A method to calculate the annual percolation rate from the soil :

the TUB-BGR-Method

Exercise with the TUB-BGR-Method

Wessolek, G., W.H.M. Duijnisveld und S. Trinks (2008): Hydro-pedotransfer functions (HPTFs) for predicting the annual percolation rate on a regional scale. Journal of Hydrology, 356: 17-27

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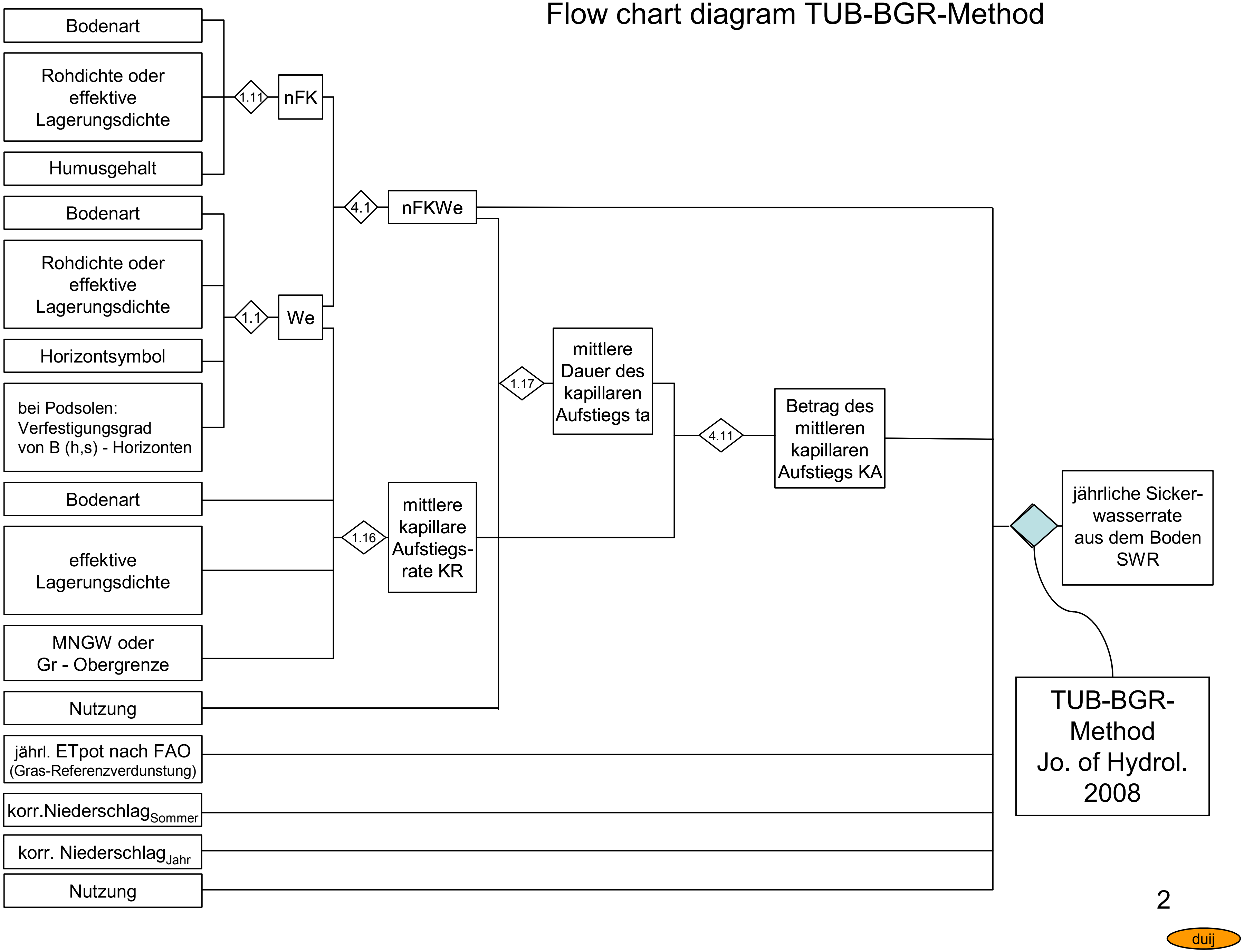
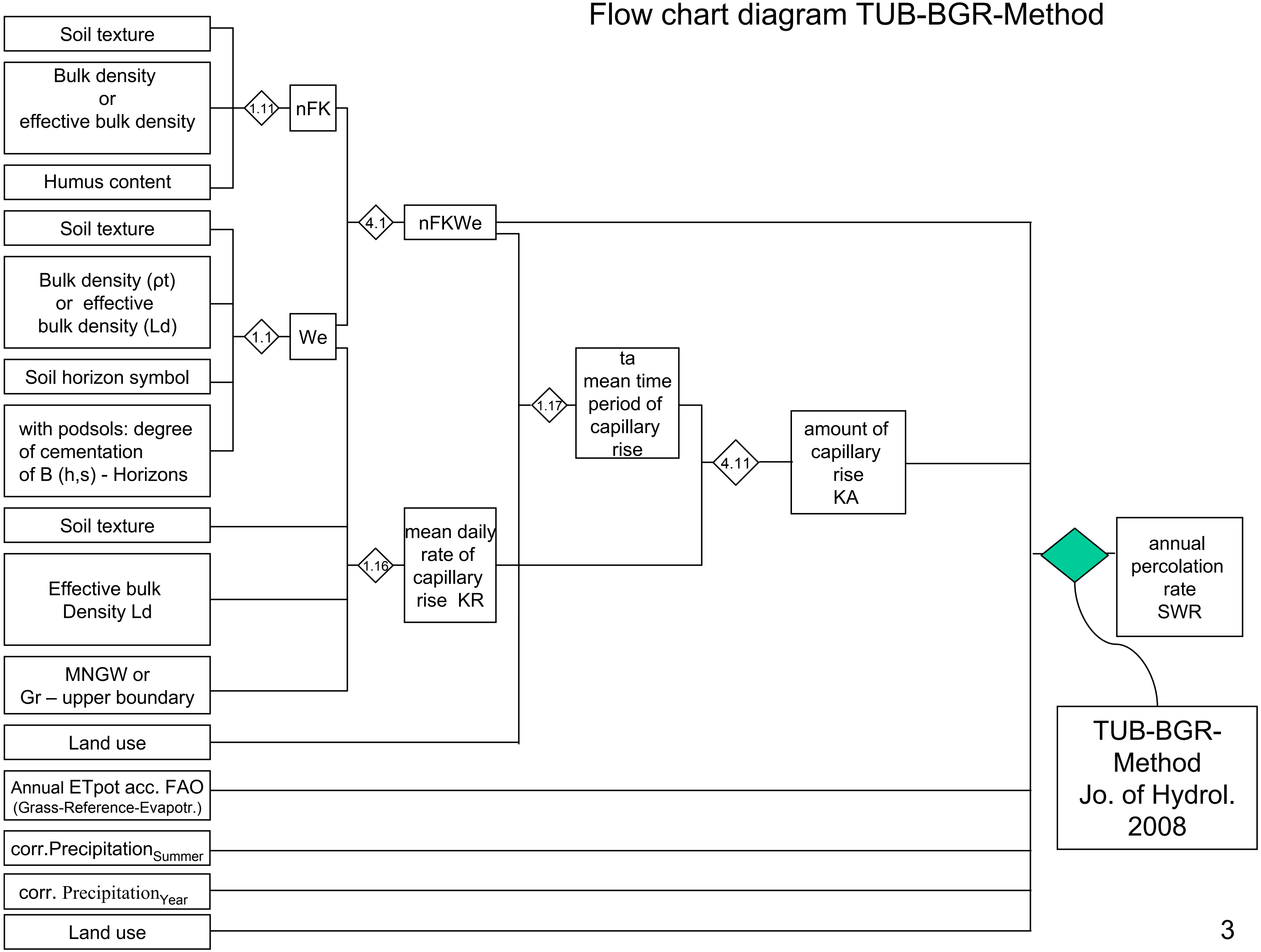
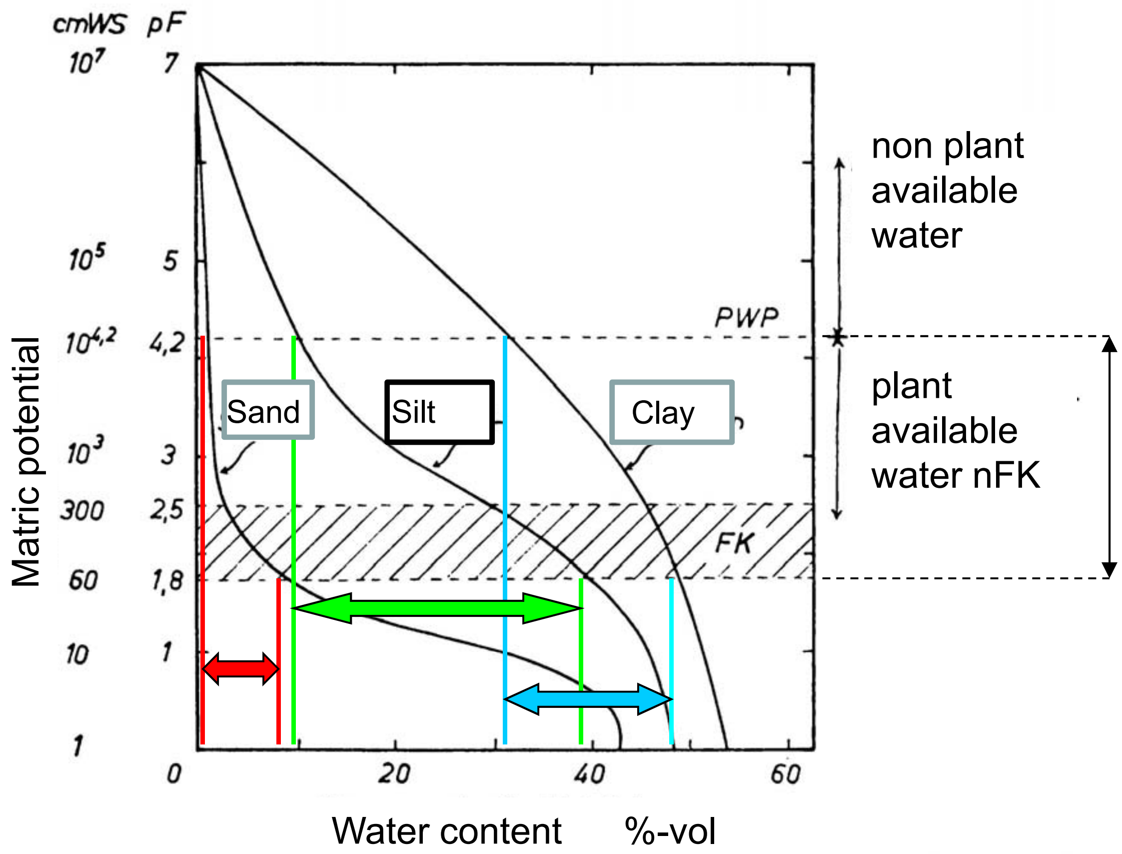
Flow chart diagram TUB-BGR-Method



Flow chart diagram TUB-BGR-Method



Water retention curves



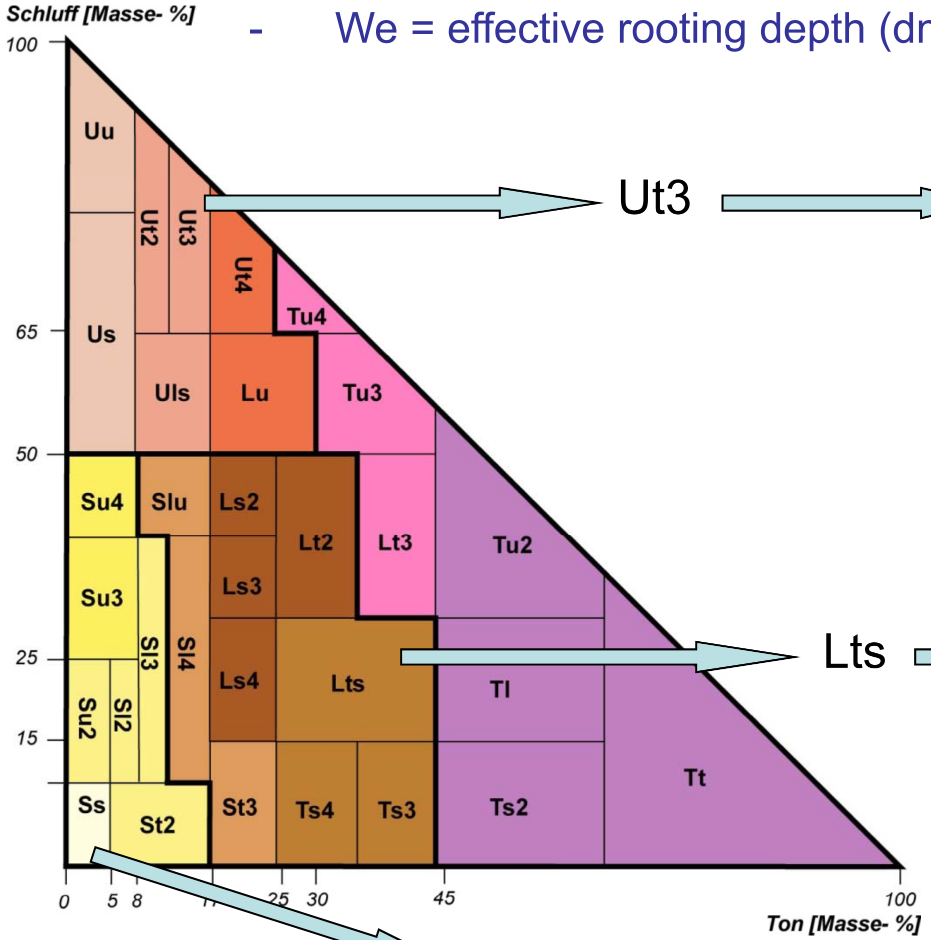
$$nFK = \theta(pF1.8) - \theta(pF4.2)$$

Relation between water content and matric potential of a sand, silt and clay soil
FK = Field capacity ; PWP = permanent wilting point; nFK = plant available water

FK and nFK are available in tables for the different soil textures: VKR 1.11

Determination of nFKWe for different soil textures

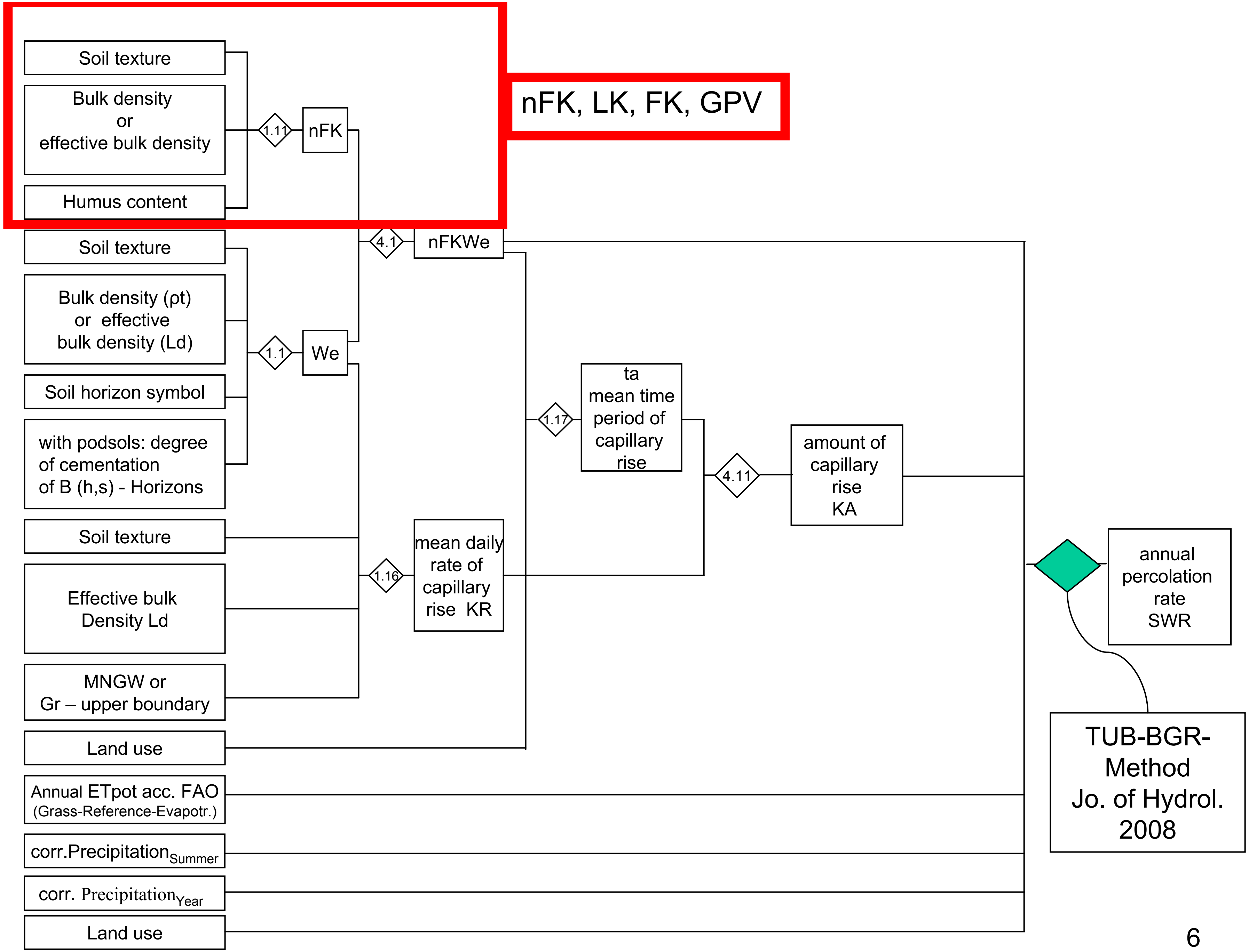
- nFKWe = plant available water in the effective rooting zone (mm)
- We = effective rooting depth (dm)



Ut3 → We: 11, nFK: 23,5 → nFKWe: 258,5 mm

Lts → We: 8, nFK: 13,5 → nFKWe: 108 mm

Ss → We: 6, nFK: 10,5 → nFKWe: 63 mm


Soil texture
Bulk density
or
effective bulk density
Humus content
1.11
nFK
nFK, LK, FK, GPV
4.1
nFKWe
Soil texture
Bulk density (ρt)
or effective
bulk density (Ld)
Soil horizon symbol
with podsols: degree
of cementation
of B (h,s) - Horizons
1.1
We
1.17
ta
mean time
period of
capillary
rise
4.11
amount of
capillary
rise
KA
Soil texture
Effective bulk
Density Ld
MNGW or
Gr – upper boundary
1.16
mean daily
rate of
capillary
rise KR
Land use
Annual ETpot acc. FAO
(Grass-Reference-Evapotr.)
corr.Precipitation Summer
corr. Precipitation Year
Land use
annual
percolation
rate
SWR
TUB-BGR-
Method
Jo. of Hydrol.
2008

Soil profile data

BÜK 1000 LE-Nr.	climate region	soil type	Horizon Nr.	Horizon	upper depth [cm]	lower depth [cm]	soil texture	soil comp. >2 mm Class	soil bulk density Class	Humus- class
1	33	GG-PP	1	Aehp	0	35	fSms	1	ρt3	h3
			2	B(s)h	35	50	fSms	1	ρt3	h1
			3	B(h)s	50	80	mSfs	1	ρt3	h1
			4	Go	80	110	mSfs	1	ρt3	h1
			5	Gr	110	200	mSfs	1	ρt3	h1

Derived horizon properties taking into account humus content and bulk density

Horizon Nr.	horizon thickness [dm]	coarse soil comp. (>2 mm) factor [Vol.-%]	nFK [mm/dm]	LK [Vol.-%]	FK [mm/dm]	GVP [Vol.-%]	CECpot [mmol c/kg]	KF [cm/d]
1	3.5	1	17.5	18	23	41		194
2	1.5	1						
3	3	1						
4	3	1						
5	9	1						

determine

Derived horizon data with additional consideration of corse soil components (> 2mm)

Horizon Nr.	horizon thickness [dm]	nFK [mm/ Horizon]	FK [mm/ Horizon]	GVP [mm/ Horizon]
1	3.5	60.64	79.7	142.07
2	1.5			
3	3			
4	3			
5	9			

nFK = pant available soil water
FK = field capacity
GVP = total pore volume
CECpot = potential cation exchange capacity
KF = saturated conductivity

Adjust nFK for coarse soil components (> 2mm)

class			in Volumen-%	in Masse-%	Vol-%
1	very low	stony, gravelly	< 2	< 3	1
2	low	stony, gravelly	2 bis < 10	3 bis < 15	6
3	medium	stony, gravelly	10 bis < 25	15 bis < 40	17.5
4	high,	stony, gravelly	25 bis < 50	40 bis < 60	37.5
5	very high	stony, gravelly	50 bis < 75	60 bis < 85	62.5
6	Extrem. high	stones, gravel	≥ 75	≥ 85	>75

Adjust nFK for coarse components:

E.g.. nFK= 20 Vol-% and coarse class 2:

nFK- adjustment = 0.94 x 20 = 18.6 Vol-%

Soil profile data

BÜK 1000 LE-Nr.	climate region	soil type	Horizon Nr.	Horizon	upper depth [cm]	lower depth [cm]	soil texture	soil comp. >2 mm Class	soil bulk density Class	Humus- class
1	33	GG-PP	1	Aehp	0	35	fSms	1	ρt3	h3
			2	B(s)h	35	50	fSms	1	ρt3	h1
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			4	Go	80	110	mSfs	1	ρt3	h1
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Horizon Nr.	horizon thickness [dm]	coarse soil comp. (>2 mm) factor [Vol.-%]	nFK [mm/dm]	LK [Vol.-%]	FK [mm/dm]	GVP [Vol.-%]	CECpot [mmol c/kg]	KF [cm/d]
1	3.5	1	17.5	18	23	41		194
2	1.5	1						
3	3	1						
4	3	1						
5	9	1						

determine nFK

Derived horizon data with additional consideration of corse soil components (> 2mm)

Horizon Nr.	horizon thickness [dm]	nFK [mm/ Horizon]	FK [mm/ Horizon]	GVP [mm/ Horizon]
1	3.5	60.64	79.7	142.07
2	1.5			
3	3			
4	3			
5	9			

nFK = pant available soil water
FK = field capacity
GVP = total pore volume
CECpot = potential cation exchange capacity
KF = saturated conductivity

Determination of nFK of the horizons with VKR 1.11

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nFK

Values of plant available soil water nFK, field capacity FK, air capacity LK, and total pore volume GPV [Vol-%] as a function of soil texture and dry soil bulk density (ρt 1-5) for mineral soils with a very low humus content

VK 1.11: Tabelle 1b

	nFK nutzbare Feldkapazität Poren-Ø 0,2 – 50 µm pF 4,2 - 1,8			LK Luftkapazität Poren-Ø > 50 µm pF < 1,8			FK Feldkapazität Poren-Ø < 50 µm pF > 1,8			GPV Gesamtporen-volumen		
Bodenart	ρt			ρt			ρt			ρt		
	1+2	3	4+5	1+2	3	4+5	1+2	3	4+5	1+2	3	4+5
Sl2	19,5	17,5	17,0	17,0	14,5	10,5	28,0	24,5	22,0	45,0	39,0	32,5
Sl3	22,5	18,5	16,0	12,5	11,5	7,5	34,5	27,0	24,0	47,0	38,5	31,5
Sl4	20,5	17,5	14,5	11,5	10,0	6,0	34,0	29,0	25,5	45,5	39,0	31,5
Slu	27,0	21,5	18,5	8,0	7,0	5,5	41,5	32,0	29,0	49,5	39,0	34,5
St2	20,0	15,5	11,5	18,5	17,0	13,0	28,5	22,5	20,0	47,0	39,5	33,0
St3	17,0	14,5	12,0	12,0	9,5	7,5	33,0	29,0	26,0	45,0	38,5	33,5
Su2	19,5	16,5	14,5	18,0	15,5	12,5	27,5	22,0	20,0	45,5	37,5	32,5
Su3	24,0	22,0	19,0	12,0	9,5	8,0	32,5	28,5	25,5	44,5	37,5	33,5
Su4	26,5	24,5	21,5	10,5	8,0	5,0	35,0	31,0	28,5	45,5	39,0	33,5
Ss	15,5	11,0	10,5	24,0	21,5	18,5	22,0	15,5	14,5	46,0	37,0	33,0
fS	20,5	20,0	22,0	23,0	17,0	13,5	23,0	22,5	25,0	46,0	39,5	38,5
fSms	19,0	16,5	17,5	21,5	19,0	16,0	22,0	19,5	20,0	43,5	38,5	36,0
fSgs	20,0	17,5	18,0	21,5	18,5	16,0	22,5	20,0	20,0	44,0	38,5	36,0
gSfs	16,0	14,0	15,0	25,5	20,0	15,0	19,5	17,5	19,0	45,0	37,5	34,0
mSfs	14,0	12,5	13,5	26,0	23,5	18,0	16,5	15,0	17,0	42,5	38,5	35,0

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Table 15: Classes of soil organic matter

Humus (soil organic matter)		
Humus class	**description**	**in Mass-%**
h0	humus free	0
h1	very low humous	< 1
h2	low humous	1 bis < 2
h3 [1)]	medium humous	2 bis < 4
h4 [1)]	high humous	4 bis < 8
h5 [1)]	very high humos	8 bis < 15
h6	extremely humous, anmoorig	15 bis < 30
h7	organic soil, peat	≥ 30

[1)] with forest land use: h3 = 2 to 5, for h4 = 5 to 10 and for h5 = 10 to 15 Mass-%

nFK

Reduction or addition to GPV, FK, nFK and LK based on soil organic matter content for mineral soils with up to 15 soil organic matter

VK 1.11: Tabelle 3

Soil texture	Soil organic matter	Reduction od addition (-) in mm/dm resp. in Vol.-%			
	in classes	nFK	LK	FK	GPV
Ss, Su2, Su3, Su4, Uu, Us, Sl2	h1	0,0	0,0	0,0	0,0
	h2	0,5	-1,5	1,5	0,0
	h3	1,0	-1,0	3,5	2,5
	h4	3,0	-1,0	7,5	6,5
	h5	3,5	0,0	10,0	10,0
St2, Sl3, Slu, Ut2	h2	0,5	0,0	1,5	1,5
	h3	1,0	1,0	3,5	4,5
	h4	3,0	2,0	8,0	10,0
	h5	4,0	2,5	11,5	14,0

Soil profile data

BÜK 1000 LE-Nr.	climate region	soil type	Horizon Nr.	Horizon	upper depth [cm]	lower depth [cm]	soil texture	soil comp. >2 mm Class	soil bulk density Class	Humus- class
1	33	GG-PP	1	Aehp	0	35	fSms	1	ρt3	h3
			2	B(s)h	35	50	fSms	1	ρt3	h1
			3	B(h)s	50	80	mSfs	1	ρt3	h1
			4	Go	80	110	mSfs	1	ρt3	h1
			5	Gr	110	200	mSfs	1	ρt3	h1

Derived horizon properties taking into account humus content and bulk density

Horizon Nr.	horizon thickness [dm]	coarse soil comp. (>2 mm) factor [Vol.-%]	nFK [mm/dm]	LK [Vol.-%]	FK [mm/dm]	GVP [Vol.-%]	CECpot [mmol c/kg]	KF [cm/d]
1	3.5	1	17.5	18	23	41		194
2	1.5	1						
3	3	1						
4	3	1						
5	9	1						

Derived horizon data with additional consideration of corse soil components (> 2mm)

Horizon Nr.	horizon thickness [dm]	nFK [mm/ Horizon]	FK [mm/ Horizon]	GVP [mm/ Horizon]
1	3.5	60.64	79.7	142.07
2	1.5			
3	3			
4	3			
5	9			

$= 3.5 \cdot 17.5 \cdot ((100-1)/100)$

nFK = pant available soil water
FK = field capacity
GVP = total pore volume
CECpot = potential cation exchange capacity
KF = saturated conductivity

Determination of nFK of the horizons with VKR 1.11

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Legendeeinheit: 3301101 - Bodenform: 21

BÜK 1000 LE-Nr.	Klima-region	Boden-typ	Horizont Nr.	Horizont	Obertiefe [cm]	Untertiefe [cm]	Bodenart	Skelett-klasse	Trd-Klasse	Humus- Klasse
1	33	GG-PP	1	Aehp	0	35	fSms	1	pt3	h3
			2	B(s)h	35	50	fSms	1	pt3	h1
			3	B(h)s	50	80	mSfs	1	pt3	h1
			4	Go	80	110	mSfs	1	pt3	h1
			5	Gr	110	200	mSfs	1	pt3	h1

Abgeleitete Horizontdaten des Feinbodens unter Berücksichtigung von Humus und Rohdichte

Horizont Nr.	Mächtigkeit [dm]	Grobboden-faktor [Vol.-%]	nFK [mm/dm]	LK [Vol.-%]	FK [mm/dm]	GVP [Vol.-%]	KAKpot [mmol c/kg]	KF [cm/d]
1	3.5	1	17.5	18	23	41		194
2	1.5	1						
3	3	1						
4	3	1						
5	9	1						

Abgeleitete Horizontdaten unter zusätzlicher Berücksichtigung des Grobbodenanteils

Horizont Nr.	Mächtigkeit [dm]	nFK [mm/ Horizont]	FK [mm/ Horizont]	GVP [mm/ Horizont]
1	3.5	60.64	79.7	142.07
2	1.5			
3	3			
4	3			
5	9			

$= 3.5 \cdot 17.5 \cdot ((100-1)/100)$

Ermittlung nFK der Horizonte mit VKR 1.11

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Legendeeinheit: 3301101 - Bodenform: 21

BÜK 1000 LE-Nr.	Klima-region	Boden-typ	Horizont Nr.	Horizont	Obertiefe [cm]	Untertiefe [cm]	Bodenart	Skelett-klasse	Trd-Klasse	Humus- Klasse
1	33	GG-PP	1	Aehp	0	35	fSms	1	ρt3	h3
			2	B(s)h	35	50	fSms	1	ρt3	h1
			3	B(h)s	50	80	mSfs	1	ρt3	h1
			4	Go	80	110	mSfs	1	ρt3	h1
			5	Gr	110	200	mSfs	1	ρt3	h1

Abgeleitete Horizontdaten des Feinbodens unter Berücksichtigung von Humus und Rohdichte

Horizont Nr.	Mächtigkeit [dm]	Grobboden-faktor [Vol.-%]	nFK [mm/dm]	LK [Vol.-%]	FK [mm/dm]	GVP [Vol.-%]	KAKpot [mmol c/kg]	KF [cm/d]
1	3.5	1	17.5	18	23	41		194
2	1.5	1	16.5	19	19.5	38.5		194
3	3	1	12.5	23.5	15	38.5		191
4	3	1	12.5	23.5	15	38.5		191
5	9	1	12.5	23.5	15	38.5		191

Abgeleitete Horizontdaten unter zusätzlicher Berücksichtigung des Grobbodenanteils

Horizont Nr.	Mächtigkeit [dm]	nFK [mm/ Horizont]	FK [mm/ Horizont]	GVP [mm/ Horizont]
1	3.5	60.64	79.7	142.07
2	1.5	24.5	28.96	57.17
3	3	37.13	44.55	114.35
4	3	37.13	44.55	114.35
5	9	111.38	133.65	343.04

All data determined

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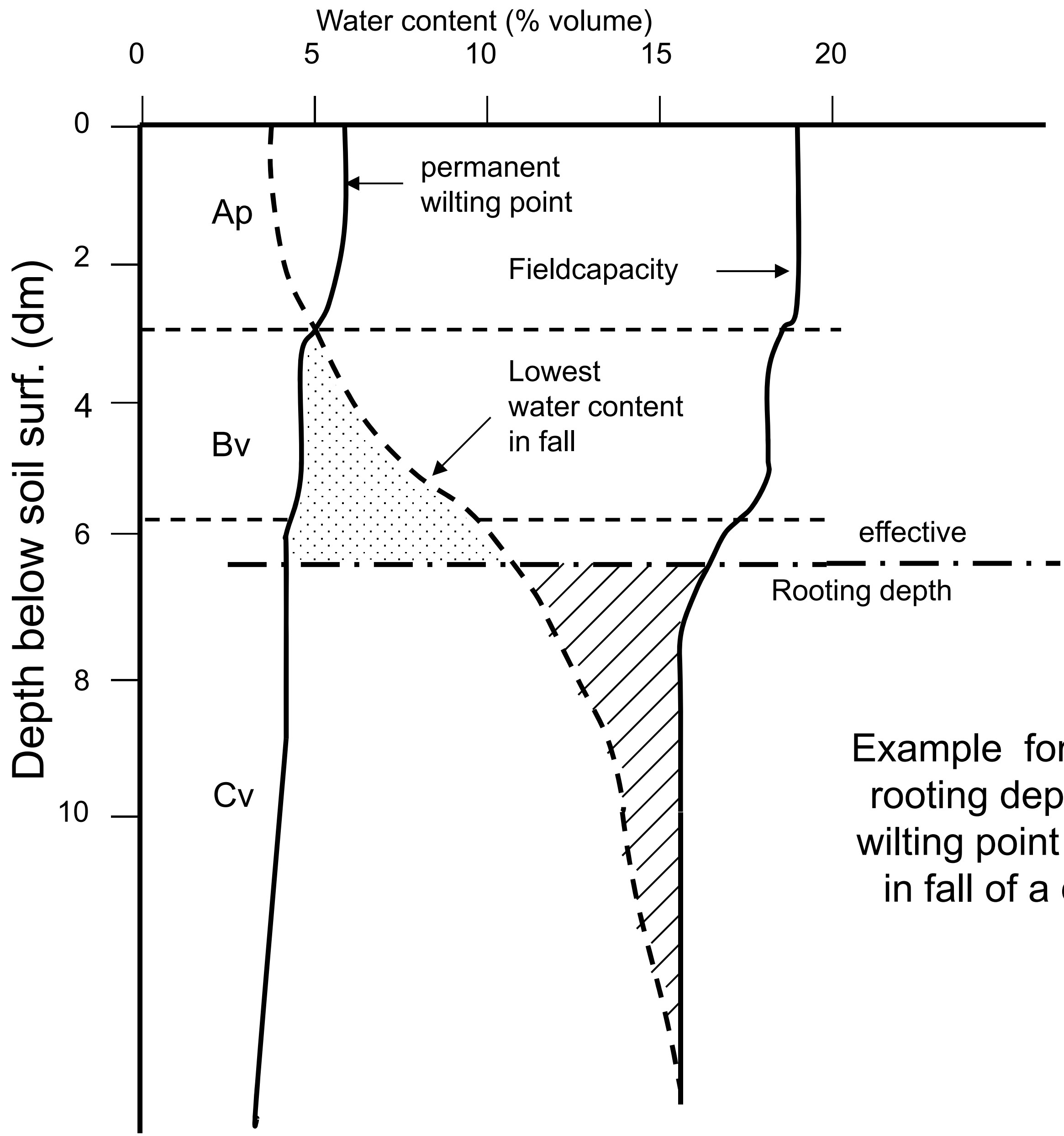
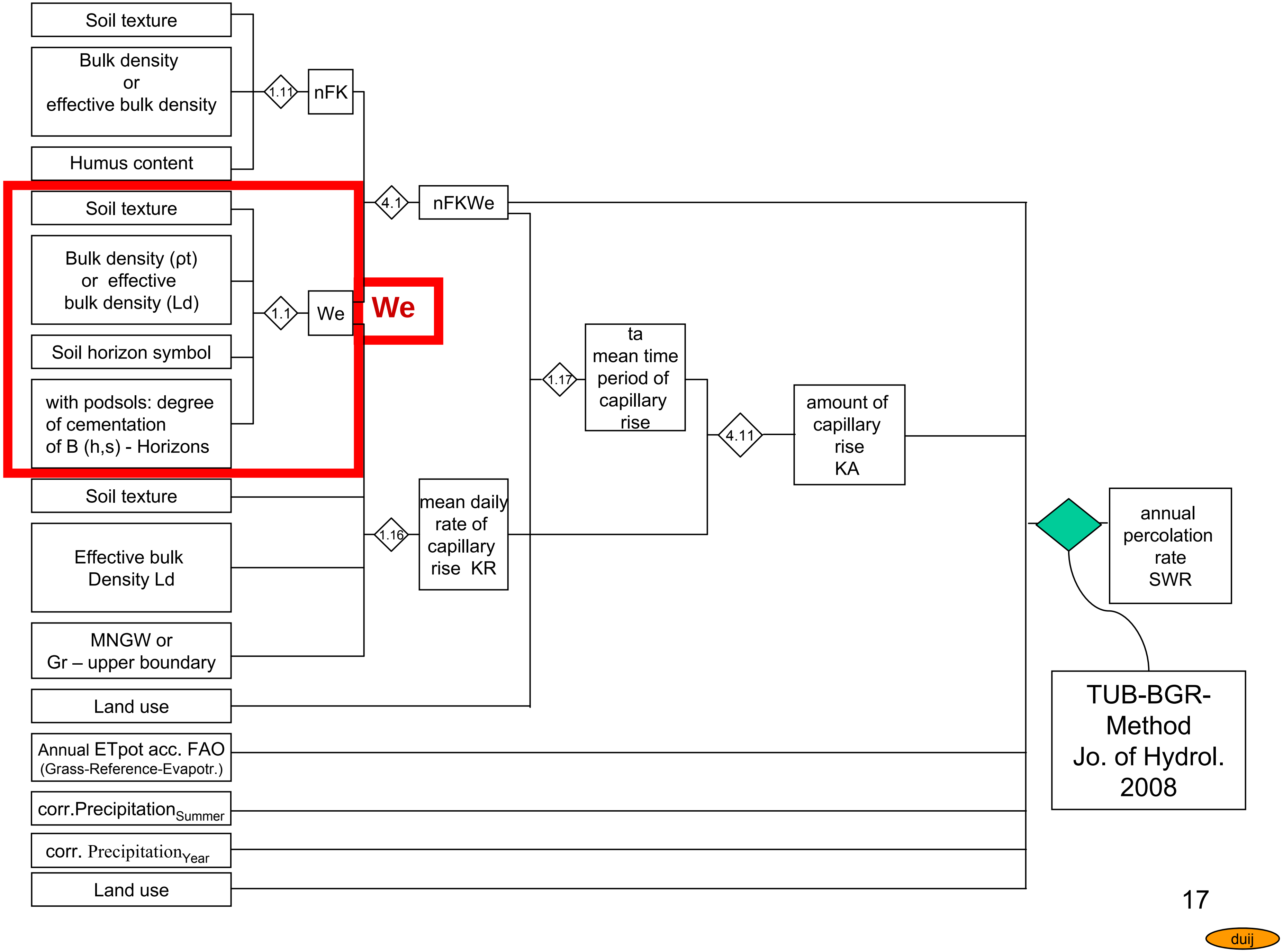
effective rooting depth We



Example for the determination of the effective rooting depth from field capacity, permanent wilting point and water content of a sandy soil in fall of a dry year (from Renger & Strebel 1980)



Soil texture
Bulk density
or
effective bulk density
Humus content
1.11
nFK
4.1
nFKWe
Soil texture
Bulk density (pt)
or effective
bulk density (Ld)
Soil horizon symbol
with podsols: degree
of cementation
of B (h,s) - Horizons
1.1
We
We
1.17
ta
mean time
period of
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KA
Soil texture
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Density Ld
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Method
Jo. of Hydrol.
2008
Annual ETpot acc. FAO
(Grass-Reference-Evapotr.)
corr.Precipitation Summer
corr. Precipitation Year
Land use
duij

Effective rooting depth We: arable land

VK 1.1

Soil texture	We effective rooting depth in dm — Dry bulk density: ρt1 - ρt2	ρt3	ρt4 - ρt5
Ss	8	6	6
Sl2	9	7	6
Sl3	10	8	7
Sl4	13	9	8
Slu	13	9	8
St2	10	8	7
St3	13	9	8
Su2	9	7	6
Su3	9	7	6
Su4	9	7	6
Uu	13	10	8
Us	13	10	8
Uls	14	11	9
Ut2	14	11	9
Ut3	14	11	9
Ut4	14	11	9

Soil texture	We effective rooting depth in dm — Dry bulk density: ρt1 - ρt2	ρt3	ρt4 - ρt5
Lu	14	11	9
Ls2	13	10	8
Ls3	13	10	8
Ls4	13	10	8
Lts	13	10	8
Lt2	13	10	8
Lt3	13	10	8
Tt	13	10	8
Tl	13	10	8
Ts2	13	10	8
Ts3	13	10	8
Ts4	13	10	8
Tu2	13	10	8
Tu3	14	11	9
Tu4	14	11	9

We as a function of soil texture and class of dry bulk density for arable land
Grassland : -10 % and Forest = +20 %

Calculation of nFKWe (plant available soil water in the rooting zone):

Legendeeinheit: 3301101 - Bodenform: 21

BÜK 1000 LE-Nr.	Klima-region	Boden-typ	Horizont Nr.	Horizont	Obertiefe [cm]	Untertiefe [cm]	Bodenart	Skelett-klasse	Trd-Klasse	Humus- Klasse
1	33	GG-PP	1	Aehp	0	35	fSms	1	ρt3	h3
			2	B(s)h	35	50	fSms	1	ρt3	h1
			3	B(h)s	50	80	mSfs	1	ρt3	h1
			4	Go	80	110	mSfs	1	ρt3	h1
			5	Gr	110	200	mSfs	1	ρt3	h1

Abgeleitete Horizontdaten des Feinbodens unter Berücksichtigung von Humus und Rohdichte

Horizont Nr.	Mächtigkeit [dm]	Grobboden-faktor [Vol.-%]	nFK [mm/dm]	LK [Vol.-%]	FK [mm/dm]	GVP [Vol.-%]	KAKpot [mmol c/kg]	KF [cm/d]
1	3.5	1	17.5	18	23	41		194
2	1.5	1	16.5	19	19.5	38.5		194
3	3	1	12.5	23.5	15	38.5		191
4	3	1	12.5	23.5	15	38.5		191
5	9	1	12.5	23.5	15	38.5		191

Abgeleitete Horizontdaten unter zusätzlicher Berücksichtigung des Grobbodenanteils

Horizont Nr.	Mächtigkeit [dm]	nFK [mm/ Horizont]	FK [mm/ Horizont]	GVP [mm/ Horizont]
1	3.5	60.64	79.7	142.07
2	1.5	24.5	28.96	57.17
3	3	37.13	44.55	114.35
4	3	37.13	44.55	114.35
5	9	111.38	133.65	343.04

We = 6 dm :

nFKWe = ∑ nFK(0 – 6 dm)
= 97,5 mm

MNGW [dm]
11

1. We
2. nFKWe
3. zg/MNGW
4. KR
5. ta
6. KA_max
7. KA_kli
8. nFKWe
9. KA
10. NS_korr
11. WV
12. Eta
13. SWR

Klimadaten Standort:

Ns_korr [mm/a]	350		
Nw_korr [mm/a]	400		
Nj_korr [mm/a]	750		
Oberfläch-enabfluss [mm/a]	0		
ET0 pot.Gras ref.verdun. [mm/a]	550	ET0(som) pot.Gras ref.verdun. [mm]	444

We und mittlerer kapillarer Aufstiegs: VKR1.1, VKR 1.16, VKR 1.17 und VKR 4.11:

		Acker	Grünland	Forst
	We [dm]	6		
	KR mm/d	3		
	ta	44.9		
4.11: 1 →	KA_max [mm]	134.6		
4.11: 2-5: →	KA_kli [mm]	67.4		

Pflanzenverfügbare Wassermenge WV im Sommerhalbjahr

	Acker	Grünland	Forst
nFKWe [mm]	97.52		
KA [mm]	67.4		
Ns_korr [mm/a]	350		
WV [mm]	514.9		

TUB_BGR-Verfahren: Berechnung von ETa und SWR

	Acker	Grünland	Nadelwald
ETa [mm/a]	462.9		
SWR [mm/a]	287.1		

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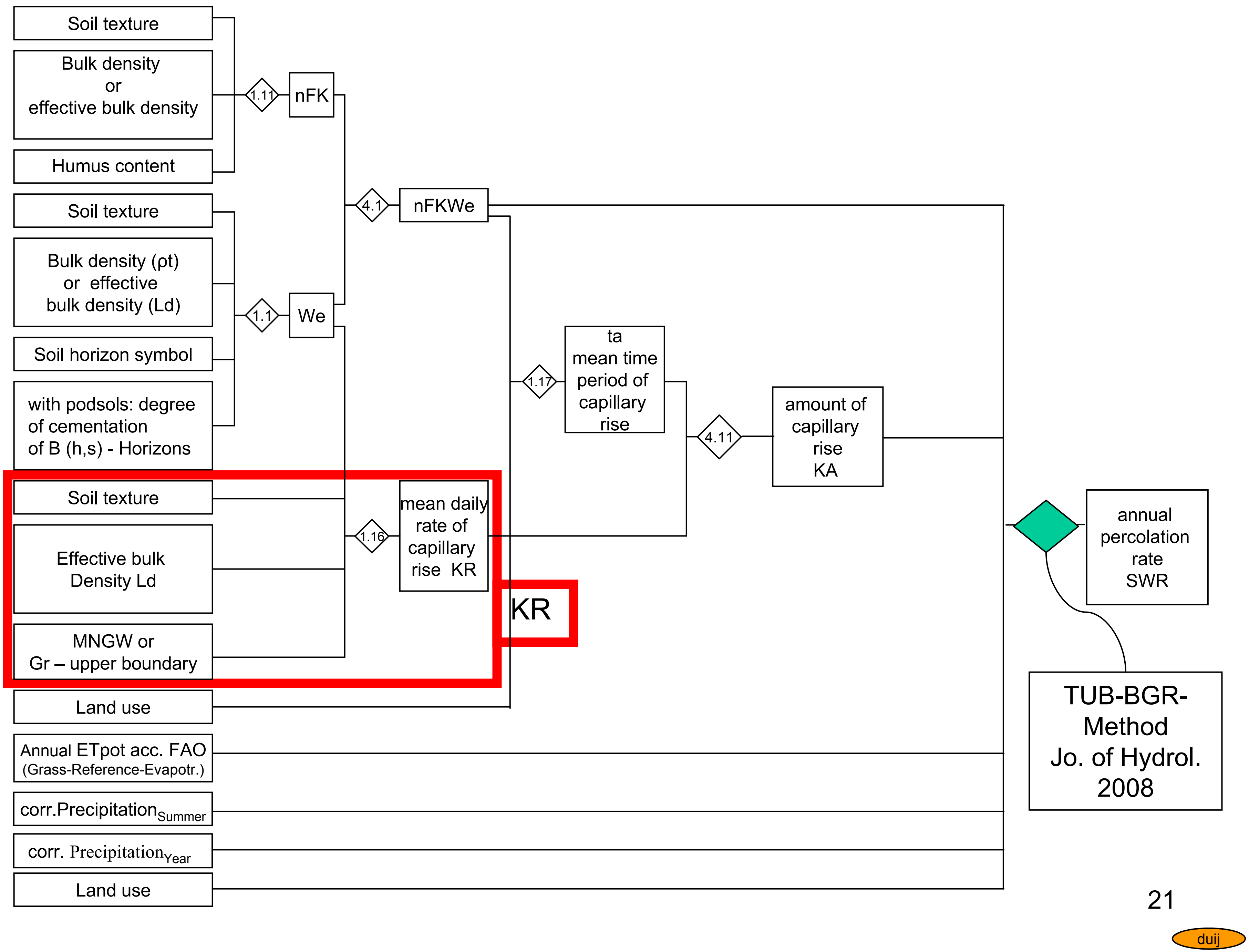
Soil texture
Bulk density or effective bulk density
Humus content
1.11
nFK
4.1
nFKWe
Soil texture
Bulk density (ρt) or effective bulk density (Ld)
Soil horizon symbol
with podsols: degree of cementation of B (h,s) - Horizons
1.1
We
1.17
ta mean time period of capillary rise
4.11
amount of capillary rise KA
Soil texture
Effective bulk Density Ld
MNGW or Gr – upper boundary
1.16
mean daily rate of capillary rise KR
KR
annual percolation rate SWR
Land use
Annual ETpot acc. FAO (Grass-Reference-Evapotr.)
corr.Precipitation Summer
corr. Precipitation Year
Land use
TUB-BGR-Method Jo. of Hydrol. 2008
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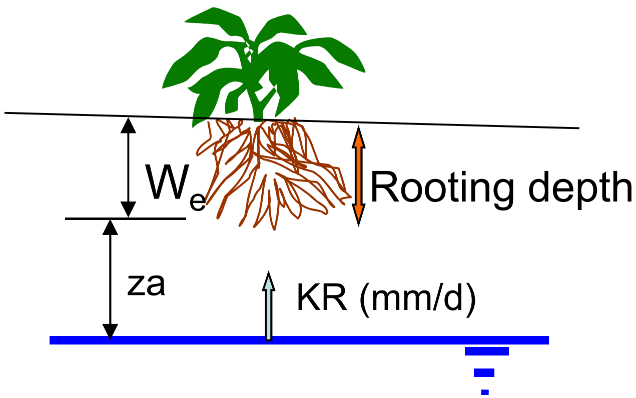
VK 1.16

Tabelle 1: Mean daily capillary rise rates for mineral soils

Soil texture	Ld	Daily capillary rise rate (mm/d) for a distance za of:													Ψ hPa
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**14**	**17**	**20 dm**	**bzw. cm WS**
Sande:															
mSgs	2 - 3	>5,0	5,0	1,5	0,5	0,2	<0,1	---	---	---	---	---	---	---	100
	4 - 5	>5,0	5,0	1,2	0,3	0,2	<0,1	---	---	---	---	---	---	---	100
mS	2 - 3	>5,0	>5,0	>5,0	3,0	1,2	0,5	0,2	<0,1	---	---	---	---	---	120
	4 - 5	>5,0	>5,0	>5,0	2,5	1,0	0,2	<0,1	---	---	---	---	---	---	120
fS	2 - 3	>5,0	>5,0	>5,0	>5,0	3,0	1,5	0,7	0,3	0,15	<0,1	---	---	---	140
	4 - 5	>5,0	>5,0	>5,0	>5,0	2,5	1,0	0,4	0,1	<0,1	---	---	---	---	140
Sl2, St2,	2 - 3	>5,0	>5,0	>5,0	>5,0	4,5	2,5	1,5	0,7	0,4	0,1	<0,1	---	---	150
Su2	4 - 5	>5,0	>5,0	>5,0	>5,0	4,0	2,0	1,0	0,5	0,2	<0,1	---	---	---	150

MNGW = 11 dm
We = 6 dm
za = 5 dm



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Groundwater-level:
MNGW [dm]
11

1. We
2. nFKWe
3. zg/MNGW
4. KR
5. ta
6. KA_max
7. KA_kli
8. nFKWe
9. KA
10. NS_korr
11. WV
12. Eta
13. SWR

site climatic data:

Ns_korr [mm/a]	350		
Nw_korr [mm/a]	400		
Nj_korr [mm/a]	750		
surface runoff [mm/a]	0		
ET0-FAO pot.Gras ref. evap. [mm/a]	550	ET0(som) pot.Gras ref.verdun. [mm]	444

We and capillary rise:
VKR1.1, VKR 1.16, VKR 1.17 and VKR 4.11:

		Arable land	Grassland	Forest
	We [dm]	6		
	KR mm/d	3		
	ta	44.9		
4.11: 1 →	KA_max [mm]	134.6		
4.11: 2-5: →	KA_kli [mm]	67.4		

crop water availability WV in the summer half year:

	Acker	Grünland	Forst
nFKWe [mm]	97.52		
KA [mm]	67.4		
Ns_korr [mm/a]	350		
WV [mm]	514.9		

TUB-BGR-Method: Calculation of ETa and SWR

	Arable land	Grassland	Coniferous forest
ETa [mm/a]	462.9		
SWR [mm/a]	287.1		

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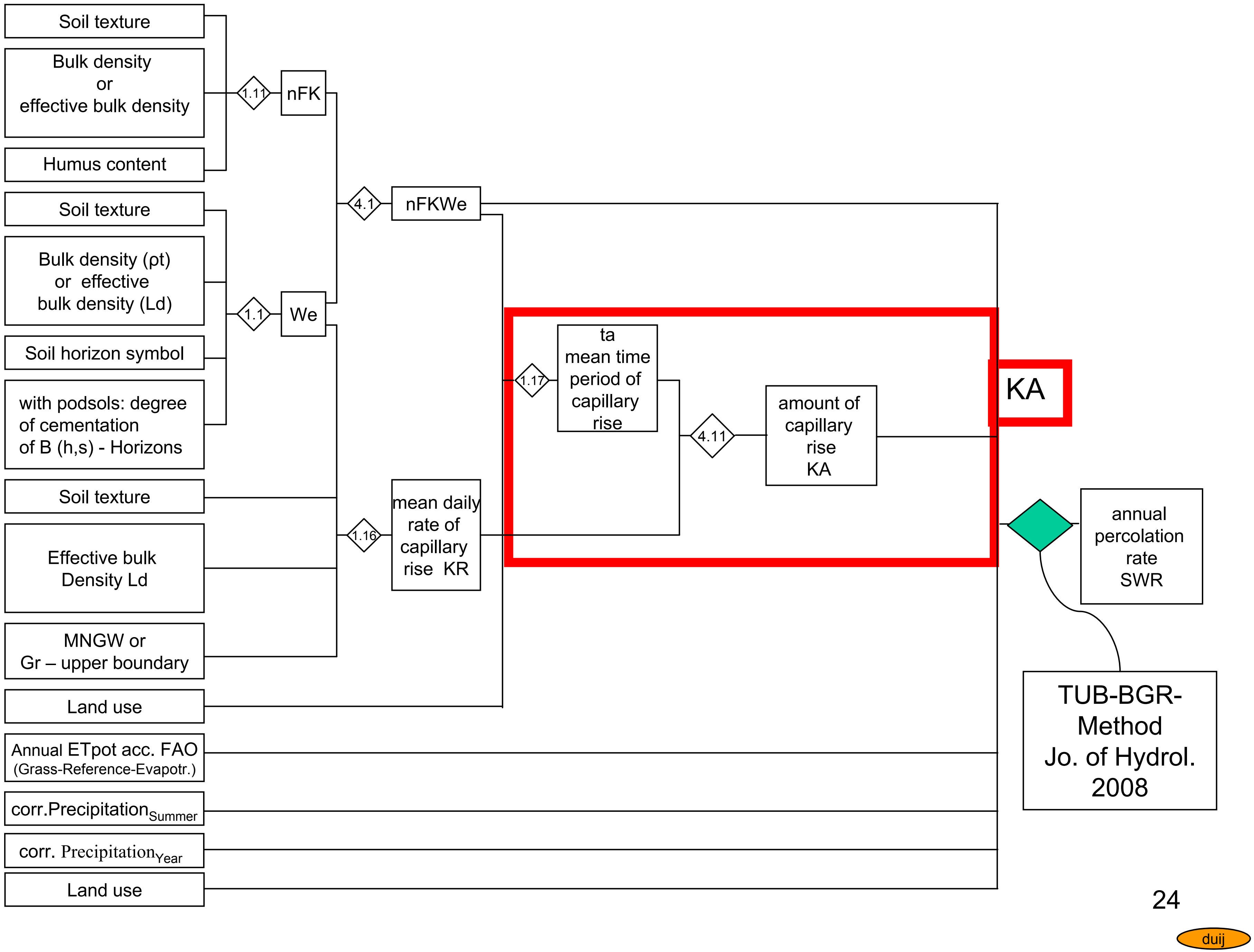
Soil texture
Bulk density
or
effective bulk density
Humus content
1.11
nFK
4.1
nFKWe
Soil texture
Bulk density (pt)
or effective
bulk density (Ld)
Soil horizon symbol
with podsols: degree
of cementation
of B (h,s) - Horizons
1.1
We
Soil texture
Effective bulk
Density Ld
MNGW or
Gr – upper boundary
1.16
mean daily
rate of
capillary
rise KR
Land use
1.17
ta
mean time
period of
capillary
rise
4.11
amount of
capillary
rise
KA
KA
annual
percolation
rate
SWR
TUB-BGR-
Method
Jo. of Hydrol.
2008
Annual ETpot acc. FAO
(Grass-Reference-Evapotr.)
corr.Precipitation Summer
corr. Precipitation Year
Land use
duij

Determination of the mean period of capillary rise for different arable crops and land use types

VK 1.17

Depending on crop type the mean period ta of capillary rise can be calculates as follows:

a) Cereals:

KR ≤ 1,0 mm/d; ta [d] = 0,075 nFKWe [mm] + 21,5
KR = 1,5 mm/d; ta [d] = 0,075 nFKWe [mm] + 25,0
KR = 2,0 mm/d; ta [d] = 0,070 nFKWe [mm] + 30,0
KR = 2,5 mm/d; ta [d] = 0,055 nFKWe [mm] + 35,0
KR = 3,0 mm/d; ta [d] = 0,050 nFKWe [mm] + 40,0 → ta = 44.9 d
KR = 3,5 mm/d; ta [d] = 0,035 nFKWe [mm] + 45,0
KR = 4,0 mm/d; ta [d] = 0,035 nFKWe [mm] + 48,0
KR ≥ 5,0 mm/d; ta [d] = 60,0

Example:

KR = 3 mm/d
nFKWe = 97.5 mm

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Groundwater-level:
MNGW [dm]
11

1. We
2. nFKWe
3. zg/MNGW
4. KR
5. ta
6. KA_max
7. KA_kli
8. nFKWe
9. KA
10. NS_korr
11. WV
12. Eta
13. SWR

site climatic data:

Ns_korr [mm/a]	350		
Nw_korr [mm/a]	400		
Nj_korr [mm/a]	750		
surface runoff [mm/a]	0		
ET0-FAO pot.Gras ref. evap. [mm/a]	550	ET0(som) pot.Gras ref.verdun. [mm]	444

We and capillary rise:
VKR1.1, VKR 1.16, VKR 1.17 and VKR 4.11:

	Arable land	Grassland	Forest
We [dm]	6		
KR mm/d	3		
ta	44.9		
4.11: 1 → KA_max [mm]	134.6		
4.11: 2-5: → KA_kli [mm]	??		

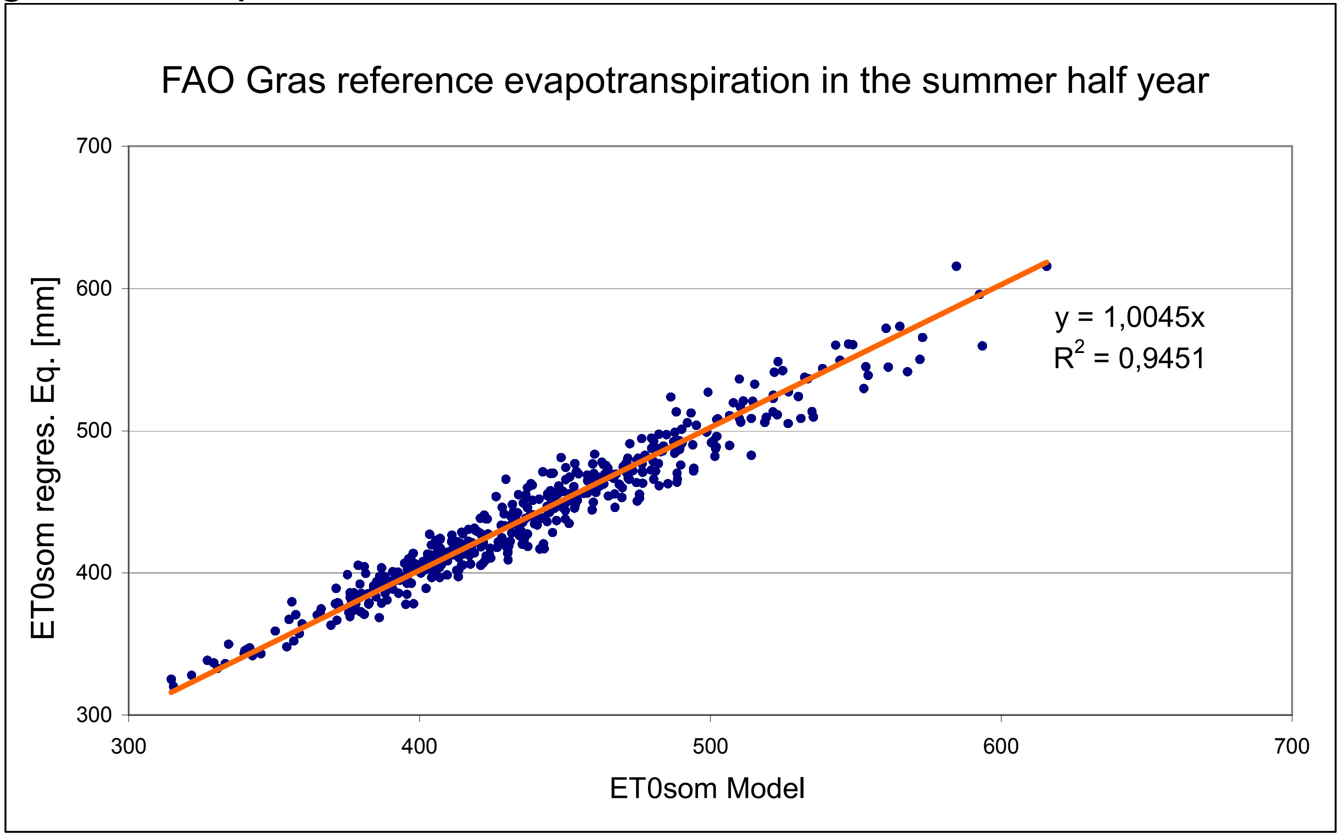
crop water availability WV in the summer half year:

	Acker	Grünland	Forst
nFKWe [mm]	97.52		
KA [mm]	67.4		
Ns_korr [mm/a]	350		
WV [mm]	514.9		

TUB-BGR-Method: Calculation of ETa and SWR

	Arable land	Grassland	Coniferous forest
ETa [mm/a]	462.9		
SWR [mm/a]	287.1		

Comparison of FAO Grass reference $ET0_{som}$-values of the summer half year calculated with the simulation model and with with a regression equation



$$ET0_{som} = 0,72 * ET0 + 48$$

VK 4.11

Arable land	$KA_{kli} = 1,05 \cdot ETpot_{so} - (N_{so} + 0,5 \cdot nFKWe)$	(eq. 2)
Grassland	$KA_{kli} = 1,20 \cdot ETpot_{so} - (N_{so} + 0,5 \cdot nFKWe)$	(eq. 3)
Forest	$KA_{kli} = 1,30 \cdot ETpot_{so} - (N_{so} + 0,5 \cdot nFKWe)$	(eq. 4)

with $ETpot_{so} = 0,72 \cdot ETpot + 48$ (eq. 5)

ETpot = potential Evapotranspiration as FAO-Grass-Reference evapotranspiration in mm/a

$ETpot_{so}$ = potential Evapotranspiration as FAO-Grass-Reference evapotranspiration in the summer half year (mm)

N_{so} = corrected precitation in the summer half year in mm

nFKWe = plant available soil water in the effective root zone in mm

Example arable land :

ETpot = 550 mm/a N_{so} = 350 mm nFKWe = 97.52 mm

$ETpot_{so} = 0.72 \cdot 550 + 48 = 444$ mm

$KA_{kli} = 1.05 \cdot 444 - 350 - 0.5 \cdot 97.52 = 67.4$ mm

Groundwater-level:
MNGW [dm]
11

1. We
2. nFKWe
3. zg/MNGW
4. KR
5. ta
6. KA_max
7. KA_kli
8. nFKWe
9. KA
10. NS_korr
11. WV
12. Eta
13. SWR

site climatic data:

Ns_korr [mm/a]	**350**		
Nw_korr [mm/a]	**400**		
Nj_korr [mm/a]	**750**		
surface runoff [mm/a]	**0**		
ET0-FAO pot.Gras ref. evap. [mm/a]	**550**	ET0(som) pot.Gras ref.verdun. [mm]	**444**

We and capillary rise:
VKR1.1, VKR 1.16, VKR 1.17 and VKR 4.11:

	Arable land	Grassland	Forest
We [dm]	6		
KR mm/d	3		
ta	44.9		
4.11: 1 → KA_max [mm]	134.6		
4.11: 2-5: → KA_kli [mm]	67.4		

crop water availability WV in the summer half year:

	Acker	Grünland	Forst
nFKWe [mm]	97.52		
KA [mm]	67.4		
Ns_korr [mm/a]	350		
WV [mm]	514.9		

TUB-BGR-Method: Calculation of ETa and SWR

	Arable land	Grassland	Coniferous forest
ETa [mm/a]	462.9		
SWR [mm/a]	287.1		

VK 4.11

Calculate KA

To make a realistic assessment of the actual amount of annual capillary rise **KA** three conditions may be distinguished:

- if $KA_{kli} < 0$, then $KA = 0$
- if $KA_{max} > KA_{kli}$ then $KA_a = KA_{kli}$ mm (16)
- if $KA_{max} \leq KA_{kli}$ then $KA_a = KA_{max}$ mm

Example:

KA_{max} = 134.6 mm
KA_{kli} = + 67.4 mm

→ KA = 67.4 mm

Groundwater-level:
MNGW [dm]
11

1. We
2. nFKWe
3. zg/MNGW
4. KR
5. ta
6. KA_max
7. KA_kli
8. nFKWe
9. KA
10. NS_korr
11. WV
12. ETa
13. SWR

site climatic data:

Ns_korr [mm/a]	350		
Nw_korr [mm/a]	400		
Nj_korr [mm/a]	750		
surface runoff [mm/a]	0		
ET0-FAO pot.Gras ref. evap. [mm/a]	550	ET0(som) pot.Gras ref.verdun. [mm]	444

We and capillary rise:
VKR1.1, VKR 1.16, VKR 1.17 and VKR 4.11:

	Arable land	Grassland	Forest
We [dm]	6		
KR mm/d	3		
ta	44.9		
4.11: 1 → KA_max [mm]	134.6		
4.11: 2-5: → KA_kli [mm]	67.4		

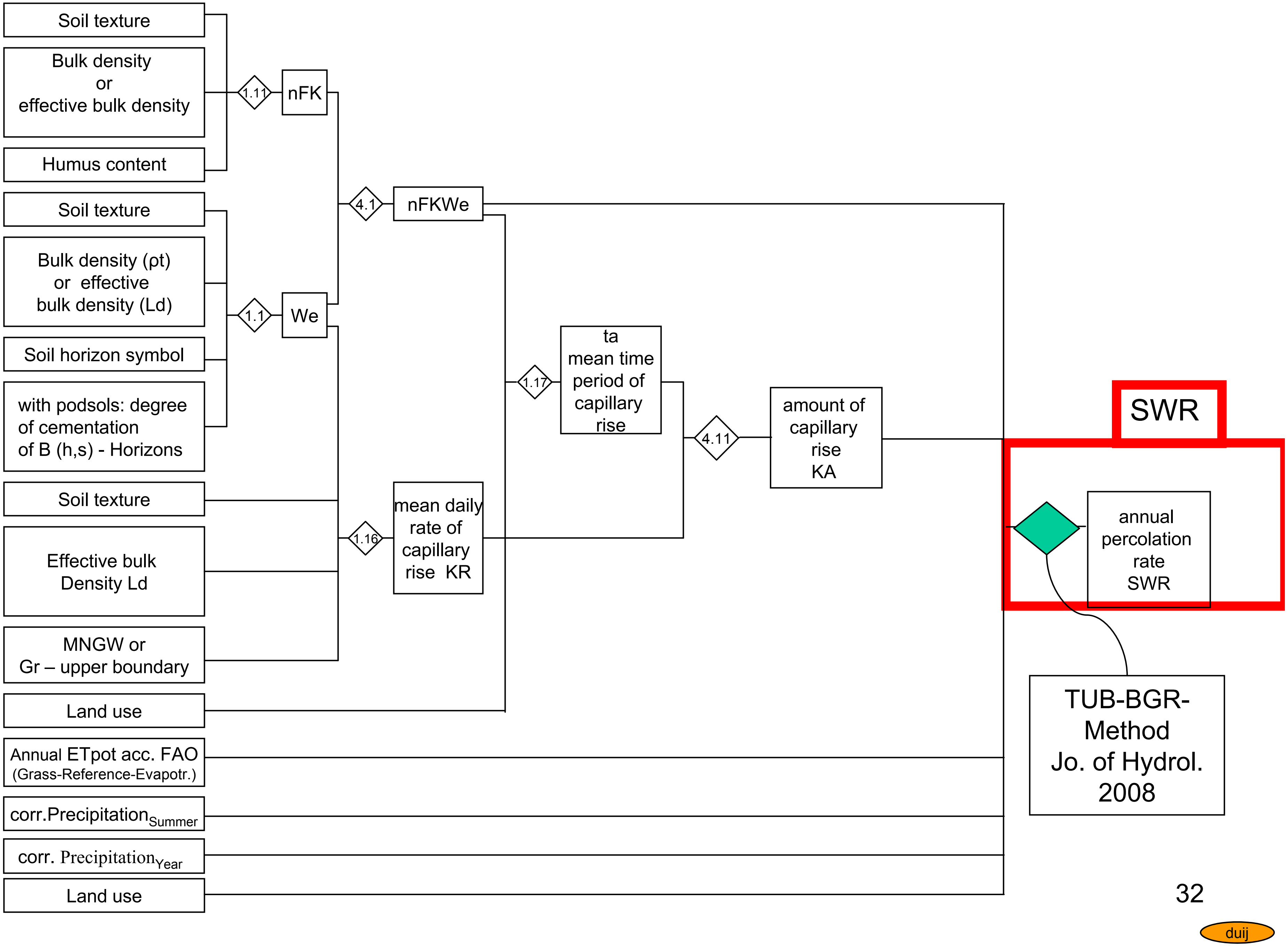
crop water availability WV in the summer half year:

	Acker	Grünland	Forst
nFKWe [mm]	97.52		
KA [mm]	67.4		
Ns_korr [mm/a]	350		
WV [mm]	514.9		

TUB-BGR-Method: Calculation of ETa and SWR

	Arable land	Grassland	Coniferous forest
ETa [mm/a]	462.9		
SWR [mm/a]	287.1		

Input into Excel-Application


Soil texture
Bulk density or effective bulk density
Humus content
1.11
nFK
Soil texture
Bulk density (ρt) or effective bulk density (Ld)
Soil horizon symbol
with podsols: degree of cementation of B (h,s) - Horizons
1.1
We
4.1
nFKWe
Soil texture
Effective bulk Density Ld
MNGW or Gr – upper boundary
1.16
mean daily rate of capillary rise KR
Land use
1.17
ta mean time period of capillary rise
4.11
amount of capillary rise KA
SWR
annual percolation rate SWR
TUB-BGR-Method Jo. of Hydrol. 2008
Annual ETpot acc. FAO (Grass-Reference-Evapotr.)
corr.Precipitation Summer
corr. Precipitation Year
Land use
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Regression equations for arable land

Mean values from winter wheat, winter barley and sugar beets

Critical point of water availability WV = 700 mm

- *WV ≤ 700 mm* :

$$SWR = Nd_{jahr} – ET0*[1.45*log(nFK_{We} + Nd_{som} + v_{kap}) -3.08]* [0.685*log(1/ET0) + 2.865]$$

- *WV > 700 mm* :

$$SWR = Nd_{jahr} – 1.05*ET0* [0.685*log(1/ET0) + 2.865]\}$$

➔ **Regression equations also for coniferous and deciduous forests**

Regression equations for Grassland

plant available water WV in the summer half year: WV= $nFK_{We} + Nd_{som} + v_{kap}$

- *WV ≤ 700 mm* :

$$SWR = Nd_{jahr} – ET0*[1.79*log(WV) -3.89]* [0.53*log(1/ET0) + 2.43]$$

- *WV > 700 mm* :

$$SWR = Nd_{jahr} – 1.2*ET0 [0.53*log(1/ET0) + 2.43]\}$$

SWR = annual percolation rate ($Nd_{Jahr} - ET_a$) mm/a

Groundwater-level:
MNGW [dm]
11

site climatic data:

Ns_korr [mm/a]	350		
Nw_korr [mm/a]	400		
Nj_korr [mm/a]	750		
surface runoff [mm/a]	0		
ET0-FAO pot.Gras ref. evap. [mm/a]	550	ET0(som) pot.Gras ref.verdun. [mm]	444

We and capillary rise:
VKR1.1, VKR 1.16, VKR 1.17 and VKR 4.11:

	Arable land	Grassland	Forest
We [dm]	6		
KR mm/d	3		
ta	44.9		
4.11: 1 → KA_max [mm]	134.6		
4.11: 2-5: → KA_kli [mm]	67.4		

1. We
2. nFKWe
3. zg/MNGW
4. KR
5. ta
6. KA_max
7. KA_kli
8. KA
9. NS_korr
10. WV
11. ETa
12. SWR

crop water availability WV in the summer half year:

	Arable land	Grassland	Forest
nFKWe [mm]	97.52		
KA [mm]	67.4		
Ns_korr [mm/a]	350		
WV [mm]	514.9		

TUB-BGR-Method: Calculation of ETa and SWR

	Arable land	Grassland	Coniferous forest
ETa [mm/a]	462.9		
SWR [mm/a]	287.1		

SWR = Nj_korr – {ET0[1.79*log(nFKWe + Ns_korr+KA) -3.89]* [0.53*log(1/ET0) + 2.43]}*

= ETa

Groundwater-level:
MNGW [dm]
11

1. We
2. nFKWe
3. zg/MNGW
4. KR
5. ta
6. KA_max
7. KA_kli
8. KA
9. NS_korr
10. WV
11. Eta
12. SWR

site climatic data:

Ns_korr [mm/a]	350		
Nw_korr [mm/a]	400		
Nj_korr [mm/a]	750		
surface runoff [mm/a]	0		
ET0-FAO pot.Gras ref. evap. [mm/a]	550	ET0(som) pot.Gras ref.verdun. [mm]	444

We and capillary rise:
VKR1.1, VKR 1.16, VKR 1.17 and VKR 4.11:

		Arable land	Grassland	Forest
	We [dm]	6		
	KR mm/d	3		
	ta	44.9		
4.11: 1	KA_max [mm]	134.6		
4.11: 2-5:	KA_kli [mm]	67.4		

crop water availability WV in the summer half year:

	Arable land	Grassland	Forest
nFKWe [mm]	97.52		
KA [mm]	67.4		
Ns_korr [mm/a]	350		
WV [mm]	514.9		

TUB-BGR-Method: Calculation of ETa and SWR

	Arable land	Grassland	Coniferous forest
ETa [mm/a]	462.9		
SWR [mm/a]	287.1		

Exercise: caculate for grassland and coniferous forest

Long term mean values of annual rainfall Nd_{Jahr} (summer Nd_{som} and winter rainfall Nd_{win}), annual FAO-grass-reference evapotranspiration $ET0_{Jahr}$ (summer $ET0_{som}$), climatic water balance in the summer half year KWB_{som} for the representative meteorological stations

Station	Nd_{som}	Nd_{win}	Nd_{Jahr}	$ET0_{Jahr}$	$ET0_{som}$	KWB_{som}
Freiburg	412	610	1022	680	528	-116
Würzburg	308	361	670	587	467	-159
Mannheim	310	428	738	619	495	-185
Stuttgart	272	460	732	598	469	-198
Coburg	387	440	827	509	419	-32
München-Riem	423	685	1109	571	454	-31
Kempten	576	838	1414	484	393	183
Bocholt	390	407	798	539	427	-37
Neumünster	435	455	890	499	411	24
Bremen	377	422	799	556	444	-67
Bad Hersfeld	379	418	797	501	410	-31
Teterow	265	345	610	542	441	-176
Magdeburg	240	314	555	555	447	-207
Uelzen	308	384	691	495	408	-100
Braunlage	770	618	1388	441	367	403
Chemnitz	351	371	722	539	427	-77

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TUB-BGR-method: Application

Gley-Podsol: LBE 1, Klimaregion 33

Groundwater-level:
MNGW [dm]
11

site climatic data:

Ns_korr [mm/a]	350		
Nw_korr [mm/a]	400		
Nj_korr [mm/a]	750		
surface runoff [mm/a]	0		
ET0-FAO pot.Gras ref. evap. [mm/a]	550	ET0(som) pot.Gras ref.verdun. [mm]	444

We and capillary rise:
VKR1.1, VKR 1.16, VKR 1.17 and VKR 4.11:

	Arable land	Grassland	Forest
We [dm]	6	5.4	7.2
KR mm/d	3	1.92	5
ta	44.9	60.8	120
KA_max [mm]	134.6	116.7	600
KA_kli [mm]	67.4	137.8	171.0

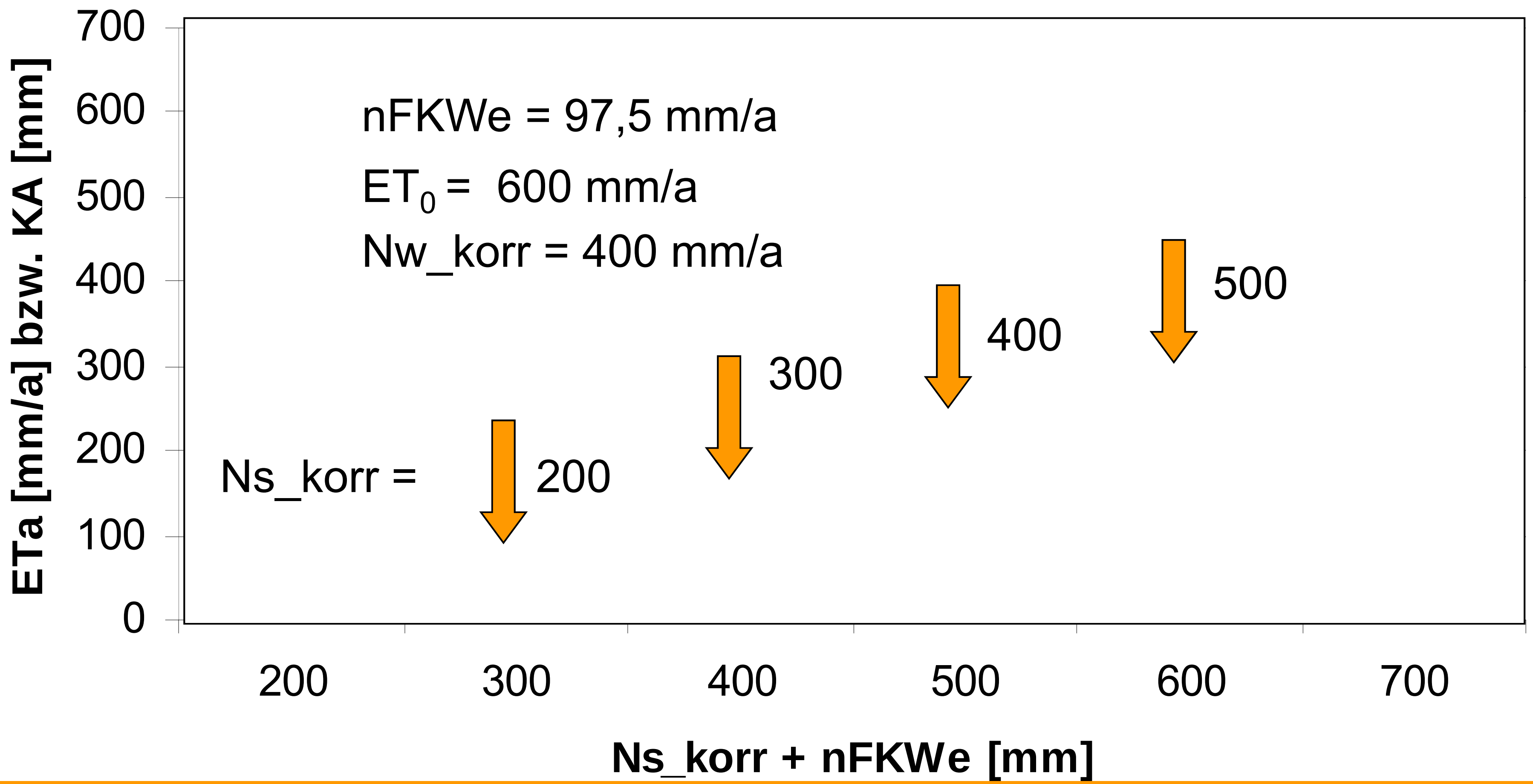
crop water availability WV in the summer half year:

	Acker	Grünland	Forst
nFKWe [mm]	97.52	90.09	112.36
KA [mm]	67.4	116.76	171
Ns_korr [mm/a]	350	350	350
WV [mm]	514.9	556.9	633.4

TUB-BGR-Method: Calculation of ETa and SWR

	Arable land	Grassland	Coniferous forest
ETa [mm/a]	462.9	551.1	640.5
SWR [mm/a]	287.1	198.9	109.5

Profile 1, arable land



Exercise: calculate ETa and KA for 4 sommer precipitation Nsom- values (200 -500 mm) and a groundwater depth of: MNGW = 11 dm resp. MNGW = 50 dm

Calculation of capillary rise amount KA:

MNGW = 11 dm →

Ns_korr	200	300	400	500	600	700
nFKWe	97.52	97.52	97.52	97.52	97.52	97.52
nFKWe +Ns_korr	297.52	397.52	497.52	597.52	697.52	797.52
KA-Kli	255.24	155.24	55.24	-44.76	-144.76	-244.76
KA_max	134.6	134.6	134.6	134.6	134.6	134.6
KA	134.6	134.6	55.24	0	0	0

MNGW = 50 dm → KA = 0 mm

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TUB-BGR-method: application

Arable land with GW influence

MNGW = 11 dm →

Ns_korr	200	300	400	500	600	700
nFKWe	97.52	97.52	97.52	97.52	97.52	97.52
nFKWe +Ns_korr	297.52	397.52	497.52	597.52	697.52	797.52
KA	134.63	134.63	55.24	0	0	0
WV	432.14	532.14	552.76	597.52	697.52	797.52
ET_a_with_GW-influence	428.1	503.7	517.5	545.8	602.1	606

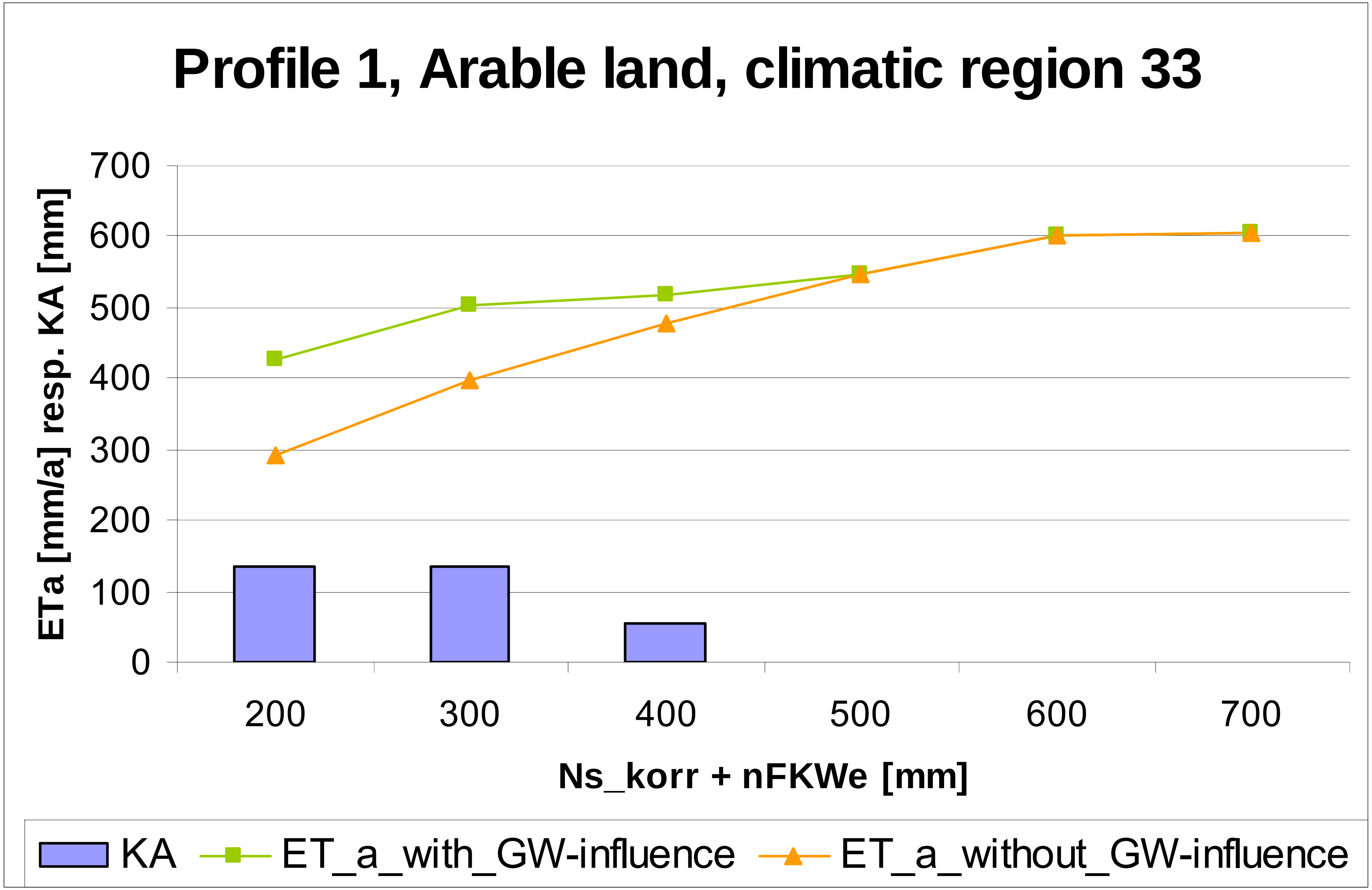
Arable land without GW influence

MNGW = 50 dm →

Ns_korr	200	300	400	500	600	700
nFKWe	97.52	97.52	97.52	97.52	97.52	97.52
NFKWe + Ns_korr	297.52	397.52	497.52	597.52	697.52	797.52
KA	0	0	0	0	0	0
WV	297.51	397.7	497.51	597.51	697.51	797.51
ET_a_without_GW-influence	292.4	397.7	479.3	545.8	602.1	606

ET_pot	**600**
Nw_korr	**400**
ET_pot_so	**480**

- with (MNGW=11 dm) and without (MNGW=50 dm) groundwater influence -



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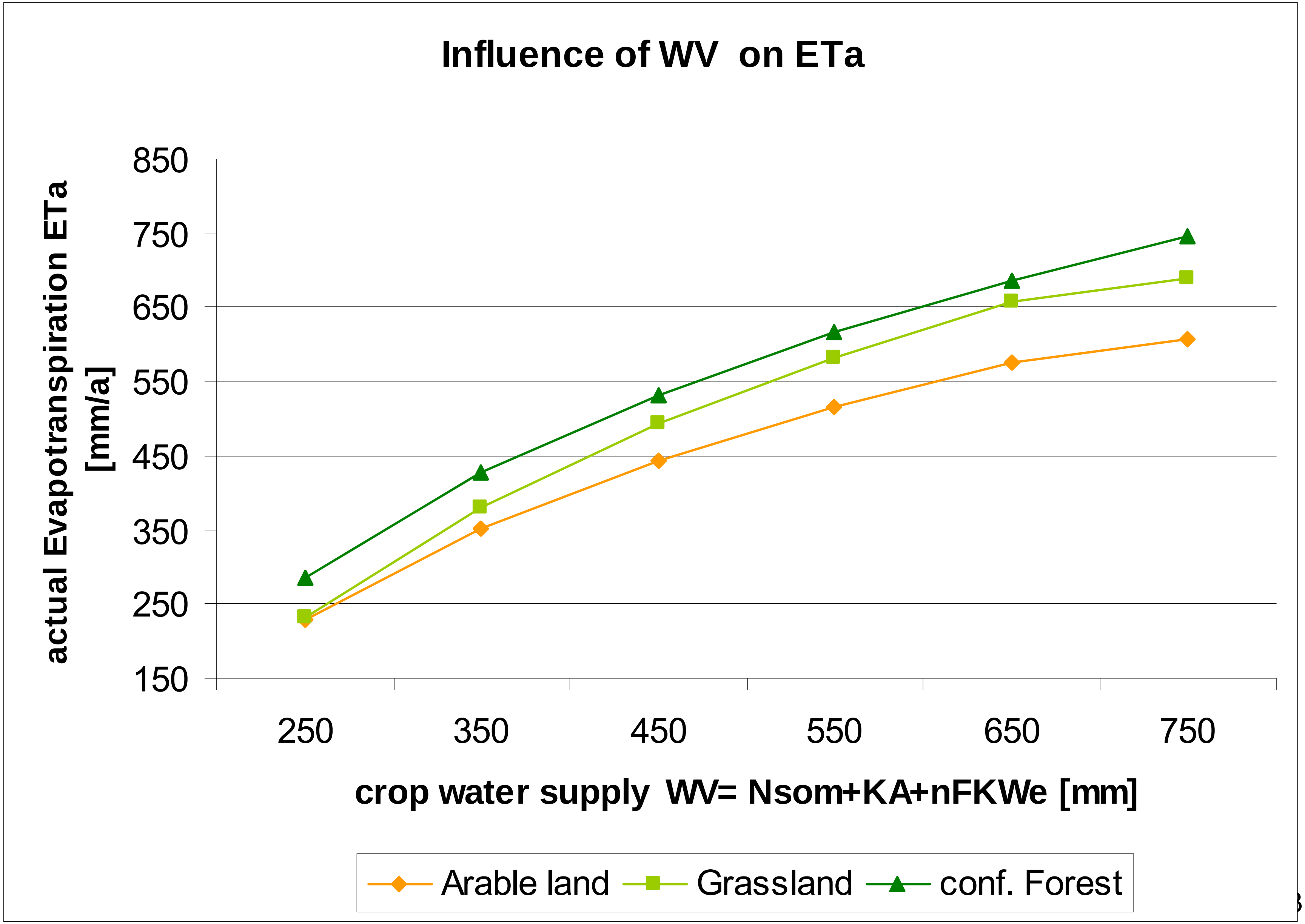
TUB-BGR-method: application



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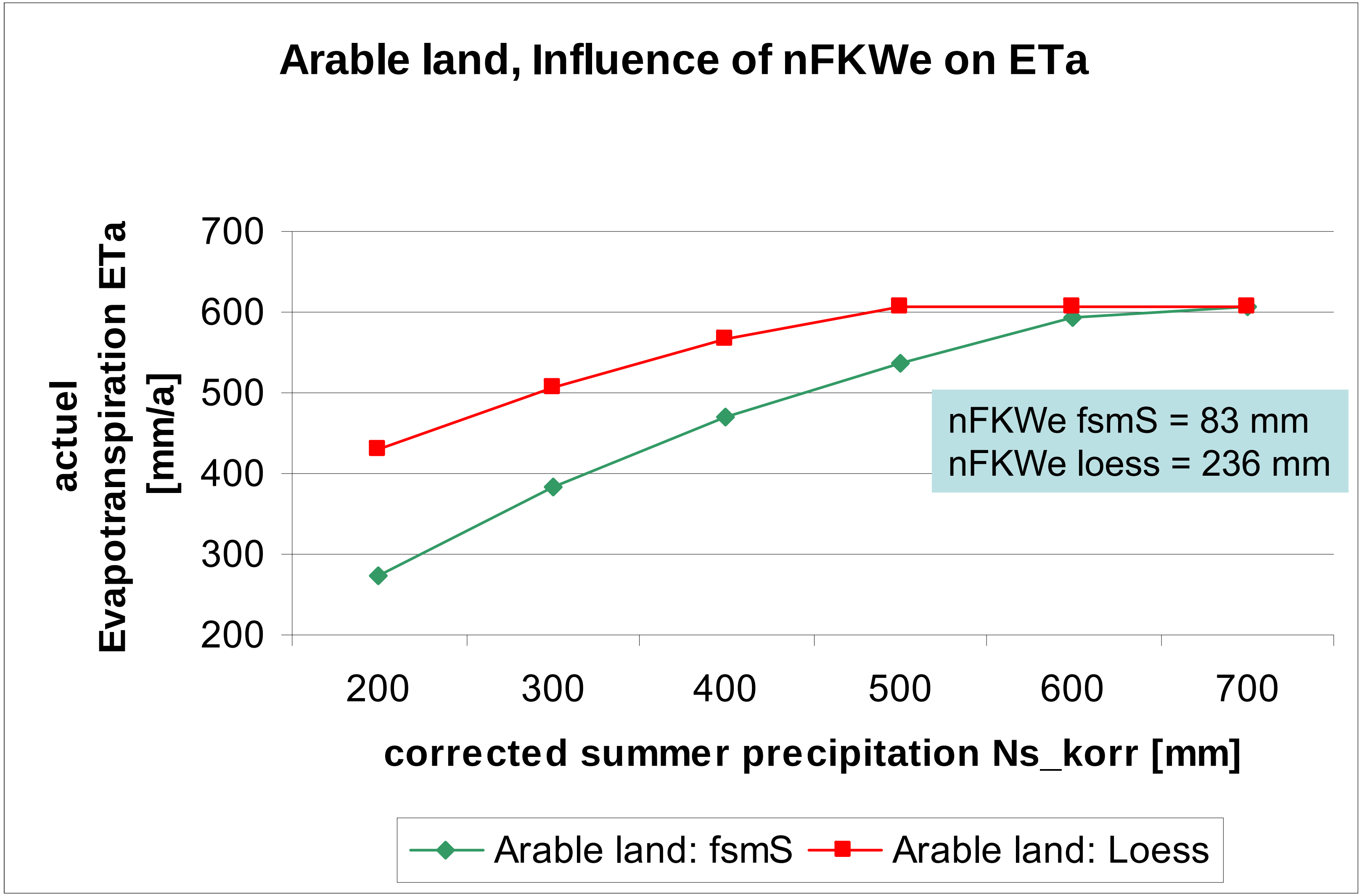

Arable land, Influence of nFKWe on ETa
actuel Evapotranspiration ETa [mm/a]
700
600
500
400
300
200
200
300
400
500
600
700
corrected summer precipitation Ns_korr [mm]
nFKWe fsmS = 83 mm
nFKWe loess = 236 mm
Arable land: fsmS
Arable land: Loess

Assignment of the CLC-keys to the 4 main land use types to determine SWR

CLC - key	description	Arable land	grassland	Deciduous forest	Coniferous forest
112	Discontinuous urban fabric	25 %	50 %	25 %	0 %
141	Green urban areas	0 %	60 %	40 %	0 %
211	Non irrigated arable land	100 %	0 %	0 %	0 %
221	vineyards	0 %	30 %	70 %	0 %
222	Fruit trees and berries plantations	0 %	30 %	70 %	0 %
231	pastures	0 %	100 %	0 %	0 %
243	Land principally occupied by agri-culture with significant areas of natural vegetation	35 %	40 %	25 %	0 %
311	Broad leaved forest	0 %	0 %	100 %	0 %
312	Coniferous forest	0 %	0 %	0 %	100 %
313	Mixed forest	0 %	0 %	50 %	50 %
321	Natural Grassland	0 %	100 %	0 %	0 %
322	Moors and heathland	0 %	70 %	30 %	0 %
324	Transitional woodland shrubs	0 %	70 %	30 %	0 %
411	Inland marshes	0 %	75 %	25 %	0 %

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saturated conductivity kf

Kurzzeichen	Bezeichnung	kf-Werte		Examples
		cm/d	cm/s	
kf1	sehr gering	<1	$<1{,}16 \cdot 10^{-5}$	tonreiche Schichten mit Ld 4-5, sehr stark zersetzte Torfe, Tl, Tu2, Tt
kf2	gering	1-10	$1{,}16 \cdot 10^{-5}$ bis $1{,}16 \cdot 10^{-4}$	tonreiche Schichten mit Ld 3, stark zersetzte Torfe, Ls4, Lt2-3, Tl, Tu2
kf3	mittel	10-40	$1{,}16 \cdot 10^{-4}$ bis $4{,}63 \cdot 10^{-4}$	schluffreiche tonarme Schichten, mittel zersetzte Torfe, Sl3, Sl4, St3, Su3-4, Ls2, Lu, Uls, Ut2-4
kf4	hoch	40-100	$4{,}63 \cdot 10^{-4}$ bis $1{,}16 \cdot 10^{-3}$	fein-mittelkörnige Sande, mittel-schwach zersetzte Torfe, Sl2, St2, fS
kf5	sehr hoch	100-300	$1{,}16 \cdot 10^{-3}$ bis $3{,}47 \cdot 10^{-3}$	mittelkörnige Sande, schwach zersetzte Torfe, mSfs, Su2, gSfs
kf6	äußerst hoch	>300	$>3{,}47 \cdot 10^{-3}$	grobkörnige Sande und Kiese, sehr schwach zersetzte Torfe, mS, gS

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