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4th International Symposium on Flood Defence

Toronto, May 7th, 2008

"Erosion and sediment yield estimation for flood protection"

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Prof. Dr. rer. nat. Dr.-Ing. András Bárdossy

Project scope

„Development of an integrated management strategy for green flood retention reservoirs and polders“

Universität Stuttgart, Germany, Inst. of Hydraulic Engineering, Prof. Dr.-Ing. B. Westrich & Prof. Dr. rer. nat. Dr.-Ing. A. Bárdossy

Universität Hohenheim, Germany, Institute for Soil Science and Land Evaluation
Prof. Dr. K. Stahr & Prof. Dr. T. Streck

Water board Erft (EV), Germany, Bergheim
Dr.-Ing. U. Kern

Project scope

Use retention basins for sediment and pollution control

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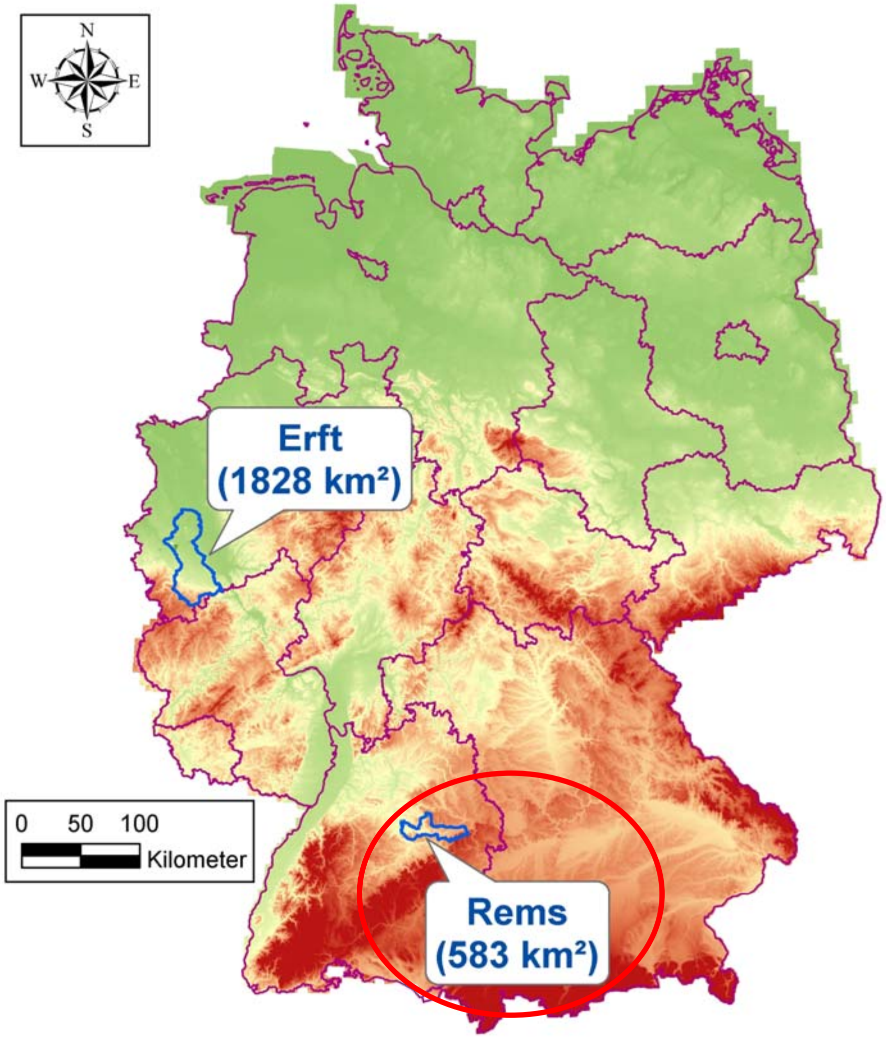
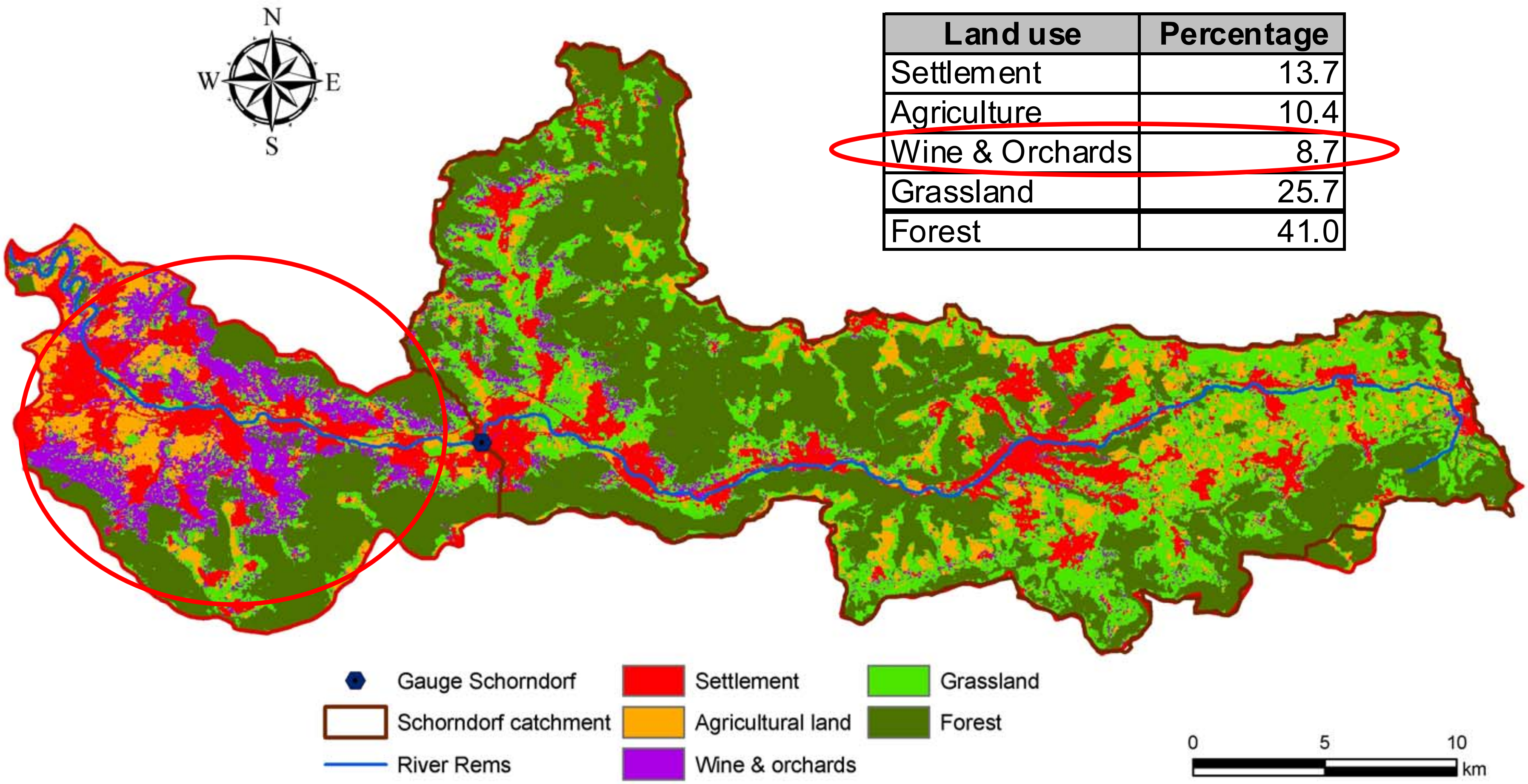
Study areas

Study areas

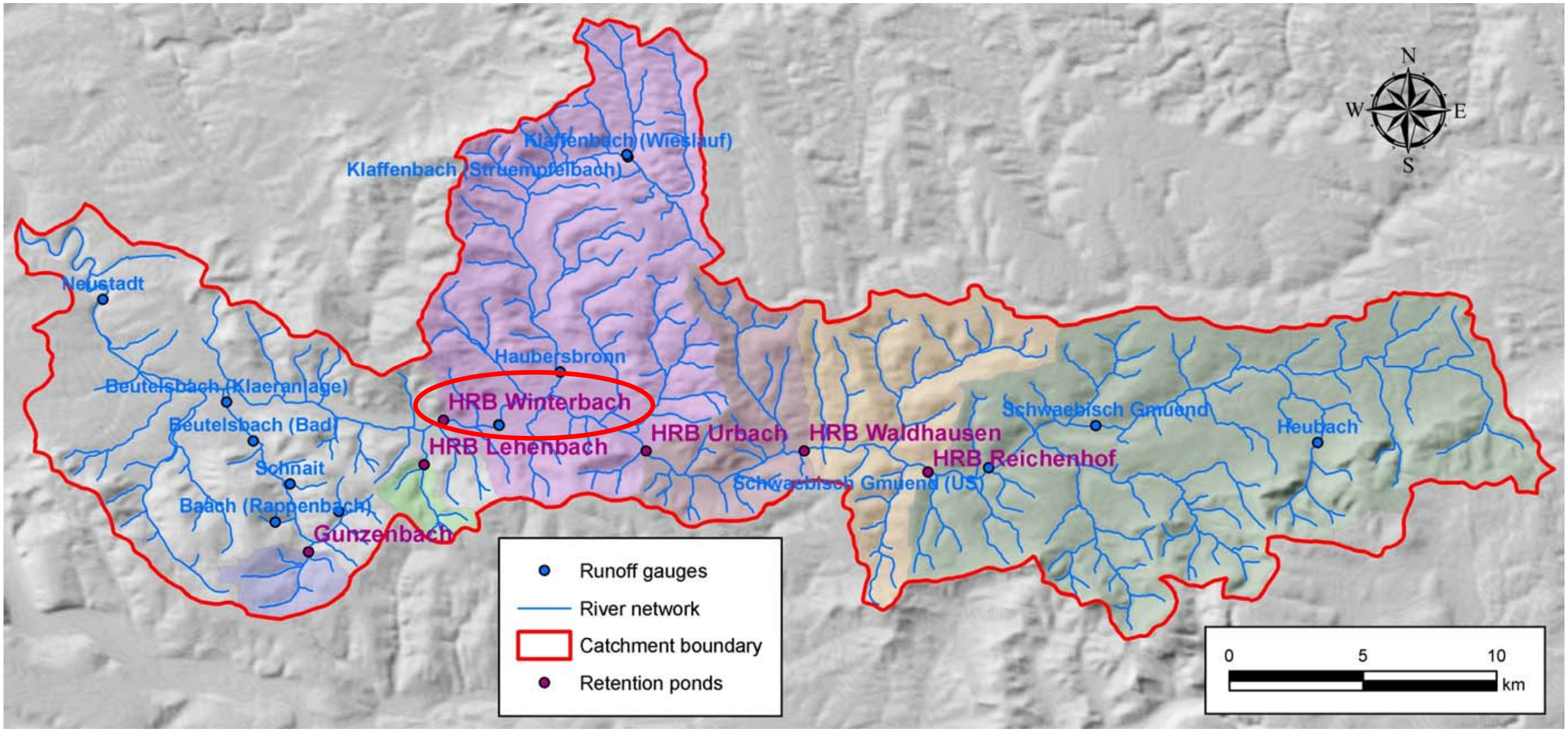


Rems catchment - Land use 2000

Land use	Percentage
Settlement	13.7
Agriculture	10.4
Wine & Orchards	8.7
Grassland	25.7
Forest	41.0



Rems catchment - Flood protection



Retention pond	River (km)	Area (km²)	Operation since	Storage (m³)	Storage area (ha)	Outflow ($m^3 \cdot s^{-1}$)
Gmuend / Reichenhof	49.5	188	2006	615,000	31.2	137
Lorch / Waldhausen	43.7	243	2007	670,000	31.7	160
Schorndorf / Winterbach	26.1	424	2005	1,170,000	62.0	196

Retention pond Schorndorf / Winterbach

River kilometer	25.5
Catchment area (km²)	428
Storage volume (m³)	1,170,000
Storage area (ha)	62.0
Ponding return period (yr)	20

MMQ ($m^3 \cdot s^{-1}$)	110
MQ_{20} ($m^3 \cdot s^{-1}$)	200
MQ_{100} ($m^3 \cdot s^{-1}$)	250
MQ_{1000} ($m^3 \cdot s^{-1}$)	412

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Course of action

- Identification and analysis of flood events in the investigation period 1990-2005
- Determination of mean annual erosion with USLE/RUSLE and mean annual sediment yield with Sediment Delivery Ratio (SDR)
- Determination of event sediment yield from observed runoff with MUSLE
- Modeling of peak runoff and runoff volume with empirical SCS Curve Number (SCS-CN) method and physics-based WaSiM-ETH

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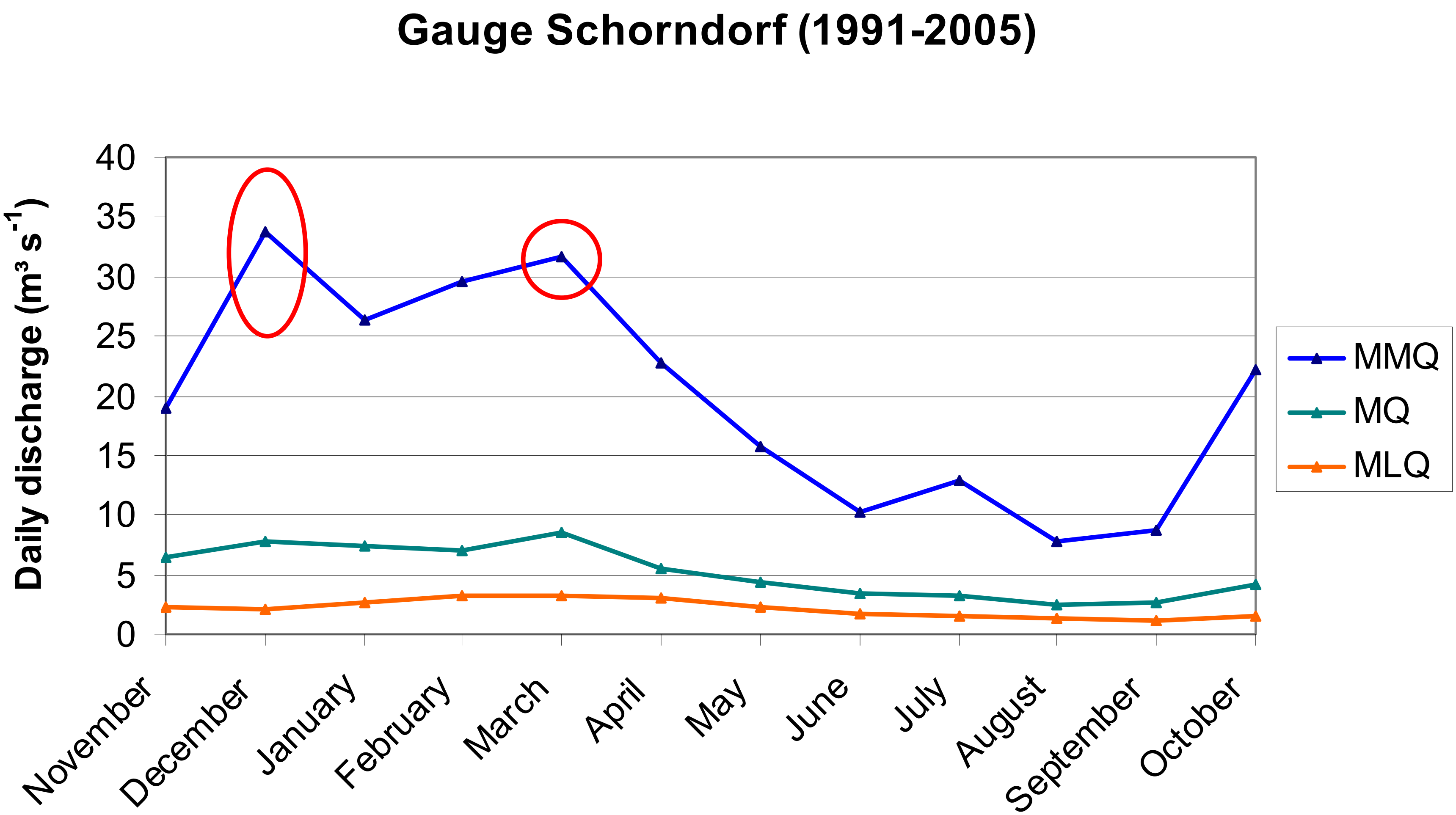
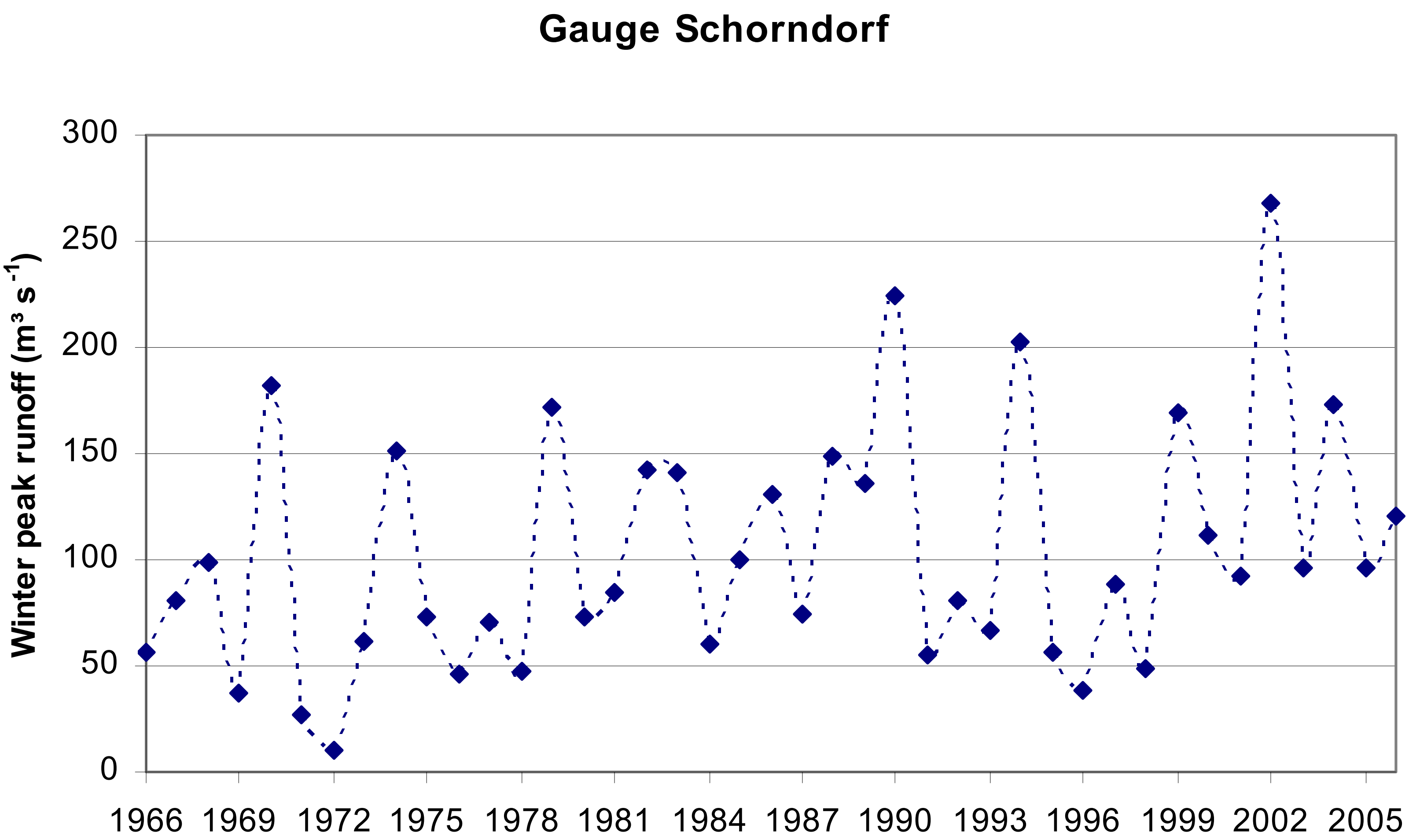
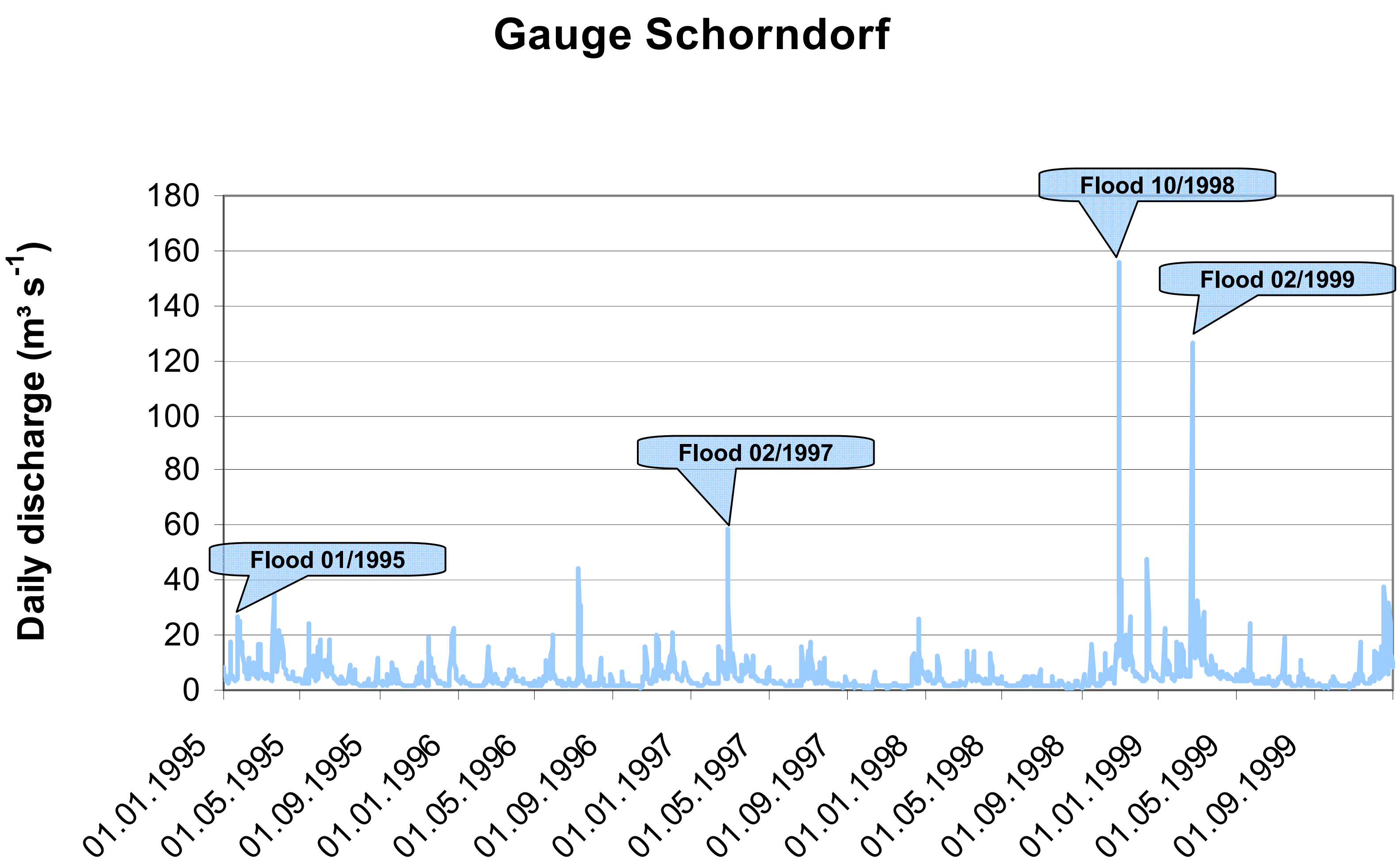
Runoff characteristics



Runoff characteristics



Flood events



Flood events - Gauge Schorndorf

Event date	Peak runoff ($m^3 \cdot s^{-1}$)	Return period (yr)	Precipitation (mm)	Circulation pattern
15.02.1990	224	20-50	101	NWZZF
21.12.1993	161	5-10	73	NWAAF
13.04.1994	202	20	103	XXZZF
25.01.1995	46	<2	47	SWZZF
26.02.1997	89	2	50	SWZZF
29.10.1998	233	20-50	136	SWZZF
20.02.1999	169	10	85	NWZAF
31.01.2000	92	2	22	NWAAF
30.03.2000	111	2-5	57	XXZZF
25.02.2002	92	2	50.2	NWAZT
31.03.2002	268	50-100	132	NWAAF
11.11.2002	97	2	50	NWZZF
14.01.2004	173	10	89	SWZZF

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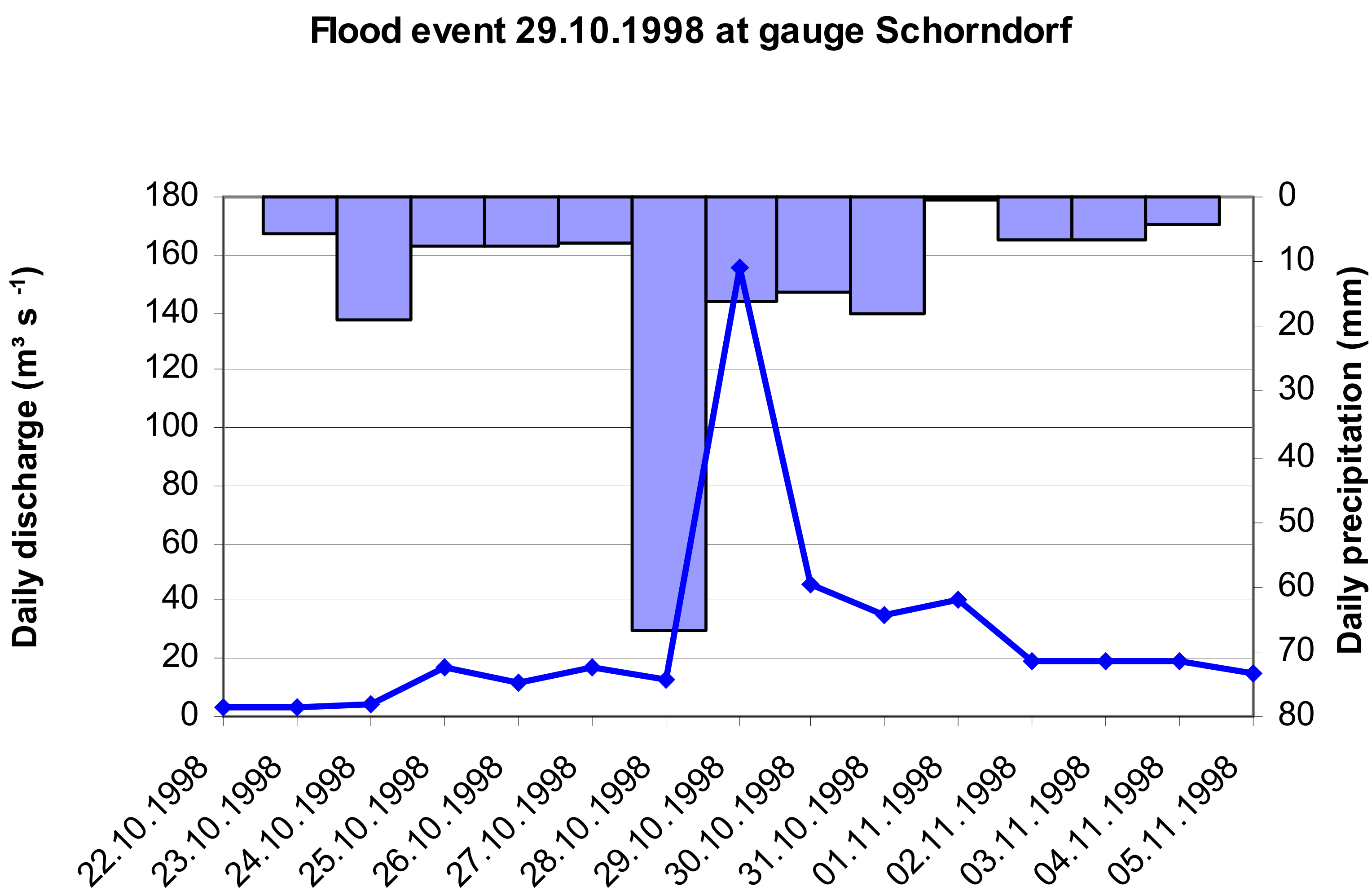
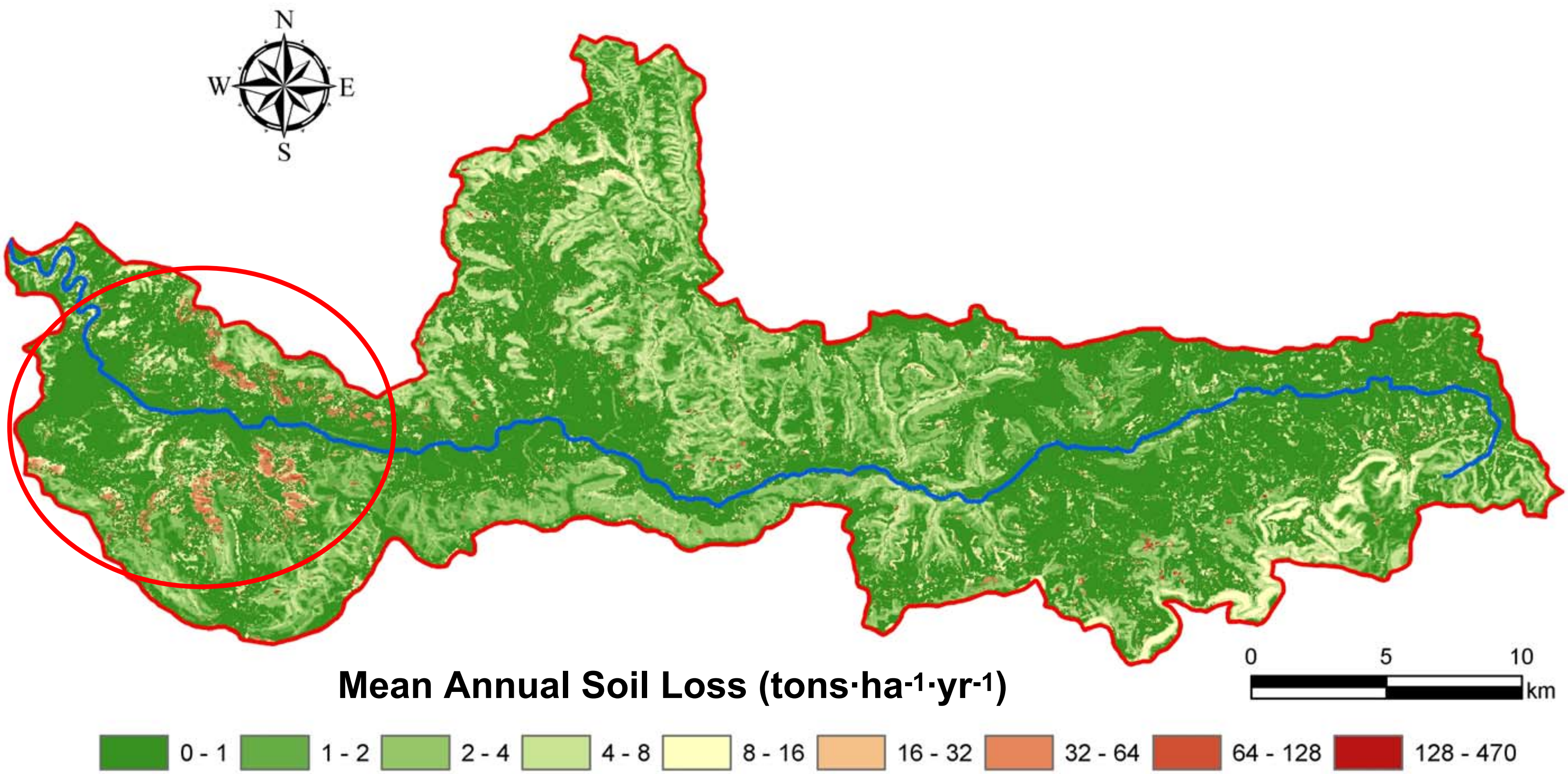
Flood events



Rems catchment - USLE/RUSLE



Erosion control - Vineyards

Bark mulch vs. uncovered

Straw mulch

Rems catchment - Erosion & Sediment yield

Study area	Rems	Baden-Wuerttemberg	Bavaria
Area A (km²)	483	35,752	7.7-1,587
SL ($tons \cdot ha^{-1} \cdot yr^{-1}$)	0-469 (Ø 3.0)	0 -117	1-8 (Ø 3.0)
SL ($tons \cdot ha^{-1} \cdot yr^{-1}$) (agric.)	0-170 (Ø 3.5)	-	1-20 (Ø 8.0)
SY ($1000\ tons \cdot yr^{-1}$)	8.8	-	8-50.2 (Ø 14.2)
Source	-	*Jaeger* (1995)	*Auerswald* (1992)

$$SY = 700 + 8.5 \cdot A \cdot \sqrt{SL}$$

Source / catchment	Rems	Schorndorf	Waldhausen	Schw. Gmuend	Heubach
Wischmeier (1975)	0.09	0.10	0.11	0.14	0.22
Neufang et al. (1989)	0.11	0.12	0.13	0.16	0.24
Auerswald (1992)	0.06	0.06	0.07	0.09	0.19
Behrendt et al. (1999)	0.34	0.27	0.41	0.55	0.03
Maner (1958)	0.15	0.20	0.26	0.32	0.87
Roehl (1962)	0.15	0.17	0.20	0.22	0.39
Williams (1977)	0.14	0.15	0.22	0.35	0.41
Williams and Berndt (1972)	0.09	0.10	0.11	0.12	0.20
Catchment area (km²)	*582*	*416*	*248*	*92*	*10*

Sediment Delivery Ratio (SDR)

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Event sediment yield - MUSLE

$$SY = 11.8 \cdot \left(Q \cdot q_p\right)^{0.56} \cdot K_m \cdot LS_m \cdot C_m \cdot P_m$$

SY (tons)	Event sediment yield
Q (m^3)	Runoff volume
q_p ($m^3 \cdot s^{-1}$)	Peak runoff
K_m, LS_m, C_m, P_m	Average USLE factors

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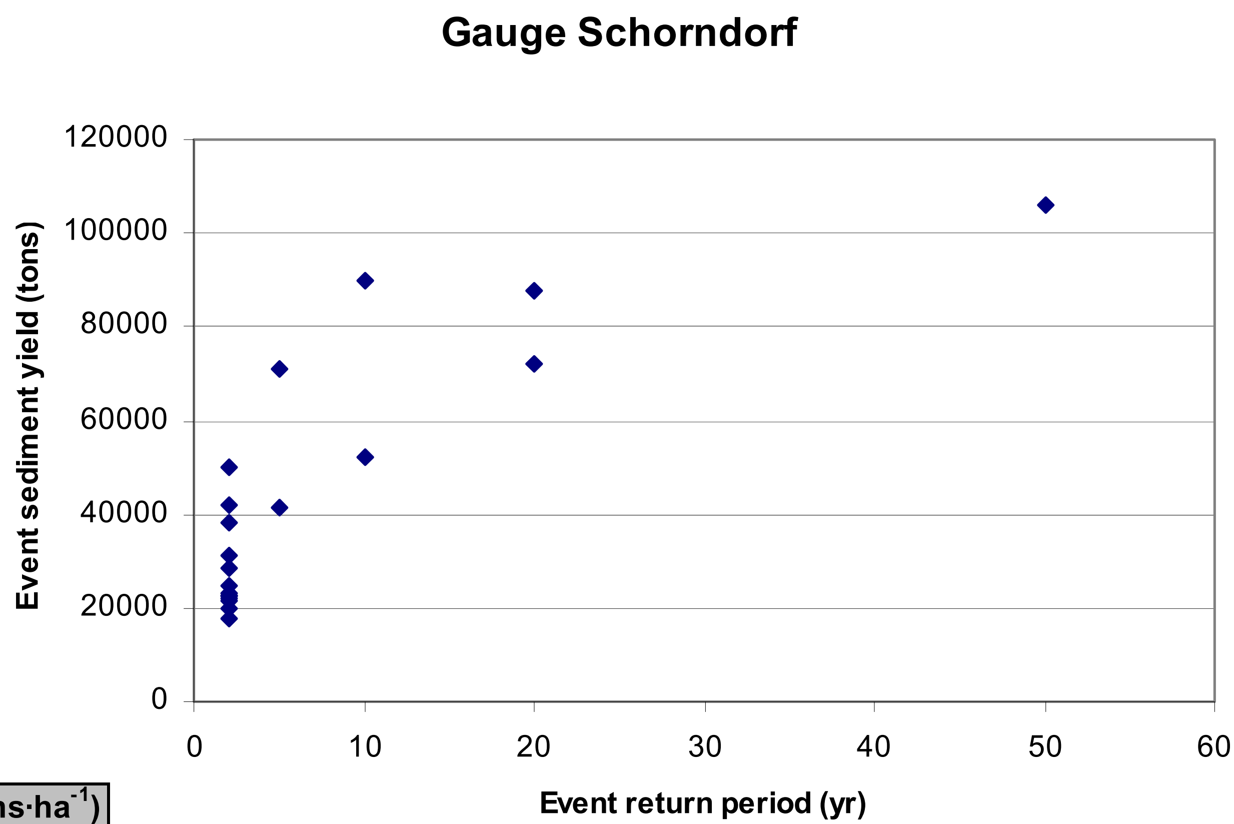
Event sediment yield - MUSLE

T (yr)	SY_m (tons·ha^{-1})	SY_e (tons·ha^{-1})
10000	5.5	
5000	5.1	
1000	4.2	
500	3.8	
200	3.3	
100	3.0	
50	2.6	2.5
25	2.2	
20	2.1	1.9
10	1.8	1.7
5	1.3	1.4
2	0.6	0.7



Catchment	Area (km²)	SY_{100} (tons·ha^{-1})
Aich	180	> 0.9
Goldersbach	72	1.4

Event runoff volume - SCS-CN method

- Original SCS-CN (*SCS*, 1986)

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad P \geq I_a$$

$$Q = 0 \qquad P < I_a$$

$$S = \frac{25400}{CN} - 254 \qquad I_a = 0.20 \cdot S$$

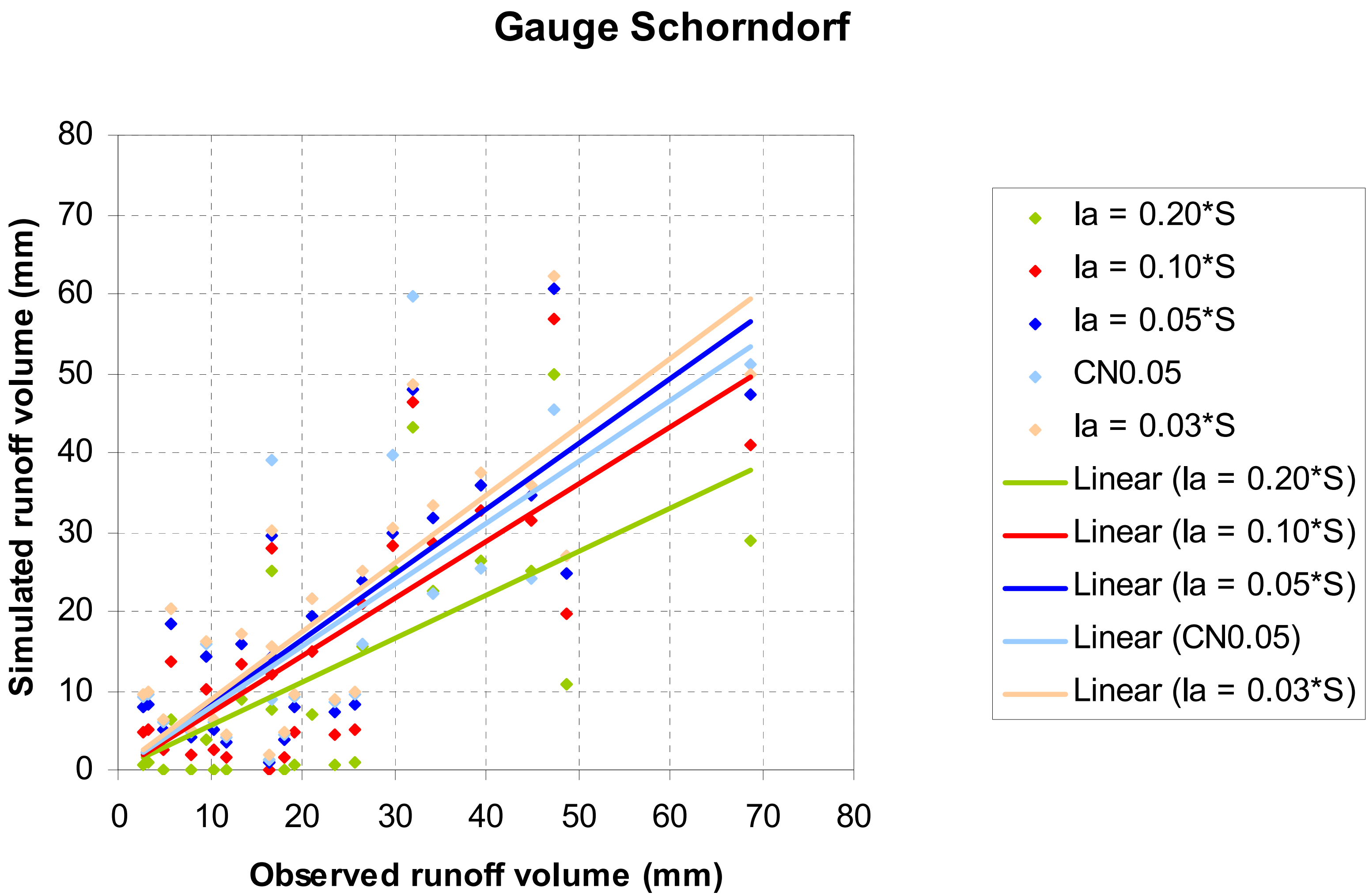
- CREAMS (*Smith and Williams*, 1980)

$$CNI = -16.91 + 1.348 \cdot CNII - 0.01379 \cdot CNII^2 + 0.0001177 \cdot CNIII^3$$

- EPIC (*Sharpley and Williams*, 1990)

$$CNII_s = \frac{1}{3} \cdot (CNIII - CNII) \cdot \left(1 - 2 \cdot e^{-13.86 \cdot s}\right) + CNII$$

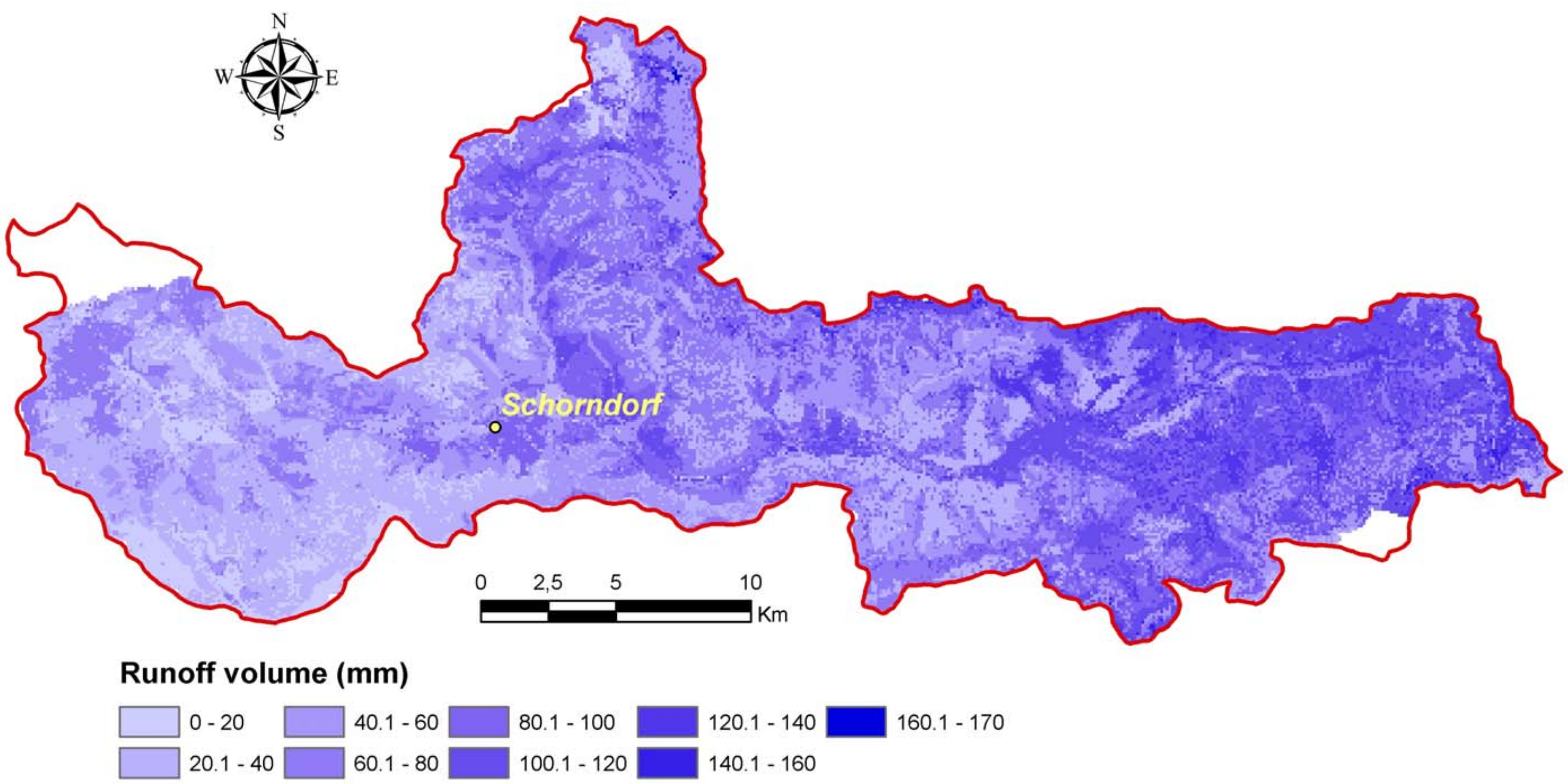
Event runoff volume - CREAMS lumped



Event runoff volume - lumped vs. distributed

Method (mm)	Lumped ME	Lumped RMSE	Lumped R	Lumped E_j	Distributed ME	Distributed RMSE	Distributed R	Distributed E_j
SCS Original	5.9	12.2	0.757	0.439	0.3	10.8	0.765	0.554
SCS (λ = 0.05)	0.6	10.4	0.793	0.593	0.0	10.8	0.765	0.552
SCS (λ = 0.03)	-0.6	10.3	0.798	0.598	-0.1	10.8	0.765	0.551
CREAMS Original	11.1	16.2	0.704	-0.005	5.5	12.0	0.750	0.447
CREAMS (λ = 0.03)	2.0	10.7	0.783	0.559	5.2	11.9	0.749	0.459
EPIC Original	13.5	18.0	0.677	-0.246	1.1	11.1	0.757	0.529
EPIC (λ = 0.03)	4.5	11.2	0.779	0.515	0.8	11.1	0.757	0.528

Event runoff volume - CREAMS distributed



Event 4 - 21.12.1993

Event peak runoff - CREAMS method

$$q_p = 3.79 \cdot DA^{0.7} \cdot s^{0.159} \cdot \left(\frac{Q}{25.4} \right)^{0.903 \cdot DA^{0.017}} \cdot LW^{-0.187}$$

DA	Drainage area (km²)
s	Main Channel Slope ($m \cdot km^{-1}$)
Q	Runoff volume (mm)
LW	Length-width ratio (-)

Method ($m^3 \cdot s^{-1}$)	ME	RMSE	R	E_j
CREAMS original	7.1	41.5	0.748	0.231
CREAMS (λ = 0.03)	-33.1	52.6	0.792	-0.233
CREAMS (CN0.05)	-25.1	54.2	0.685	-0.308
AGNPS original	24.3	40.9	0.744	0.256
AGNPS (λ = 0.03)	-4.1	31.4	0.795	0.561
AGNPS (CN0.05)	1.7	38.5	0.683	0.341

Event runoff - WaSiM-ETH

- Physics-based hydrological model (*Schulla*, 1997)
- Raster discretization
- Runoff generation with combined TOPMODEL (*Beven and Kirkby*, 1979) and Green & Ampt (1911) infiltration or Richards (1931) equation
- Runoff routing with kinematic wave approach and single linear storages
- Snow accumulation and snow melt (*Anderson*, 1973; *Braun*, 1985)
- Multi-layer two-dimensional groundwater model

Event runoff - WaSiM-ETH

- Spatial discretization with cell size 100 x 100 m
- Combined TOPMODEL and Green & Ampt
- LANDSAT land use for 1993 & 2000
- Continuous simulation for the years 1993 & 2000 with a preceding one year warm-up period
- Model calibration and validation based on daily observed discharge at 4 gauging stations
- Calibration as a combination of trial-and-error adjustment and automatic parameter estimation with PEST (Doherty, 2002)

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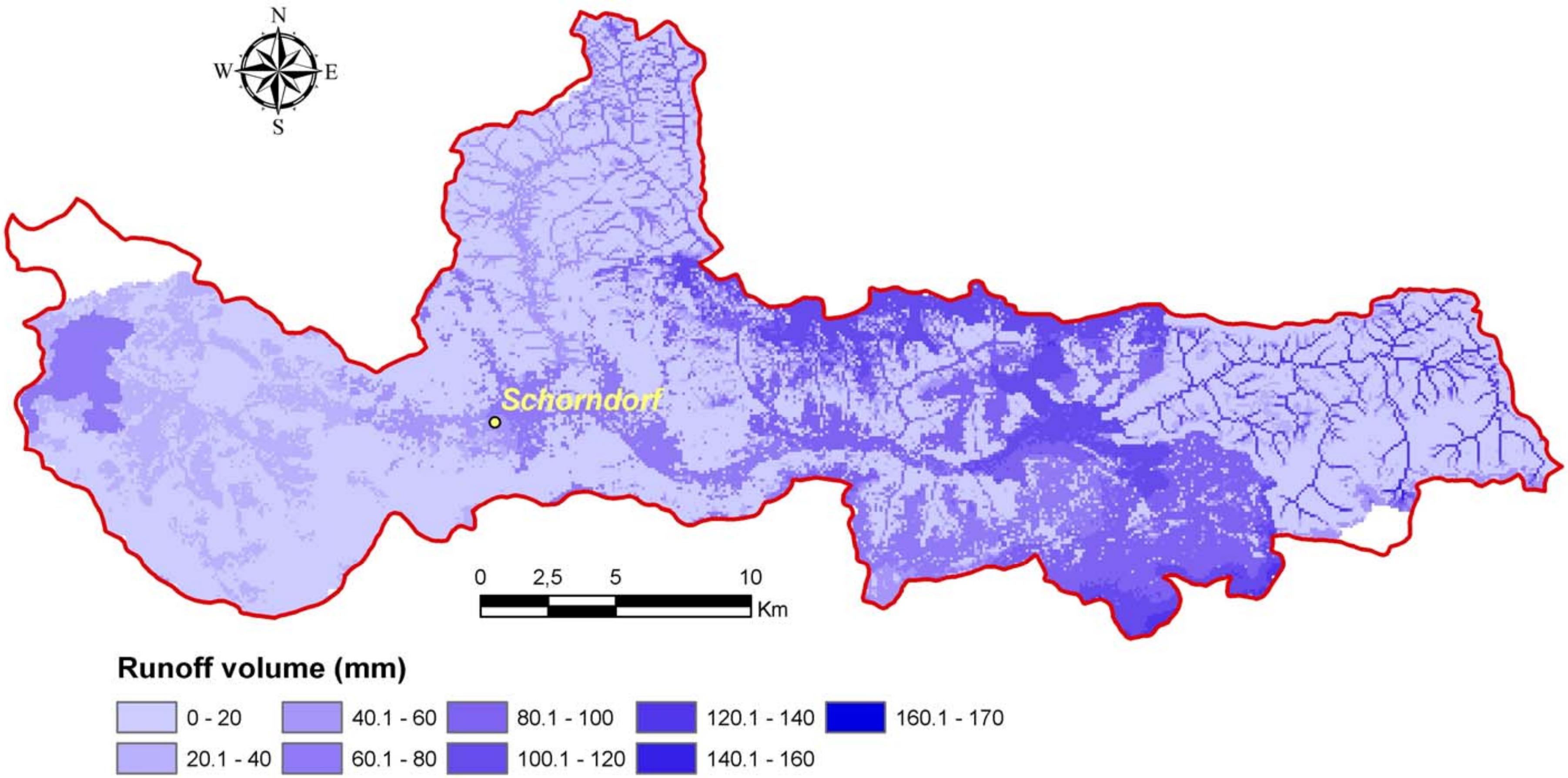
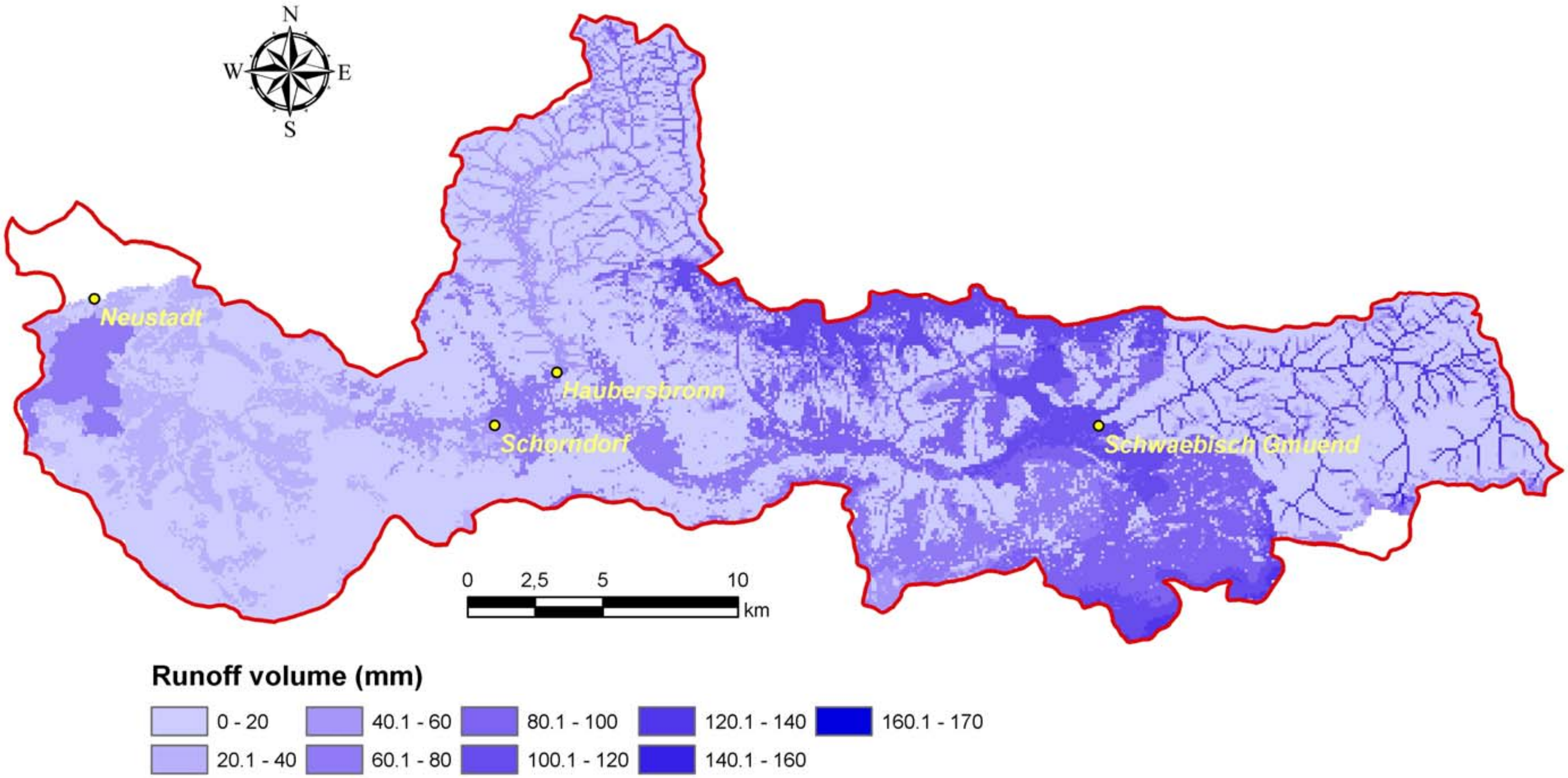
Event runoff volume - WaSiM-ETH



Event 4 - 21.12.1993

Event runoff volume - WaSiM-ETH



Event 4 – 21.12.1993

Event peak runoff - WaSiM-ETH

		Observation			Simulation				
No.	Date	q_p ($m^3 s^{-1}$)	Q (mm)	P_e (mm)	q_p ($m^3 s^{-1}$)	Q (mm)	RMSE (mm)	R	E_j
4	21.12.1993	97.2	32.0	74.0	63.9	39.9	21.7	0.89	0.76
5	13.04.1994	170.6	48.7	97.8	126.9	58.8	5.9	0.95	0.76
16	31.01.2000	45.3	16.4	27.0	30.2	10.0	4.4	0.97	0.81
18	22.03.2001	50.1	26.6	65.5	44.1	14.5	13.2	0.88	0.87

No.	Date	Q (mm)	q_p ($m^3 s^{-1}$)	P_e (mm)	P_5 (mm)	ψ (-)	WaSiM	AGNPS
4	21.12.1993	32.0	97.2	74.1	44.5	0.43	0.0020	0.019
5	13.04.1994	48.7	171	97.8	14.3	0.50	0.0038	0.013
16	31.01.2000	16.4	45.3	27.0	0.20	0.60	0.0007	0.002
18	22.03.2001	26.6	50.1	65.5	19.2	0.41	0.0007	0.010

Summary

- Erosion-prone areas can be identified, but uncertainty in quantification exists
- Current data basis not adequate for detailed analysis, only rough estimations possible
- Suspended load measurements with high temporal resolution of major importance for calibration and validation
- Additional uncertainty due to runoff and erosion by snow melt

Outlook

- Better incorporation of antecedent moisture condition and vegetation state
- Consideration of snow melt effects
- MUSLE with sediment routing
- Refined WaSiM-ETH calibration for reasonable runoff pattern
- Sensitivity analysis
- Land use and precipitation scenarios

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Thank you

for the attention !

Erft Verband

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