tr-mf	0/1
	Talus deposits, fine soil, loose	Gullies in the underlying talus	mf-f	4*
	Fine soil, cohesive (varying content of coarse material)	Newly graded sites: first showers lead to compaction of surface (splash erosion), linear erosion (small gullies)	tr-f	5*
	Rock, fissured - clearly fissured	Some gullies at the underlying slope but running out in the talus deposits		3-4
	Rock, poorly fissured, compact	Erosion, significant gullies at the underlying slope		5

* High freight of solid matter and high disposition for linear erosion (development of gullies and debris flow).

1.3 Grass vegetation, grasslands – meadows

<table>
<tr><th>Vegetation-unit</th><th>Soil</th><th>Cultivation / utilization special features</th><th>Humidity</th><th>Runoff-coefficient class</th></tr>
<tr><td rowspan="6">Grassland (without Nardus stricta)</td><td>Coarse Soil, (rich skeleton), granular - loose</td><td>no pasturing</td><td>mf-f</td><td>1</td></tr>
<tr><td>Coarse soil, granular - loose</td><td>no pasturing, ground cover > 80%</td><td>f</td><td>2</td></tr>
<tr><td rowspan="2">Fine-soil (rich in skeleton), cohesive, dense</td><td>Pasture, ski piste</td><td>f</td><td>3</td></tr>
<tr><td>Pasture, ski piste</td><td>ff</td><td>4</td></tr>
<tr><td>Fine-soil (rich in skeleton), cohesive,</td><td>Pasture, ski piste</td><td>ff-n slope water</td><td rowspan="2">5</td></tr>
<tr><td>(Very) shallow soil on native rock,</td><td>Grassland alternates with bare rock dense open talus, steep channels, no-few dwarf shrubs</td><td>mf-f</td></tr>
</table>

<table>
<tr><th>Vegetation-unit</th><th>Soil</th><th>Cultivation / utilization special features</th><th>Humidity</th><th>Runoff-coefficient class</th></tr>
<tr><td rowspan="4">Nardus stricta grassland</td><td>Coarse soil, shallow due to reasons of substratum, granular - loose</td><td>No grazing</td><td>mf-f</td><td>3</td></tr>
<tr><td rowspan="2">Fine soil (rich in skeleton), cohesive, dense</td><td>with and without pasturing, dwarf shrub heath up to 25%</td><td>mf-f</td><td>4</td></tr>
<tr><td>Grazed / extensified</td><td>mf-ff</td><td>5</td></tr>
<tr><td>Very shallow on native rock</td><td>Grassland alternates with bare rock dense open talus, steep channels, no-few dwarf shrubs</td><td>mf-f</td><td>5</td></tr>
</table>

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient class
Meadows	**Coarse-soil,** loose	only mowing	mf-f	1
	Coarse-soil, loose	short grazing period (max. 2 weeks)	mf-f	2
	Fine-soil, loose, (rich in skeleton)	slope characterized by shallow subsurface runoff, no grazing and other cultivation	ff	3
	Fine-soil	humid, grazing, ski track	ff	4
	Fine-soil, dense	slope characterized by shallow subsurface runoff, intensive grazing, ski track	ff-n	5

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient class
Marsh areas and low moors (fens)	High content of organic matter, cohesive, dense	Slope water, water logging	ff-n	5
		Permanently wet, damages due to livestock steps; erosion	n	6

1.4 Dwarf shrub heath

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient Class
Alpenrose* and blueberry heath	**Coarse-soil,** loose	none	mf-f	0/1
		on small parts damages by livestock (compaction, erosion)	mf-f	2
	Fine-soil, (rich in skeleton)	matgrass, damages by livestock (compaction, erosion) on max. 25% of the area	mf-f	3
	Fine-soil	humid, moist - network of small brooks	f-ff	4
		wet, dense network of small brooks	n Sphagnum**	5

* Two types of Alpenrose with different habitat preferences are common in the Eastern Alps:
Rhododendron hirsutum favours coarse, permeable and mostly dry stands.
Rhododendron ferrugineum grows on cohesive, even wetter soil and sometimes shows higher runoff coefficients.
** Mosses like ***Sphagnum*** sp. combined with dense channel network and other plants indicating humidity or wettness underline the high runoff disposition of a site (AKI **5**). Without the "related" fine channel network Sphagnum sp. often indicates long

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient Class
Scotch heather (*Erica, Calluna* sp.) and *Juniperus* sp.	**Coarse soil,** loose (also on carbonate substratum)	No pasturing (partlygrass covered)	mf	1
	Coarse soil, loose (also on carbonate substratum)	partly grass covered, grazed	mf	2
	(rich in skeleton), Fine soil, high content of organic matter in the topsoil (hydrophobic under dry conditions)	partially dry sites, high ground cover (> 80%)	mf	3
		Associated with *Nardus stricta* (thatched roof effect), partly grass covered, grazed	mf-f	4

duration of snow cover, and at such site normally deliver surface runoff at a lower level (AKl **4**).

1.5 Bush associations

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient Class
Green Alder and willow bushes	**Coarse soil** with fines, loose		f-ff	3-4
	Fine soil	Periodiclly wet, slope water		4
		Slope water, Waserstau, waterlogging, dense network of fine channels	ff-n	5

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient Class
Grey Alder and Willow bushes	**Coarse soil with fines, loose**		mf-f	2-3
	Fine soil, loose	Periodiclly wet, slope water	f-ff	3-4
	Fine soil (cohesive)	Slope water, Waserstau, waterlogging, dense network of fine channels	ff-n	5

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient Class
Pinus mugo (dwarf shrubs and single trees added)	**Coarse soil**, loose, humus layer	No pasturing, no other type of land use	tr-mf	1
	Shallow coarse soil on rock,** loose	intensive pasturing, some signs of erosion	tr - mf	3
		grassland covered sites with bare rock in between		4
	Fine soil, high content of organic matter	associated with Green Alder	f - ff	
	Fine soil with coarse material embedded in the matrix	Intensive pasturing, numerous signs of erosion	mf-ff	5

** quick development of interflow, emerging on deeper parts of the slope as return flow.

1.6 Tall forb associations

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient class
Tall forb associations	**Coarse soil,** loose		mf-f	0-1
	Coarse soil, with fines, loose		mf-f	2
		Pasture	mf-f	3
	Fine soil		f-ff	3-4
		Pasture	f-ff	4
	Fine soil, cohesive	Dense network of small channels, mechanical impact	ff-n	5

1.7 Forests

The information is valid for stands with a canopy cover of ≥ 0,8 in principle. If canopy cover is further reduced more attention must be paid to the ground cover / soil vegetation. In this case the runoff coefficient can be assessed for the tree covered area and the tree free area (e.g. grassland in the forest, pastured area, wet plot) separately.

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient class
Spruce forest, > 50% Spruce (no or few ground vegetation cover - *nudum*)	**Coarse soil,** also with fines, loose		mf-f	1
	Coarse soil with fines, **fine soil**	Dry mould layer		2
		Moderate pasturing, dry mould layer	mf-ff	3
	Fine soil, dense	Slope water supply, intensive pasturing, dense channel network	mf-ff	4
	Fine soil, cohesive dense	Water logged, dense channel network	ff-n	5

1.7.1 Coniferous forests

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient class
Spruce forest, > 50% Spruce (with groundcover - herbs / dwarf shrubs)	**Coarse soil,** also with fines, loose, (raw)humus layer, no hydrophobic effects	Überschirmungsgrad > 0,7, dichter Unterwuchs (Strauchschicht, Zwergsträucher...)	mf-f	1
	Coarse soil, with fines, loose	Loose stand, < 50% covered by dwarf shrubs, vergrast		2
	Fine soil	Pasture		3
	Fein-Boden, cohesive or dense	Slope water, humid	f-ff	4
	Fine soil (cohesive)	Wet	ff-n	5*

* normally only on small areas in the stand

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient class
Meadows with Larch (Larch-Meadows)	**Coarse soil**, also with fines, loose	No pasturing, mowing, not levelled	mf-f	1
	Coarse soil, with fines	Short time grazing, not levelled		2
	Fine soil	Short time grazing, partailly levelled		3
	Fine soil, dense	Intensive grazing, partially levelled		4

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient class
Forests rich in *Pinus cembra* (with dwarf shrubs - Alpenrose, blueberries…)	**Coarse soil,** also with fines, loose	Raw humus layer, no additional impact	mf-f	0-1
	Fine soil	Slope water, moderate pasturing	f-ff	3
		Slope water, *Sphagnum* sp., moderate pasturing		4

* found seldom (unsuitable to site)

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient class
Forests rich in Larch (> 50%)	**Coarse soil**, also with fines, loose		mf-f	0-1
	Coarse soil, with fines	Kurzweide		2
	Fine soil	mäßige Beweidung bzw. sonstige Belastungen		3
	Fine soil, dense	Beweidung, deutl. Hangwasserzug, feucht	f-ff	4*

1.7.2 Deciduous forests and mixed forests (deciduous and coniferous trees)

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient class
Deciduous forests and mixed forests (deciduous trees and conifers)	**Coarse soil**, also with fines, loose	Intensive bioturbation, leaf litter layer, ground vegetation existing	mf-f	0-1
	Fine soil, loose	Intensive bioturbation, leaf litter layer, ground vegetation existing	mf-f	1
	Coarse soil, also with fines, loose	Partially grass covered, extensively pastured	mf-f	2
	Coarse soil with fines, **fine soil**	Intensive pasturing or other mechanical load	mf-f	3
	Fine soil,	periodically wet conditions	f-ff	3
	Fine soil,	Periodically wet conditions, mechnaical load (e.g. pasturing, damages from tree-harvesting)	f-ff	4
	Fine soil, cohesive	Periodically wet conditions, often associated with Green Alder or Grey Alder	f-ff	4
	Fine soil, cohesive, dense	(periodically) wet conditions, channel network, often associated with Green Alder or Grey Alder	f-n	5

1.8 Graded / levelled and sealed areas (sites changed by anthropogenous impact like roads, road embankments, ski pistes, parking places…)

Vegetation-unit	Soil	Cultivation / utilization special features	Humidity	Runoff-coefficient Class
Levelled areas with and without planting of trees and grass	**Coarse-soil**, loose	with and without grazing	mf-f	1
	Fine-soil, (rich in skeleton)	mowing, well tended ski piste no grazing	mf-f	3
	Fine-Soil, (rich in skeleton), cohesive, dense	mowing, ski piste with short grazing period	mf-f	4
		mowing, ski piste with short grazing period	ff-n	5
		intensive grazing / compaction by vehicles	mf-n	

Annex 2

Examples for the assessment of surface runoff coefficients and surface roughness coefficients in convective torrential rain for typical vegetation forms of the Eastern Alps.

The vegetation forms and types of land use presented in the following chapters represent frequently found in the Eastern Alps. The list primarily contains extremes in runoff behavior, i.e. units with low and high surface runoff disposition. The list is incomplete (which is inevitable), it will be improved in periodical further releases of the Code of Practice.

2.1 Pioneer vegetation – immature soils

Rock – poorly fissured / coarse textured talus

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Rock without vegetation	**Rock**, **Poorly fissured**,	None	Retention potential due to missing cracks and fissures negligible; after a short abstraction time high surface runoff occurs (immediate linear concentration)	**1**	**5***

*Runoff often buffered in talus deposits below the rock band

Higly drainable talus deposits - acting as a highly effective runoff buffer

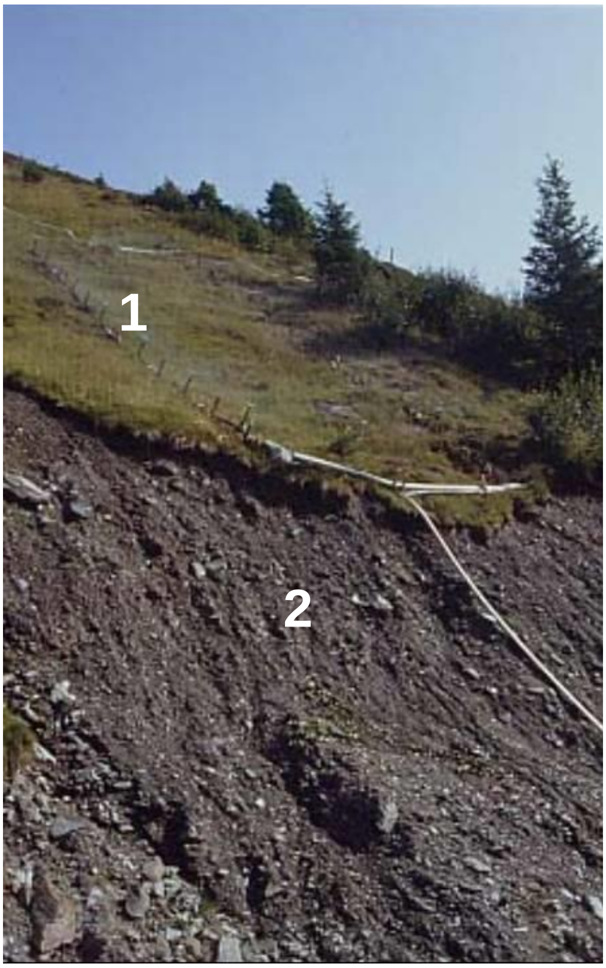
 

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Talus deposits	Talus - coarse grained, low content of fines, not solidified	None	High hydraulic conductivity / permeability in torrential rain	6	1
	Talus deposits with overlying massive rock, coarsely grained		The debris band is cut linearly by water supply from the overlying rock (buffering effect depending on content of coarse material and fines, vertical extent of the debris band and the overlying rock)	6	3-4

Talus deposits, rich in fines

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Talus deposits	Debris, coarse grained soil, rich in skeleton with high content of fines, steps of livestock	Pasture	mf, site former covered by *Pinus mugo*, now eroded due to grazing by sheep, in torrential rain high surface runoff (Appearance: Edge of the Alps, esp. Limestone Alps)	2	4-5

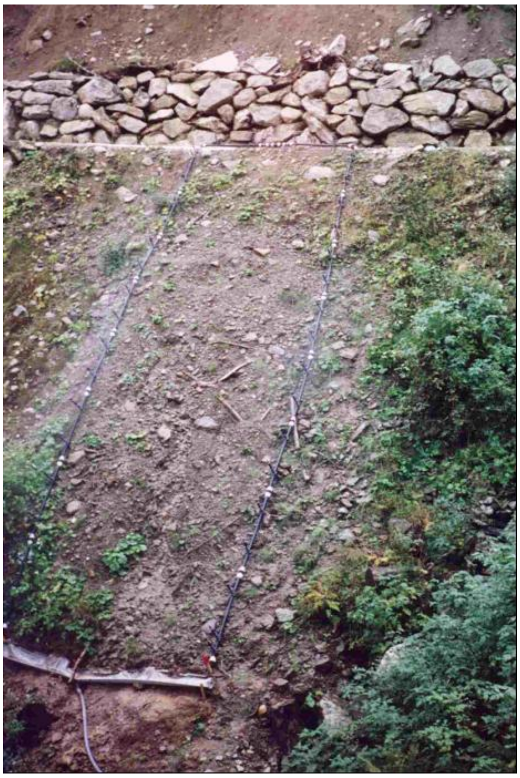
Erosional grassland scar in steep slopes of gullies



Rain simulation experiment with i_N = 100 mm h^{-1} on a steep slope to an alpine gully. The experiment had to be terminate after 30 min due to danger of slope failure. Location: Schusterbauerngraben in the Löhnersbach valley near Saalbach (Salzburg).

Association / unit	**Site / soil**	**Land use**	**Hydrological characteristics**	**Roughness class**	**Runoff coefficient class**
1 Succession phase to *Nardus stricta* grassland (matgrass)	Steep, ground cover < 70%, shallow soil, coarse grained soil, with high content of fines – adjusted parallel to the direction of the slope, high content of sand	Moderately pastured	mf-f Because of grazing impact, the hydrophobic effect of *Nardus stricta* and the limited percolation due to slope parallel oriented skeleton high SR and shallow interflow rates must be expected High disposition for slips or landslides	1-2	4
2 Talus deposits, debris	Coarse soil, rich in skeleton, high content of fines		Missing ground cover and slope parallel oriented skeleton ⇒ high SR, high erosion potential, high potential for landslide and debris flow	2	4

Sites without ground cover – uncovered embankments on steep slopes




Left picture: Simulation of torrential rain on a partially uncovered road embankment (Location: Großsölk - Styria).
Right picture: Slope newly prepared for revegetation after a simulation of torrential rain (plot size: 50 m²). The experiment was finished 31 min after the beginning due to a mudslide (Location: Meran 2000 – South Tyrol, Italy)
In both pictures the formation of small channels because of the missing soil stabilizing effect by the vegetation cover is visible.

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Raw soil and initial soil respectively, pioneer vegetation; vegetation cover << 70%	**Coarse soil with fines**, Fine soil levelled **(Anthrosol)**, high erosion potential, steep	None	Because of lacking vegetation cover and destruction of soil structure (e.g. by levelling or filling): Saturation of top thin soil layer and formation of a soil crust at the beginning, followed by high surface runoff and erosion rates; Increased disposition for landslides and slips.	2	4-5

2.2 Grass vegetation, grasslands – meadows

Alpine grasslands (not *Nardus stricta*)

Association / unit	**Site / soil**	**Land use**	**Hydrological characteristics**	**Roughness class**	**Runoff coefficient class**
Subalpine oligothrophic grassland on limestone	**Coarse grained soil**, rich in skeleton, loose	None	**mf,** (*Sesleria varia – Carex sempervirens*) quick infiltration into the mineral soil and the substratum.	**2-3**	**2**

Association / unit	**Site / soil**	**Land use**	**Hydrological characteristics**	**Roughness class**	**Runoff coefficient class**
Subalpine pasture with *Cynosurus cristatus* and *Carex ferruginea*	**Fine soil, rich in coarse material / skeleton**, cohesive, dense	Pasture	**mf-ff,** (*Cynosurus cristatus, Carex ferruginea)*, reduced infiltration potential, esp. in high and late summer (damages by steps from livestock, loss of ground cover, accumulation of dead biomass); network of channels	**1-2**	**4-5**

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
subalpine and alpine grassland 1	**Subalpine grassland on rock, coarse grained soil, with fines, very** shallow soils on native rock	None	**mf-f**, in the steep shallow grassland (with a short greensward and a dense root felt) and from the bare rocks surface runoff immediately after the start of the precipitation event must be expected.	**1-2**	**4-5**
2	**subalpine grassland, on coarse grained soil,** with fines, very shallow-medium deep, on talus deposits	Formerly pastured, possibly mowed, today extensive pasturing	Short greensward and dense root felt limit infiltration, in addition donation with surface runoff from higher parts of the mountain aggravates runoff situation.	**2**	**4-5**
3 Vegetationless sites, sites with initial vegetation	**Talus debris, coarse soil**	None, linear passing by deer and livestock	High reception capacity for precipitation (no gullies, channels or gullies from the upper part of the slope finish in this part, they drain out)	**5-6**	**1**

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
(Sub)Alpine grassland	**Subalpine grassland on coarse soil,** with fines**, very** shallow soil on native rock,	Erosion due to sheep-grazing; esp. in the northern edge of the Alps (Limestone Alps)	**mf,** because of reduced ground cover and steep inclination high surface runoff potential	2-3	4

Nutrient-rich alpine pastures where cattle concentrate to rest (Lägerflur)

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Nutrient-rich alpine pastures where cattle concentrate to rest (**Lägerflur**)	**Fine-soil**, **dense**, ev. cohesive coarse material embedded in the matrix of the topsoil	Intensive pasture	**mf-ff,** indicators like *Rumex sp.;* reduced infiltration potential due to mechanical impact by livestock, esp. in high and late summer.	**3-4**	**4-5**

Grassland with *Nardus stricta – Carex sempervirens*

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Nardus stricta **socialized with other grasses or dwarf shrubs** (coverage < 25%)	**Coarse soil with fines,** also **fine-soil** (dense by root felt, and thatched roof effect)	None / pasture	**mf-ff,** thatched roof effect and root felt by *Nardus stricta* overlay possible good infiltration characteristics of mineral soil – high surface runoff	1-2	4
Nardus stricta (> 70%)**)**				1	5

Alpine meadow (pastured)

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
***Glaux* sp.-meadow –** rich alpine pasture	**Fine soil**, (rich in coarse material and skeleton), **loose**, medium deep - deep	Mowed, short term grazing, intensive maintenance (e.g. manuring, drainage)	tr-f; Runoff disposition low-medium in spring and early summer; increased by mowing and pasturing till late summer (loss of ground cover, compaction of topsoil, damages by livestock steps)	1-3	3
	Fine soil, dense	mowed, short term grazing in autumn	mf-ff; High runoff disposition (immigration of *Nardus stricta*, increase of root felt in the topsoil...)	1-3	4

Meadow – no pasturing

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Association / unit	**Site / soil**	**Land use**	**Hydrological characteristics**	**Roughness class**	**Runoff coefficient class**
Meadow	**Fine-soil loose**, with content of coarse material, this is not embedded in the matrix	No additional use, no passing over with heavy machines	**tr-mf,** no indicators for compaction like *Rumex* sp., *Alchemilla* sp.; No indicators for high slope water supply and soil humidity; Carefully mowing and earning of grass with light machines and not under wet conditions. *) After mowing and by use of heavy machines	2*-3	1-2 3*

Wet meadows and fens

Association / unit	**Site / soil**	**Land use**	**Hydrological characteristics**	**Roughness class**	**Runoff coefficient class**
Wet meadows / fens	**Fine-soil**, cohesive	None / pasture	**ff-n,** indicators like *Trollius europaeus* (yellow) and *Ranunculus aconitifolius* (white) in the left picture; with *Carex paniculata* in the right picture; due to high antecedent moisture content is infiltration potential significantly reduced.	4	5

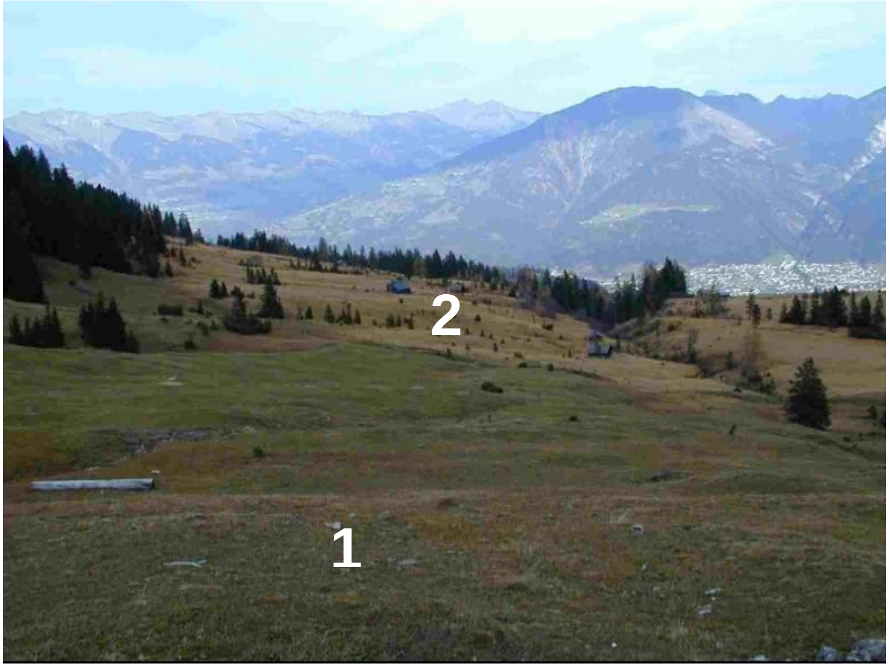


Foto: H. Bertle

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
1 **Almweide**	**Histosols around springs, gleyic and dystric Planosol;** **Fine soil,** partially cohesive and rich in organic matter; medium deep - deep	Pasture	**ff-n**, surface water and water logging, (partial) compaction of topsoil by livestock	**1-2**	**4-5**
2: ***Carex nigra*-Fen**	**Histosol**, deep soil	None	High antecedent soil moisture content due to permanent water supply (springs, small brooks,…)	**4**	**5**

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Low moor (histosol)	**Histosol,** deep, peaty, high content of organic matter	none	ff-n, with *Molinea caerulea* and *Torfsegge* (left picture), *Juncus sp.* and *Trollius europaeus* (right picture). High antecedent water content due to permanent supply with surface water. High surface runoff in torrential rain – delayed due to high surface roughness	4	5

2.3 Dwarf shrub communities

Alpenrose heath

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
1 **Alpenrose heath with blueberries** (left picture Bild)	**Coarse soil, loose**, high content of skeleton	None	mf-f, quick infiltration into the subsoil, scarcely flow processes on the soil surface	6	0/1
2 **Alpenrose** with *Vaccinium uliginosum*	**Fine soil**	None	Ff, supply with slope water	6	4
3 **Alpenrose heath** with *Sphagnum* sp.	**Fine soil**	Extensive pasture	ff-n, surrounded by wet areas, dense channel network	6	5

Calluna vulgaris associated with *Nardus stricta* and other dwarf shrub species

Association / unit	**Site / soil**	**Land use**	**Hydrological characteristics**	**Roughness class**	**Runoff coefficient class**
Calluna vulgaris* with *Nardus stricta (cover by dwarf shrubs < 50%)	**Coarse soil**, rich in fines, shallow - medium deep; skeleton and coarse gravel reaching up to the soil surface (area covered by *Nardus stricta* < 25%)	None	**mf,** *Nardus stricta* limits infiltration rate (thatched roff effect, root felt)	2-3	3
	Fine soil, area covered by *Nardus stricta* < 50%	Pasture	**mf,** *Nardus stricta* limits infiltration rate (thatched roof effect, root felt); no preferential infiltration paths due to missing skeleton reaching up to the surface, therefore high surface runoff	3-4	4

2.4 Bush associations

Bush and tree vegetation on shallow soils

Fotos: A. Haas

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
1 Pinus mugo and tree vegetation, (vegetation covered area above the bare rocks)	**Coarse soil**, raw humus layer; shallow soil on native rock, grass-covered with bare rock in between	none	tr-mf, immediate surface runoff and near surface runoff / interflow which concentrate on the bare rock and flow downwards as linear runoff	5-6	4

Green Alder

Foto: H. Hartl

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
1 Green Alder, (avalanche path) in the upper part associated with *Pinus mugo* or dwarf shrubs respectively	**Coarse soil**, humic layer, shallow carbonate coarse grained soil on native rock; with grass covered areas and bare rock in between	none	mf-ff, quick surface runoff and near surface runoff from the rock covered areas; runoff concentrates on bare rock	**4-5**	**4**
2 Green Alder, (avalanche path)	**Coarse grained soil** with fines, humous layer, shallow carbonate soil on native rock	none, perhaps in the lower left part of the picture indicates moderate pasturing activity	f-ff, infiltration only near to the surface possible; partially development of return flow ; no slope water, no water logging	**4-5**	**3*-**

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
1 Green Alder	**Coarse material** embedded in fine material; **fine grained soil,** partially dense	None / moderate pasturing activity	Slope water, mostly high initial moisture content	4-5	4

2.5 Tall forb associations

Simulation of torrential rain by use of the spray irrigation installation of the LfU (i_N = 100 mm h^{-1}, plot size: 100 m^2. Location Enning-alp near Garmisch (Bavaria, Germany).

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Tall forb association (*Adenostyles alliariae***)** with a loose stand *Acer pseudo-platanus*	Fine soil, cohesive, dense	None	**ff**, Infiltration only possible along single fissures and (dry) cracks	4-5	4-5
		Pasture		4	5

2.6. Forests

Spruce-stands without ground cover (*Piceetum nudum*)

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Piceetum nudum (Spruce stand without ground cover)	**Coarse soil with fines; Soil rich in fines; Fine soil, loose- Boden locker** (siliceous Cambisol), rich in skeleton, loose, mould layer	None	Hydrophobic effects after dry periods	1-2	2
	As mentioned above, but topsoil, compacted by mechanical impact (e.g. livestock)	Moderate pasturing	Hydrophobic effects after dry periods, infiltration limited by mechanical impact (livestock); Infiltration takes place along fissures formed by skeleton or root channels	1-2	3

Spruce with a layer of herbs and /or mosses

Foto: A. Haas

Association / unit	**Site / soil**	**Land use**	**Hydrological characteristics**	**Roughness class**	**Runoff coefficient class**
Spruce forest grass covered (without dwarf shrubs and dense regeneration)	**Coarse soil, loose; Coarse grained soil with fines,** loose (carbonate soil – Rendzina)	Pasture (moderate-medium intensity)	Native soil skeleton at least partially reaches the surface (fissured rocks). Infiltration possible on medium steep slopes and moved relief after short overland flow.	4	2
			On steeper slopes with smooth surface infiltration capacity is reduced (longer overland flow paths)	3	3

Simulation of torrential rain (i_N = 100 mm h^{-1}, plots size = 75 m²). Spray irrigation installation of the BFW at Innsbruck. To prevent rain losses the outsides are irrigated too. Location: Seyfriedbach in the Großsölk valley (Styria, Austria).

Association / unit	**Site / soil**	**Land use**	**Hydrological characteristics**	**Roughness class**	**Runoff coefficient class**
Piceetum (Spruce stand with mosses and single dwarf shrubs)	**Coarse soil with fines; Fine soil – loose** (silicatic Cambisol), mould layer	None	Loose humus-layer, elastic when passing over; esp. in steeper slopes breaking through the humus-layer down to the mineral soil is possible.	3-4	1

Wet spruce stands (on cohesive substratum)

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
***Adenostyles*-Spruce forest-** (*Adenostyles alliariae*)	**Fine soil, cohesive,** (dystric or haplic Planosol), medium-deep	None	**f-ff**, topsoil dense, skeleton and coarse material only effective locally in percolation due to the high content of fines; infiltration and percolation mainly along secondary pores (fissures, cracks, root channels,…)	4-5	4

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Wet forests (here with Spruce, *Grey Alder* and *Chaerophyllum hirsutum*	**Fine soil, often cohesive;** wet soils with high slope water supply (dystric or haplic Planosols, Gleysols, Histosols,…) medium-deep soils	None	**ff**, mostly very high supply with slope water; thus low infiltration and reception potential and high surface runoff	**4-5**	**4-5**

Pinus cembra (Cembran pine) with dwarf shrub heath

Foto: S. Sauermoser

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
1 *Pinus cembra* with dwarf shrub heath ground cover (Alpenrose, blueberries**)**	**Coarse soil**, rich in fines, **loose,** raw humus layer	None	**mf-f**, quick infiltration, cinetic energy of precipitation is broken by vegetation cocer and humus layer; dosed percolation of water in deeper soil horizons	**6**	**1**
2 *Pinus cembra* with grass cover (*Nardus stricta, Festuca*, sp.)	**Coarse soil**, rich in fines, **loose**	Moderate pasturing	Locally reduced infiltration due to root felt and accumulation of dead biomass (thatched roof effect)	**2-3**	**2-3**

Deciduous forests – mixed forests

Simulation of torrential rain (i_N = 100 mm h^{-1}, plots size = 60 m²). Spray irrigation installation of the BFW at Innsbruck. To prevent rain losses the outsides are irrigated too. Location: Kreisbach near Wilhelmsburg (St. Pölten, Lower Austria).

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
Beech stand with marginal ground cover (herbs)	**Fine soil, cohesive** (e.g. Flysch; Planosols); humus layer: mull-mould	None	**mf-f**, Infiltration primarily along fissures, cracks, root channels,…); these paths are not available in case of high antecedent soil moisture content. In addition a high amount of the near surface stormflow comes back to the surface (return flow, e.g. at slope edges). Hints upon surface flow (fine gullies, eroded litter) in the lower parts of the slopes.	2	4

Association / unit	**Site / soil**	**Land use**	**Hydrological characteristics**	**Roughness class**	**Runoff coefficient class**
Beech stands (pure or mixed) with herbal ground cover	**Fine soil, loose**; humus layer: mull-mould Shallow soils-deep soils	None	**tr-f**, water can infiltrate easily due to the good soil structure and the loose layering of the soil. On shallow variations of such sites direct access to fissured rock allows easy infiltration (along fissures, cracks, root channels,…).	3	1

2.7 Graded and sealed areas

Levelled areas with high runoff potential

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
(Upper picture): **revegetated levelled ski piste**	**Fine soil, dense** (high content of silt), Anthrosol, soil depth: medium, gleyic	Ski piste; pasture;	**ff-n**; humidity indicators: *Juncus* sp., *Cirsium* sp.); slope water supply, water logged; marginal retention capacity due to high antecedent water content ⇒ high surface runoff in torrential rain	**1-2**	**5**
(Lower picture): ***Trifolium repens*-meadow** (manured)	**Fine soil, dense**; former Histosol, levelled (Anthrosol)	Ski piste; meadow, pastured	**ff-n**, slope water supply, topsoil compacted by passing over (with heavy machines) and pasturing (e.g. horses), infiltration potential reduced	**1**	**5**

Association / unit	**Site / soil**	**Land use**	**Hydrological characteristics**	**Roughness class**	**Runoff coefficient class**
1 Levelled area revegetated with high altitude seed mixture	**Fine soil,** (rich in coarse material), shallow-medium deep (Anthrosol)	Pasture, ski piste	**mf-f**, increasing accumulation of dead biomass with time; forming of root felt and fine channel network	1	4-5

Levelled sites with low-medium runoff potential

Foto: W. Gallmetzer

Association / unit	Site / soil	Land use	Hydrological characteristics	Roughness class	Runoff coefficient class
(left picture): **Levelled site,** revegetated with high altitude seed mixture	**Coarse soil with higher content of fines; loose** shallow-deep Anthrosol	Pasturing with sheep, low intensity	mf-f, increasing accumulation of dead biomass with time, formation of root felt, formation of single spots with higher runoff potential (*with very fine channel network)	1-2	2-3*
(right picture): **Levelled site** revegetated with high altitude seed mixture)	**Coarse soil with low content of fine, loose;** shallow-deep Anthrosol	None	mf-f, well fissured, coarse grained material reaching to the surface and not embedded in the matrix	2	1

2.8 Rain on snow cover

Shallow wet snow cover on grassland

Preparation of heavy torrential rain simulation on a wet snow cover (*Nardus stricta* grassland) in the melting phase. The test plots have been sprinkled four times: In autumn 1998, in spring 1999 und in winter 1998 und 1999 with different snow depth and snow wetness. Location: Patscherkofel near Innsbruck (Tyrol, Austria).

Association / unit	Site / soil	Land use	Hydrological characteristics	Runoff coefficient class
1 Nardus stricta grassland under shallow WET snow cover (0- 25 cm snow depth)	Soil does not act as a receptor or reception capacity is reduced due to frozen topsoil / ice lenses or high antecedent moisture content in topsoil	Pasture, ski piste	In the state of snowmelt, of highly wetted snow cover and highly saturated topsoil high and relatively quick surface runoff must be expected	5
2 Nardus stricta grassland under deep snow cover (< 75 cm snow depth)	Soil at least partially acts as a receptor. Reception capacity not reduced so much as in Pos. 1.	Pasture, ski piste	Longer delay of surface runoff development, but finally high surface runoff	5

Annex 3

Plants - indicator values

The following chapter contains an information about typical plants which are quite common in the Eastern Alps.

These indicator plants allow the assessment of mean annual soil humidity (annual mean) or the characterization of site water balances. The assignment of surface runoff coefficients based upon the indicator value of a single plant does not make sense. So the runoff coefficient of sites with single individuals of *Caltha palustris* generally is lower than on sites where this plant covers a high percentage of the surface.

As a simplified rule of the thumb:

Single plants indicating humidity	RCL **3** – low RCL **4**
Accumulation of humidity indicators	mean - high RCL **4**
Humidity and wetness indicators	RCL **5**
High percentage of wetness indicating plants	RCL **6**

The Information about the following plant indicator values is based on the field experiences and the investigations done by Schauer (2002) and Hemund et al. (2011). The plants listed in the Chapters 10.3.1 to 10.3.4 form a basic informtion. For further detailed information upon plant indicator values we refer to the colour plant guide books presented by Schauer und Caspari (2001, 2008).

3.1 Forests

Foto: H. HARTL

Petasites albus

Site	RCL
Humid forests	3-4

Foto: T. SCHAUER

Adenostyles alliariae

Site	RCL
Tall forb associations Humid mountain forests	4

Foto: T. SCHAUER

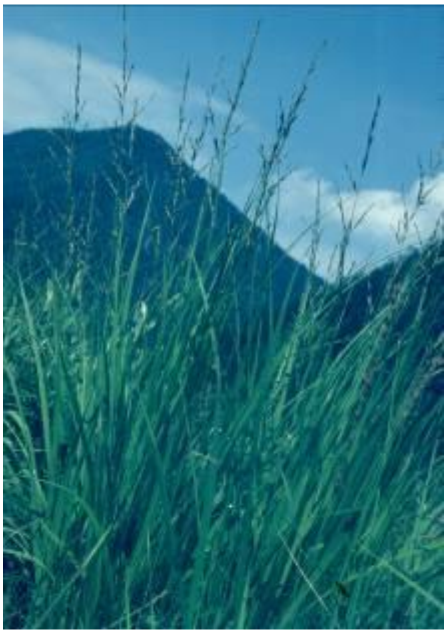
Chaerophyllum hirsutum

Site	RCL
Humid forests	4

Foto: H. HARTL

***Saxifraga rotundifolia*)**

Site	RCL
Humid forests	4

Fotos: H. HARTL

Molinia caerulea

Site	RCL
Humid-very humid forests	4-5

Eupatoria cannabina

Site	RCL
Humid forests	4

Foto: H. HARTL (Bild Alnus incana)

Grauerle

(*Alnus incana*)

Site	RCL
Steep forests, steep forests with springs (often rich in spruce)	3-4

3.2 Forests and humid grassland or humid meadows

Foto: T. SCHAUER

Equisetum palustris

Site	RCL
Forests and grassland, very humid-wet	4-5

Foto: H. HARTL

Equisetum telmateja

Site	RCL
Forests and grassland, very humid-wet	4

Fotos: H. HARTL

Crepis paludosa

Site	RCL
Forests and grassland, very humid-wet (pasture-indicator)	4-5

Caltha palustris

Site	RCL
Wet meadows and forests	5

Fotos: H. HARTL

Vaccinium uliginosum ***Lysimachia nemorum***

Site	RCL	Site	RCL
Humid forests and grassland	4	Humid forests	3-4

Foto: H. HARTL

Angelica sylvestris

Site	RCL
Humid forests, alluvial forests, marsh areas	4

Fotos: H. HARTL

Deschampsia cesapitosa

Site	RCL
Humid meadows, grassland and forests Indicates pasture, water logging and compaction (on cohesive soils)	4

Polygonum bistorta

Site	RCL
Humid meadows	4

Foto: T. SCHAUER

Foto: H. HARTL

Ranunculus aconitifolius

Site	RCL
Wet meadows and forests, marsh areas	5

Mentha longifolia

Site	RCL
Wet meadows and forests, marsh areas	5

3.3 Pastures, humid meadows and moors / fens

Fotos: H. HARTL

Ranunculus repens ***Parnassia palustris***

Site	RCL	Site	RCL
Wet meadows and grassland, indicates pasturing and compaction	4	Wet meadows, grassland and fens	4-5

Foto: H. HARTL

Foto: T. SCHAUER

Cirsium oleraceum ***Cirsium palustre***

Site	RCL	Site	RCL
Wet meadows; marsh areas, alluvial forests, tall forb associations	3*-4**	Wet meadows, grassland and fens	4*-5**

* single individuals
** extensive appearance

Fotos: H. HARTL

Trollius europaeus

Primula farinosa

Site	RCL	Site	RCL
Fresh meadows marsh areas, fens;	3*-5**	Marshy meadows, shallow mors on limestone, around springs	5

* single individuals ** extensive appearance

Fotos: H. HARTL

Valeriana dioica *Pinguicula alpina* *Pinguicula vulgaris*

Site	RCL	Site	RCL	Site	RCL
Peatland meadows – deficent in lime, shallow fens, spring water mires	5	Shallow fens, spring water mires, humid mossy rock	4-5	Shallow fens, spring water mires, humid meadows	4-5

In the foreground: ***Juncus* sp.** in the background: ***Cirsium palustre***

Site	RCL	Site	RCL
Humit and wet meadows	4-5*	Humid forests and dwarf shrub stands	4-5*

* dependent on frequency (few individuals – lower RCL, extensive appearance – higher RCL)

Fotos: H. HARTL

Carex nigra

Site	RCL
Wet meadows and fens	5

Foto: T. SCHAUER

Sphagnum sp.

Site	RCL
Moors, associated with dwarf shrubs in locations with snow accumulation	5

Fotos: T. SCHAUER

Juncus inflexus

Site	RCL
Waysides, clearcuts, humid pastures (indicates pasturing)	4*-5**

***Juncus effusus*)**

Site	RCL
Peatland meadows, marsh areas, spüring water mires	5

* single individuals

** extensive appearance

3.4 Plants indicating sites with high infiltration potential

Fotos: H. HARTL

Achillea millefolium		***Avenella flexuosa***	
Site	**RCL**	**Site**	**RCL**
Meadows, (half) dry grassland, acres	**1-3**	Forests, cuttings and grassland (RCL value only valid for the plant in front of the picture, the eroded area i the center of the picture is RCL **5**)	**1-2**

Fotos: H. HARTL

Campanula barbata		***Campanula scheuchzeri***	
Site	**RCL**	**Site**	**RCL**
Acidic neglected grassland and dwarf shrub heaths	**1-2**	Neglected grassland deficient in lime, stony mats	**1**

Fotos: H. HARTL

Calamagrostis arundinacea, C. varia

Site	RCL
Loosely structured forests, edges of forests, rock debris vegetation, sunny near forest grassland, cuttings	1-2

Helianthemum grandifflorum

Site	RCL
Sun exposed neglected grassland, stony grassland	1

Fotos: H. HARTL

Hypericum perforatum

Site	RCL
Neglected grassland, sunny edges of forests	1-2

Luzula luzulina

Site	RCL
Forests on acidic soils, neglected meadows, dwarf shrub communities	1-2

Fotos: H. HARTL

Maianthemum bifolium

***Oxalis acetosella*)**

Site	RCL	Site	RCL
Deciduous and coniferous forests (loose soils)	1	Coniferous and mixed forests, rich in herbs, tall forb associations, dwarf shrub communities	1-2

Fotos: H. HARTL

Solidago virgaurea

Vaccinium myrtillus

Site	RCL	Site	RCL
Deciduous and coniferous forests rich in herbs, neglected pastures	1-2	Coniferous forests on acidic soils, dwarf shrub heaths	1*-2**

* single individuals

** extensive appearance

Fotos: H. HARTL

Vaccinium vitis-idaea
Veronica fruticans

Site	RCL	Site	RCL
Coniferous forests, dwarf shrub heaths	1-2	Rocky bands and ridges, stony mats	1*/4**

* single individuals

** extensive appearance