Low-Flow Conditions in the Rhine basin - Developments in the 20th century

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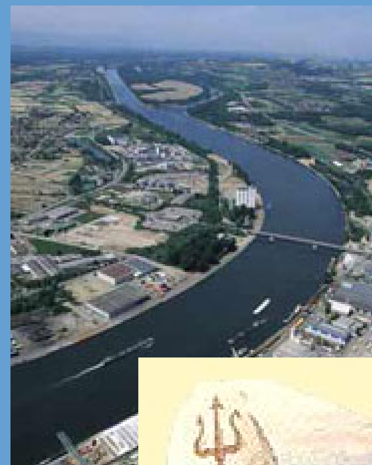

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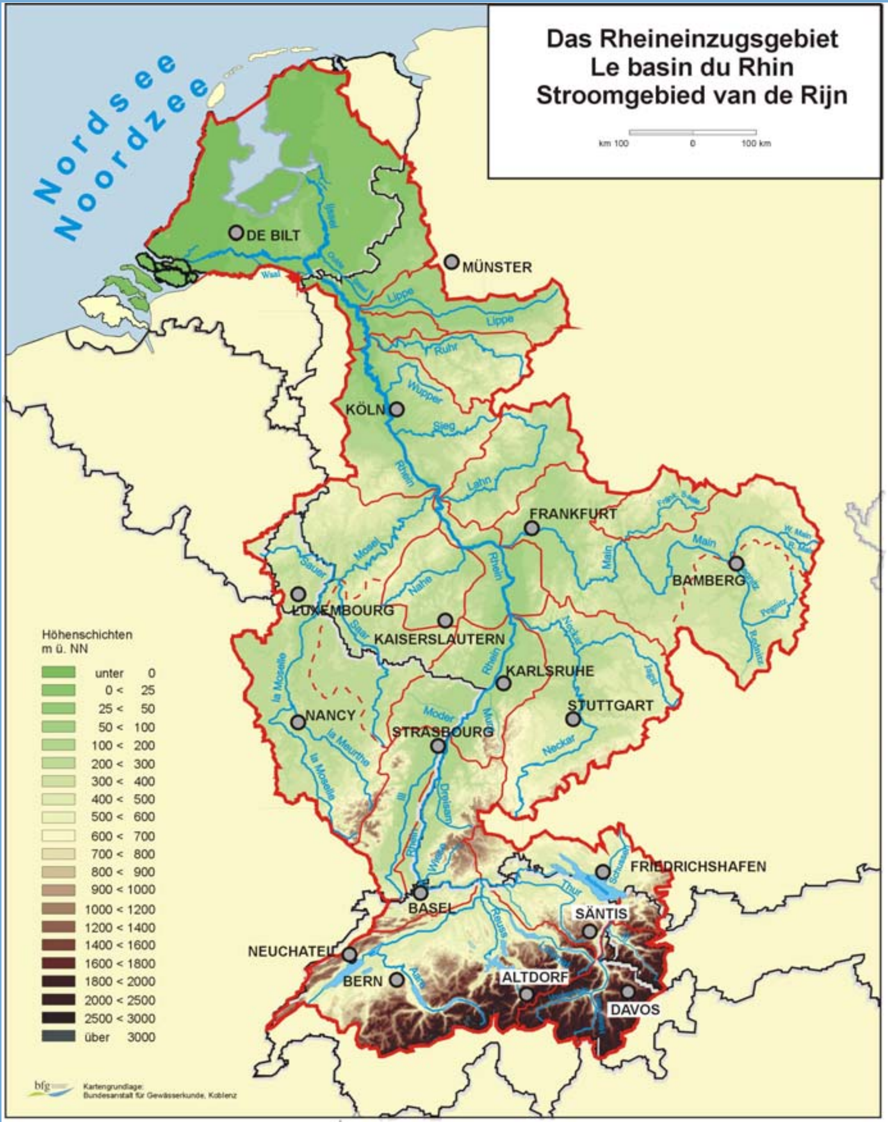
River Rhine: Basin characteristics



- $A_{Eo} \sim 197.000\ km^2$
- ~ 58 Mio. inhabitants
- 9 riparian countries

- river length: ~ 1320 km
- primary flow parameters near the mouth:

  NNQ ~ 600 m^3/s

  MQ ~ 2.500 m^3/s

  HHQ ~ 12.000 m^3/s

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Results concerning low-flow development are excerpts from the more comprehensive report of the KHR/CHR-project

„Flow regime of the river Rhine and its tributaries during the 20th century - analysis, changes, trends“

(=**„Das Abflussregime des Rheins und seiner Nebenflüsse im 20. Jh. - Analysen, Veränderungen, Trends“**)

Belz, J.U.
Brahmer, G.
Buiteveld, H.
Engel, H.
Grabher, R.
Hodel, H.
Krahe, P.
Lammersen, R.
Larina, M.
Mendel, H.-G.
Meuser, A.
Müller, G.
Plonka, B.
Pfister, L.
van Vuuren, W.

During the 20th century:

River Rhine - Running...

...slowly out of water ?

Contents

- Low-flow extremes: trend-dynamics in the 20th century
- Underlying framework and processes
- The role of glacier-decline
- Special anthropogenic impacts: The „Neckar-example“
- Changes in the times of occurence of low flow-extremes
- Regional patterns of low flow dynamics

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Analysed parameter, analysing method:

NM7Q

„the lowest arithmetic mean of streamflow over 7 consecutive days within a given time interval (year, half-year)“

(DVWK, 1983)

Trend

„Minimum-square“ method

Test of trend-significance

Mann-Kendall

- **„discoverer‘s level“: 80%**
- **„validation level“: 95%**

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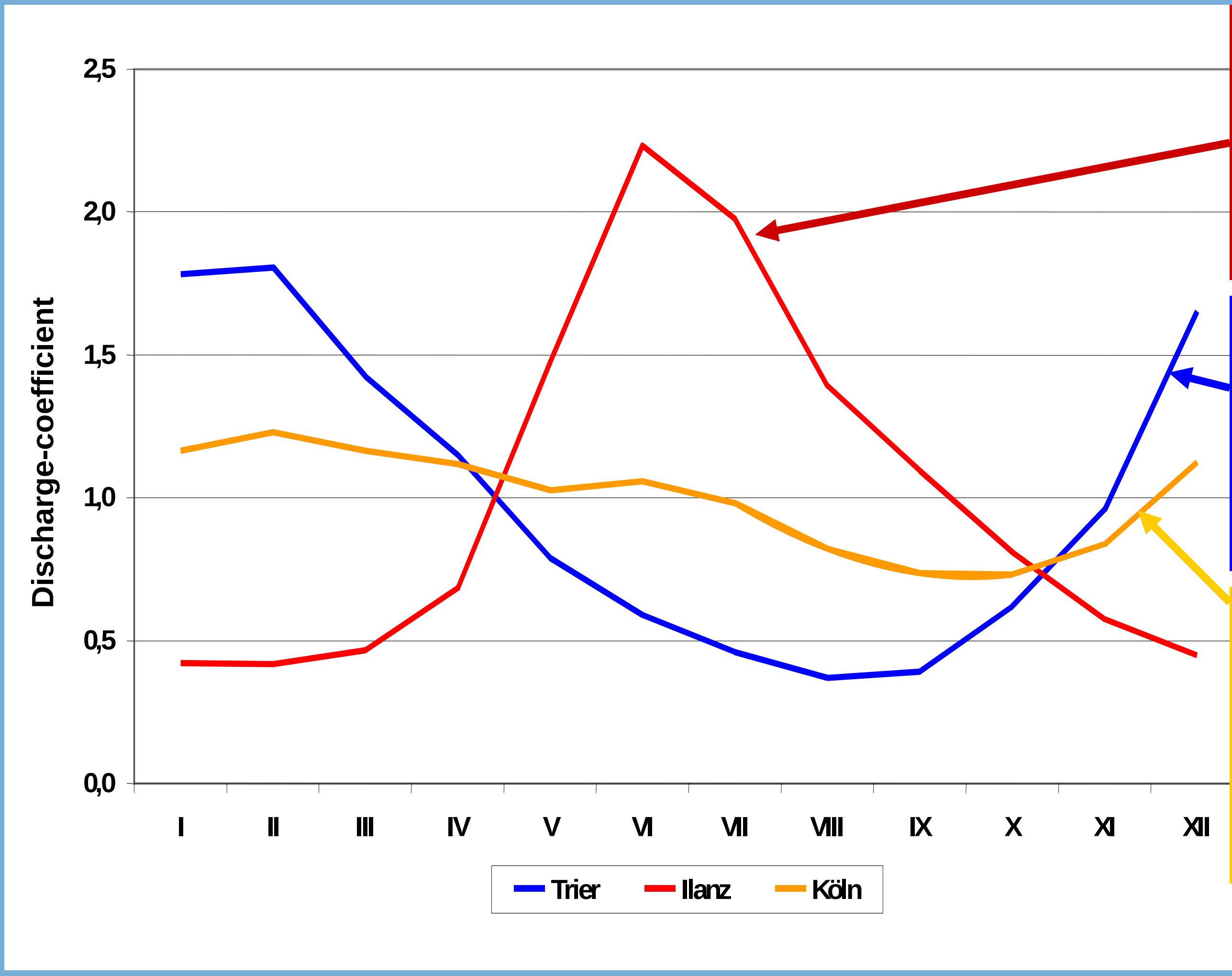
Trends and tendencies of half-yearly and yearly values of NM7Q at gauges with long observation series in the Rhine basin, period 1901 – 2000

Period 1901 - 2000	NM7Q Year	NM7Q Winter	NM7Q Summer
Lower Rhine			
Lobith	(-)	(+)	(-)
Rees	(+)	(+)	(-)
Köln	(+)		(-)
Middle Rhine			
Andernach			(-)
Cochem (Mosel)	(+)	(+)	(+)
Trier (Mosel)			
Kaub			(-)
Upper Rhine			
Würzburg (Main)		(+)	
Worms			(-)
Maxau			(-)
High Rhine			
Basel			(-)
Untersiggenthal(1905) (Aare)			
Mellingen(1905)/Reuss			(+)
Seedorf (1905)/Reuss			
Rekingen (1905)			
Andelfingen(1905) (Thur)	(-)	(+)	(-)

decreasing trend 80% significance — increasing trend
decreasing trend 95% significance — increasing trend
(-) decreas. tendency no significance (+) increasing tendency

Standardised diagram of characteristic types of flow regimes in the Rhine basin, reference period 1951-2000



Nival (= snow-dominated) regime of mountainous areas, very wide range of amplitude, single-peak, maximum in summer due to snowmelt, frost-inducted minimum in winter

Pluvial (= rain dominated) oceanic regime, wide range of amplitude, single-peak, maximum in the mild rainy winter months, minimum in summer resulting from intensive evapotranspiration

Balanced pluvial mixed regime ("complex regime 2nd order") of the rain-snow type, two-peaks, with the main maximum in late winter and a minimum in autumn

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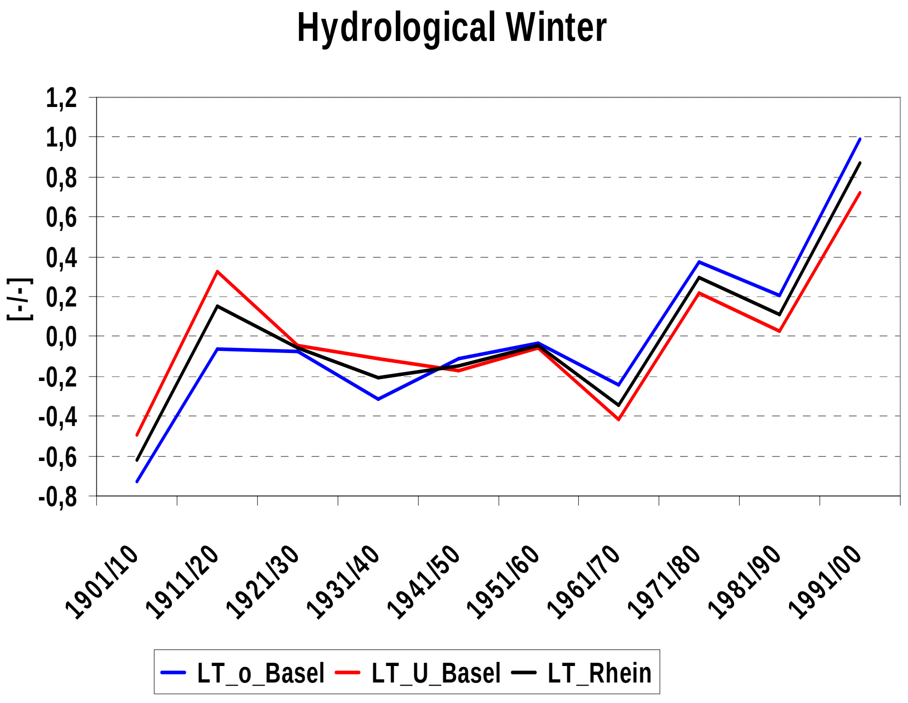
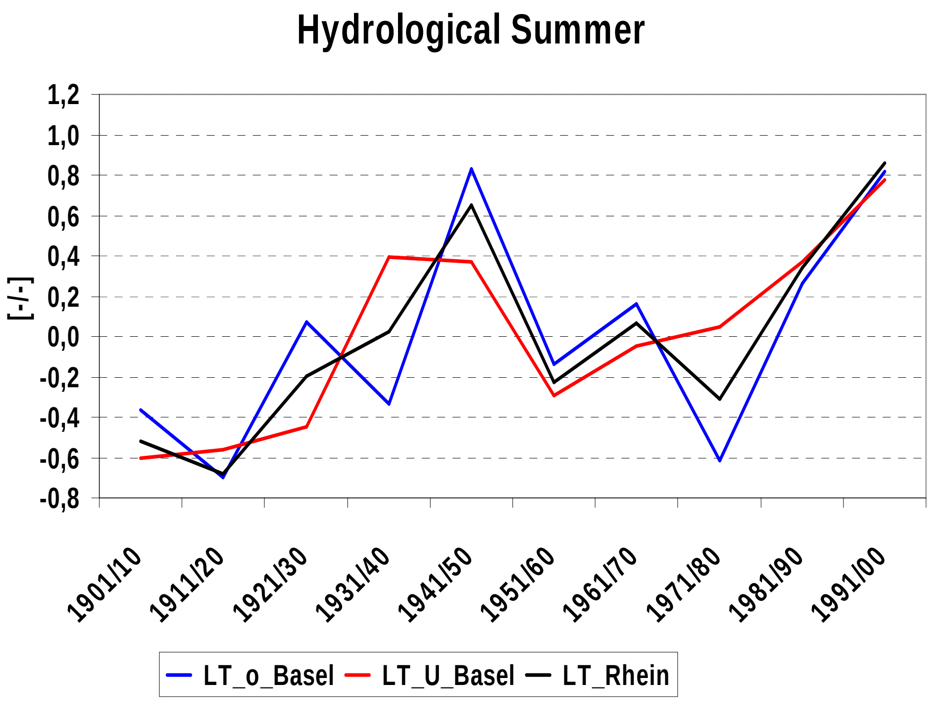
Standardised ten-year means of air temperature (LT) in the Rhine basin in the hydrological winter- and summer-seasons, period 1901 – 2000





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Trends and tendencies of half-yearly and yearly values of areal precipitation (SumhN) in sub-catchments of the Rhine basin in the series 1902 – 2000

Period 1902 - 2000	SumhN Year	SumhN Winter	SumhN Summer
Lower Rhine			
Lobith	increasing trend 80%	increasing trend 95%	(+)
Rees	increasing trend 80%	increasing trend 95%	(+)
Köln	increasing trend 80%	increasing trend 95%	(+)
Middle Rhine			
Andernach	increasing trend 80%	increasing trend 95%	(+)
Cochem (Mosel)	increasing trend 80%	increasing trend 80%	(+)
Kaub	increasing trend 80%	increasing trend 95%	(+)
Upper Rhine			
Würzburg (Main)	increasing trend 95%	increasing trend 95%	(+)
Worms	increasing trend 80%	increasing trend 95%	(-)
Maxau	(+)	increasing trend 95%	(-)
High Rhine			
Basel	increasing trend 80%	increasing trend 95%	(-)
Untersiggenthal(1905) (Aare)	(+)	increasing trend 80%	(-)
Mellingen(1905)/Reuss	(+)	increasing trend 95%	(-)
Rekingen (1905)	(+)	increasing trend 80%	(-)
Andelfingen(1905) (Thur)	(+)	increasing trend 80%	(-)

Legend:

- decreasing trend 80% significance
- decreasing trend 95% significance
- (-) decreas. tendency no significance
- increasing trend 80% significance
- increasing trend 95% significance
- (+) increasing tendency no significance

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Modified climatic effects on the hydrologic cycle in the Rhine basin during the 20th century

- increase of cumulative winter precipitation
- changes in the form of precipitation ("more rainfall, less snow") lead to a higher rate of direct runoff and a smaller portion of snow-storage
- some results indicate basin-wide increase of real evapotranspiration

  - in the more southern part of the catchment therefore pluvial elements have been gaining in importance, thus weakening the nival main component of the flow regime of the River Rhine, all-in-all causing seasonal redistributing of runoff
  - in the more northern part of the catchment primarily the winterly runoff-component has been strengthend

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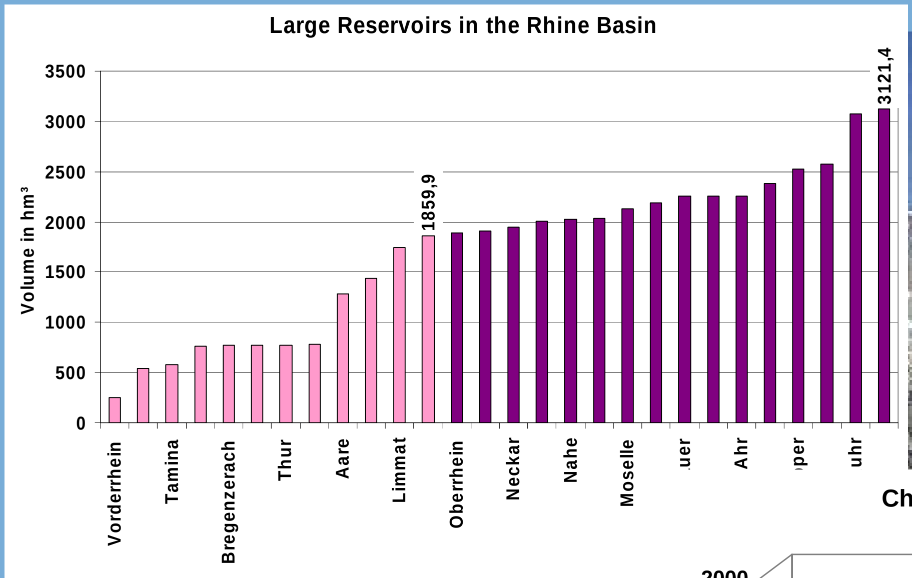
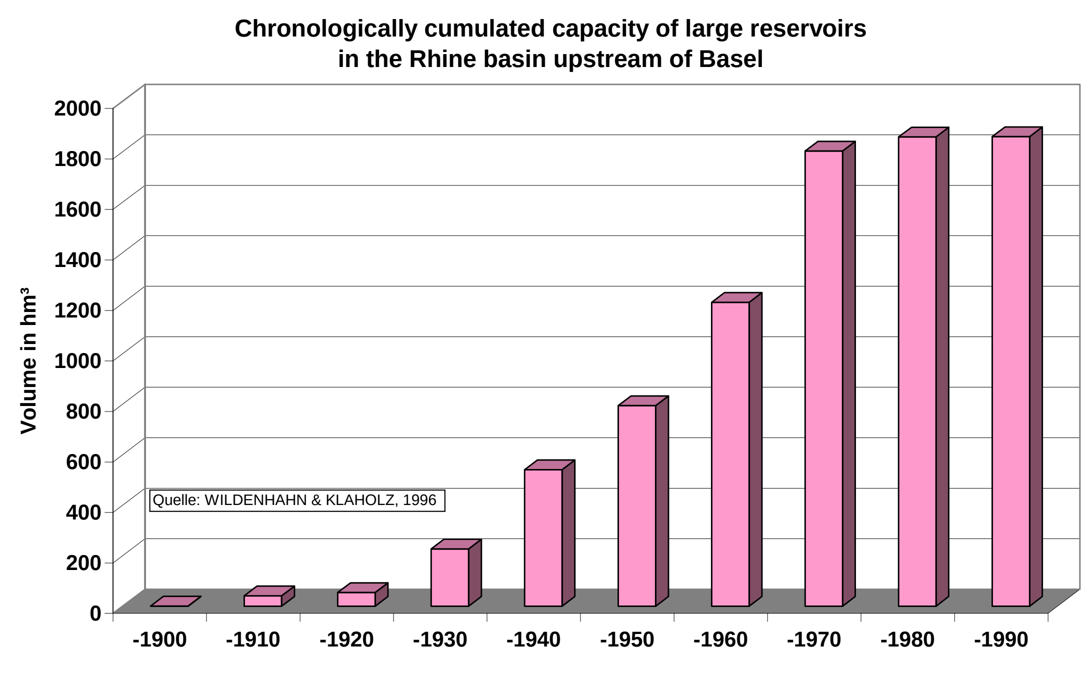
Large reservoirs in the Rhine basin





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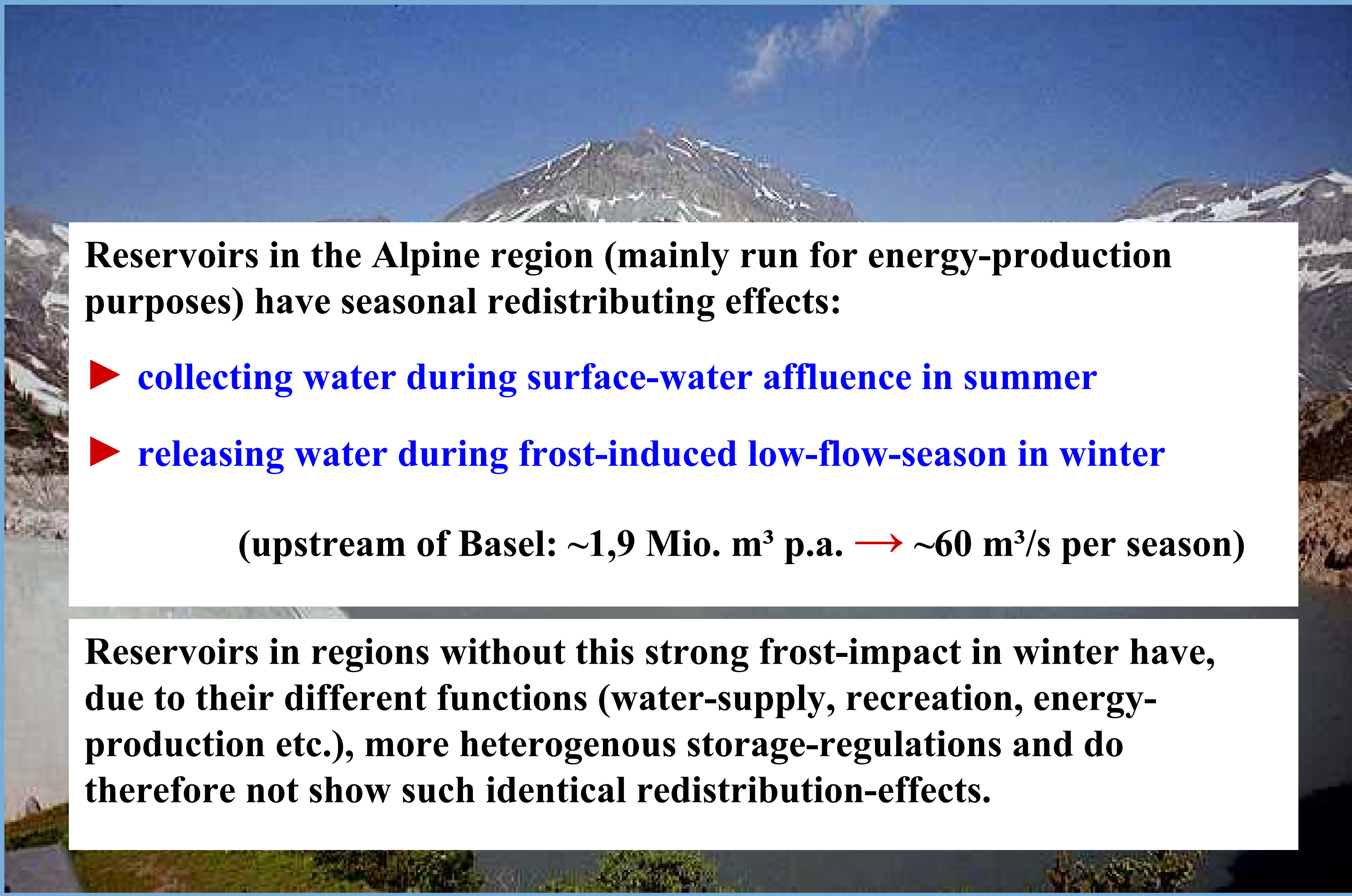
Large reservoirs in the Rhine basin



Reservoirs in the Alpine region (mainly run for energy-production purposes) have seasonal redistributing effects:

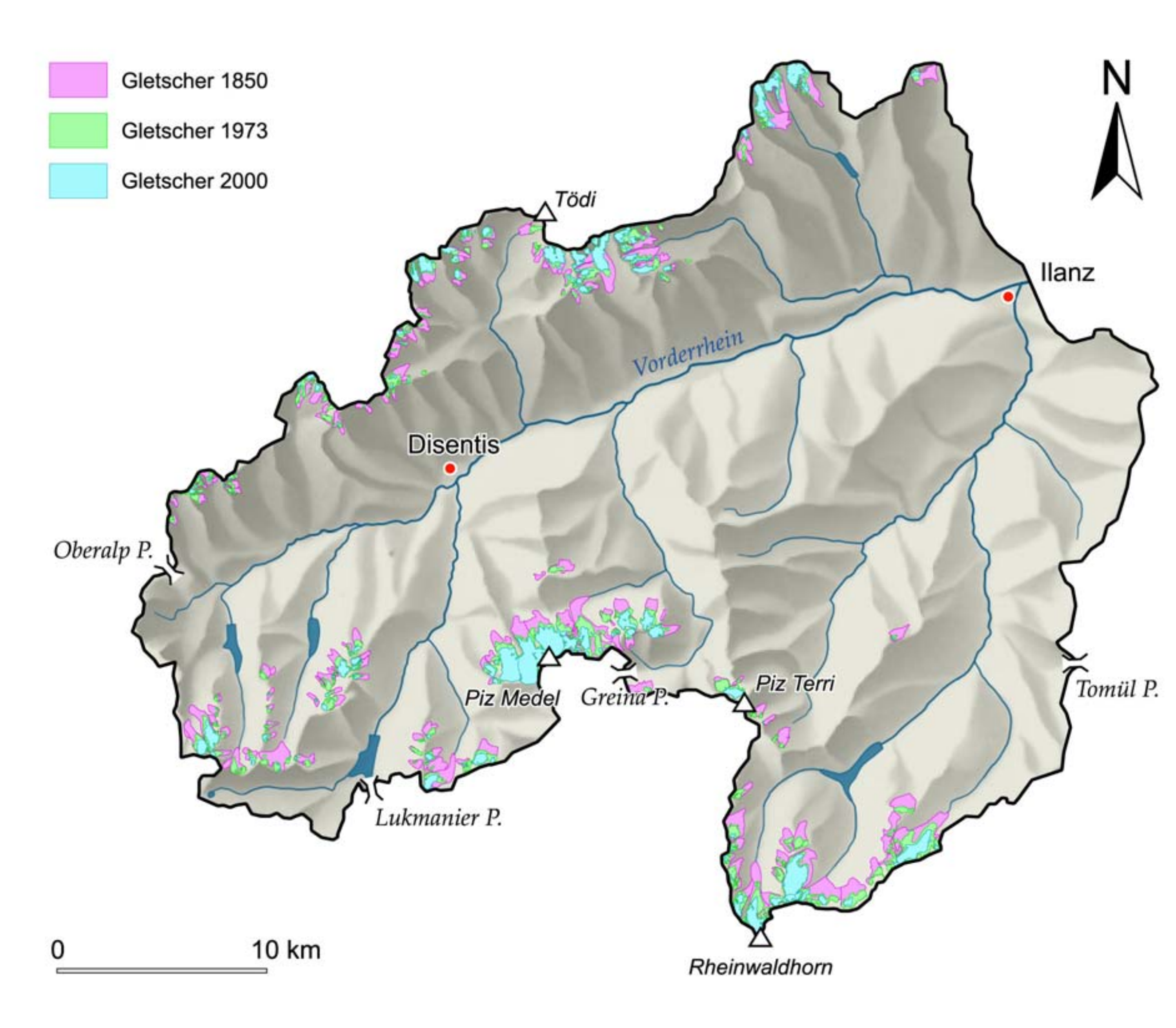
- **collecting water during surface-water affluence in summer**
- **releasing water during frost-induced low-flow-season in winter**

(upstream of Basel: ~1,9 Mio. m³ p.a. → ~60 m³/s per season)

Reservoirs in regions without this strong frost-impact in winter have, due to their different functions (water-supply, recreation, energy-production etc.), more heterogenous storage-regulations and do therefore not show such identical redistribution-effects.

Intensified glacier-melting (IGM) in the Rhine basin
Map of sub-catchment ILANZ / Vorderrhein

A_{Eo} 776 km²   Period 1850- 2000



Glacier-covered area

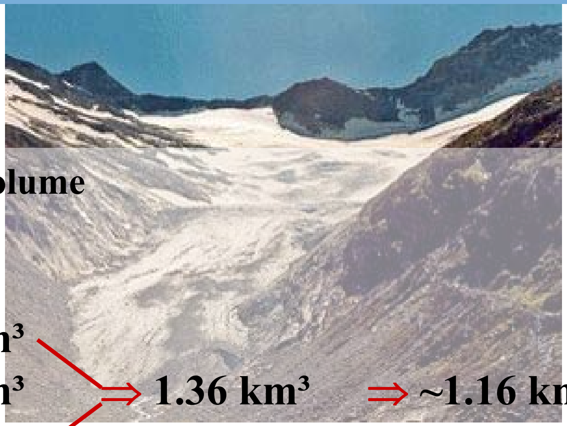
Inventories for the years 1850 (pink), 1973 (light green) and 2000 (light blue)

Source:

FRAUENFELDER-KÄÄB & MAISCH in: BELZ et al. (2007)

Intensified glacier-melting (IGM) in the Rhine basin
Example: sub-catchment ILANZ / Vorderrhein

A_{Eo} 776 km² Period 1850- 2000



Source:

FRAUENFELDER-KÄÄB & MAISCH in: BELZ et al. (2007)

Year	Portion (%)	Glacier-volume (total)
1850	100.0	1.79 km³
1973	45.2	0.81 km³
2000	24.0	0.43 km³

⇒ 1.36 km³ ⇒ ~1.16 km³ water-equivalent since 1850

⇒ ~0.0077 km³ water p.a.

MQ Ilanz : 33.5 m³/s ⇒ ~1.0700 km³ water p.a.

⇓

~0.7 %

=percentage of MQ related to IGM in the Ilanz sub-catchment (⇒0.24 m³/s)

(in warm summers up to ~1 %)

▶ **momentary maximum during intensive radiation-days in high summer: ~ 12 m³/s**

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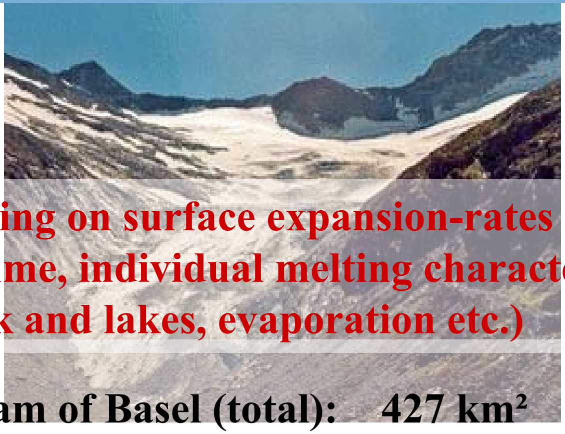
Intensified glacier-melting (IGM) in the Rhine basin
Extrapolation to the sub-catchment BASEL

A_{Eo} 35925 km²



Simplistic extrapolation, basing on surface expansion-rates only (not considering glacier-volume, individual melting characteristics of glaciers, retention-effects of the stream-network and lakes, evaporation etc.)

Glacier-covered area upstream of Basel (total): 427 km²
Glacier-covered area upstream of Ilanz (total): 20.9 km² (i.e. 1/20)

Melting-contribution at Ilanz (year), 0.25 m³/s
if assigned to the 4 high-summer months: 0.75 m³/s

0.75 x 20 = 15 m³/s
Comparison: mMQ (August): 1270 m³/s

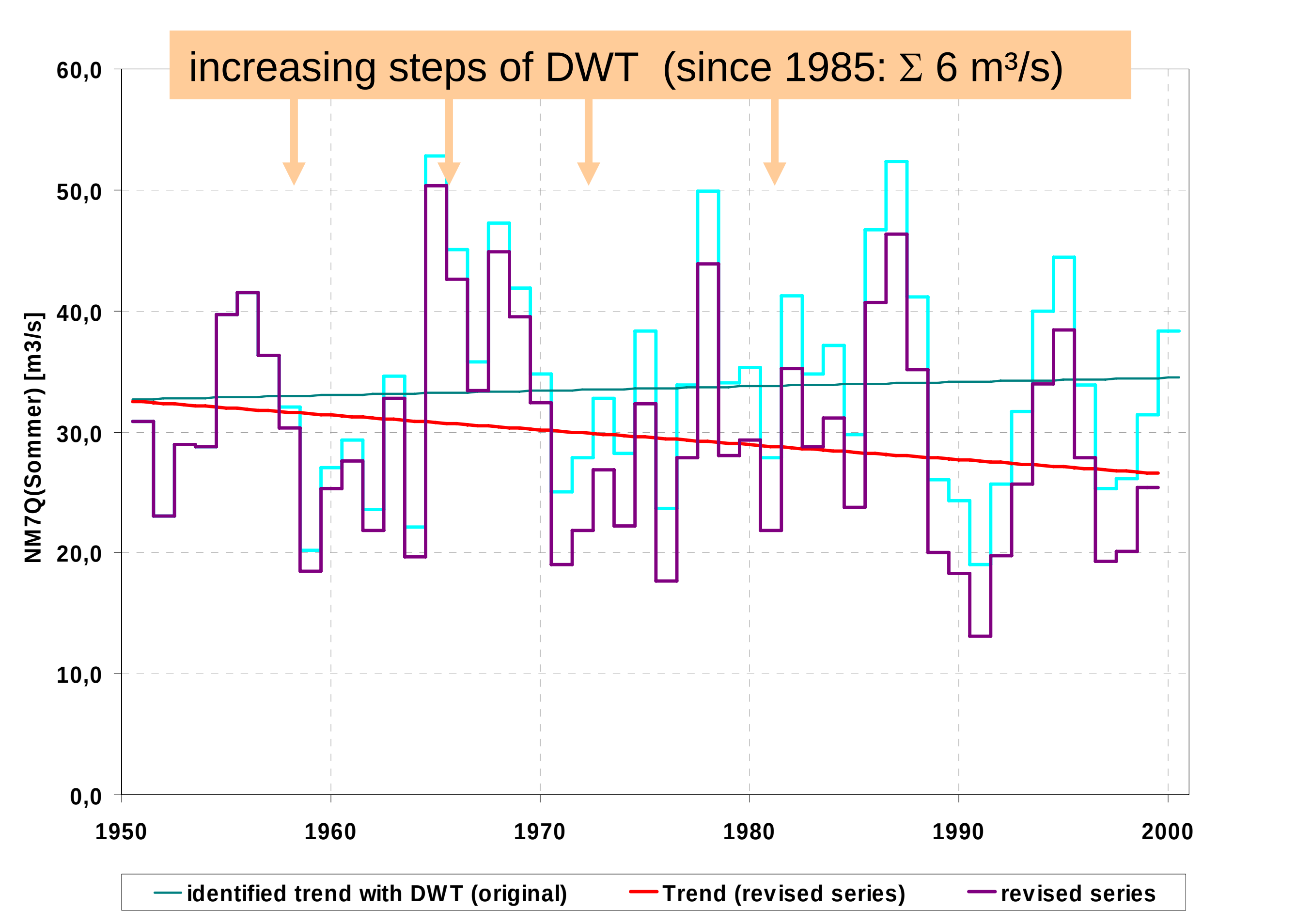
⇓

percentage of mMQ(August) related to IGM in the Basel sub-catchment: 1.2 %

MOREOVER - A MATTER OF FLOW-REGIME:

‚IGM' IS NOT CRUCIAL FOR LOW-FLOW DYNAMICS IN THE RHINE BASIN, AS SUMMER IS THE TIME OF ABUNDANT WATER, NOT FOR LOW-FLOW IN THE ALPINE-RHINE AND HIGH-RHINE SUBCATCHMENTS

Lauffen / River Neckar: Interbasin runoff-transfer
Trend and reversed trend in the summer half-year NM7Q series against the background of DWT (drinking-water transfer), period 1951-2000



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Rhine basin:
Seasonality index according to BURN / most probable dates of occurrence of NM7Q

	Period 1901-1925		Period 1926-1950		Period 1951-1975		Period 1976-2000		Shift [in weeks]
	Occur-rence [KW]	P	Occur-rence [KW]	P	Occur-rence [KW]	P	Occur-rence [KW]	P	
Diepoldsau			6	0,89	4	0,89	2	0,85	4
Rekingen	6	0,77	4	0,86	3	0,65	5	0,78	-1
Untersiggenthal	51	0,73	52	0,76	51	0,73	50	0,69	1
Basel	2	0,73	2	0,80	52	0,65	1	0,71	1
Maxau	1	0,7	1	0,77	48	0,69	47	0,50	6
Rockenau					42	0,65	41	0,84	1
Worms	1	0,68	52	0,73	48	0,65	44	0,66	9
Würzburg	31	0,67	36	0,57	35	0,69	35	0,79	-4
Kaub	51	0,62	51	0,71	46	0,67	43	0,69	8
Cochem	33	0,83	35	0,83	36	0,79	35	0,85	-2
Andernach	47	0,66	51	0,51	45	0,58	42	0,75	5
Köln	46	0,65	50	0,49	45	0,58	42	0,75	4
Rees	45	0,55	50	0,49	45	0,53	42	0,75	3
Lobith	46	0,58	51	0,36	45	0,55	42	0,71	4

(KW = calendar weeks)

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Main results of these impacts on low-flow conditions in the Rhine basin during the 20th century

- **Mitigation of low-flow extremes is most intensive there, where the winter season is the actual low-flow season, this means in the southern Rhine basin that is characterised by a nival regime.**

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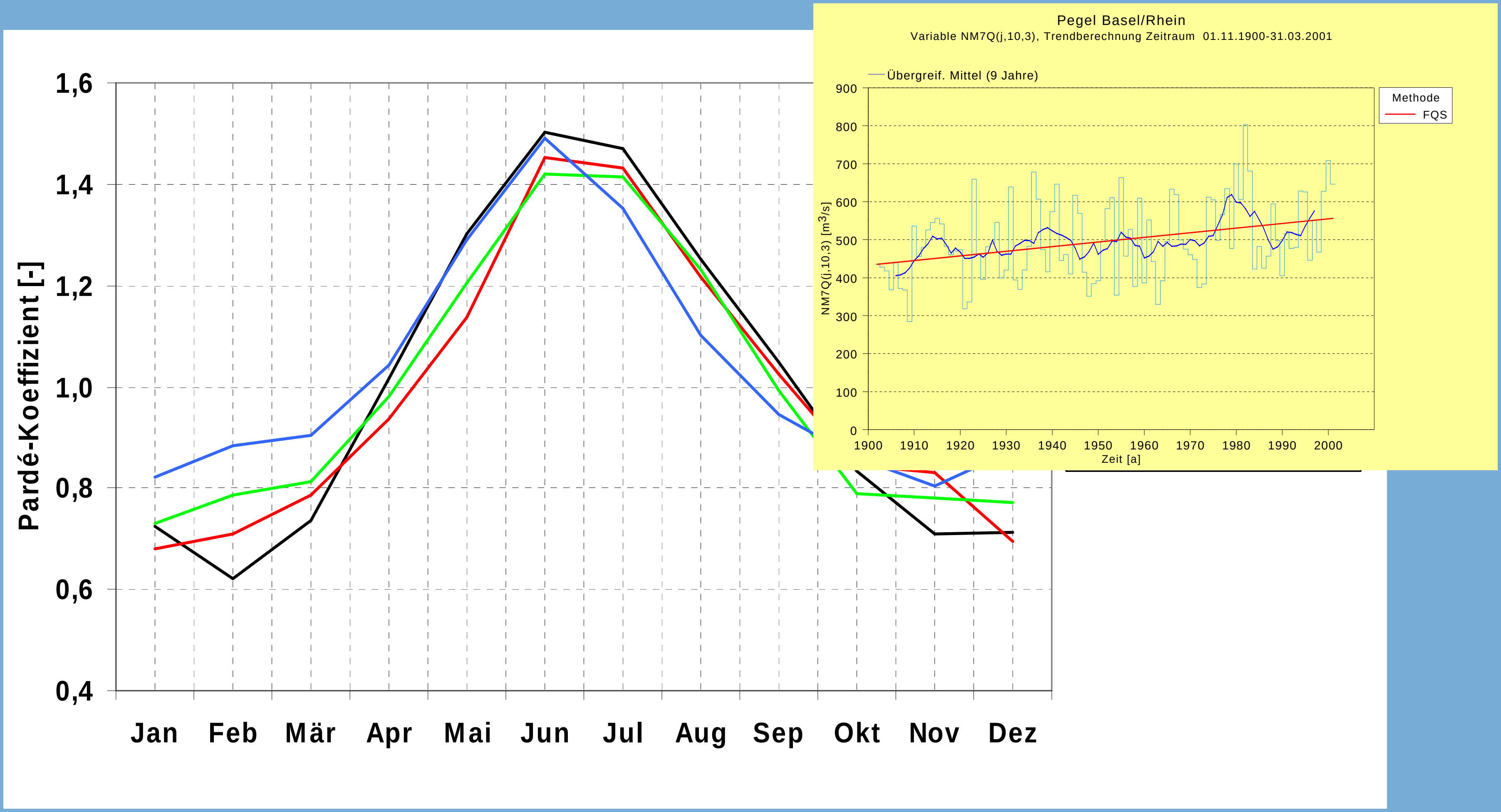
Southern Rhine Basin:
Changes in flow-regime of the River Rhine at Basel during the 20th century, differenciated in 4 sub-periods



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Main results of these impacts to low-flow conditions in the Rhine basin during the 20th century

- Mitigation of low-flow extremes is most intensive there, where the winter season is the actual low-flow season, this means in the southern Rhine basin that is characterized by a nival regime.

- **Conversely, in the pluvial upland- and lowland-regions, where the low-flow period occurs usually in autumn (regionally in late summer), this tendency to mitigation of extremes is lacking. Nevertheless substantial intensification of low-flow extremes (significant trends) usually cannot be ascerted. Exception: additional anthropogenic impacts.**

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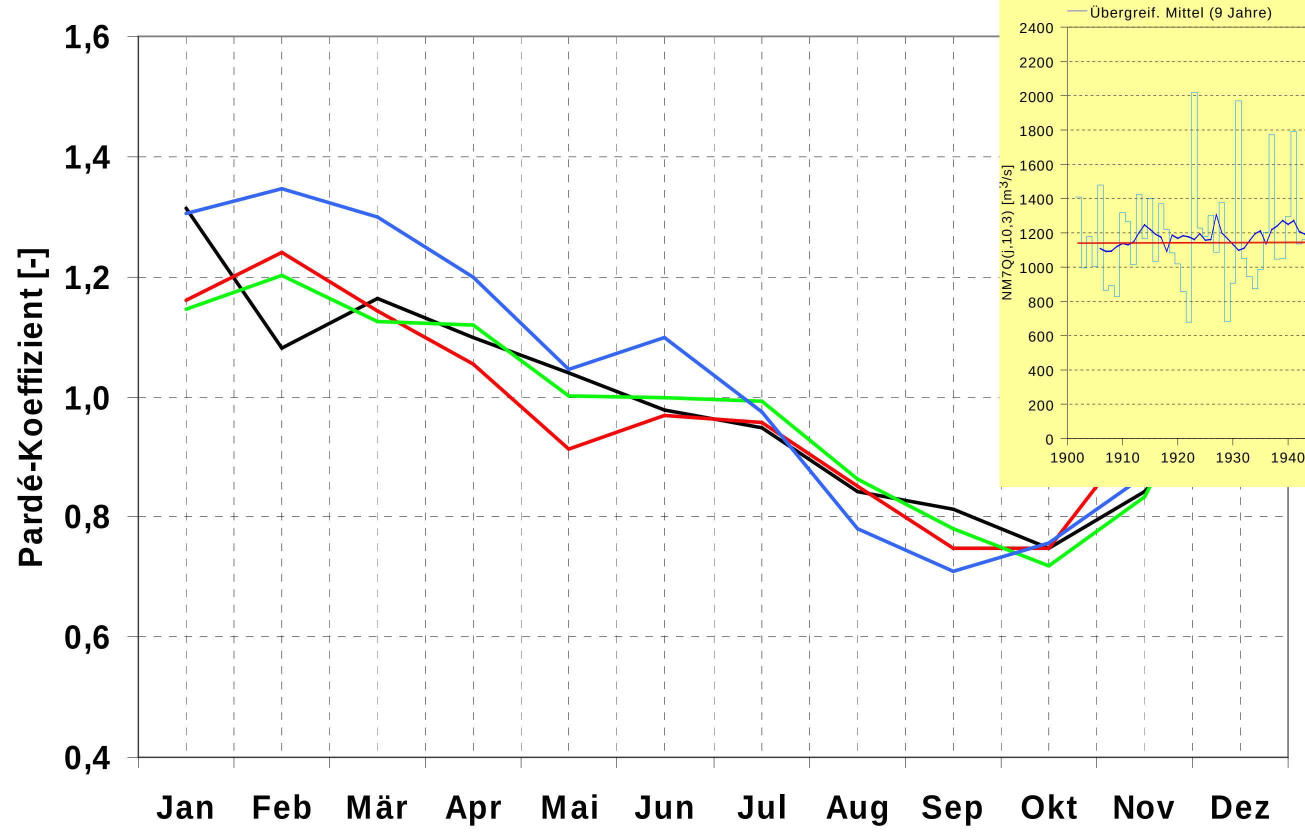
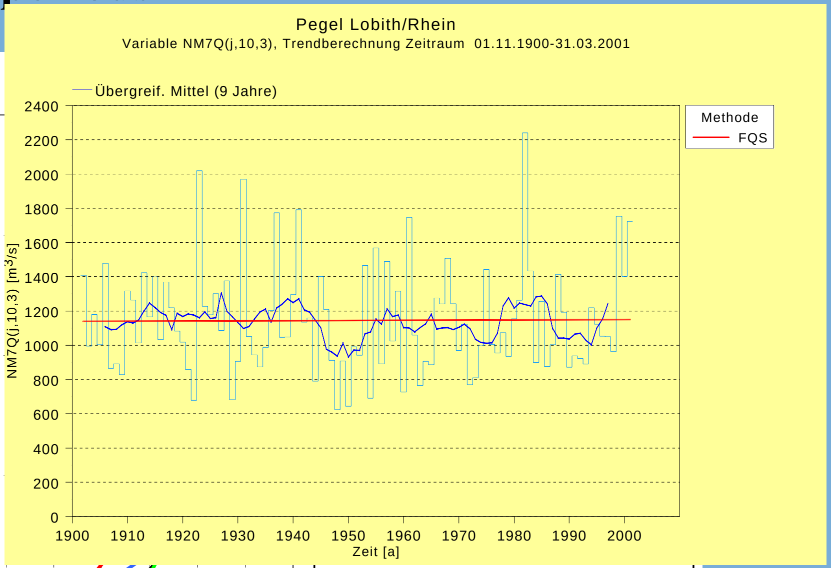
Northern Rhine basin:
Changes in flow-regime of the River Rhine at Lobith (NL) during the 20th century, differenciated in 4 sub-periods





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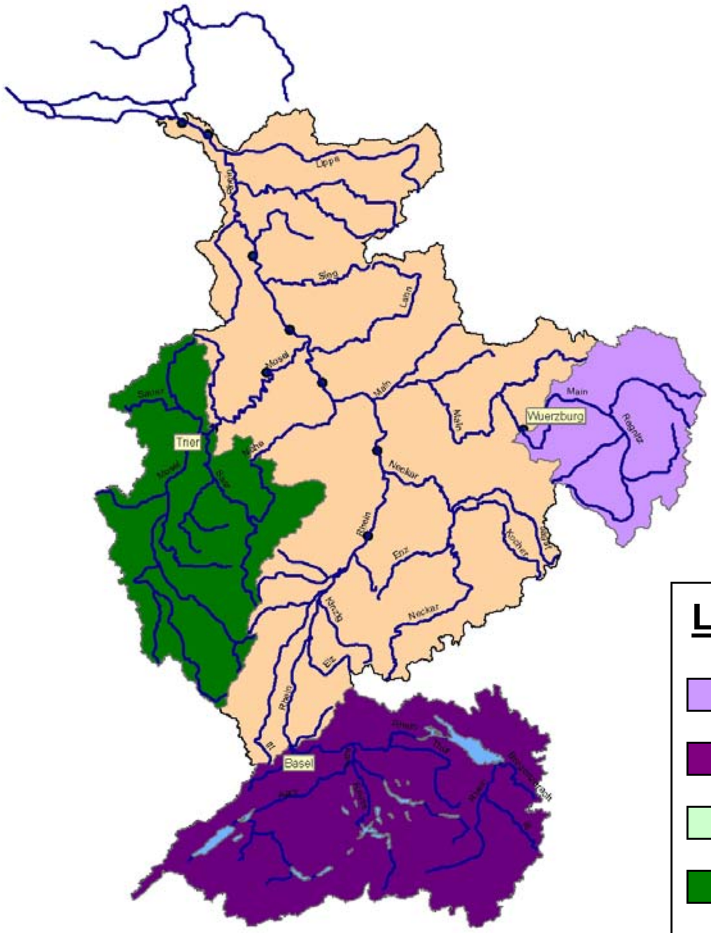
Rhine basin: Regional trend characteristics NM7Q (yearly series)

FQS with M-K (95%) / period 1901-2000



Legend

- increasing tendency, no significance at 95%-level
- increasing trend, significance at 95%-level
- decreasing tendency, no significance at 95%-level
- decreasing trend, significance at 95%-level
- not surveyed subarea of the basin

Rhine basin: Regional trend characteristics NM7Q (yearly series)

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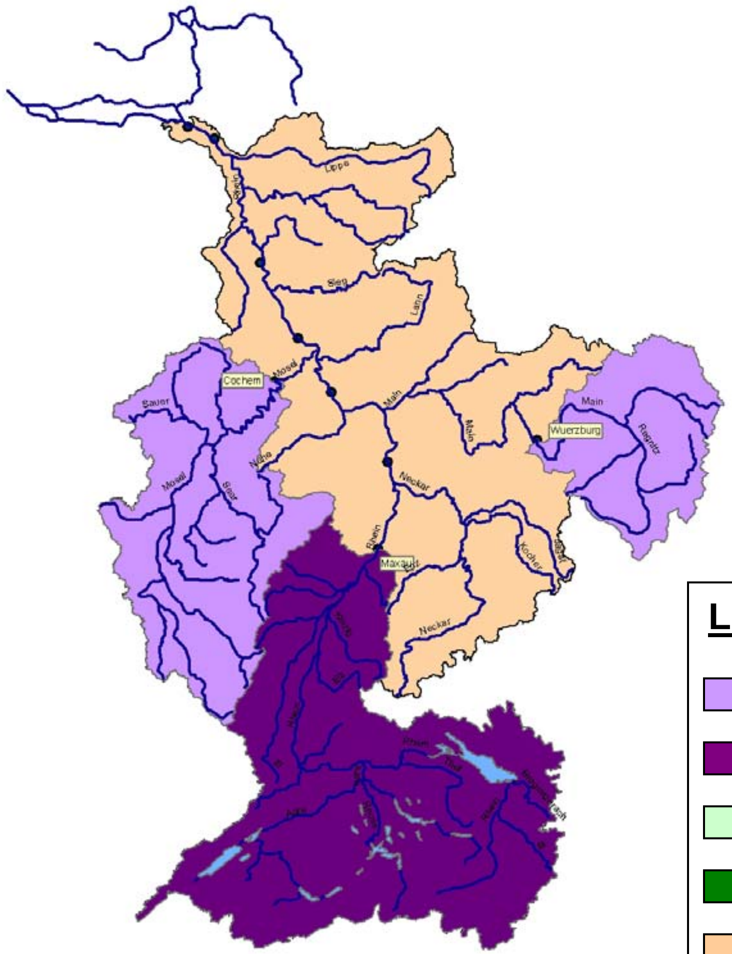

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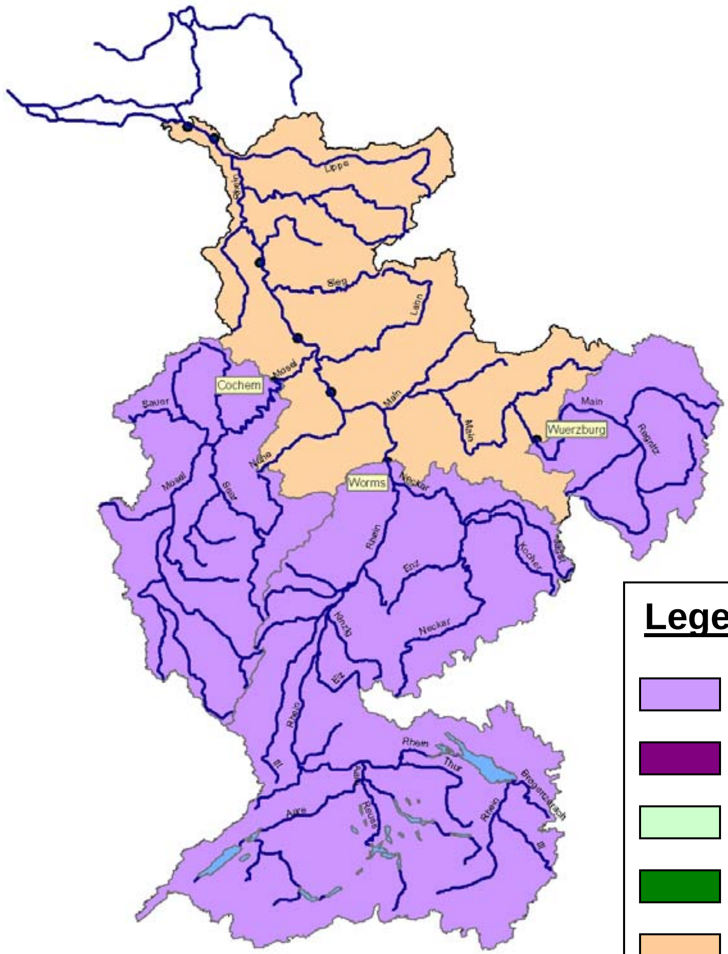

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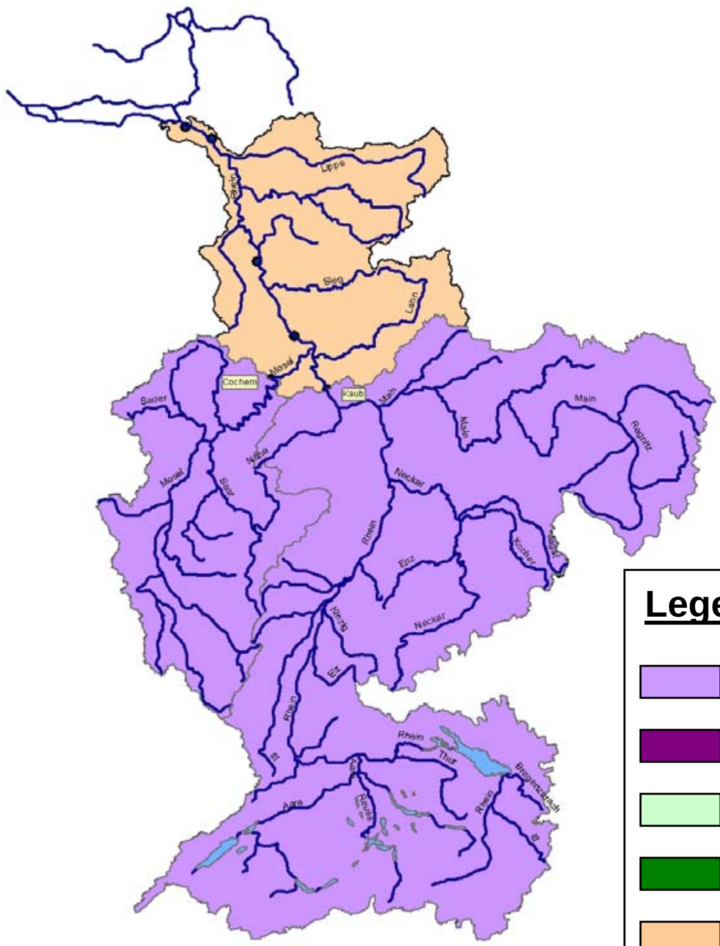

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Rhine basin: Regional trend characteristics
NM7Q (yearly series)

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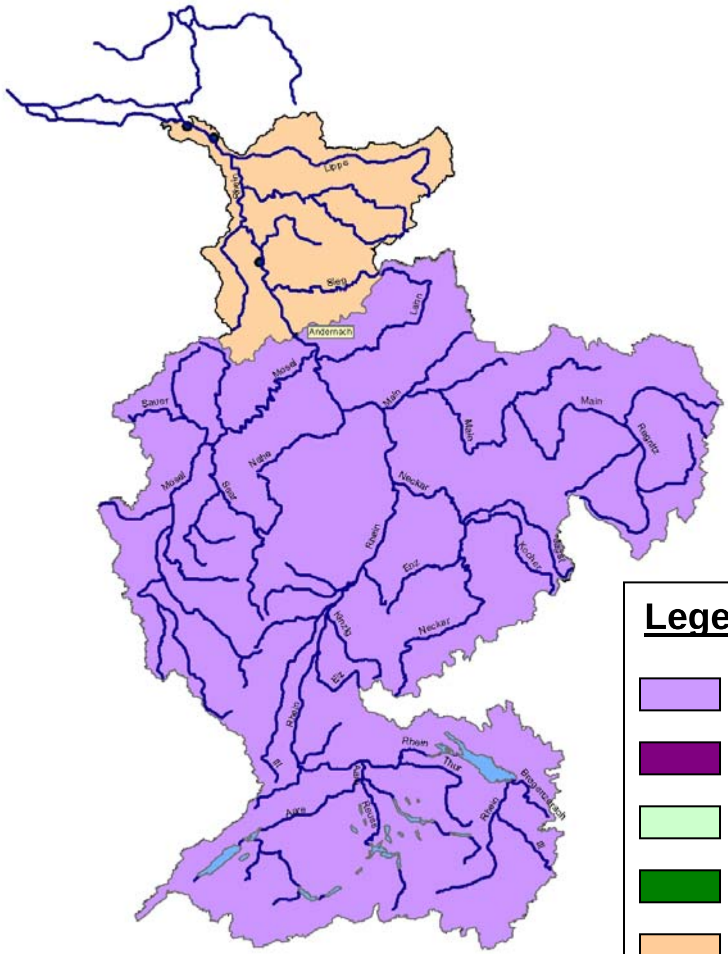

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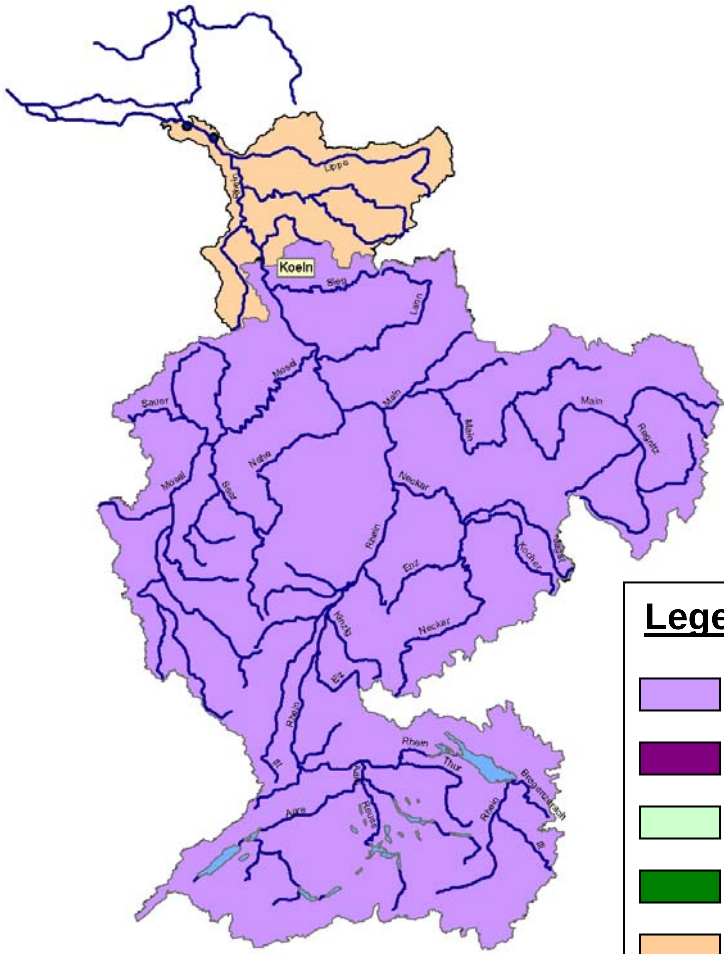

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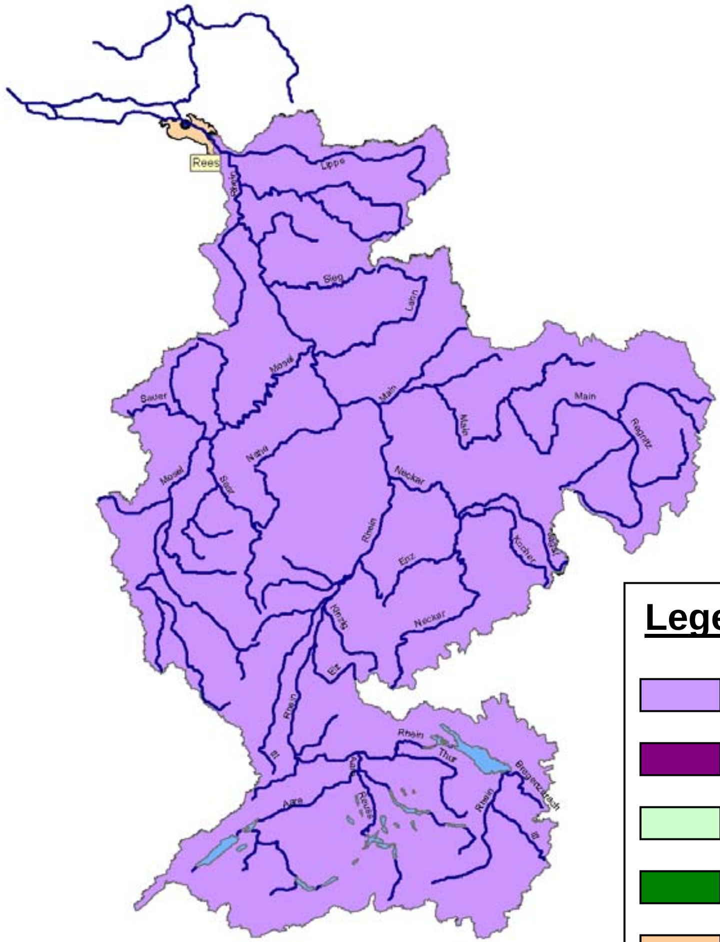

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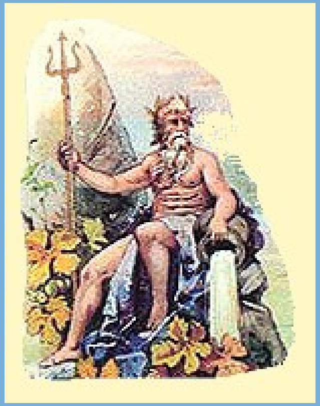
Thank you for your kind attention !



CHR
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