HydroPredict' 2010

Predictions for Hydrology, Ecology, and Water Resources Management
Session C: *How can we quantify/predict changes in water-related hazards*

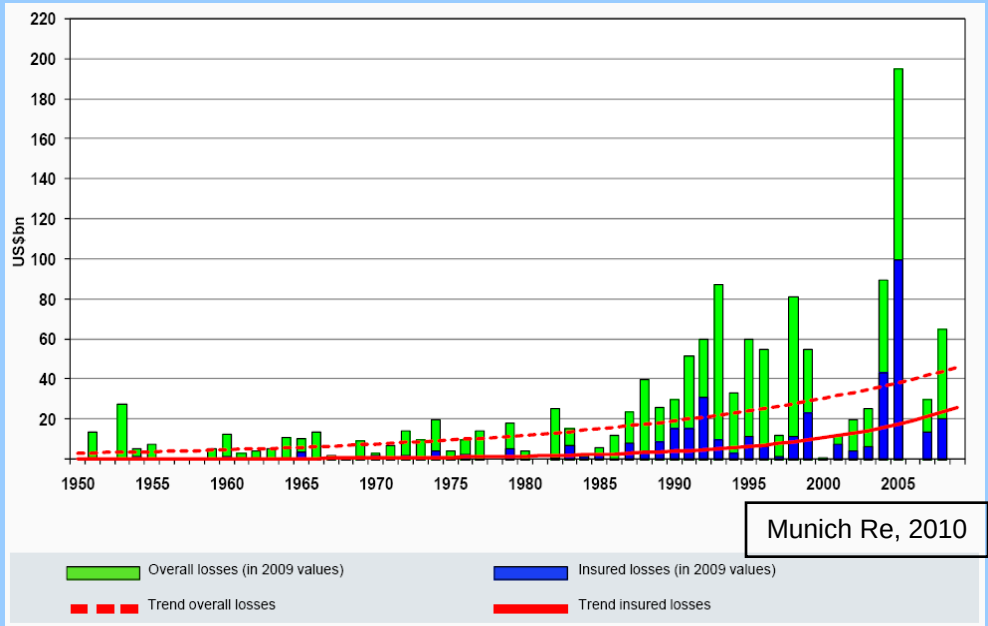
Comparative simulation of the effects of land use change, river training and altered climate on floods of the Rhine

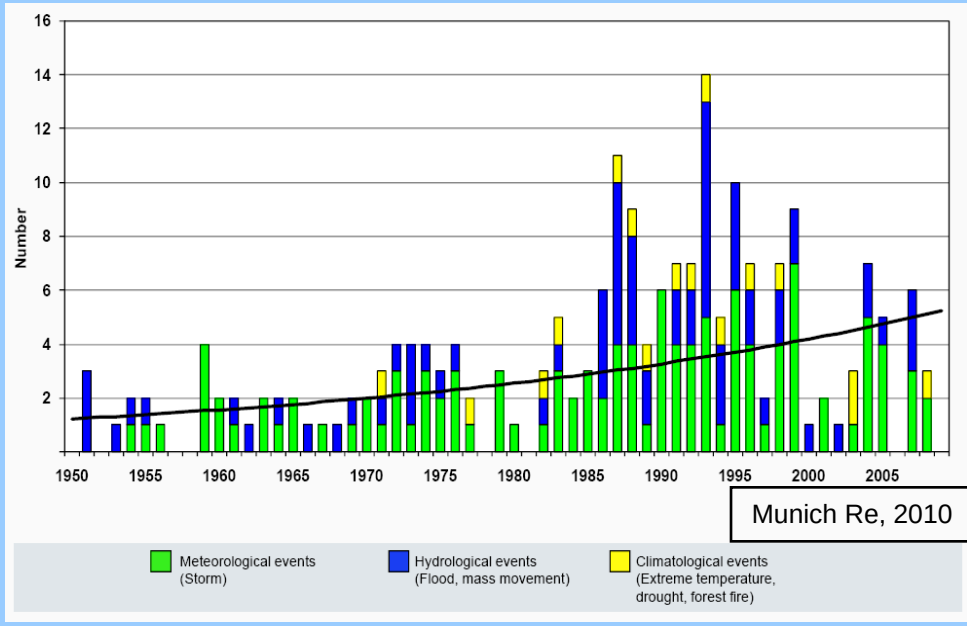
Axel Bronstert

Chair for Hydrology and Climatology
Institute for Earth and Environmental Sciences
University of Potsdam, Germany

Comparative Simulation of the effects of environmental change on Rhine floods

Motivation





Increase in number of flood events (left) and related damages (right)

Comparative Simulation of the effects of environmental change on Rhine floods

Motivation

What is the impact of environmental changes on flooding conditions ?

? *Land use change*
? *Climate change*
? *River training measures*
? *Anything else*
? *Nothing at all*

Comparative Simulation of the effects of environmental change on Rhine floods

Motivation

The Rhine:

- *3rd biggest European river*
- *Most important European river*

Rhine action plan for flood defence (ICPR,1998):

- *Reduce damage risks by 25%*
- *Reduce flood stages downstream impounded reaches up to 70cm*
- *Increase flood risk awareness*
- *Improve flood forecasting*

Quantification needed !!

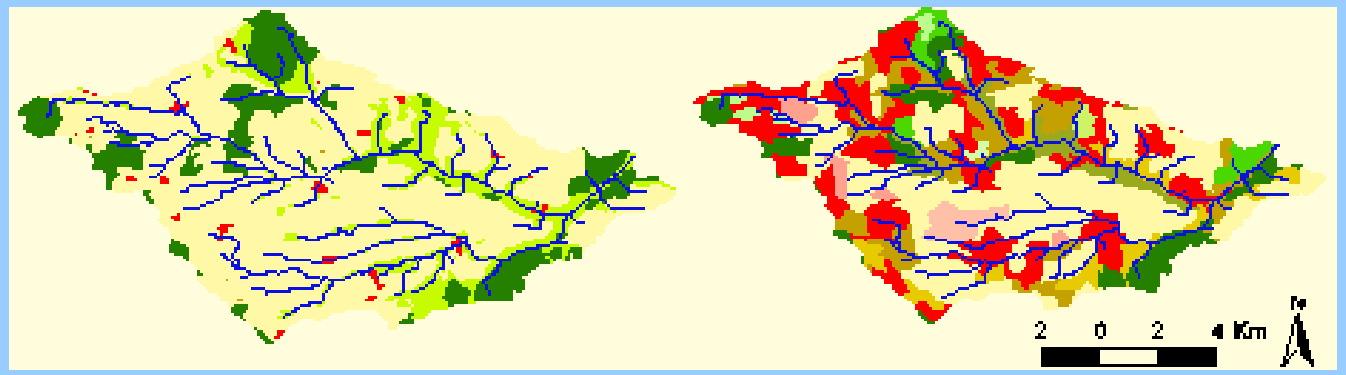
Comparative Simulation of the effects of environmental change on Rhine floods

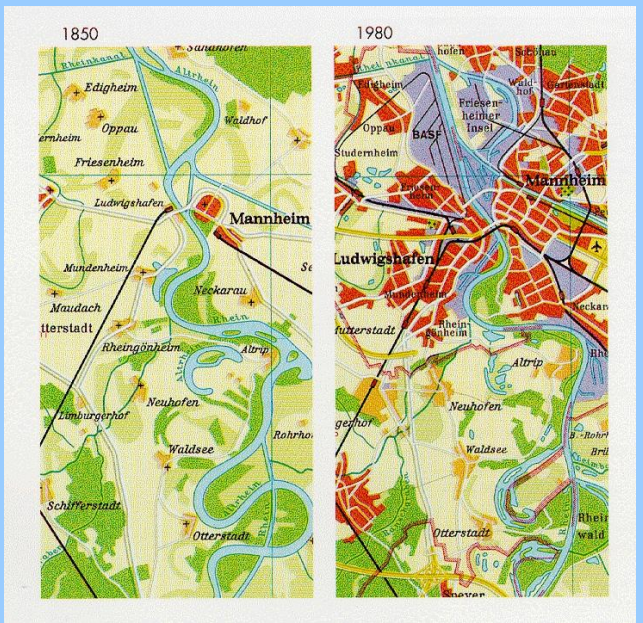
Major environmental changes in the Rhine basin during the last century

1) *Urbanisation*

- *doubling of urban areas (housing, industry, traffic etc.) during the last 60 years*
- *Reduction of farm land*

- *Examples: Körsch-Catchment 1850 ➔ 1990*
  Mannheim / Ludwigshafen 1850 ➔ 1980

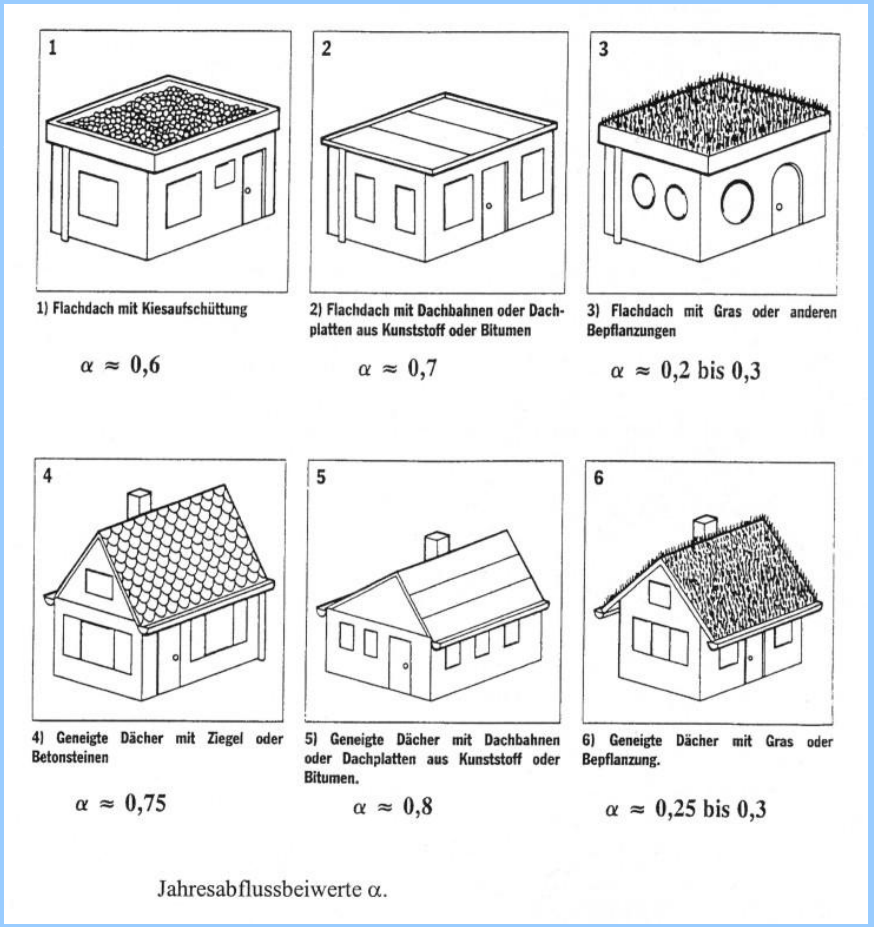




Major environmental changes in the Rhine basin during the last century

2) decentralised storm water management

- *retention on roofs etc.*
- *Small scale retention in the landscape*



Jahresabflussbeiwerte α.

Major environmental changes in the Rhine basin during the last century

3) Changed management practice of farm land

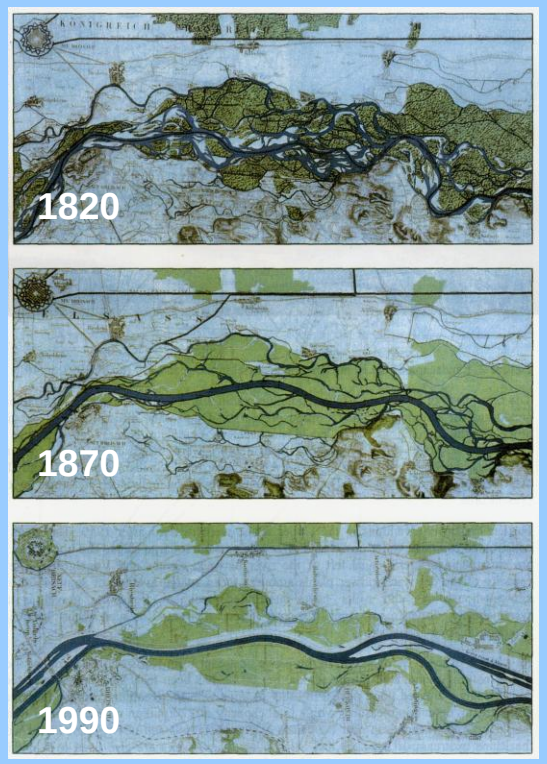
- *conventional tillage vs. ecological oriented tillage*

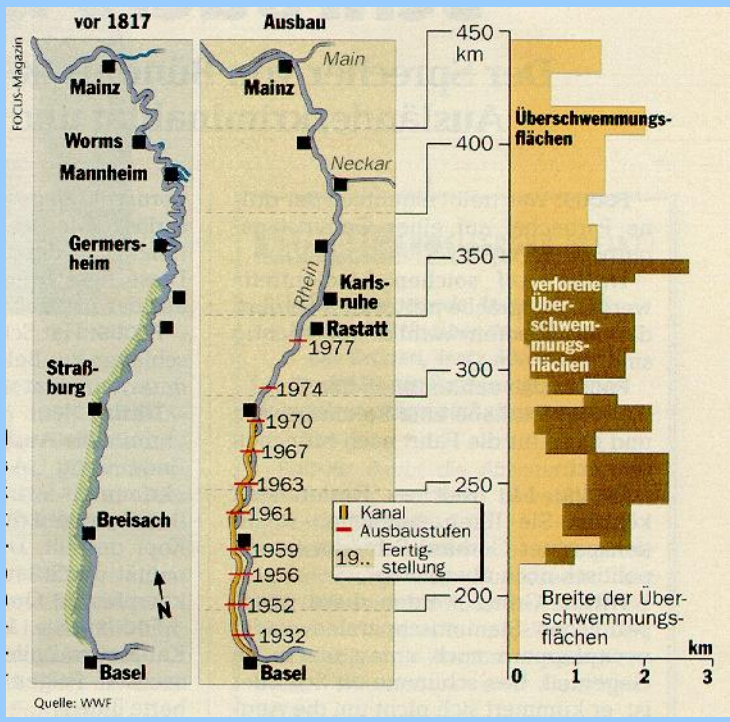
- *rationalisation of farm land*

Comparative Simulation of the effects of environmental change on Rhine floods

Major environmental changes in the Rhine basin during the last century

4) river training and river channelling



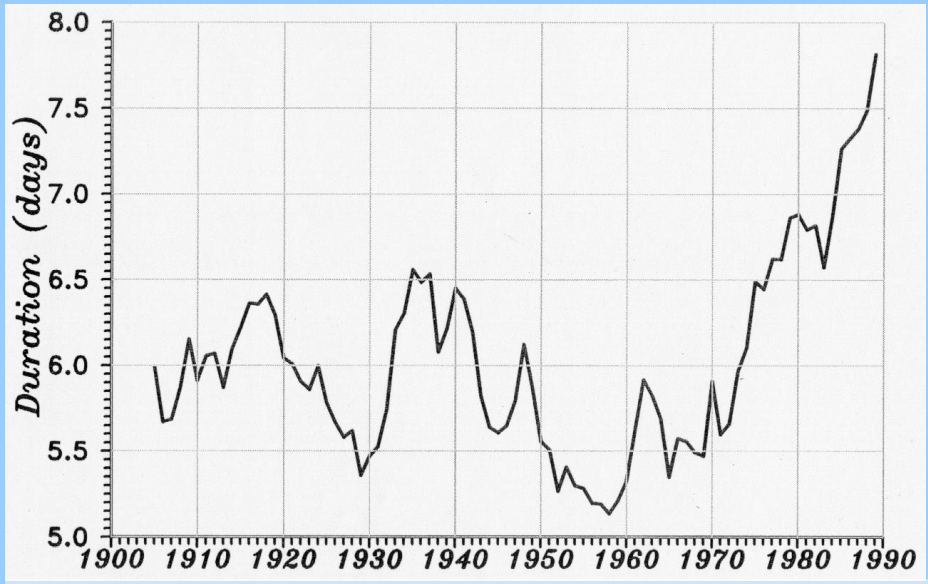


- *faster flood wave propagation*
- *reduced retention in flood plains*

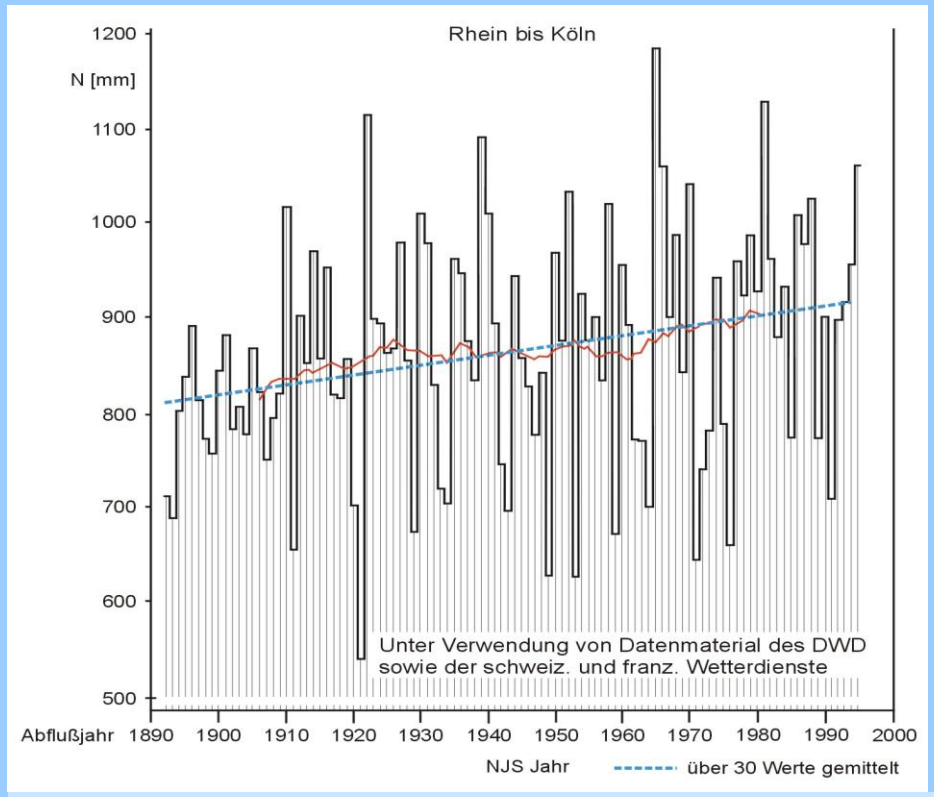
Comparative Simulation of the effects of environmental change on Rhine floods

Major environmental changes in the Rhine basin during the last century

5) Climate change



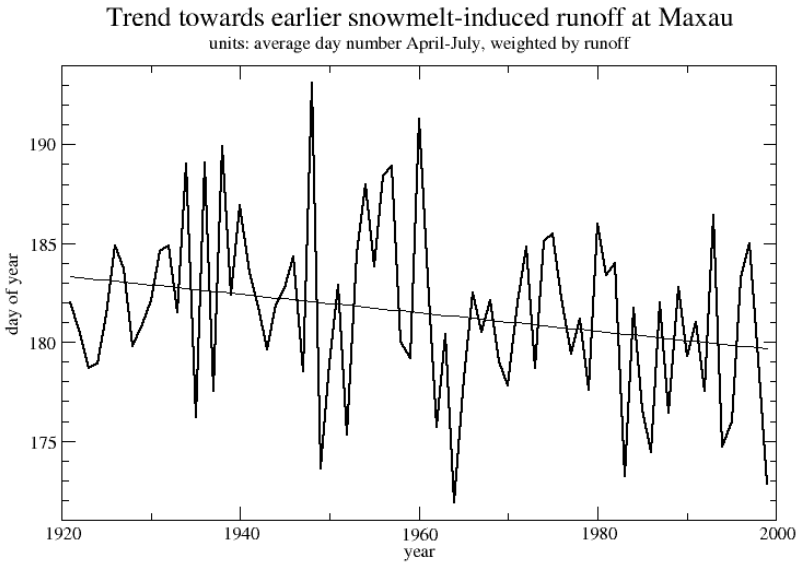
Persistence of weather type „Western-Zonal“, 1900 - 1990. (Bárdossy, 1995)



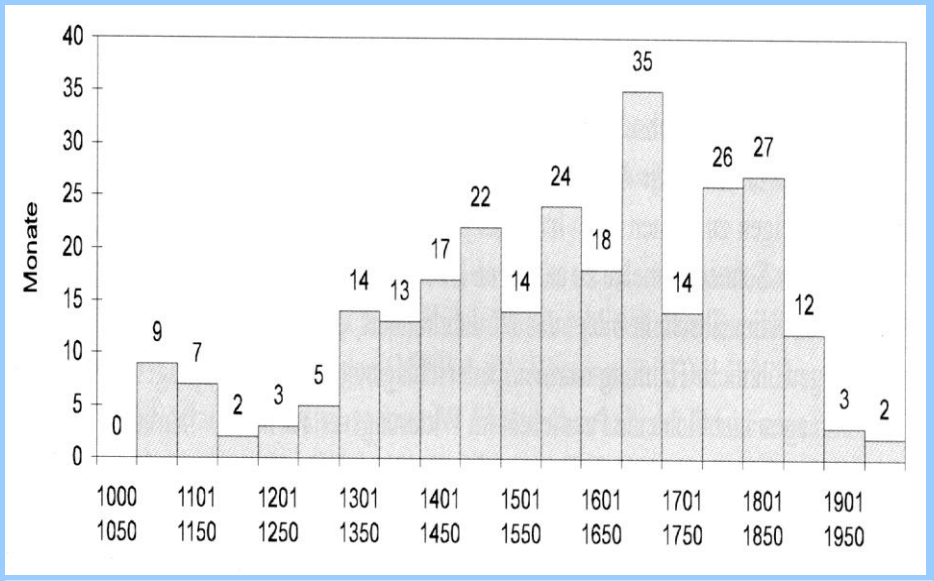
Annual precipitation over the Rhine Area upstream Köln. (Engel, 1995)

Major environmental changes in the Rhine basin during the last century

5) Climate change



Timing of spring flood peak flood at gauge Maxau 1920 - 2000 (Bürger, 2002)



Months / 50 years with frozen river surface at Köln. (Krahe, 1997)

Comparative Simulation of the effects of environmental change on Rhine floods

The modelling concept

1) Storm runoff generation influenced by land use
➔ *process-oriented modelling in some sub-catchments*

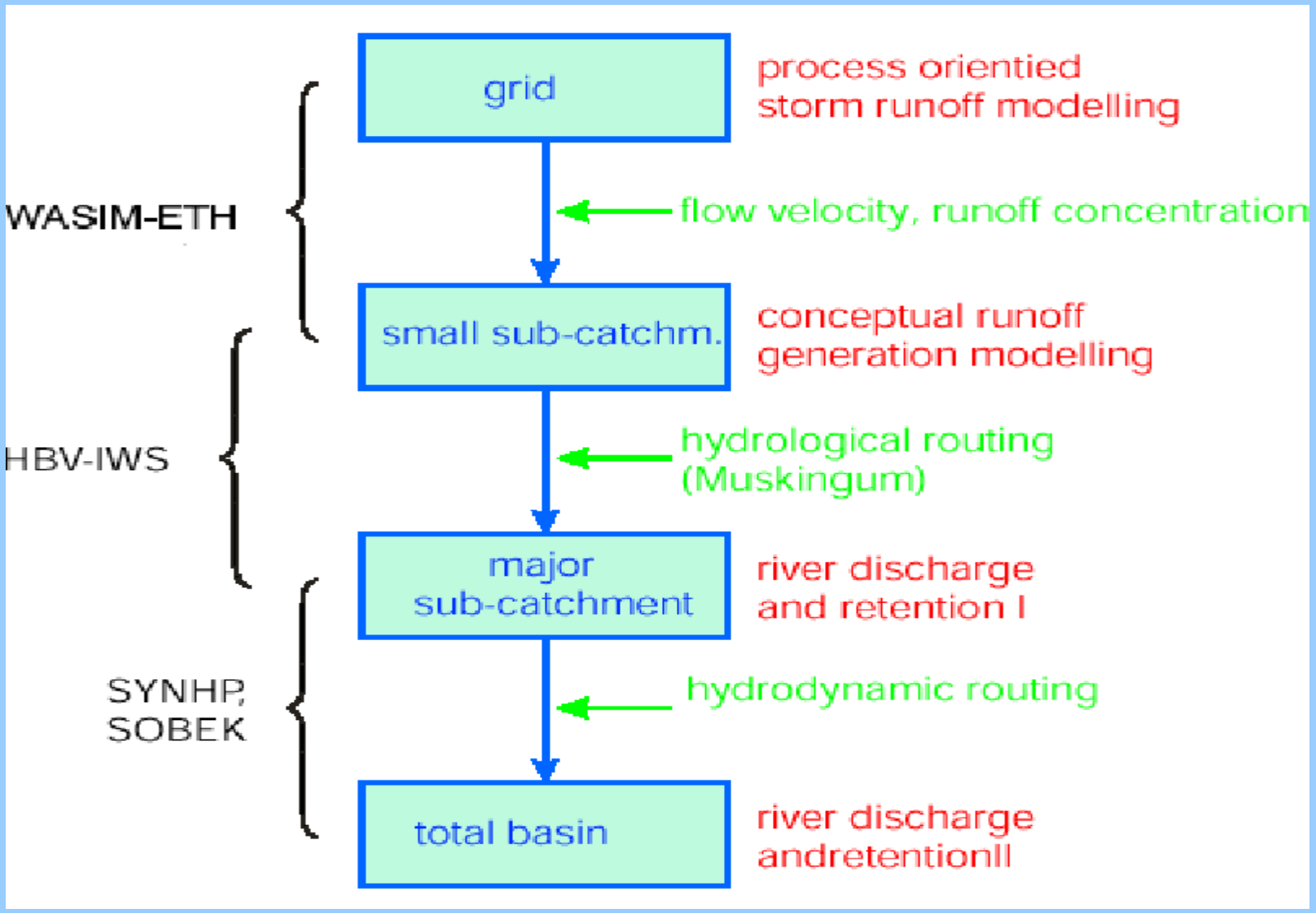
2) Regionalization of runoff generation
➔ *macro scale hydrol. modelling in all sub-catchments*

3) Flood routing and retention in flood plains
➔ *hydrodynamic routing in the main river system*

4) Modelling of the whole hydrological-hydraulic system
➔ *meteorological perturbations / climate scenarios*

Comparative Simulation of the effects of environmental change on Rhine floods

The modelling approach: nested and scale-specific models



Comparative Simulation of the effects of environmental change on Rhine floods

I process-oriented modelling

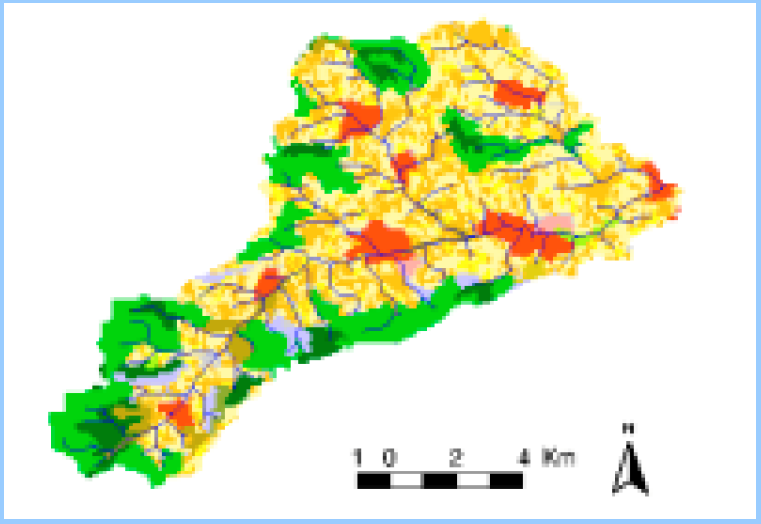
The Lein Sub-Catchment:

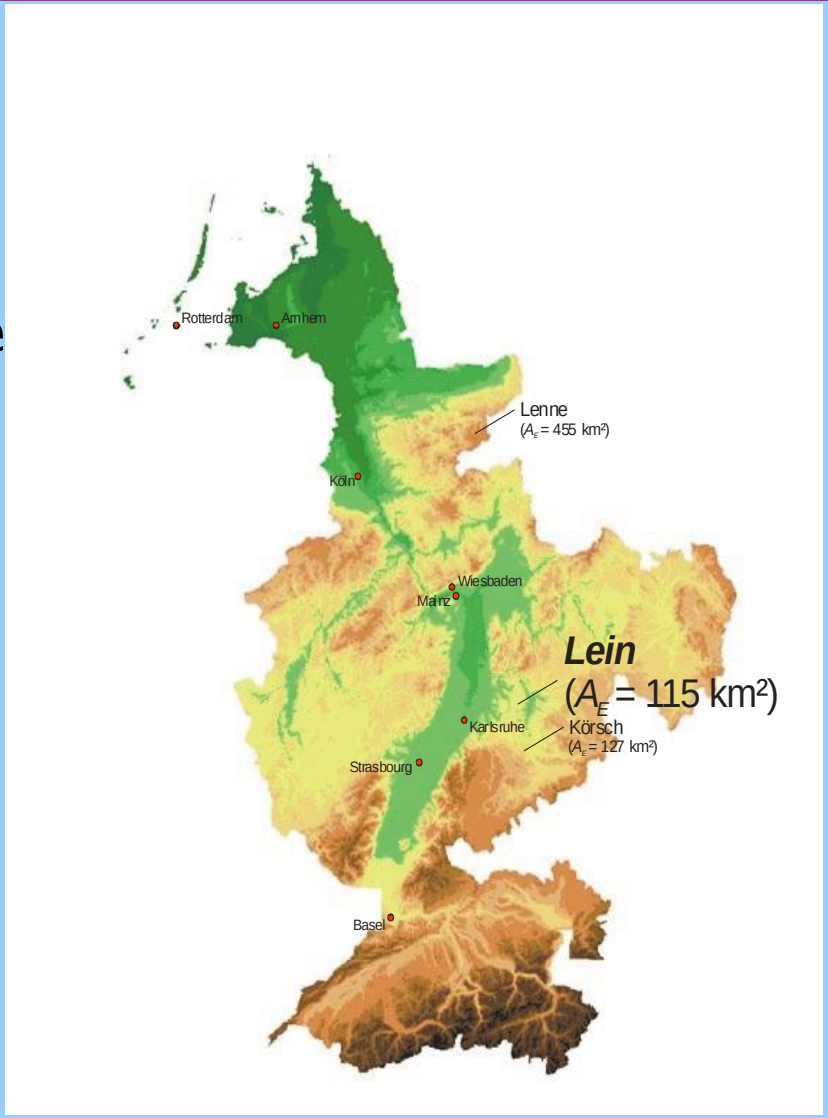
Area: 115 km²

Location: Kraichgau (SW-Germany);

land use: intensive agriculture

soils: deep loess soils





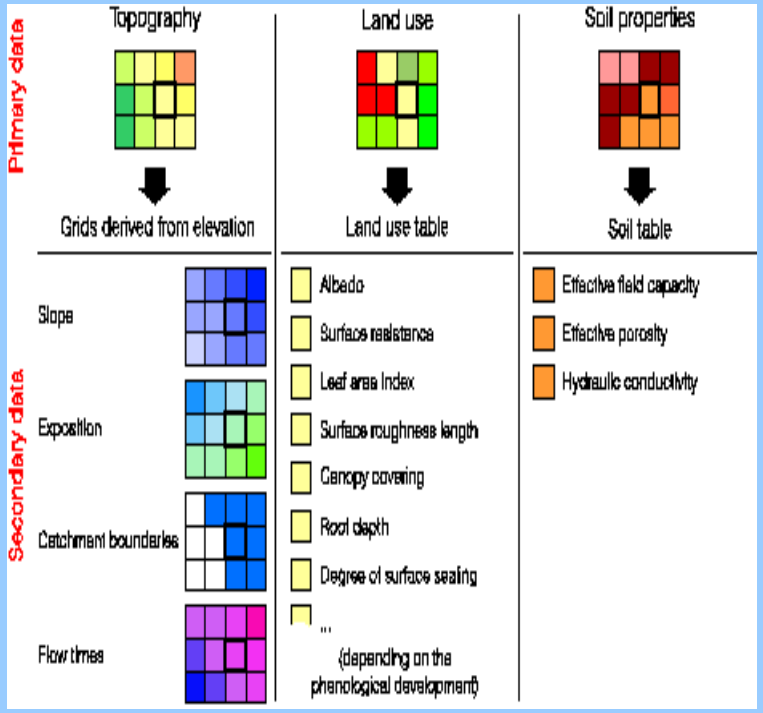
Comparative Simulation of the effects of environmental change on Rhine floods

WASIM-ETH (Schulla, 1979)

- grid based (fully distributed)
- process oriented:
- interception,
- evapotranspiration,
- quick runoff ('Hortonian overland flow'; saturation overland flow)
- inter flow
- ground water response

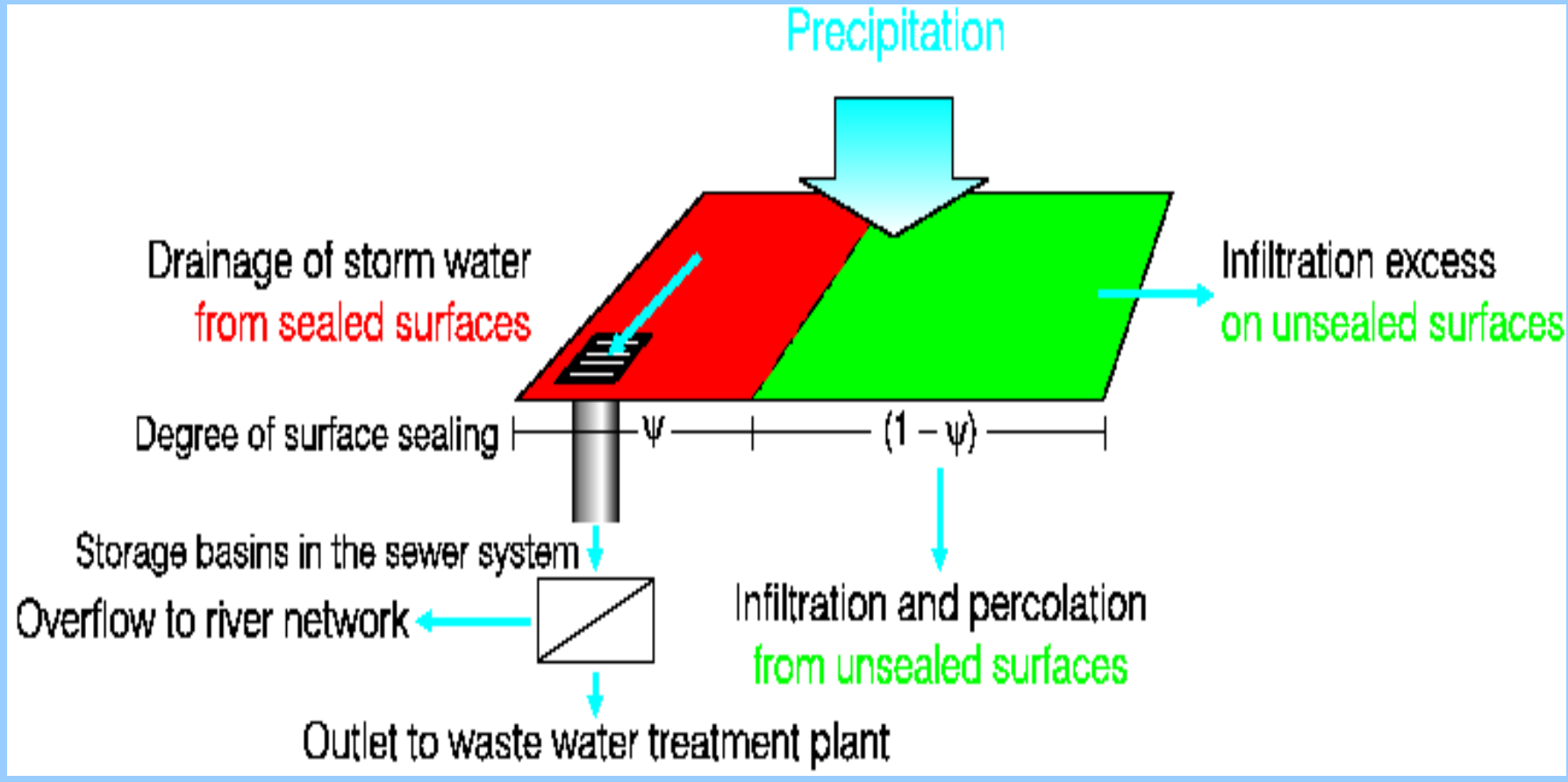
extended version (Niehoff, 2002):

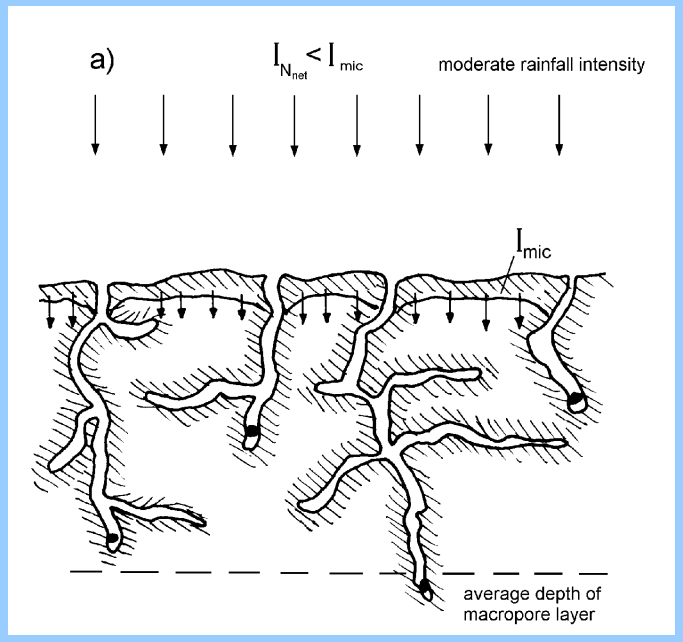
- agricultural areas **(macropore flow; sealing)**
- urbanized areas (**sealed vs. non-sealed; decentralized storm water infiltration**)
- **water retention in the landscape**

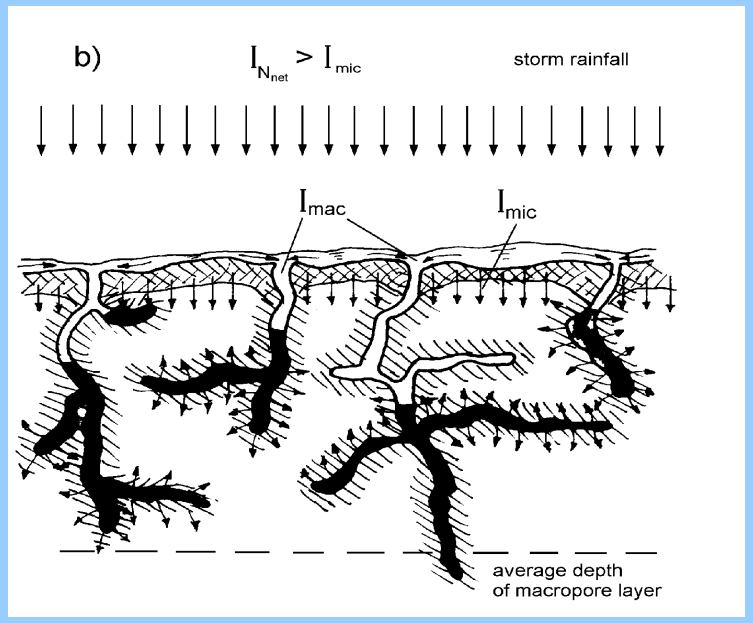


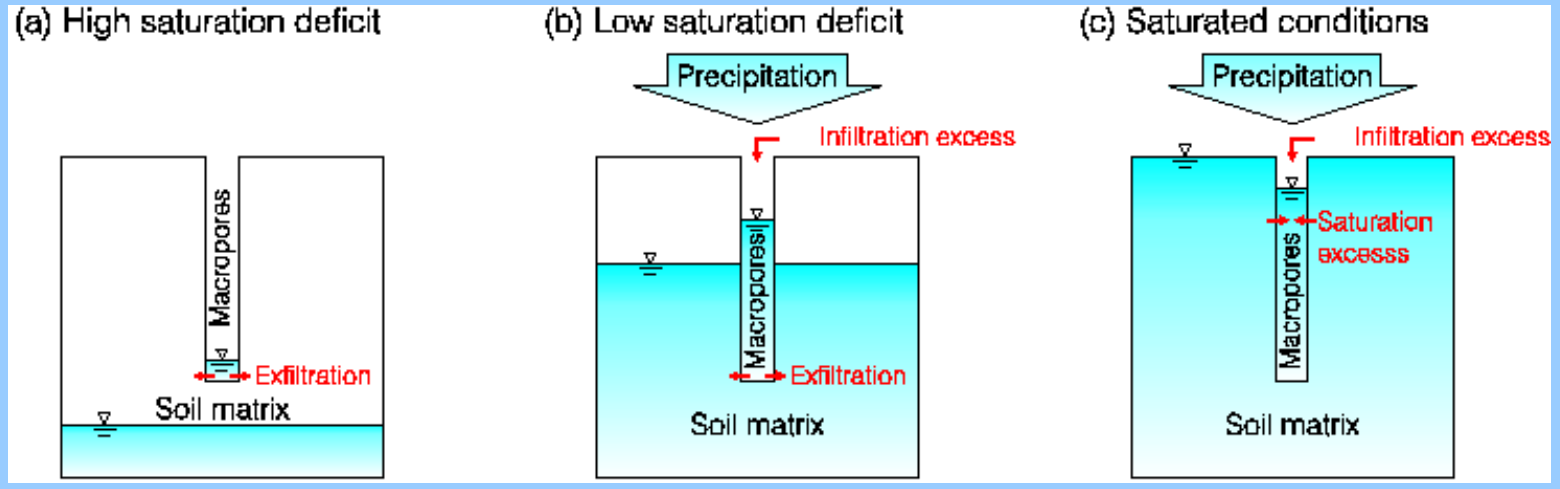
(Niehoff, 2002)

Process-oriented hydrological Model: extended WASIM-ETH


Precipitation
Drainage of storm water
from sealed surfaces
Infiltration excess
on unsealed surfaces
Degree of surface sealing
ψ
(1 – ψ)
Storage basins in the sewer system
Overflow to river network
Infiltration and percolation
from unsealed surfaces
Outlet to waste water treatment plant


a)
$I_{N_{net}} < I_{mic}$
moderate rainfall intensity
I_{mic}
average depth of
macropore layer


b)
$I_{N_{net}} > I_{mic}$
storm rainfall
I_{mac}
I_{mic}
average depth
of macropore layer

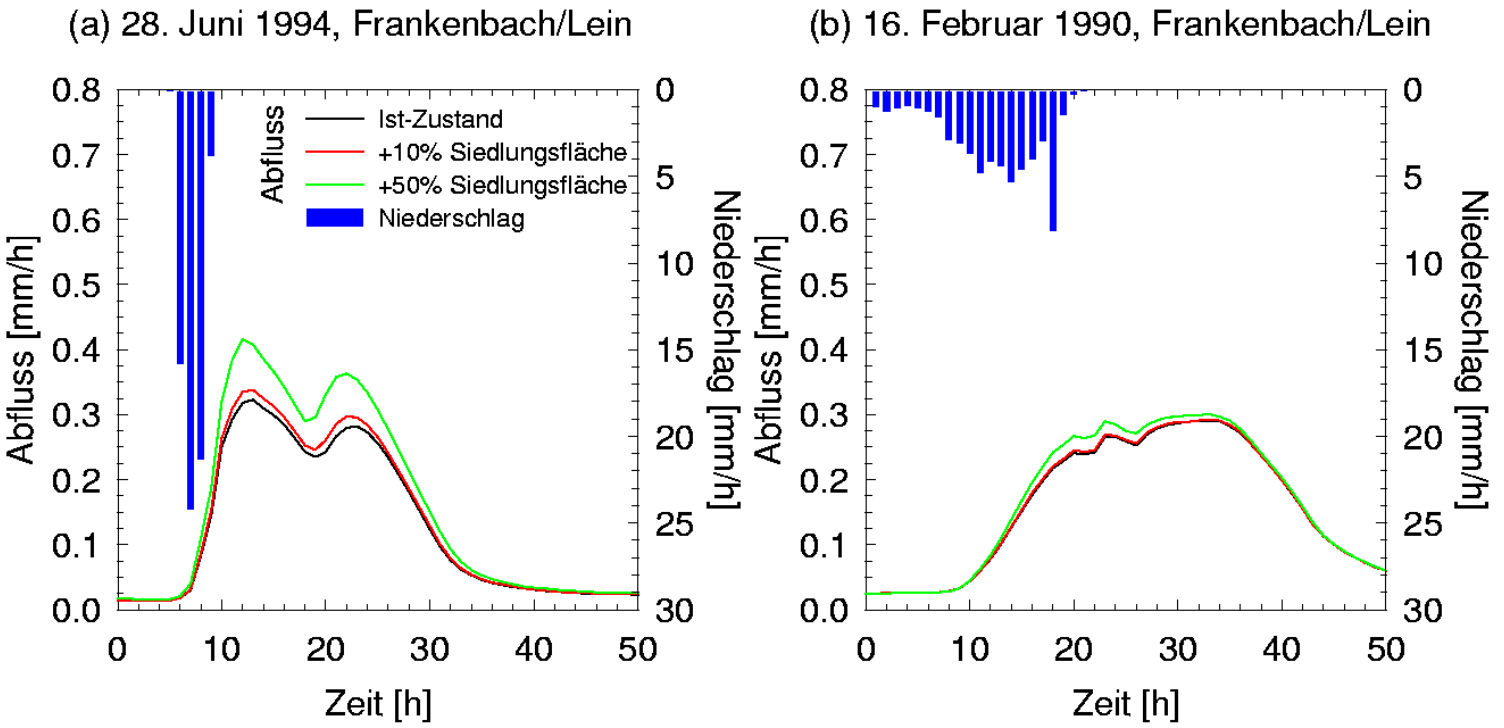

(a) High saturation deficit
Macropores
Exfiltration
Soil matrix
(b) Low saturation deficit
Precipitation
Infiltration excess
Macropores
Exfiltration
Soil matrix
(c) Saturated conditions
Precipitation
Infiltration excess
Saturation
excesss
Macropores
Soil matrix

Parameters for the extended WASIM-ETH-model

	parameter	unit
topography	grid altitude	[m a.s.l.]
soil	soil depth	[m]
	hydraulic conductivity	[m/s]
	saturation content	[Vol-%]
	macroporosity	[Vol-%]
	mean depth of the macroporous layer	[m]
	reduction of hydraulic conductivity of the soil surface in case of	[-]
urban areas	settlement type;	[-]
	fraction of sealed surface within a settlement,	[%]
	capacity of urban retention reservoirs;	[m^3]
	controlled outflow from urban retention reservoirs;	[m^3/s]
	local catchment area of local storm water control measures (in	[m^2]
	retention capacity of local storm water control measures (both in	[m^3]
	maximum seepage from the storm water control measures	[l/s]
land cover	maximum interception storage	[mm]
	soil cover index	[-]
	leaf area index	[-]
	root depth	[m]

Comparative Simulation of the effects of environmental change on Rhine floods

Results I: The Lein sub-catchment

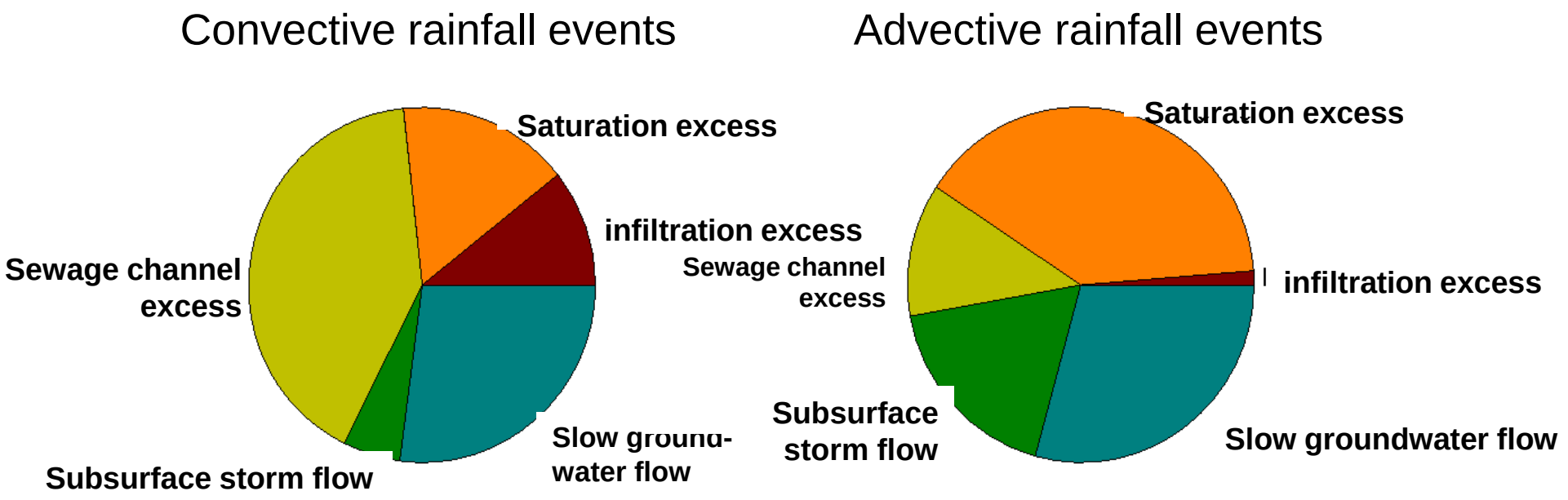


Niehoff et al. 2002

Simulated storm runoff after (a) a convective rain event (b) an advective rain event; present land use and urbanisation scenarios

Comparative Simulation of the effects of environmental change on Rhine floods

Results I: The Lein sub-catchment



Niehoff et al. 2002

Lein-sub-catchment: runoff generation processes for different rainfall event types

Comparative Simulation of the effects of environmental change on Rhine floods

Results I: The Lein sub-catchment

Year, month	Increase in runoff compared to present conditions		Simulated baseflow contribution to volume [%]	Duration [h]	Return period approx. [a]
	Maximum [%]	Volume [%]			
1990, February	3,4	3,7	19	150	2
1993, December	5,9	2,7	17	250	8
1997, February	3,9	2,7	19	150	7
1982, December	1,7	1,5	27	225	3
1983, May	0,6	0,9	39	300	4
1988, March	0,0	0,0	52	650	3
Mean	**2,6**	**1,8**	**29**	**290**	**4,5**

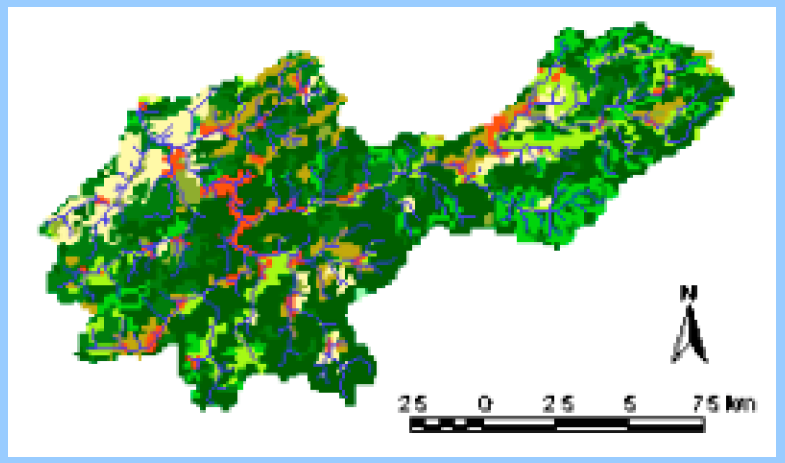
Increase in runoff volume and peak due to a 50 % growth of settlement and industrial areas in the Lein catchment. The events are sorted by the urbanisation impact on runoff volume

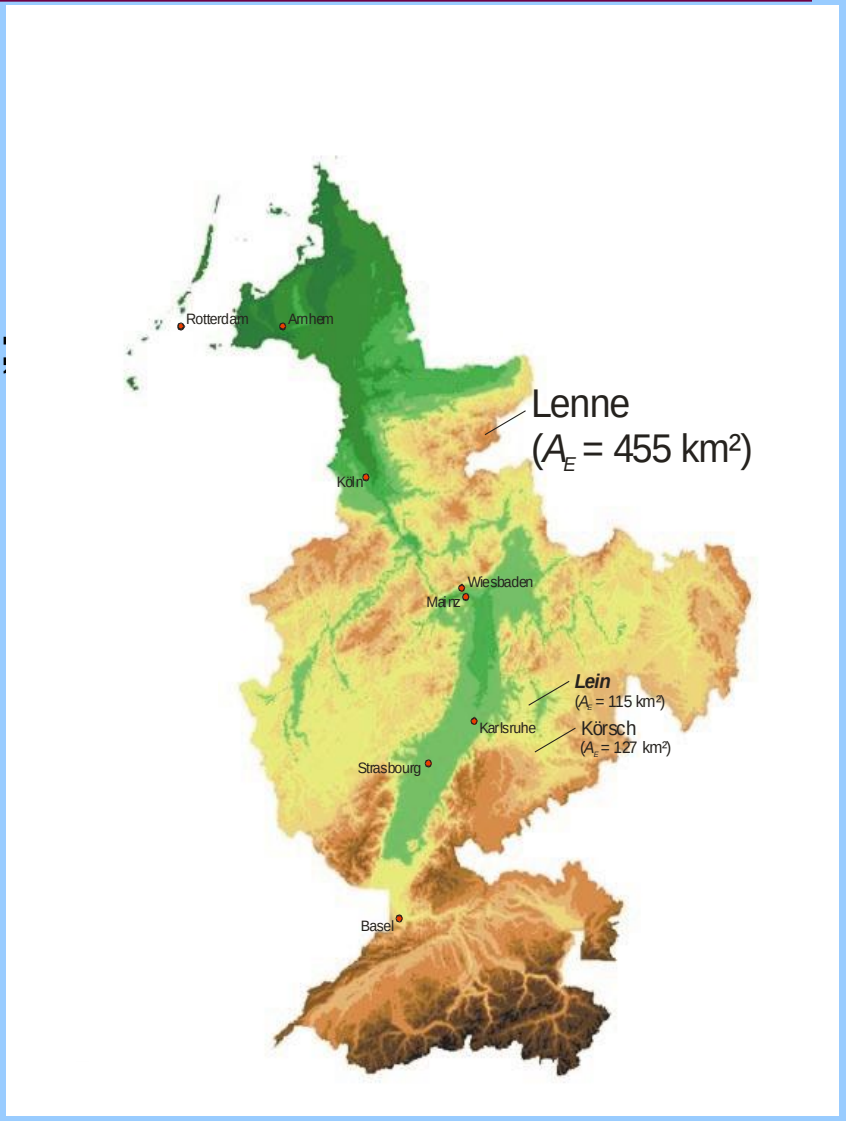
Comparative Simulation of the effects of environmental change on Rhine floods

Results II: The Lenne sub-catchment

The Lenne sub-catchment

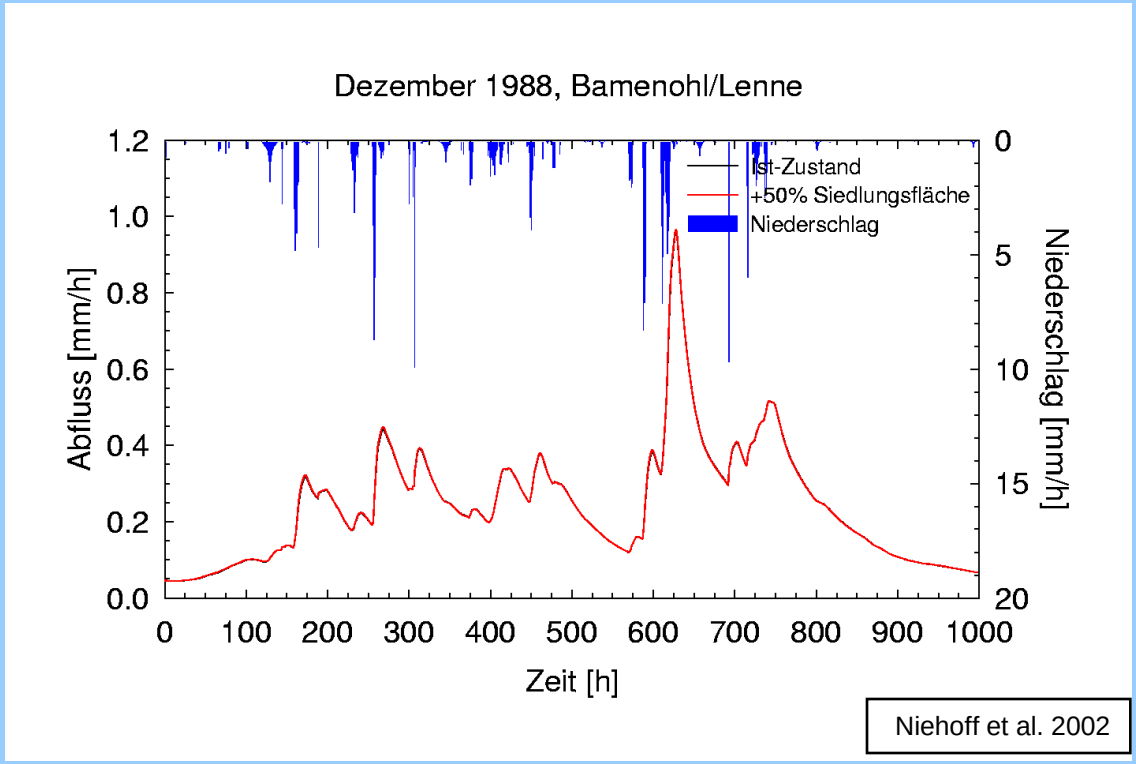
Area: 455 km²
Location: Sauerland (W-Germany);
Land Use: mainly forest and pasture; few settlement
soils: shallow, permeable
hydrological model: extended WASIM-ETH



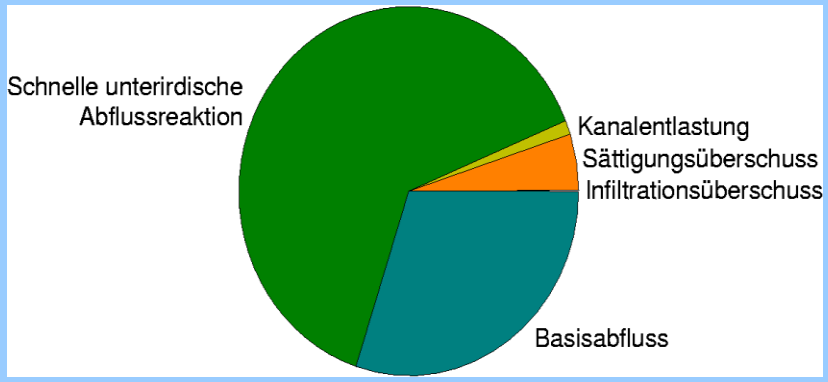


Comparative Simulation of the effects of environmental change on Rhine floods

Results II: The Lenne sub-catchment



Niehoff et al. 2002



Simulate storm runoff after (a) a convective rain event (b) an advective rain event; present land use and urbanisation scenarios

Comparative Simulation of the effects of environmental change on Rhine floods

III Regionalization of runoff generation

Rhine basin Maxau - Lobith:

Area: 110 600 km²

Catchment sub-division:

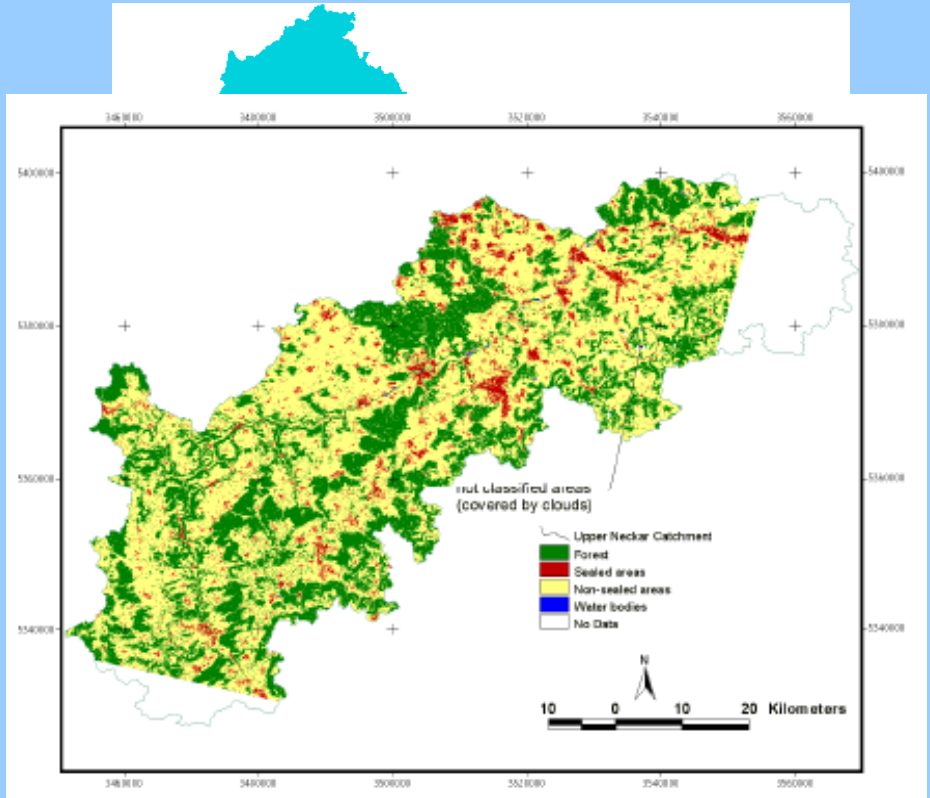
95 sub-catchments

12 major sub-catchments

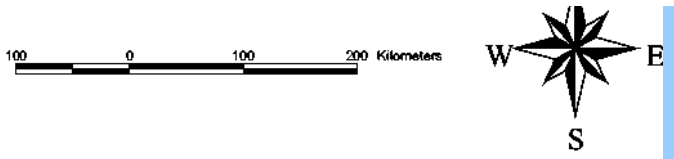
Hydro-meteorological data:

1514 precipitation stations

313 climate stations



Land-cover map of the Upper Neckar Catchment in 1984, based on a LANDSAT TM image

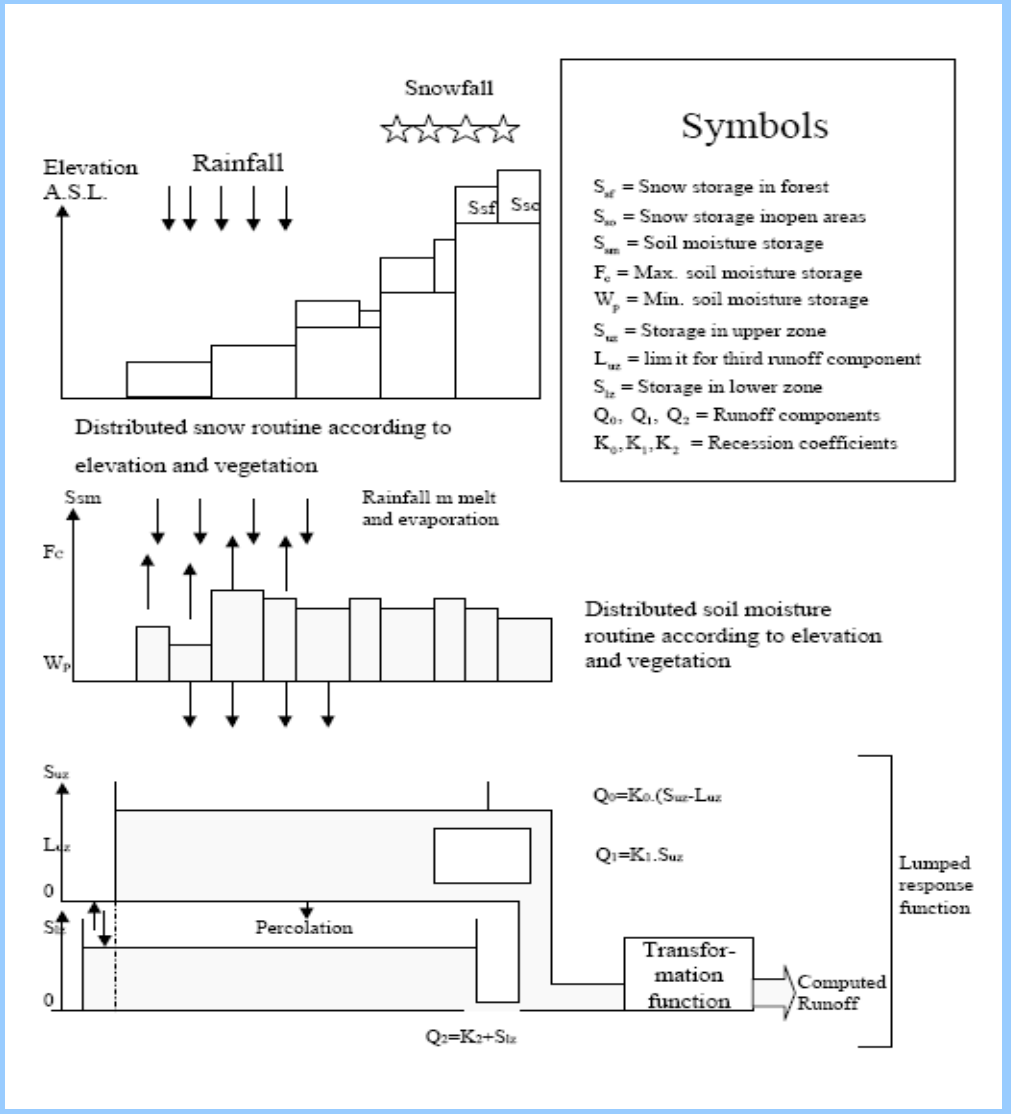


Comparative Simulation of the effects of environmental change on Rhine floods

III Regionalization of runoff generation

Hydrological Model: extended HBV-IWS

(extended for urban areas, specific parameterization of storage processes for different land-use)



Comparative Simulation of the effects of environmental change on Rhine floods

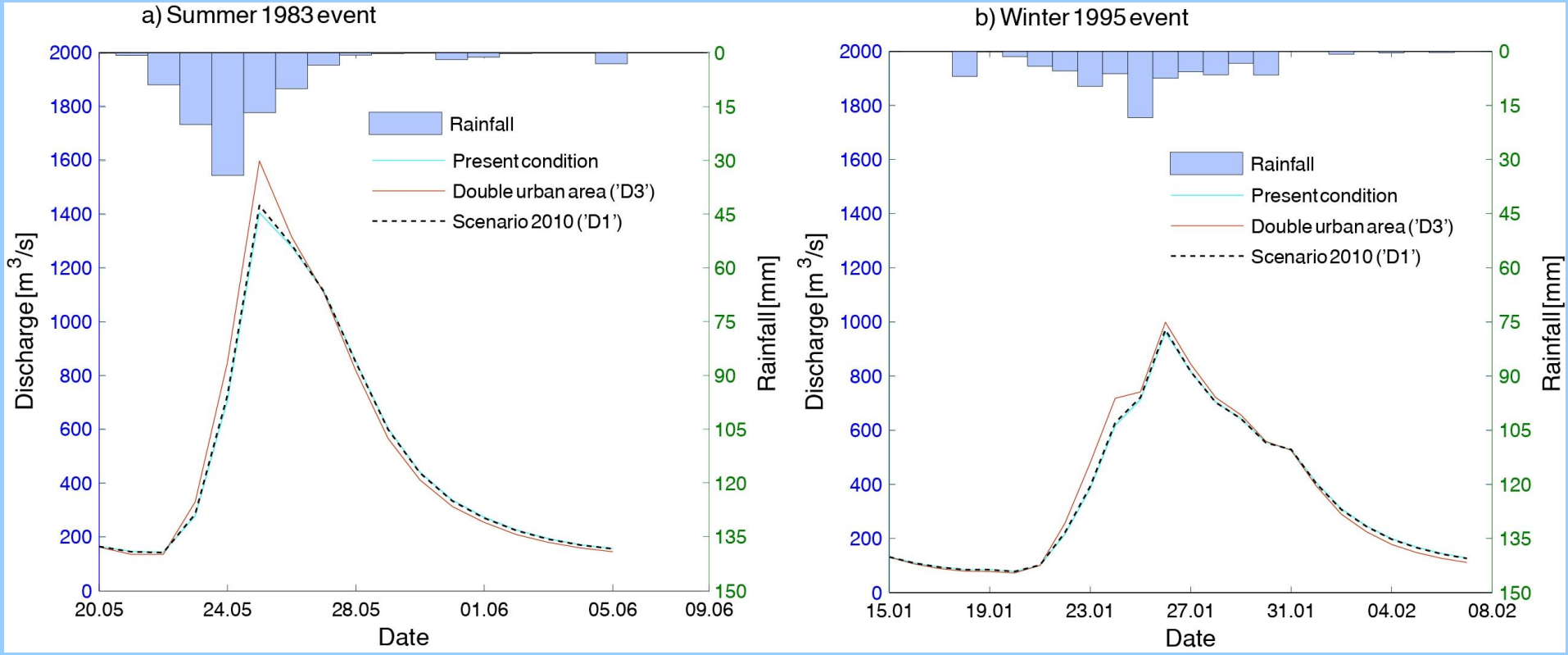
Regionalization of runoff generation

Parameter	Sensitivity		Source	Regionalisation on the basis of
	In general	land-use related		
Runoff generation				
Permanent wilting point	-	+	Estimated	Soil map
Field capacity	+++	+++	WaSiM-ETH, field capacity	Soil map, Land-use map
Recession coefficient beta	-/+	+	Estimated	Soil map
Snow storage, snowmelt				
Degree-day	+	+	Estimated	Land-use map
Tcrit	+	+	Estimated	Land-use map
Evapotranspiration				
Interception storage	+/-	++	Literature	Land-use map
Potential evapotranspiration	+	+++	WaSiM-ETH, literature	Land-use map
CFA	-	+++	Estimated	Land-use, position
Runoff concentration				
alpha	+++	+++	f(density of settling)	Land-use map
Storage coefficient Ki, percolation	+++	+	Estimated	Soil map
Degree of sealing	+++	+++	f(density of settling)	
Siltation parameter	+++	+++	WaSiM-ETH	Soil map, land-use map
Maxbas	+/-	+	Estimated	Topography

Model parameters of HBV-IWS, their potential relations to land-use characteristics and basic data sources for regionalisation (after Hundecha & Bárdossy, 2004)

Comparative Simulation of the effects of environmental change on Rhine floods

Results III: Regionalization of runoff generation



Bronstert et al., 2003

Simulations for 3 land-use scenarios at sub-catchment Neckar, gauge Rockenau (12676 km²); Intense summer rainfall of shorter duration (left); Winter precipitation of lower intensity and longer duration (right). Present land use (green) and 2 urbanization scenarios (red; dashed)

Comparative Simulation of the effects of environmental change on Rhine floods

Results V: Effects of land-use changes on the macro-scale

River network from Maxau to Lobith:

total length of simulated river stretches:

~ 1100 km

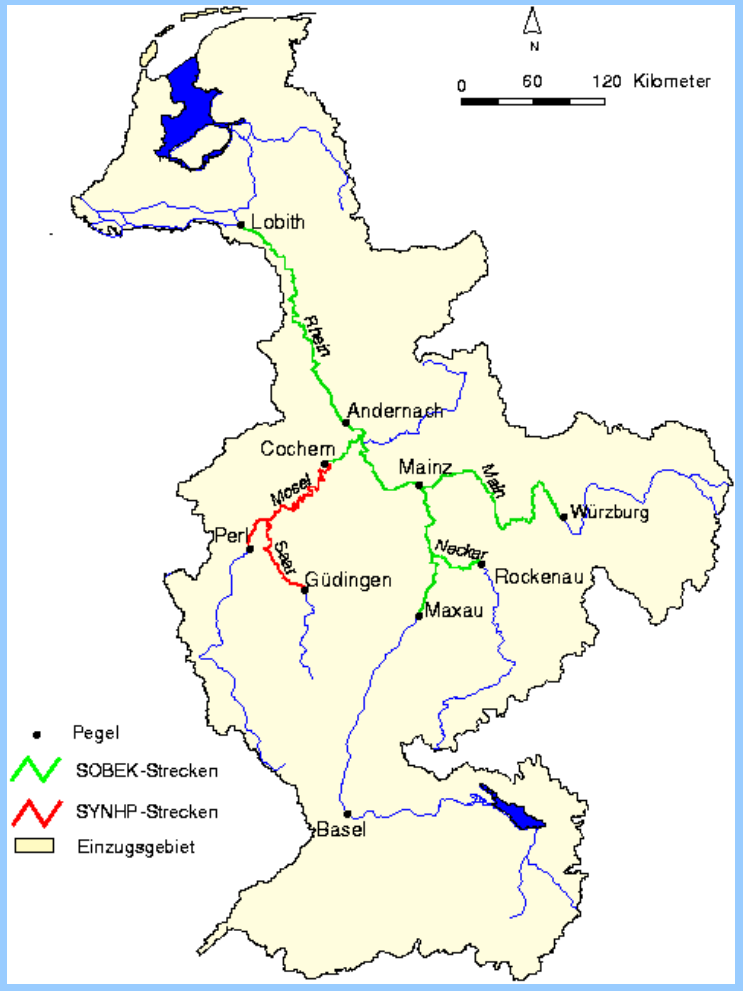
routing model:

SOBEK (1D-fully hydro-dynamic)

SYNHP (hydrological routing)

42 simulated scenarios:

- ☞ land-use change
- ☞ extreme precipitation scenarios
- ☞ retention in polders and flood plains



Comparative Simulation of the effects of environmental change on Rhine floods

Land-use change scenarios

- LN1: Current land use conditions and a 10% increase of urban area
- LN2: Current land use and increase of urban area (D1) *plus* controlled infiltration of urban storm runoff
- LN100: Current land use and a 50% increase of urban area ("extreme urbanisation scenario")
- LNW: All area covered with forest (hypothetical scenario)

Note: The scenarios LN1, LN2, and LN100 also account for the river training measures along the Rhine

Bronstert et al., 2003

Comparative Simulation of the effects of environmental change on Rhine floods

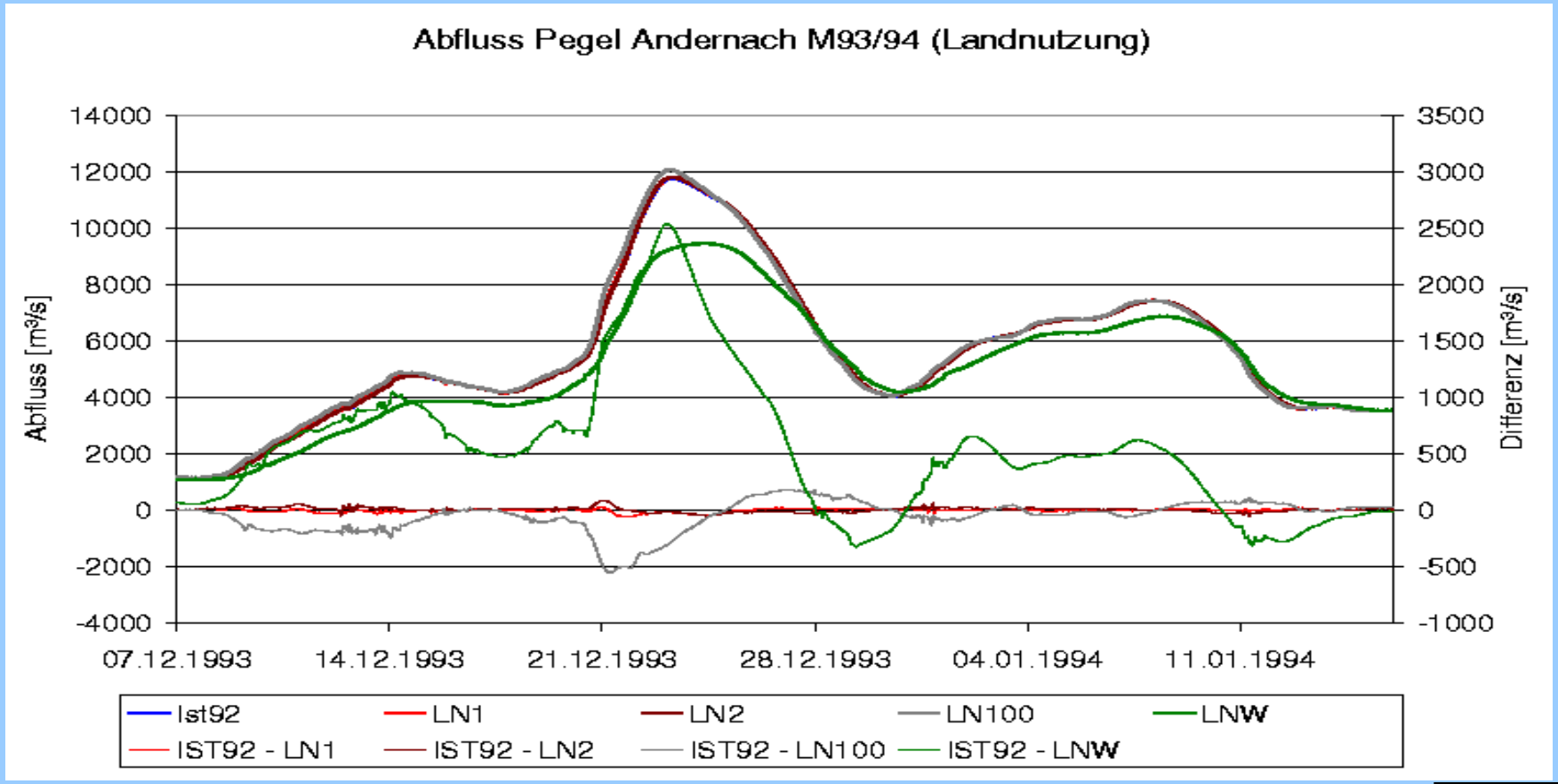
Hydro-meteorological scenarios

- M95: Meteorological forcing (in its observed spatial and temporal distribution) of January/February 1995
- M95+: Meteorological forcing of January/February 1995 *plus* a linear increase of precipitation of 20%
- M95++: Meteorological forcing of January/February 1995 *plus* 20% increase of precipitation *plus* an additional pre-event snow water equivalent of 20 mm

Bronstert et al., 2003

Comparative Simulation of the effects of environmental change on Rhine floods

Results V: Effects of land-use changes on the macro-scale



Bronstert et al., 2003

Rhine catchment: gauge Andernach (~ 100 000 km²):

simulation of the 1993 flood with present and scenario land-use conditions

Comparative Simulation of the effects of environmental change on Rhine floods

Results V: macro scale simulation of environmental change scenarios

Rhine gauging station (km downstream Lake Constance)	Meteorological Scenario		
	M95	M95+	M95++
Worms (km 444)			
LN1	0 (0/0)	10 (0/10)	16 (0/16)
LN2	0 (1/0)	9 (0/10)	16 (-1/17)
LN100	0 (-1/1)	-10 (-1/-9)	15 (-1/16)
Kaub (km 546)			
LN1	1 (-1/2)	8 (-1/9)	9 (-2/11)
LN2	1 /-1/2)	8 (-1/9)	9 (-1/11)
LN100	-5 (-7/3)	3 (-6/8)	3 (-9/11)
Andernach (km 614)			
LN1	0 (-1/1)	5 (-1/6)	6 (-1/8)
LN2	1 (0/1)	6 (-1/6)	7 (-1/8)
LN100	-5 (-7/2)	1 (-5/6)	2 (-6/8)
Köln (km 688)			
LN1	0 (-2/1)	5 (-1/6)	4 (-2/6)
LN2	1 (0/1)	5 (-1/6)	5 (-1/6)
LN100	-8 (-9/2)	-1 (-7/6)	-3 (-9/7)
Lobith (km 857)			
LN1	2 (-1/3)	2 (-1/3)	2 (-1/3)
LN2	2 (-1/3)	3 (-1/3)	2 (-1/3)
LN100	-1 (-5/3)	-2 (-6/3)	-5 (-8/3)

Simulated changes in water level [cm] at five Rhine gauges

Conclusions

- The nested and scale-specific modelling approach applied here is an adequate methodology
- Land-use changes may significantly influence floods in small catchment (in case of convective rainfall)
- In large catchments the impact is (very) small, e.g. about 5-15 cm (rising limb), 0-5 cm (peak)
- controlled retention in polders reduces peaks near the retention but very little far downstream
- Effects of changing meteorological / climatic conditions require further research

Comparative Simulation of the effects of environmental change on Rhine floods

More Information ?

- Bronstert et al. (2003): Quantifizierung des Einflusses der Landoberfläche und der Ausbaumaßnahmen am Gewässer auf die Hochwasserbedingungen im Rheingebiet. *Reports of the Commission for Hydrology of the River Rhine (CHR),* Series II, No. 18, 85pp.

- Bronstert et al. (2007): Multi-scale modelling of land-use change and river training effects on floods in the Rhine basin*. River Research and Applications,* **23**(10), 1102-1125.

Thank you !!

Comparative simulation of the effects of land use change, river training, and altered climate on floods of the Rhine

András Bárdossy[1], Hendrik Buiteveld[2], Markus Disse[3], Heinz Engel[4], Uta Fritsch[5], Yeshewatesfa Hundecha[6], Rita Lammersen[2], Daniel Niehoff[5,7], Nicole Ritter[8]

[1]Institute of Hydraulic Engineering, University of Stuttgart, D - 70550 Stuttgart, Germany
[2]Institute for Inland Water Management, RIZA, Postbus 9072, NL - 6800 ED Arnhem, The Netherlands
[3]Institute for Water Science, Bundeswehr Univ. Munich, Heisenberg-Weg 39, D - 85577 Neubiberg, Germany
[4]German Federal Institute of Hydrology (BfG) P.O. Box 200253, D - 56002 Koblenz, Germany
[5]Potsdam Institute for Climate Impact Research, P.O. Box 60 12 03, D - 14412 Potsdam, Germany
[6]GFZ Potsdam, Section hydrology, Germany
[7] now at: SAP AG, Dietmar-Hopp-Allee 16, D-69190 Walldorf, Germany
[8]Water and Navigation Office, Heidelberg, P.O. Box 10 59 46, D - 69049 Heidelberg, Germany

Universität Potsdam

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