Landwirtschaftliches Technologiezentrum Augustenberg

Prognosis of Groundwater Nitrate Pollution in the Upper Rhine Valley Aquifer for Land Use Scenarios and Remedial Actions

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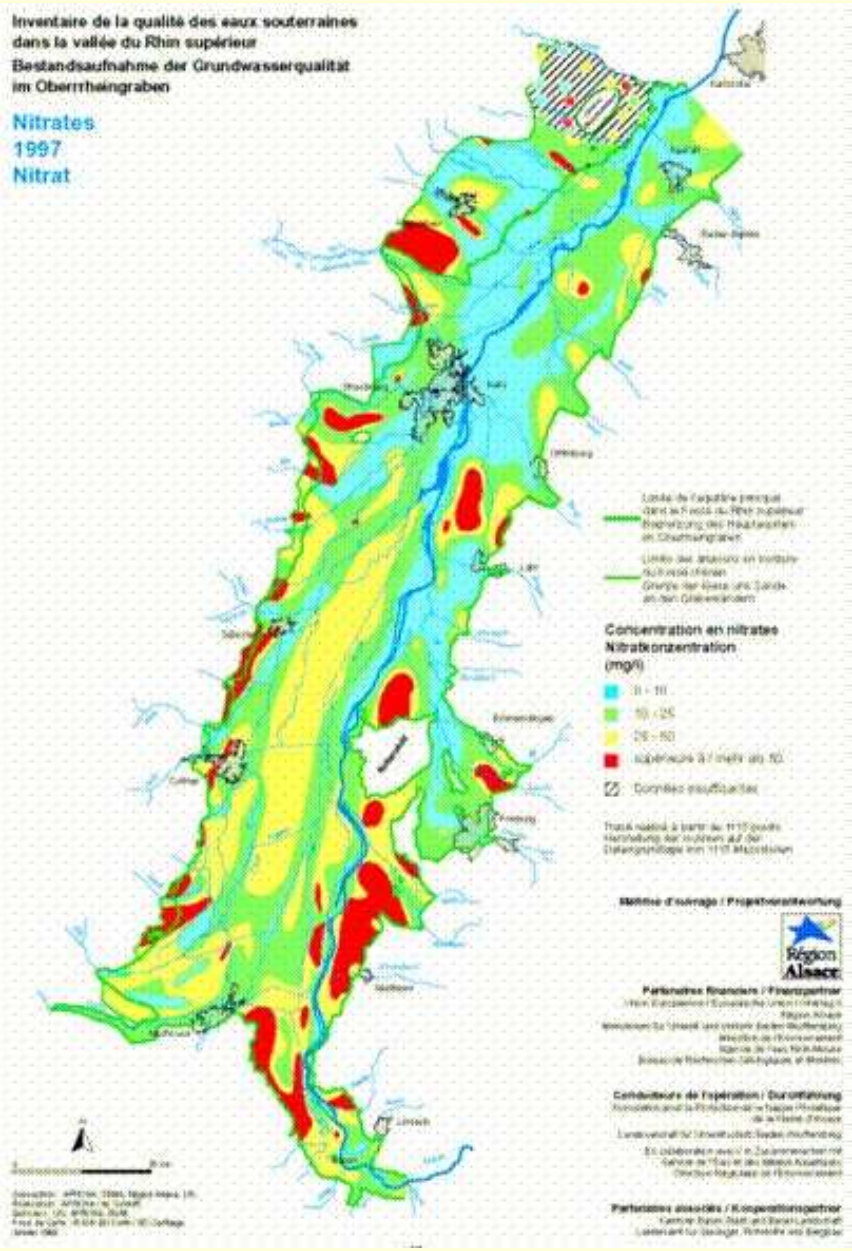
Background

- One of the largest ground water resources of Europe: 80 km^3 (1,6 x Lake Constance)
- Significant parts exhibit high nitrate loads
- Despite actions to reduce pollution (EU-Nitrate Directive, German Fertilizer Directive, SchALVO etc.) only very gradual mitigation (D) or stagnantion on a high level (F)
- Doubts about effectivity and efficiency of the protection measures (e. g. SchALVO)
- Decision support system (DSS) needed to predict future development of land use and to evaluate remedial actions

➔ German-French-Swiss Projekt

Nitrate loads 1997



EU-Interreg IIIA-Projekt MoNit „ Modellierung der Grundwasserbelastung durch Nitrat im Oberrheingraben“
“Modelling groundwater contamination by nitrate in the Upper Rhine Valley”

Partners:

Project-coordination:
Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW), Karlsruhe

Duration: 2003 – 2006

Budget: 3 Mio €

Goals of the project

Developing a **model system** to

a) reproduce magnitude and spatial distribution of the **current nitrate pollution** in the groundwater body

b) assess possible developments in agricultural practice due to **socio-economic changes** and to evaluate their effect on nitrate leaching and nitrate concentration in groundwater

c) evaluate **measures of cultivation** concerning their effect on nitrate leaching and nitrate concentration in groundwater.

Model-system MoNit

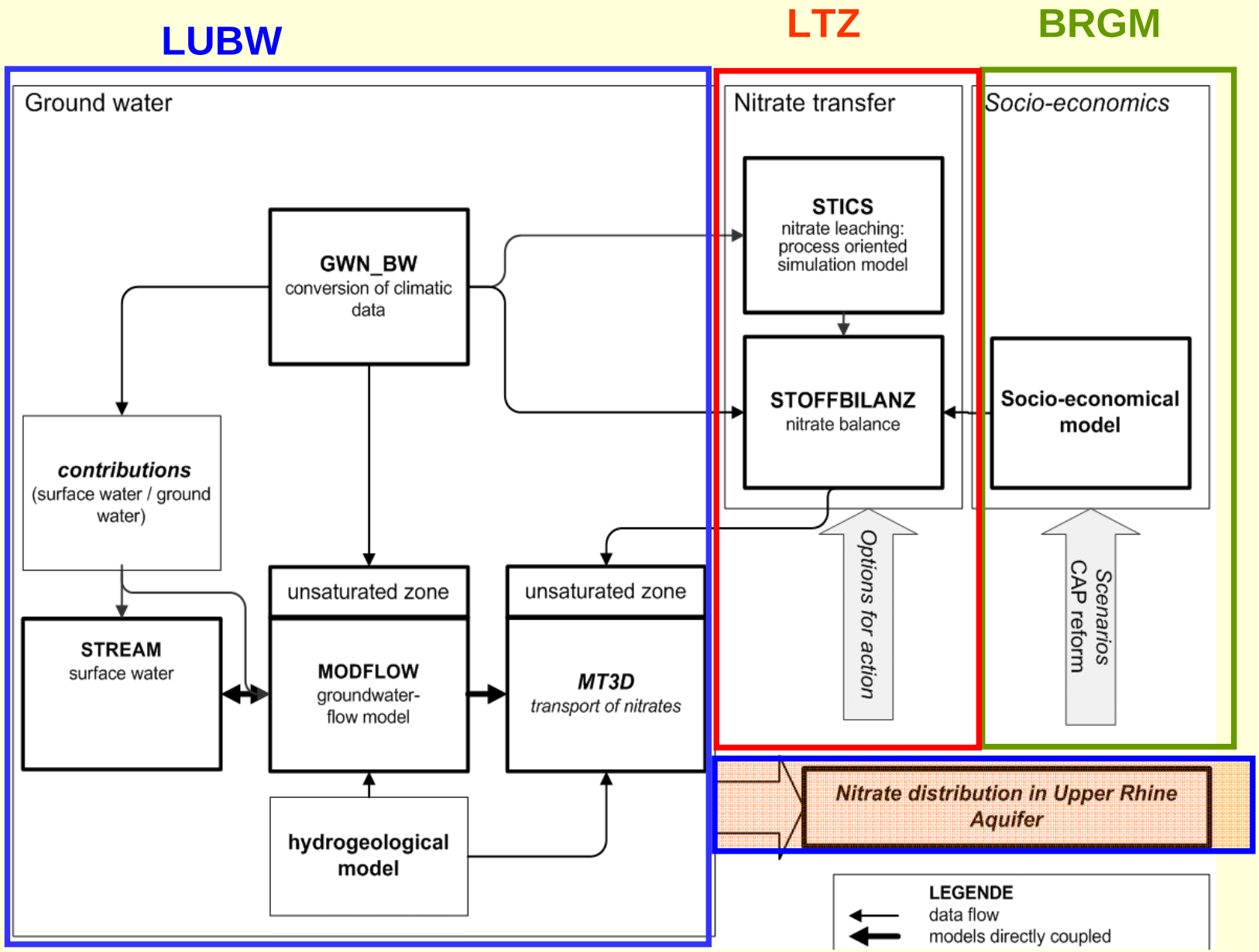
Different models were coupled:

Coordination:

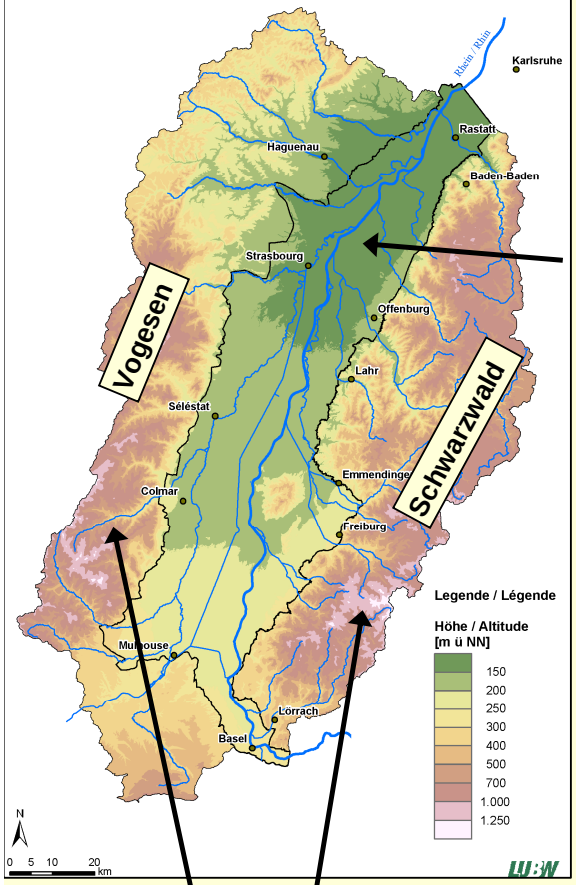
Groundwater flow and transport of nitrate, Recharge from climatic data

N-Emission at large scale and at plot scale → measures of cultivation

Scenarios → changes in land use or cropping pattern



Study area



outer project area
catchment of tributaries from Black Forest and Vosges

internal project area (IPA):

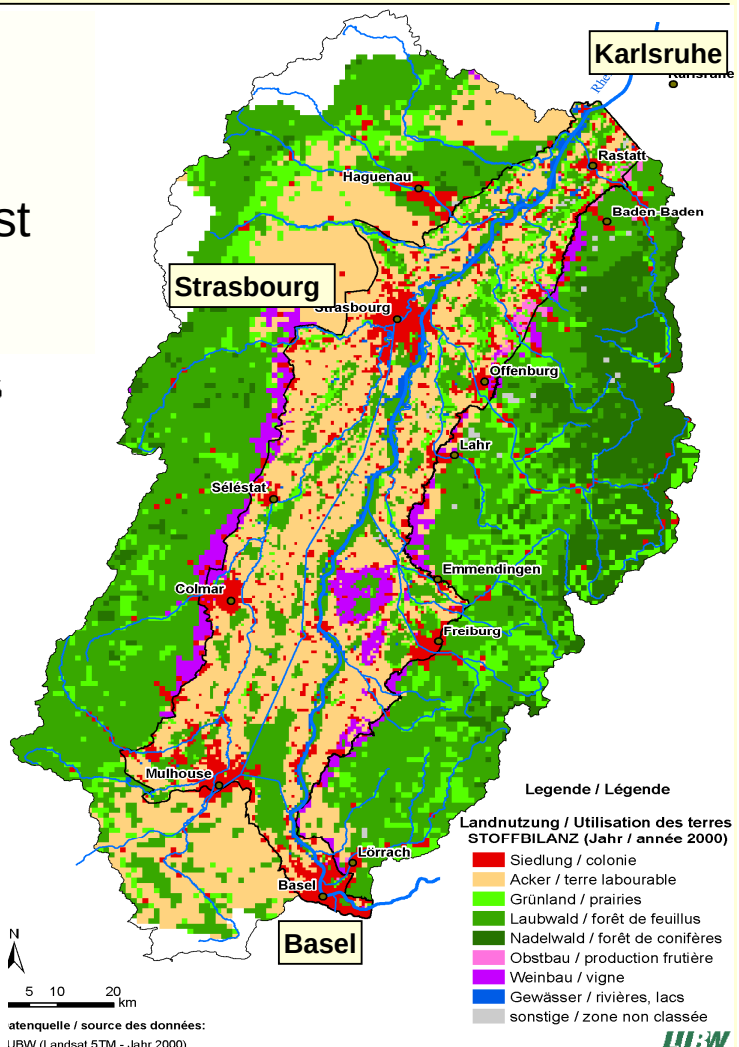
- southern/middle part of Upper Rhine vally
- water volume: 80 km³ (1,6 x Lake Constance)
- area: **4‘294 km²**
  D: 1‘700 km², F: 2‘600 km²

→**60%** of internal project area (IPA) is agriculturally used

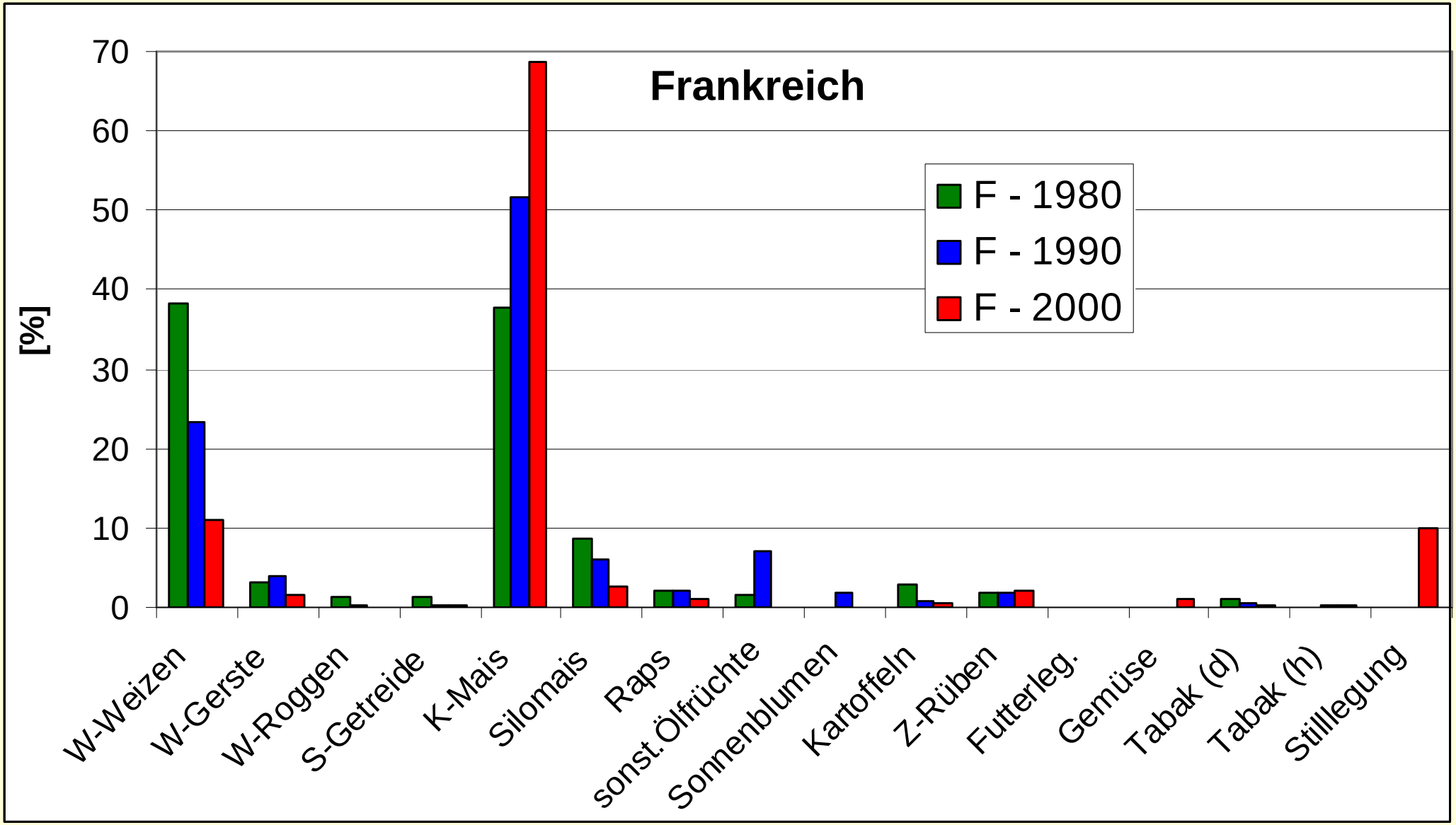
→ outer project area: 63% forest

Landnutzung / Utilisation des terres STOFFBILANZ (Jahr / année 2000)

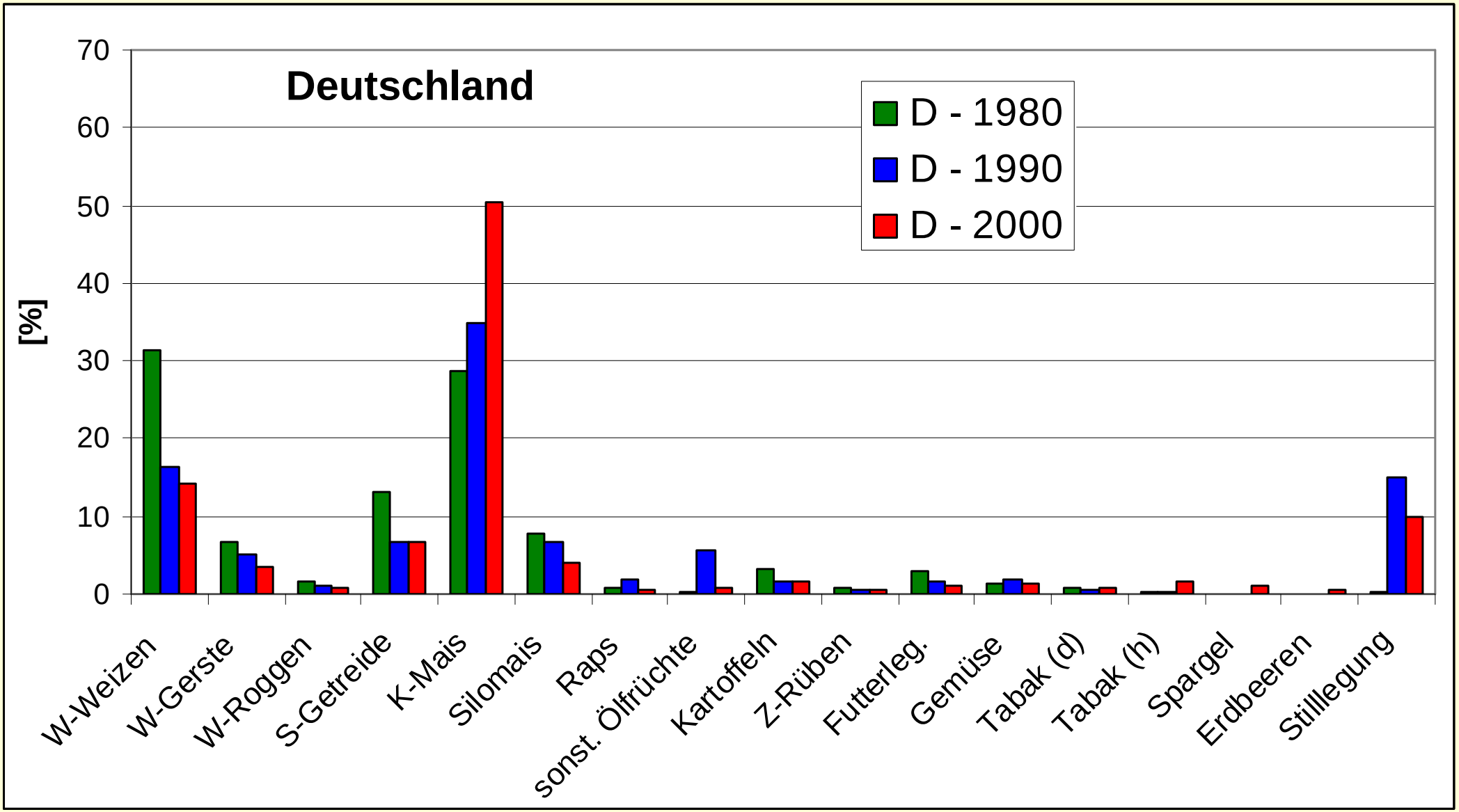
- Siedlung / colonie
- Acker / terre labourable
- Grünland / prairies
- Laubwald / forêt de feuillus
- Nadelwald / forêt de conifères
- Obstbau / production frutière
- Weinbau / vigne
- Gewässer / rivières, lacs
- sonstige / zone non classée

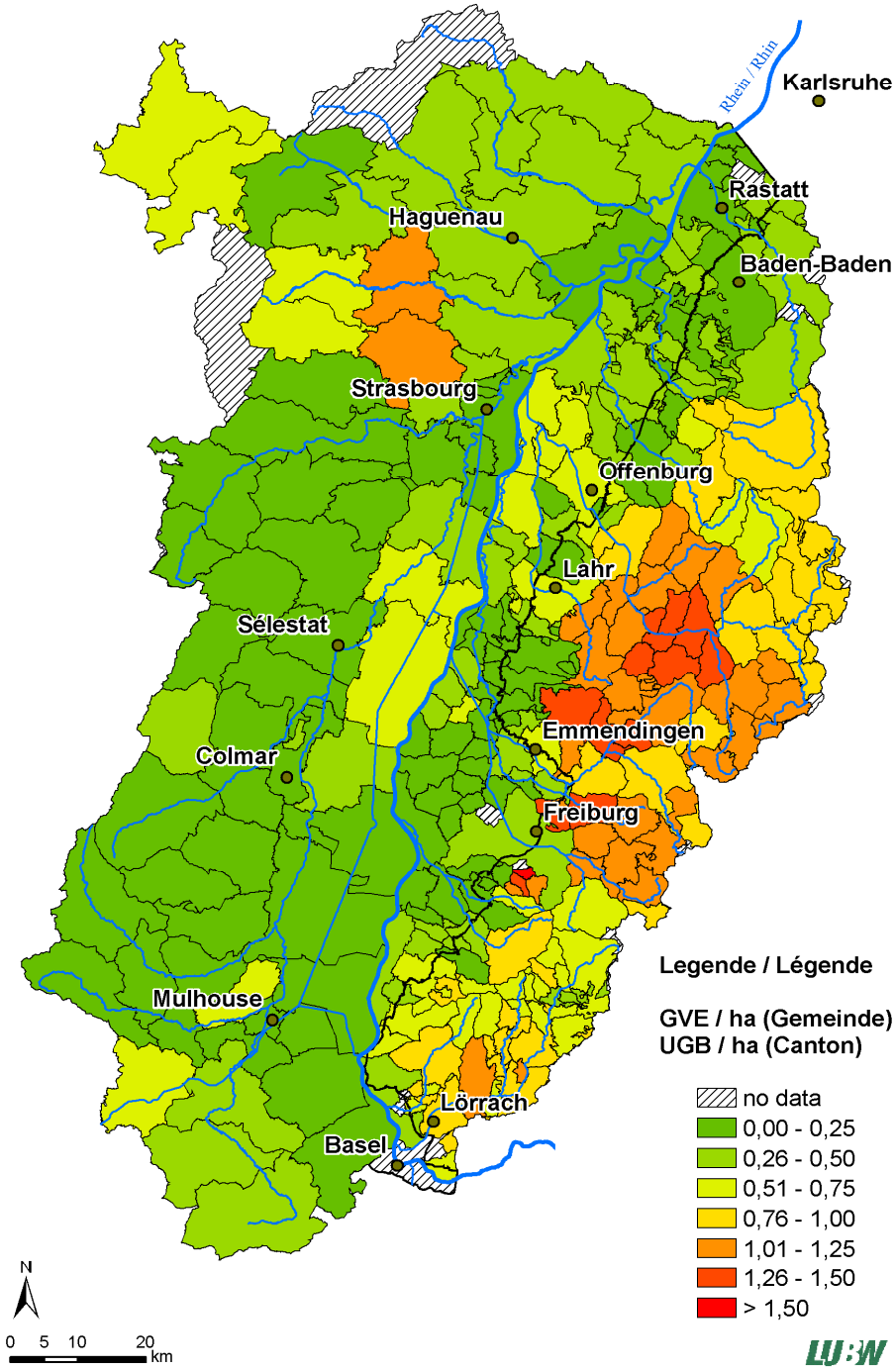


Cropping pattern of arable land, in %
Internal project area (IPA)



Cropping pattern of arable land, in %
Internal project area (IPA)





Livestock 2000

Internal project area (IPA):

F: 0,4 cattle units/ha

D: 0,3 cattle units/ha

Data source:
D: Stat. Landesamt, BNHE 1999
F: SCEES

Conzept

1. Compiled list of remedial actions from the preceding project has been extended and evaluated by 20 agricultural authorities from Germany, France and Switzerland

- efficacy
- feasibility
- regional relevanz,
- model-technical feasibility

8 options of action chosen for prediction ➔ **"remedial actions"**

2. Potential developments in agricultural economics have been estimated

3 scenarios defined for prediction ➔ **"Szenarios"**

Estimation of future developments in agriculture

26 driving forces assorted and evaluated

- importance
- uncertainty
- feasibility

➡ 6 driving forces selected for defining **"Scenarios"**

-- 2003 CAP reform (Luxenburg 2003)

– corn rootworm proliferation

– increase in energy price & costs for fertilizer (+ 40 bis + 200%)

– expansion of acreage for bio fuels (rape, corn)

– increasing costs and tax for water (France)

– EU enlargement (costs of seasonal labor, Germany)

The three Scenarios

- **tendency scenario T**: the most probable development
- Two more extreme scenarios following IPCC:
  - **scenario A1** “liberalized policy”
    - 100% decoupling financial subsidies from quantity of production also in France
    - less increase in energy prices (by state subsidies)
    - no problem with the corn rootworm (pesticides)
    - ....
  - **szenario B2** “energy-ecologically oriented policy”
    - high energy prices
    - taxes on water and fertilizer
    - acreage restriction for corn (rotation cropping to reduce corn rootworm)
    - ....

Remedial Actions

concerns:

M1 fertilizing

a. fertilisation of grain maiz according to legal requirements (ogD)

b. further 20% reduced fertilisation of grain maiz (reD)

c. fertilisation of grain maize <u>and</u> wheat according to legal requirements (ogD)

M2 maximum amount of intercropping

crop management

M3 conversion of 20% of arable land into grassland

a. at "hot spots" (highest N surplus) within internal project area (IPA)

b. at "hot spots" per municipality

c. spots of unfavourable site characteristics (low denitrification, little dilution by surface water)

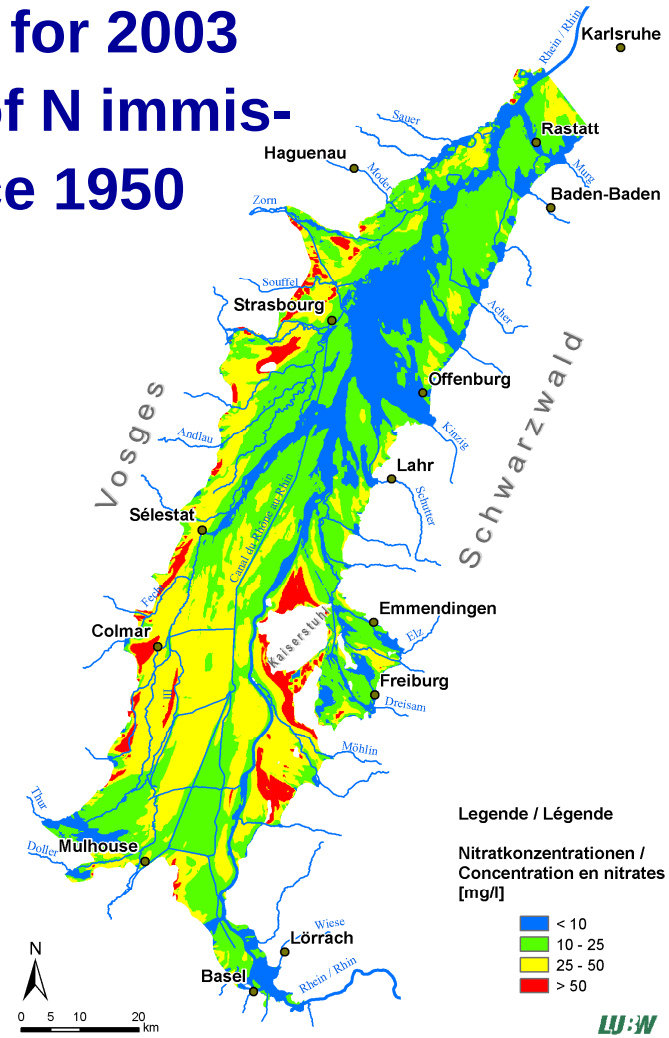
land use pattern

M4 Combination M1a, M2 und M3a

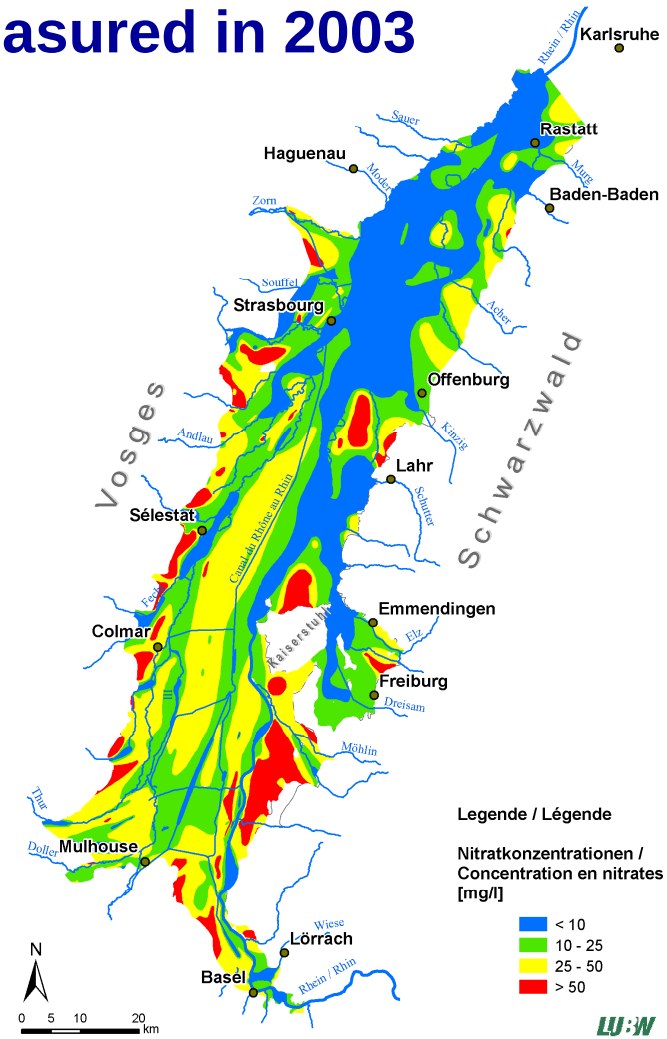
crop management <u>and</u> land use pattern

Basis for Prognosis: Valid modeling of the status quo of nitrate in groundwater

Calculated for 2003 as a result of N immission since 1950

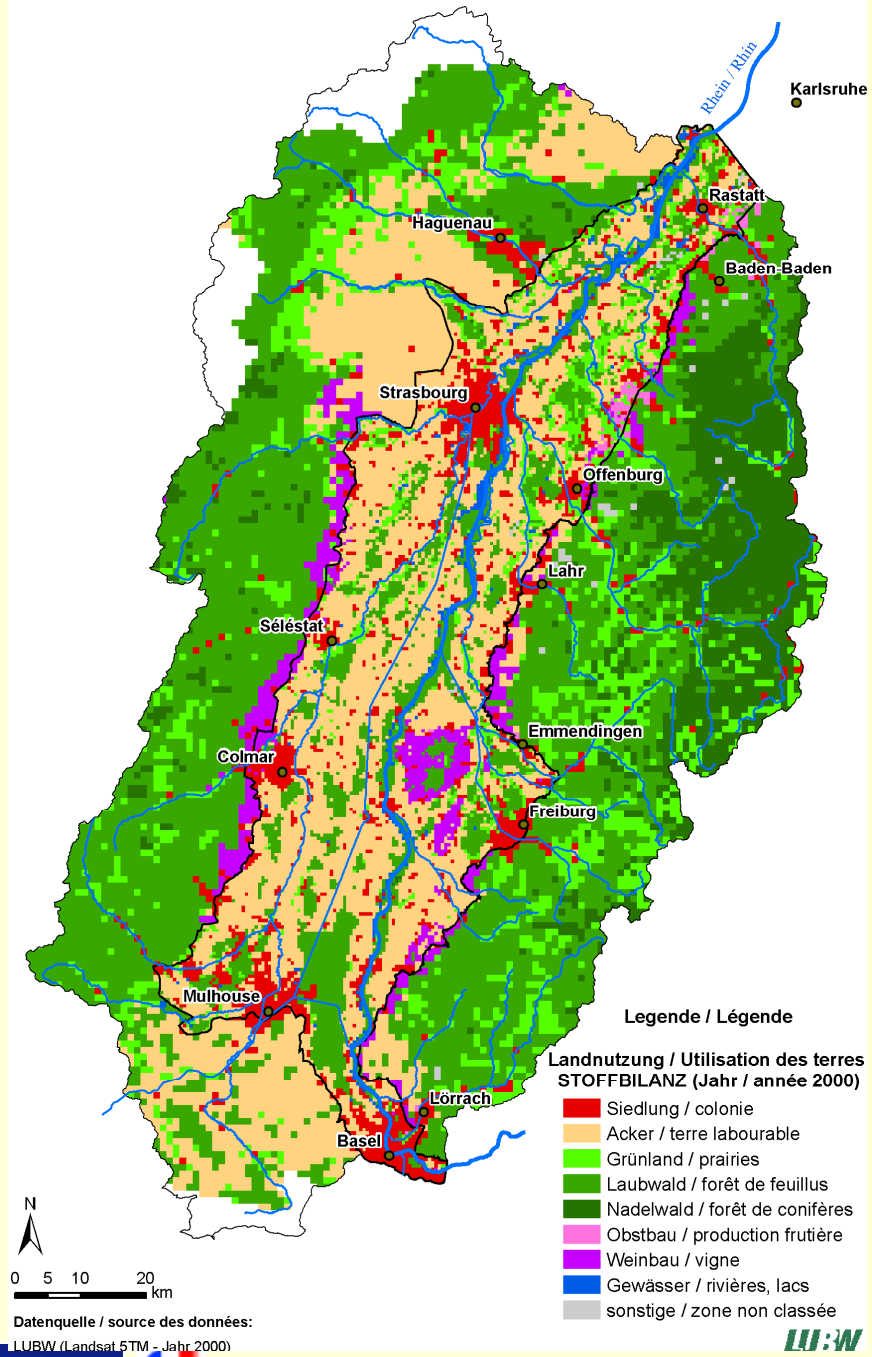


Measured in 2003



Essential features of spatial distribution and magnitude of nitrate concentration are reproduced satisfatorily

How did we model the N emission?



Landsat: 1975, 1991 and 2000

Main categories of land use:
Arable land, grassland, viticulture, fruit production, deciduous forest, coniferous forest, water bodies, urban area and degradation

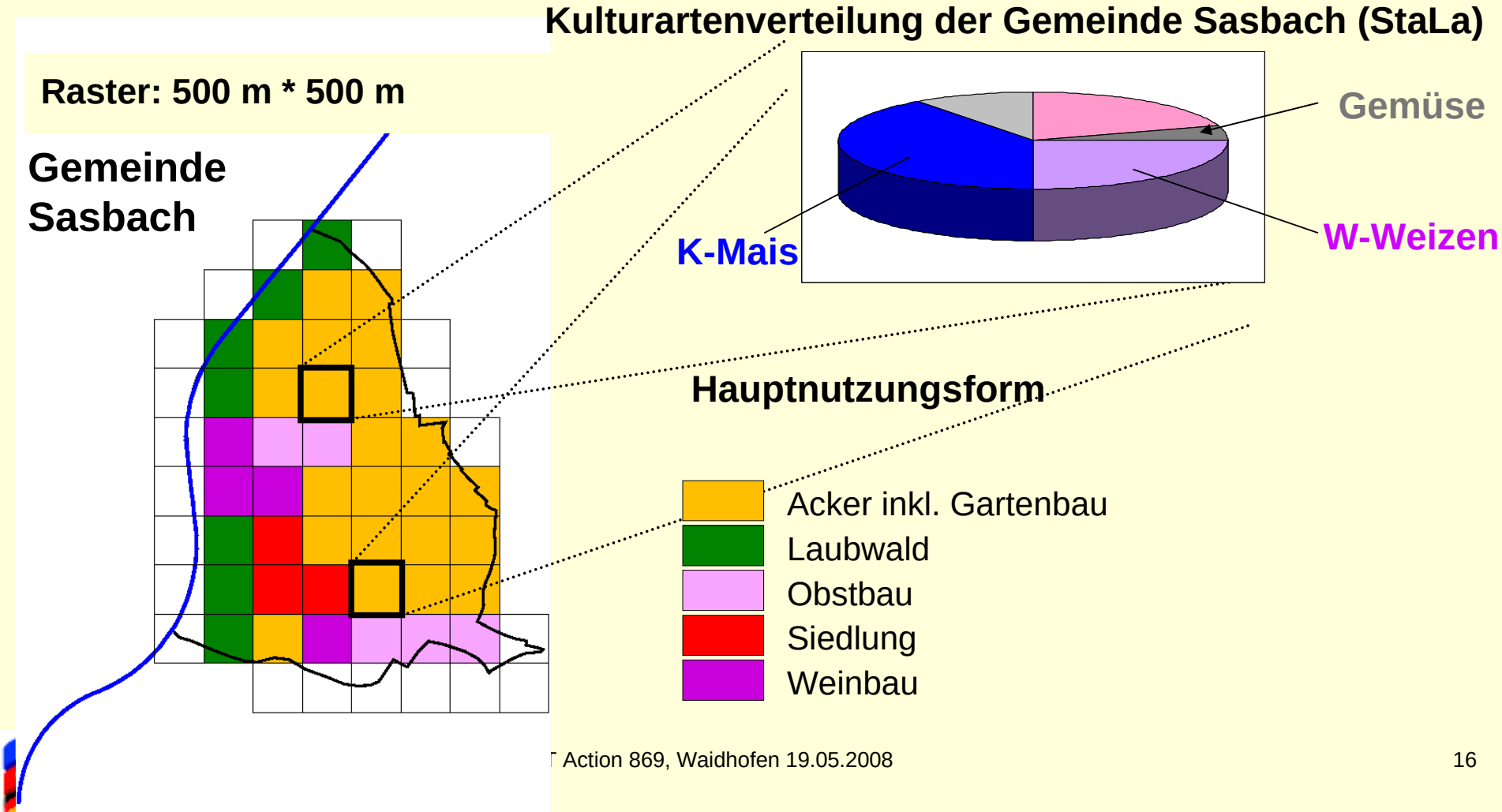
Allocation to
500 m grid (inner project area)
1000 m grid (outer project area)

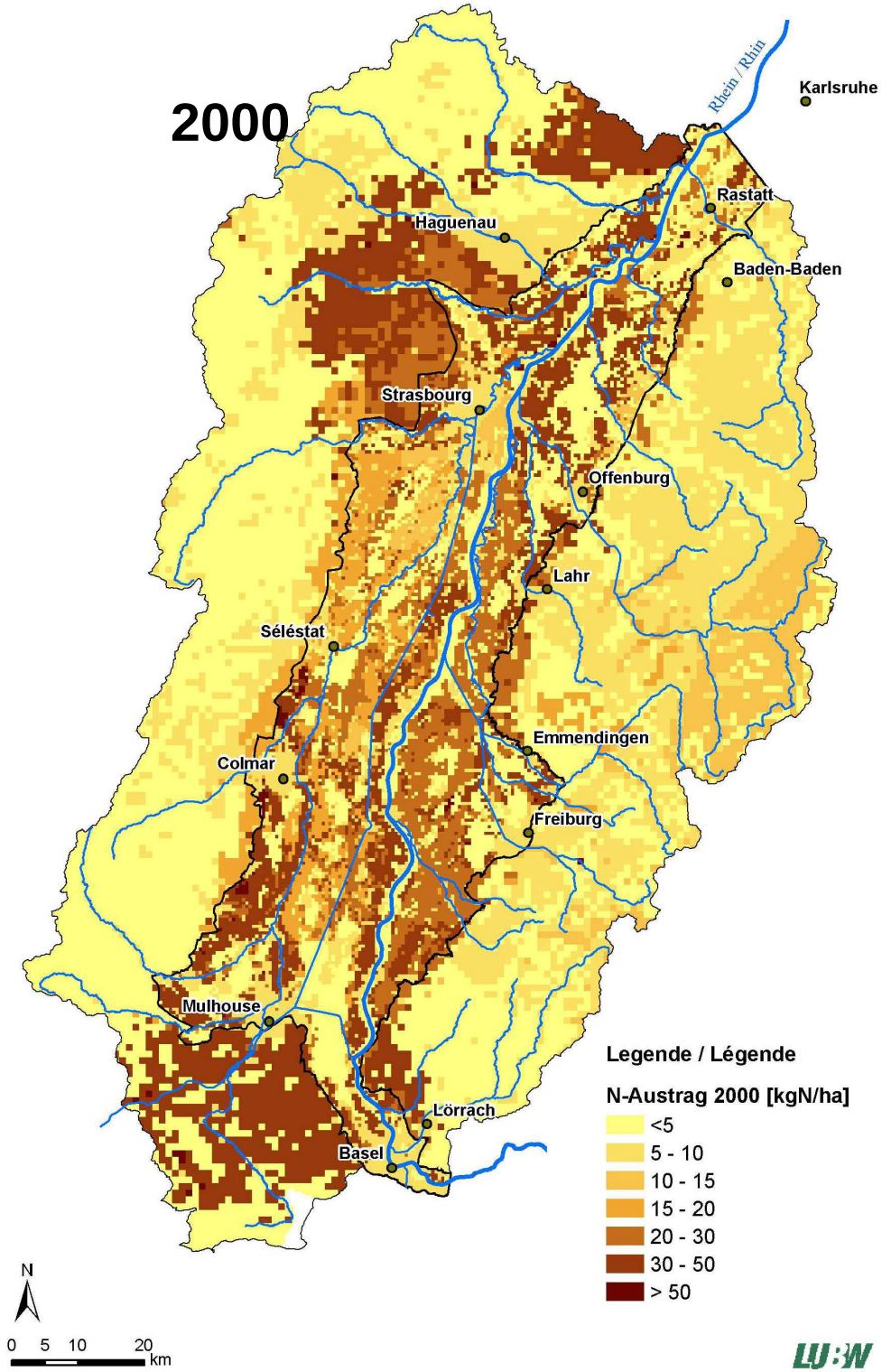
→ **N balance (annual balance)**

= N emission in kg N/ha spatially differentiated

Bilanzierungsansatz Ackerbau

1. kulturartspezifische N-Salden
2. gemäß Anbaustatistik flächengewichtet





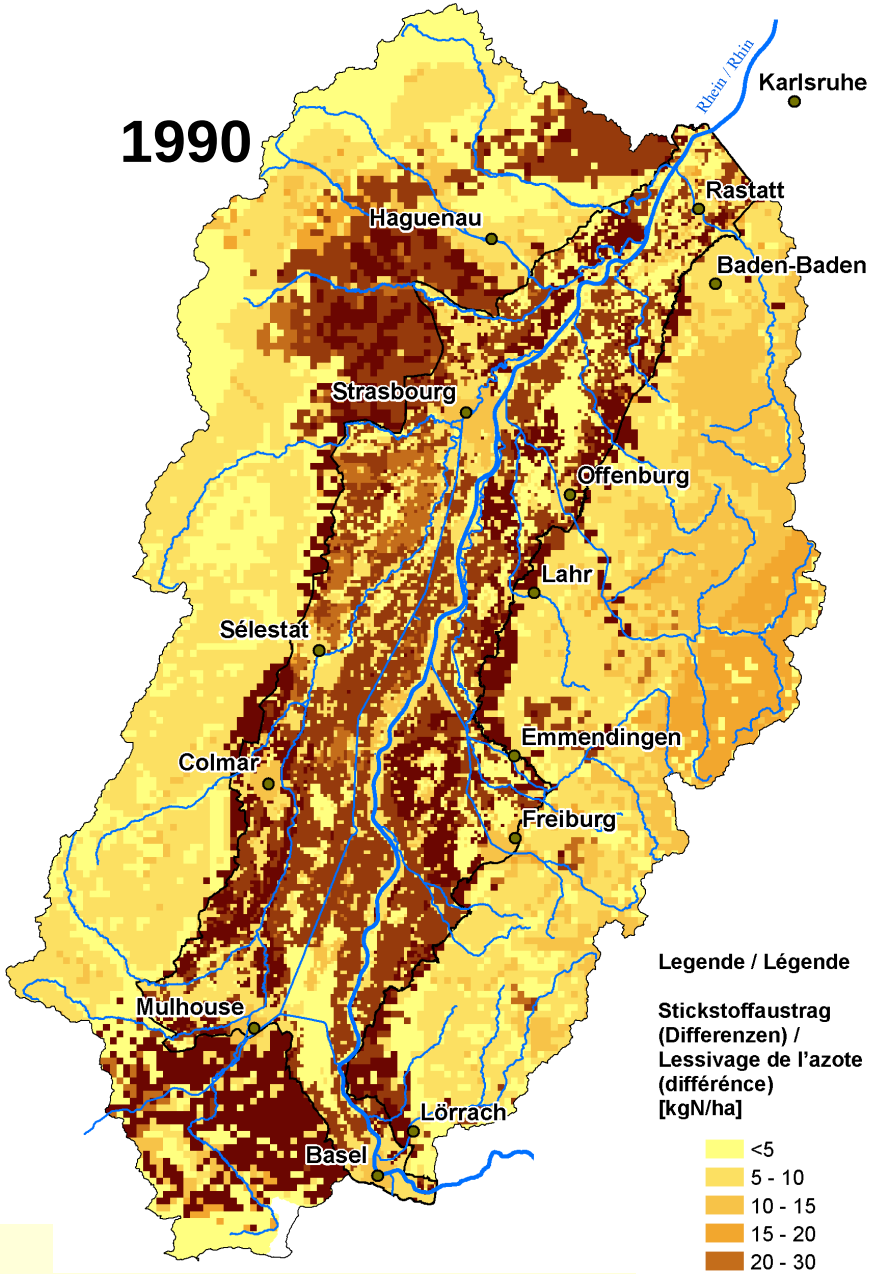
N emission 2000

Internal project area (IPA):

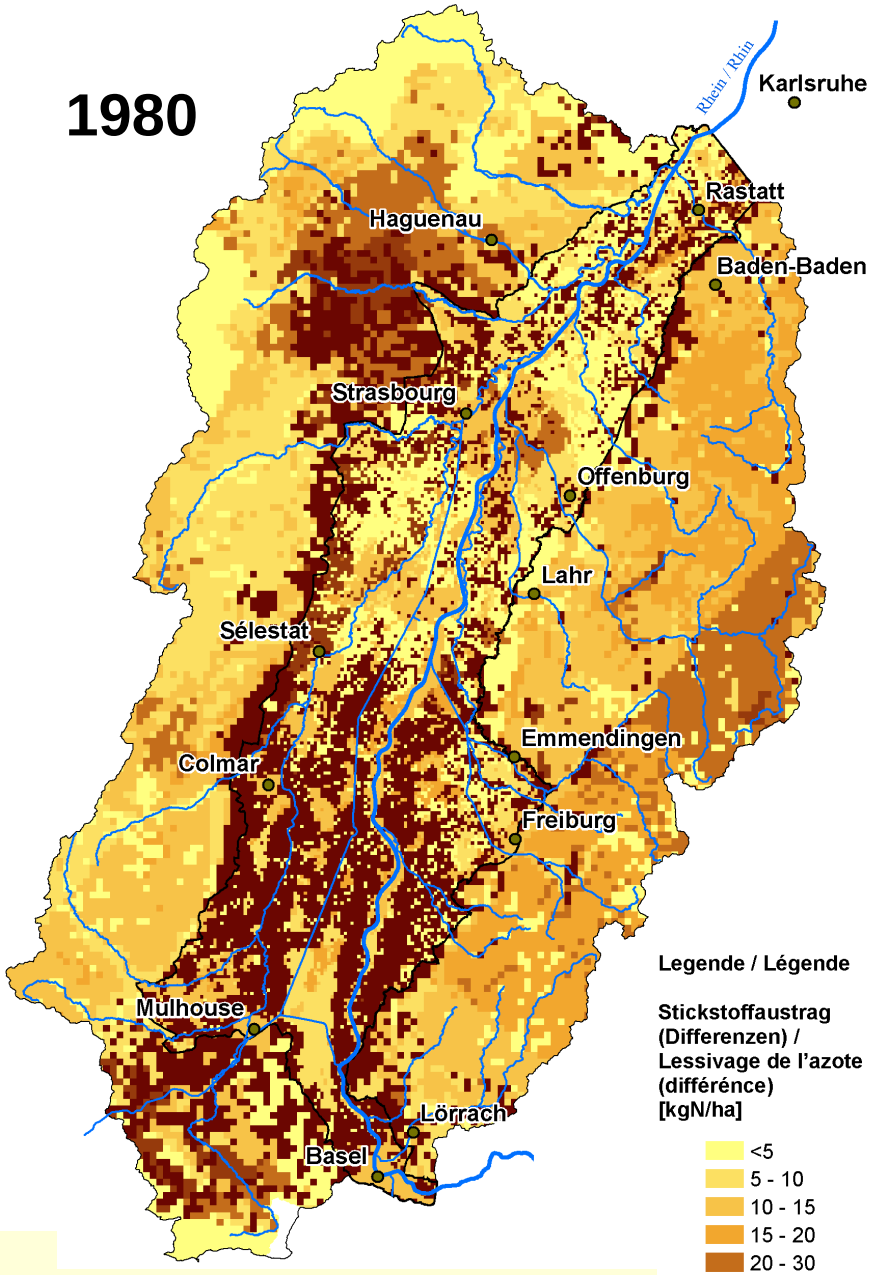
D = 17 kg N/ha

F = 17 kg N/ha

N emission 1990 and 1980

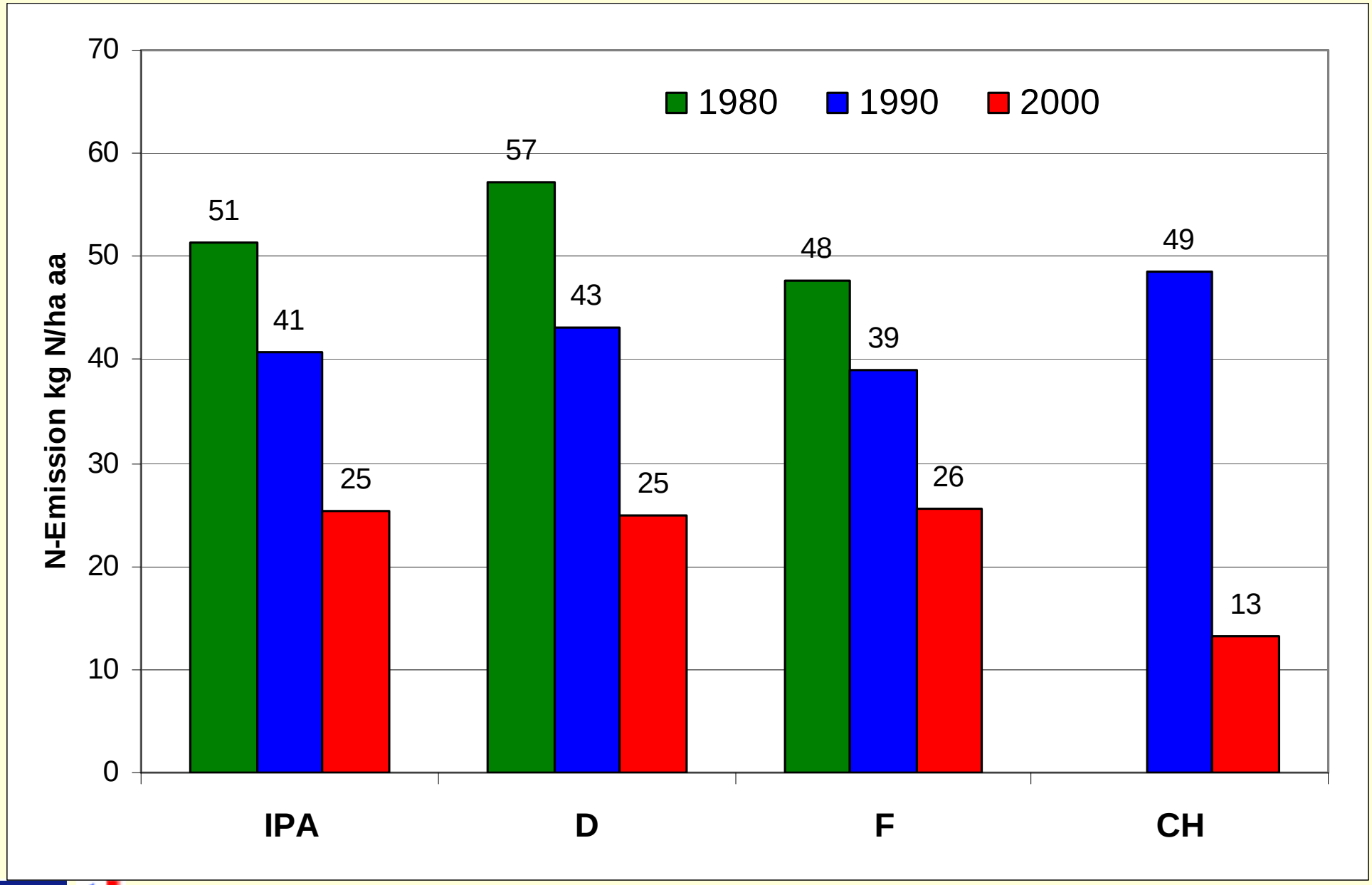


Internal project area (IPA):
D = 29 kg N/ha
F = 26 kg N/ha

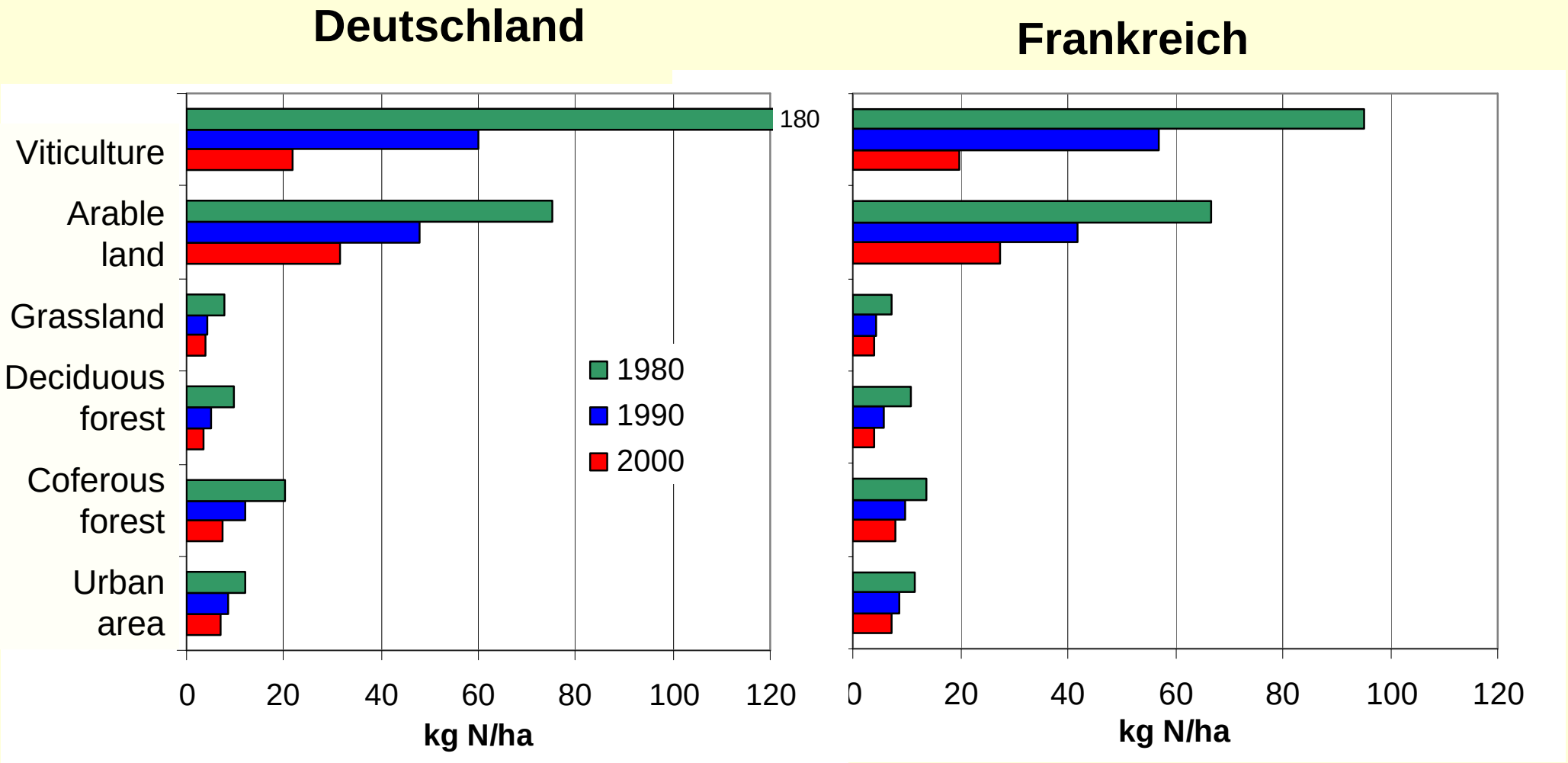


Internal project area (IPA):
D = 45 kg N/ha
F = 38 kg N/ha

N emission [kg N/ha] from agricultural area (aa)
Internal project area (IPA)



N emission from main land use categories
Internal project area (IPA)



Reasons for decreasing trend

1. Yield increases
2. Reduction of livestock
3. Improvement in fertilization practices (particularly with regard to viticulture)
4. Decline in atmospheric N deposition

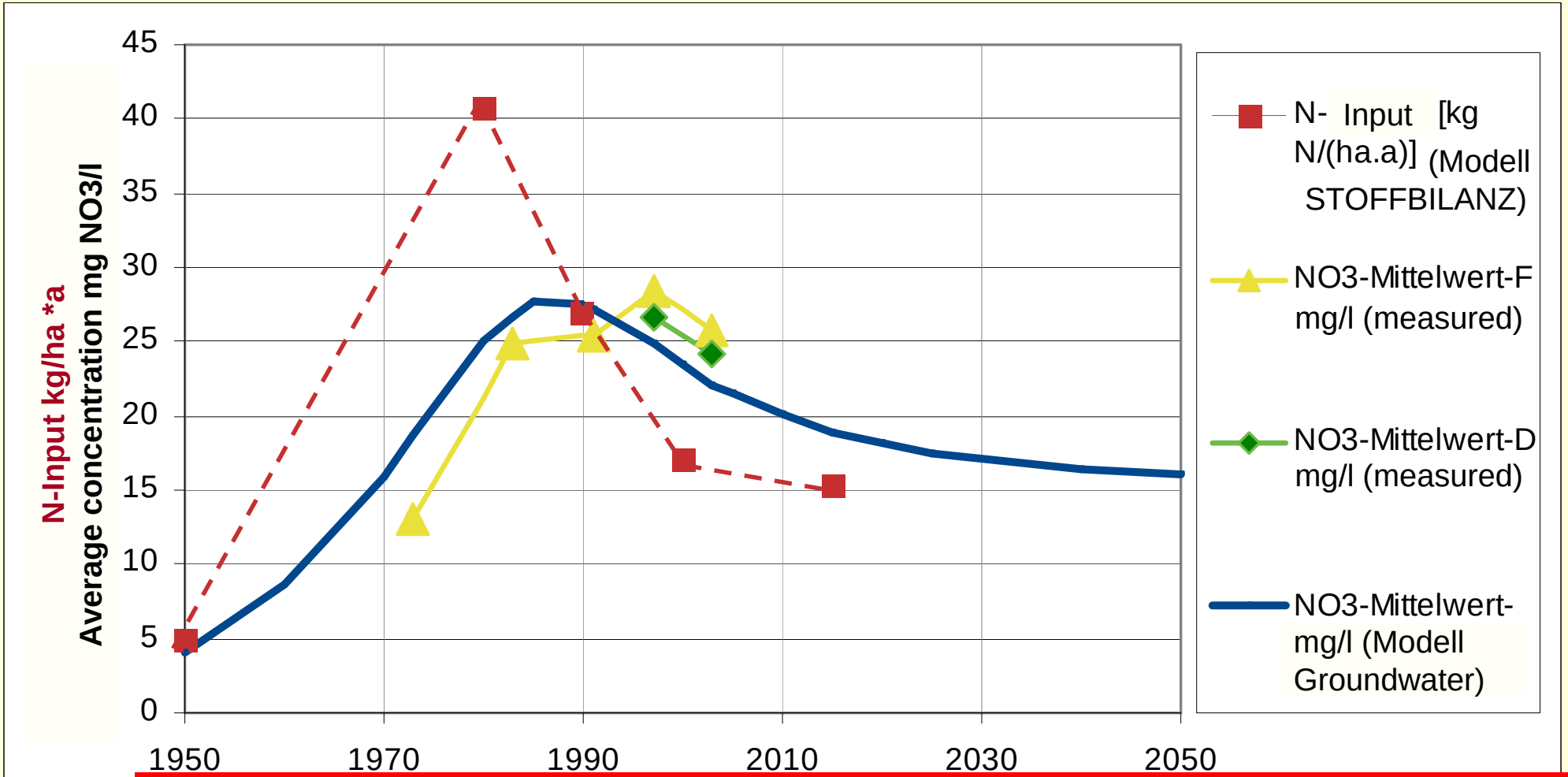
Despite opposing effects

1. Increase of arable land from 34% to 49% in the inner study area, whereas the grassland percentage declined
2. Acreage of grain maize expanded and on the other hand winter wheat reduced

N charge [t]
Internal Project Area IPA

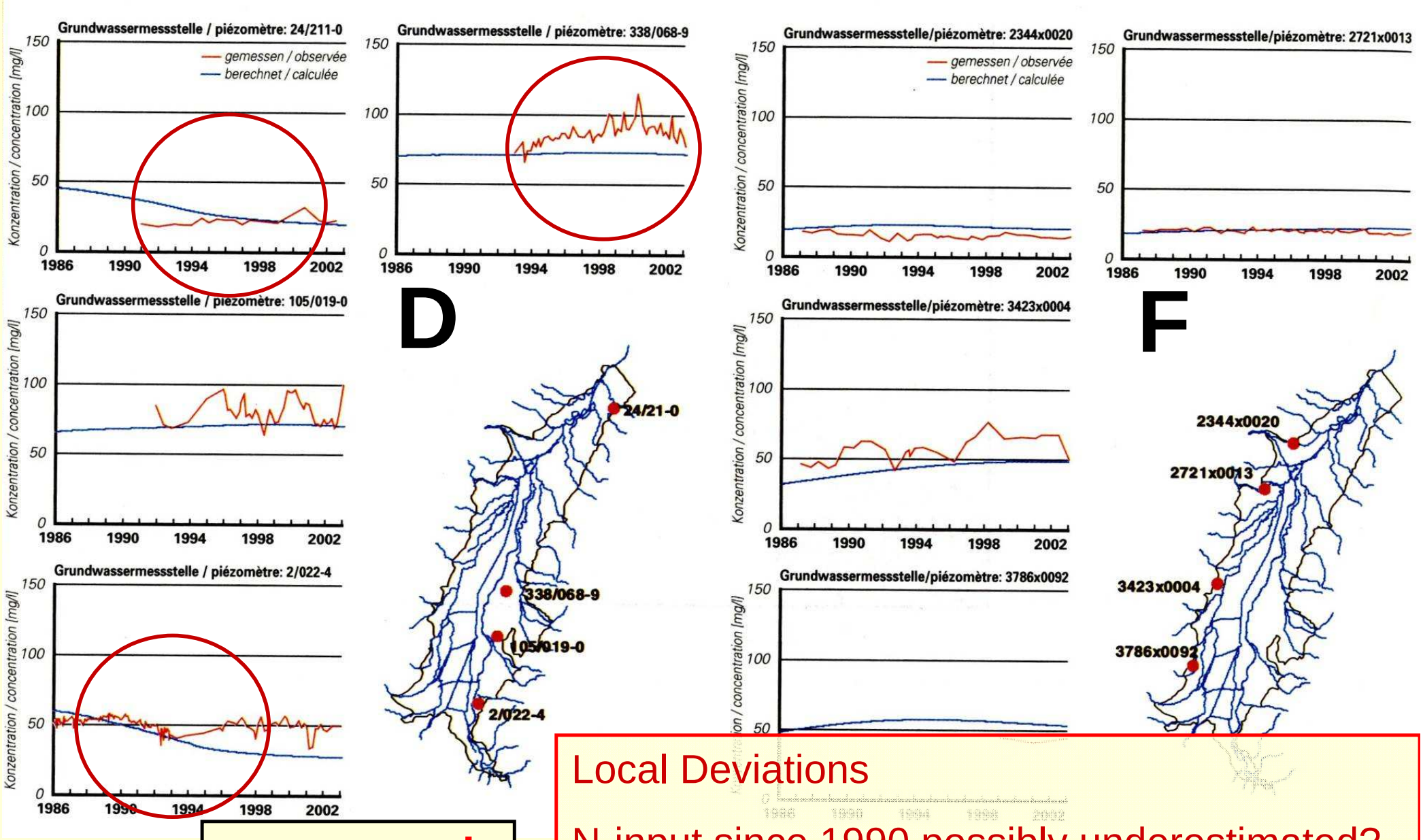
N charge [t]	1980	1990	2000	reduction 1990 versus 1980, in %	reduction 2000 versus 1980, in %
Germany	8.406	5.368	3.183	**36**	**62**
France	10.368	7.134	4.733	**31**	**54**
Switzerland	129	58	36	**56**	**72**
Total of internal project area (IPA)	18.903	12.559	7.952	**34**	**58**

Validation of modell system



- maximum/model: a bit early, (at least for F) possibly to low compared with measured values
- Later and higher maximum of concentration could point to a later (1985?) and higher (45 kg N/(ha a)?) maximum of N input
- Coherent dimension of N immission and calculated concentrations
- trend/model: similar to measured values → model can be used for prognosis.

Simulated vs. measured: Concentration time series 1986-2003



Local Deviations

N-input since 1990 possibly underestimated?

-- measured

-- simulated

Prognosis

1. Agroeconomic Scenarios

2. Remedial actions

Socio-economic modelling with SEM (SÖM)

Identification of homogeneous small agricultural regions (PRA)

Development of a farm typology

Sample farm case studies (interviews)

Development of micro-economic farm models

Definition of scenarios

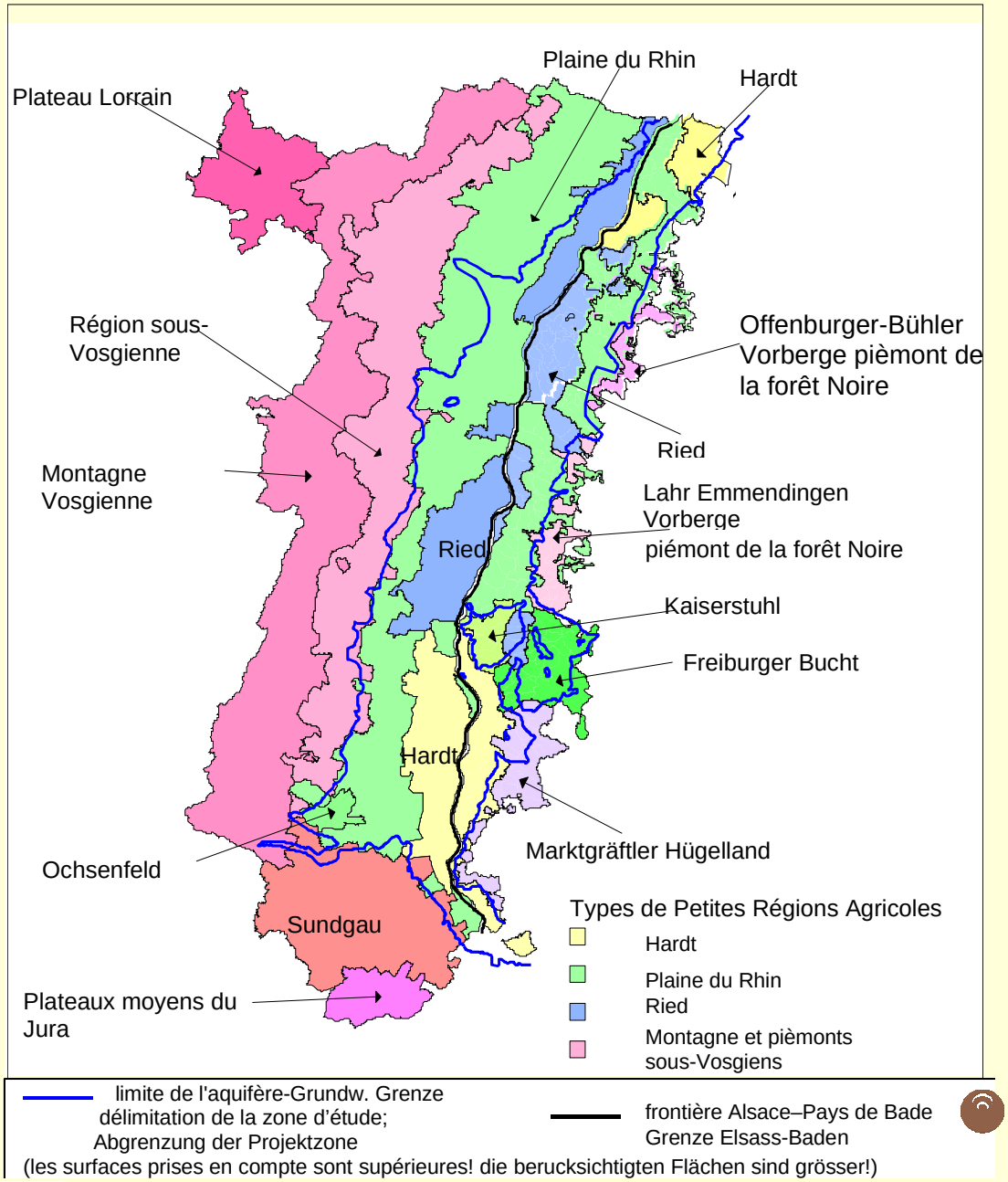
Identification of instruments for agricultural diffuse pollution management

Simulation runs

Extrapolation of the results on regional level

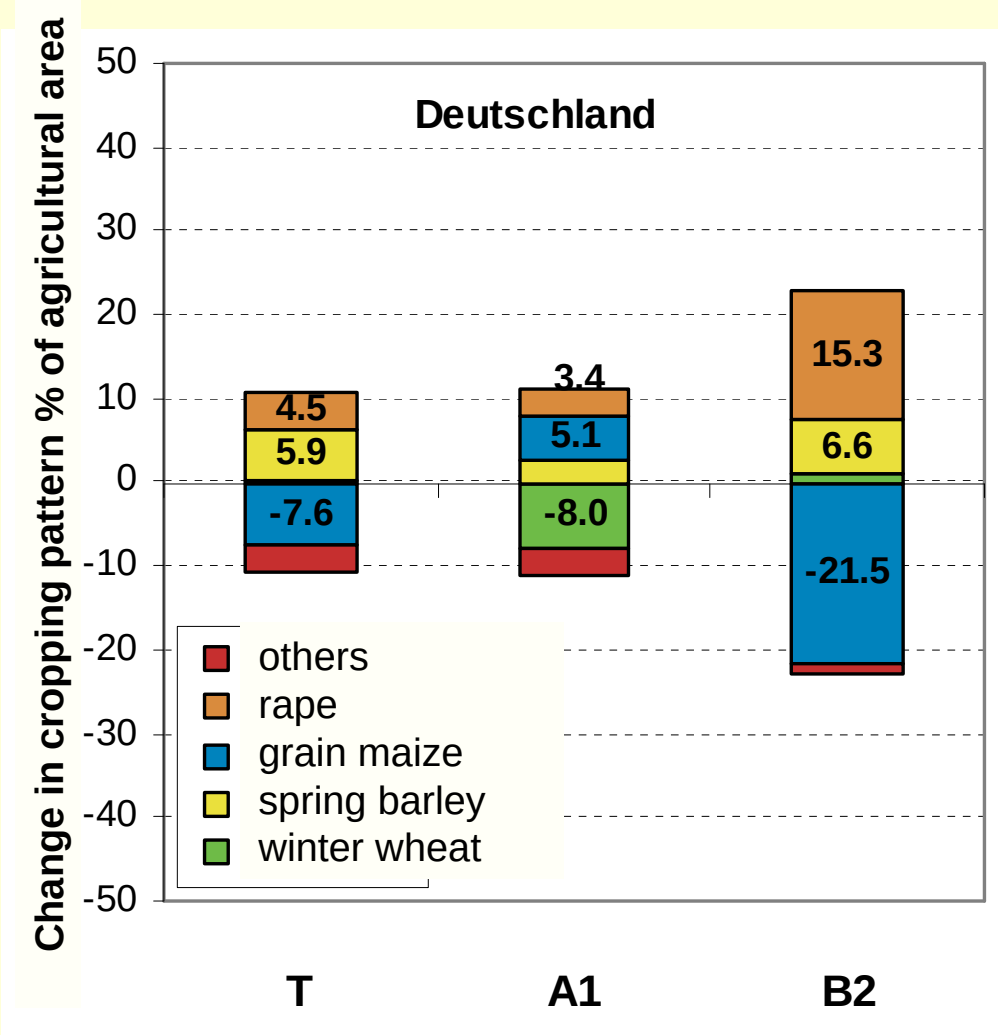
Linkage with the N-Emission Modell STOFFBILANZ

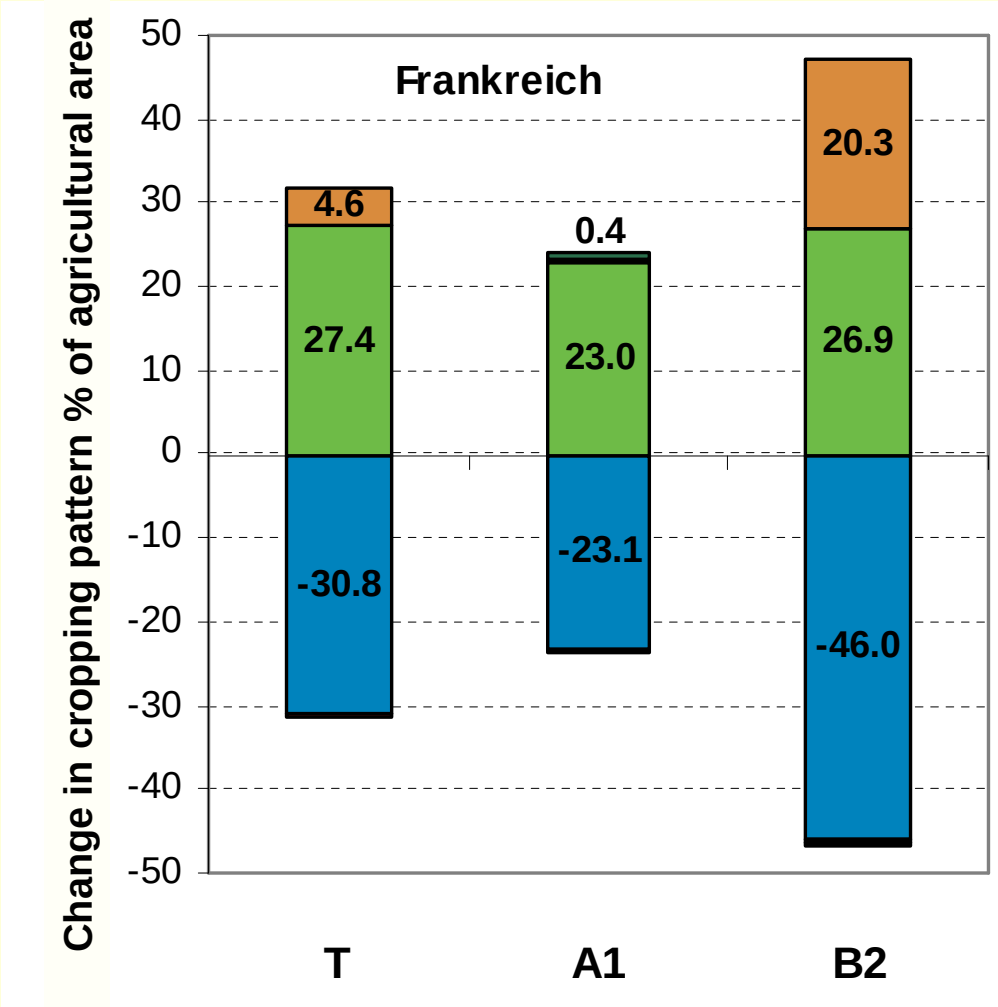
13 Small agricultural regions (PRA)



Scenarios: Changes in cropping pattern until 2015

Calculated by the socio-economic model SEM (SÖM)





Changes in land use cause changes in N emission

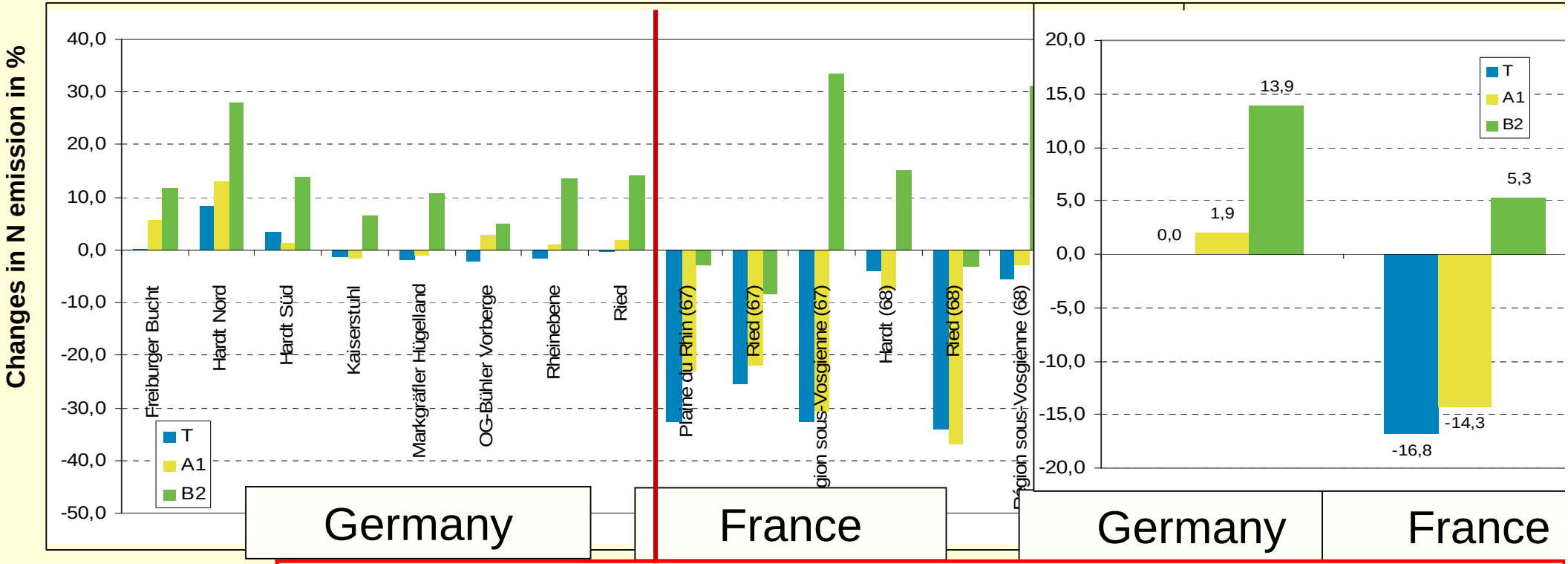
Change in N-emission 2015 vs. reference 2003 in % according to STOFFBILANZ

T – Tendency scenario

Scenario A1

Scenario B2

13 small agricultural regions → averages



Differences between small agricultural regions (PRA) and F - G

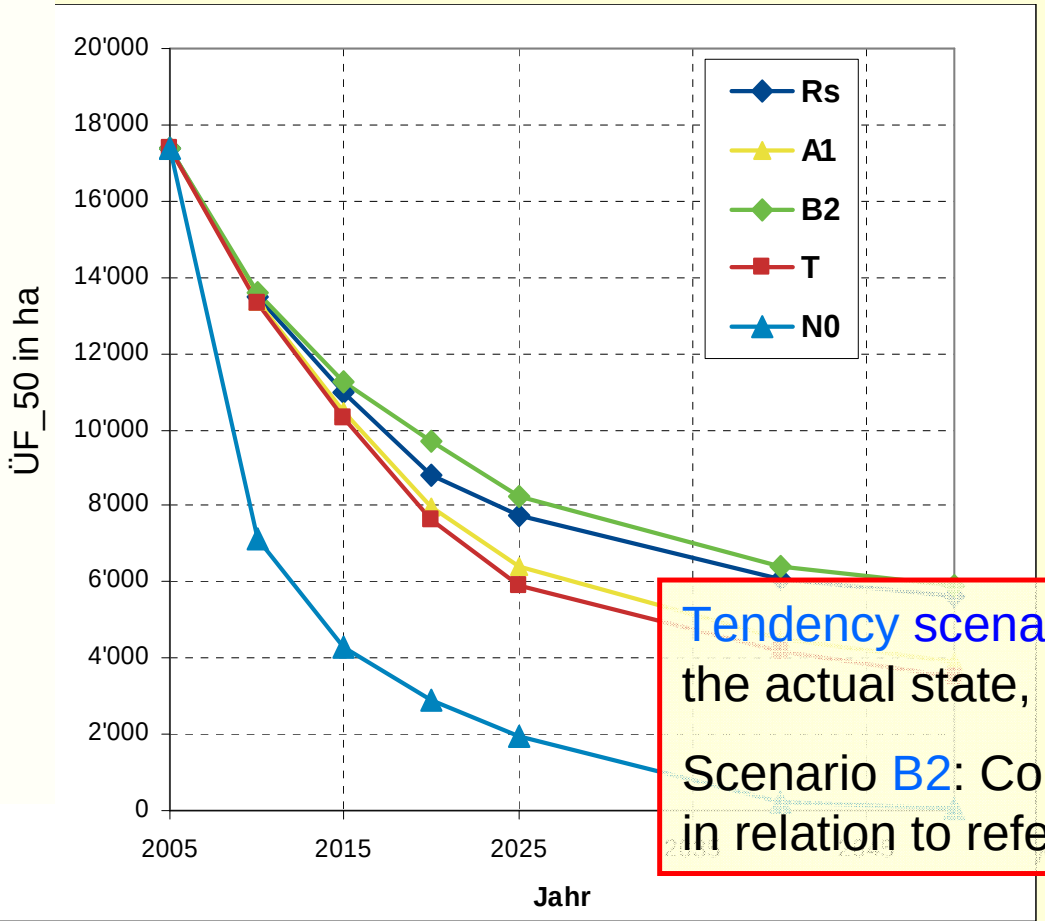
Groundwater: prognosis for scenarios

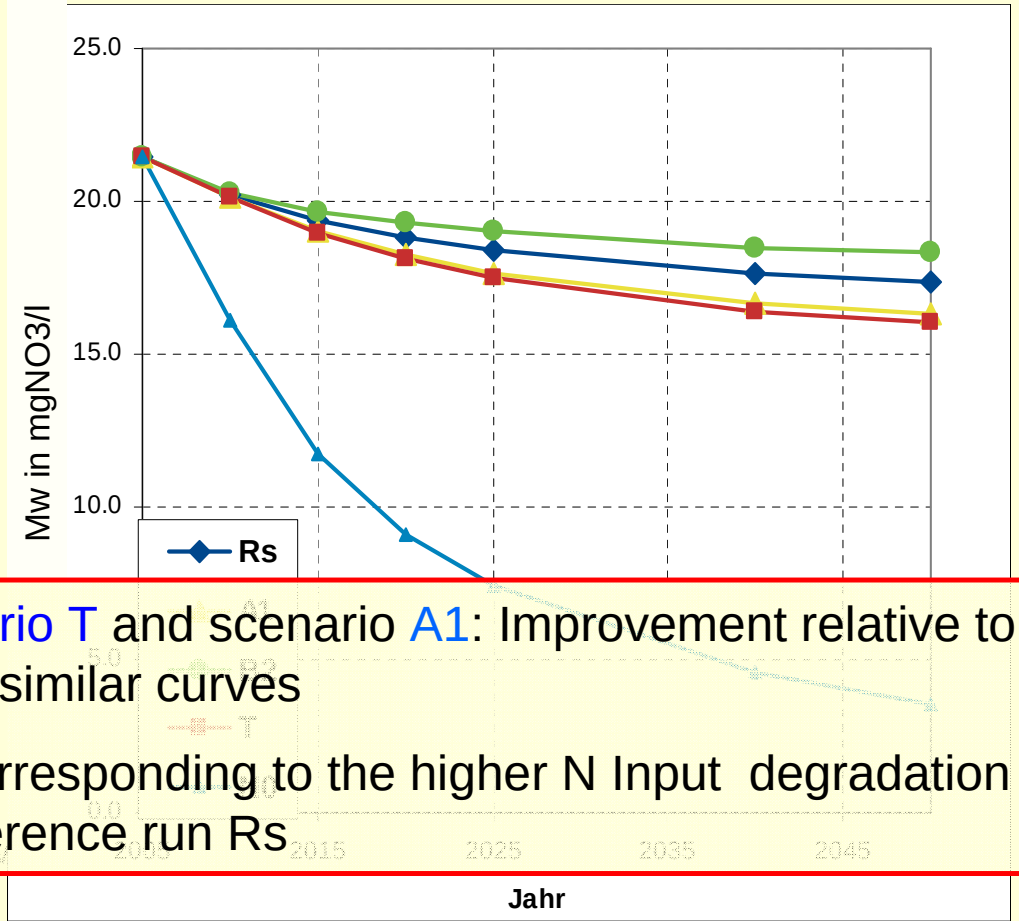
Indicator **ÜF_50**: Total area, in which c_{NO3}= 50 mg/l is exceeded

Indicator **Mw**: Average of c_{NO3} for inner project area (IPA)

Zero-Input-Run (N0): Any N input stopps directly and completely from 2006 on (fictitious)

Reference run (Rs): N-Emission of 2000 (aggregated for the small agricultural areas) remains constant until 2050 ("No action")

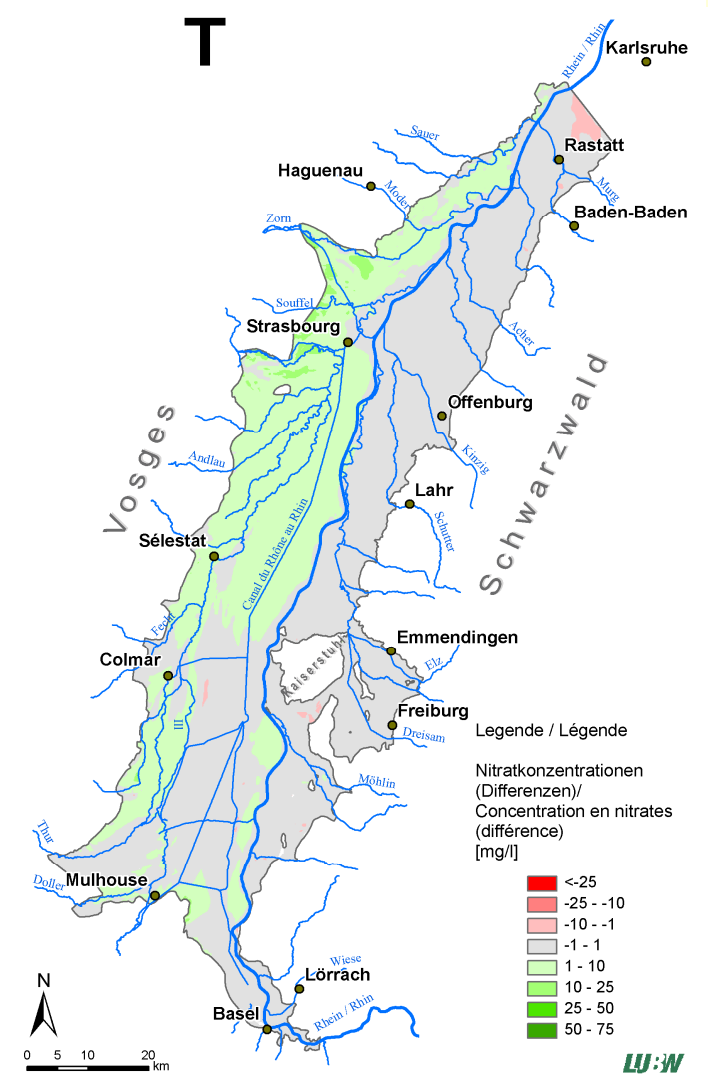


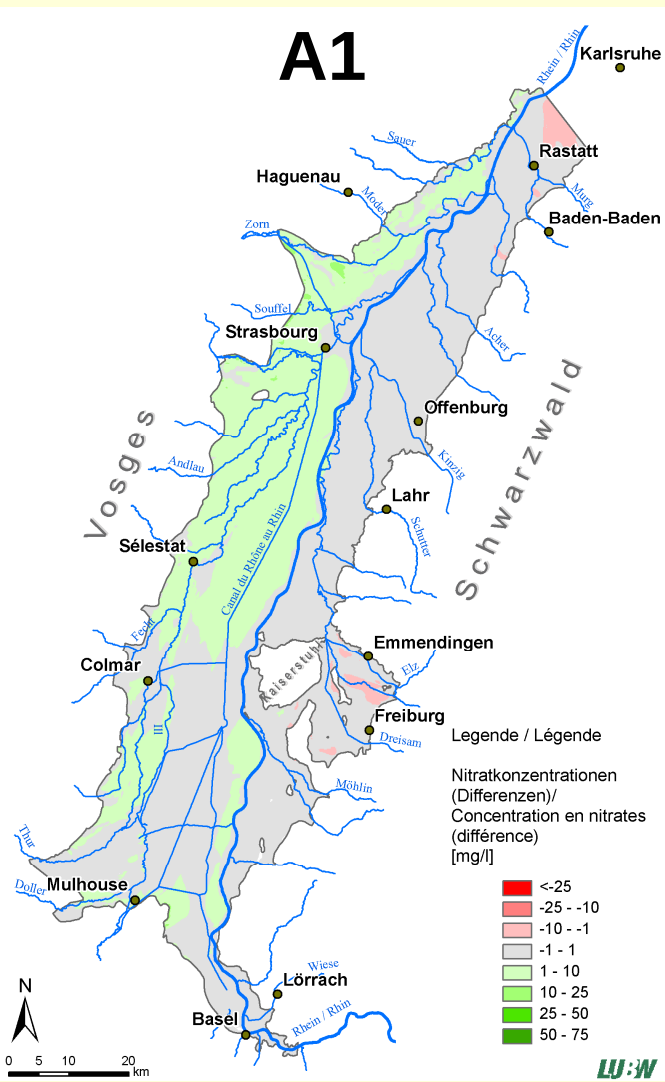


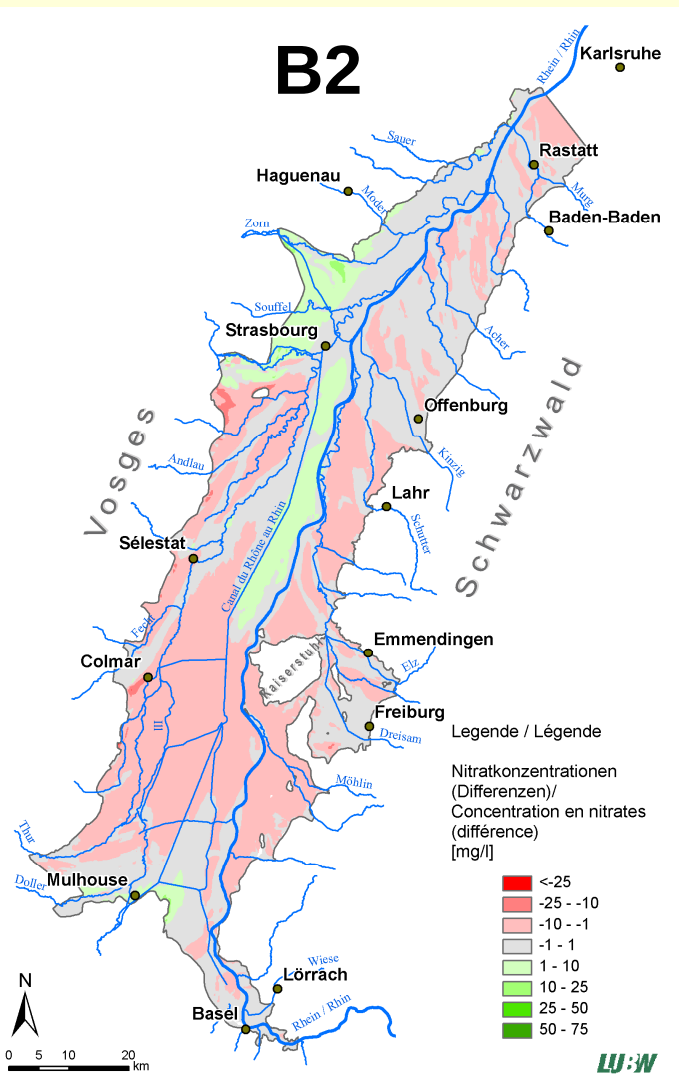
Tendency scenario T and scenario A1: Improvement relative to the actual state, similar curves

Scenario B2: Corresponding to the higher N Input degradation in relation to reference run Rs

Prognosis of change of nitrate concentration for 2050, layer 0 – 10 m, in mg NO3/l - Compared to reference run (Rs)







Implementation of remedial actions

At the present time some of the options for action concerning fertilization and intercropping are already practiced partially

But: regional differences and missing data

→ **The N emission for year 2000, where no remedial actions are considered, is the reference**

Changes in N leaching due to changes in the **amount of fertilizer** or due to **intercropping** depend largely on site characteristics and climate

→ Process-orientated plant-soil-model: STICS (INRA, Avignon)

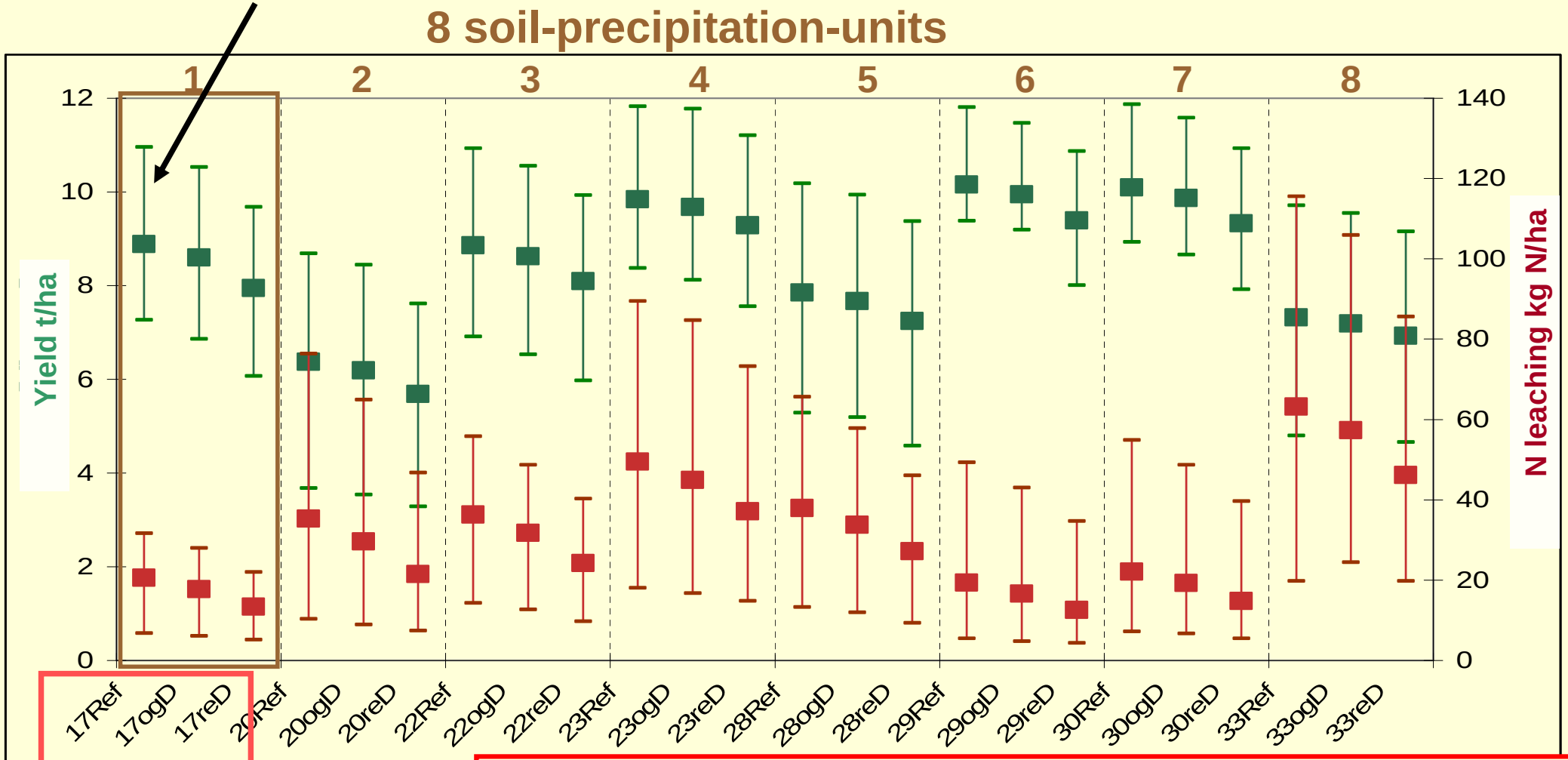
Simulateur mulTIdisciplinaire pour les Cultures Standard

Regionalization: Simulations were made for 43 soil-precipitation areas = 85% of the arable land of the IPA. In the remaining area average values were used

→ 94 % of the arable land is considered in forcasting

Reduction in yield and N leaching for grain maize in the German project area (Model STICS)

Variability: Simulation over 17 years (climate data 1985 – 2002)



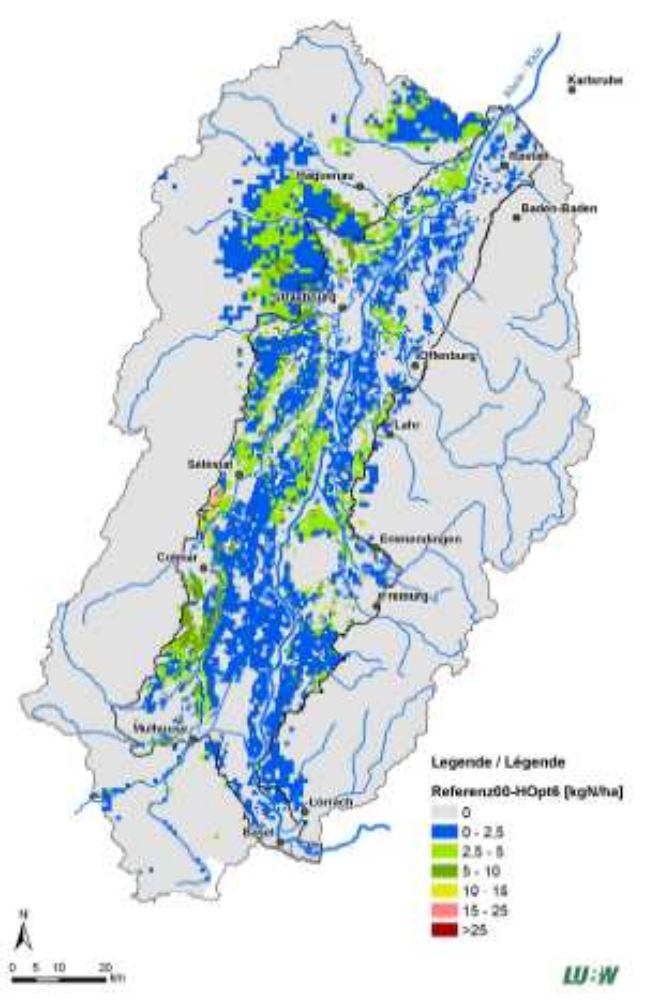
3 variants in fertilizing

Calculated reduction of N-emission expressed as percentages is transfered to STOFFBILANZ

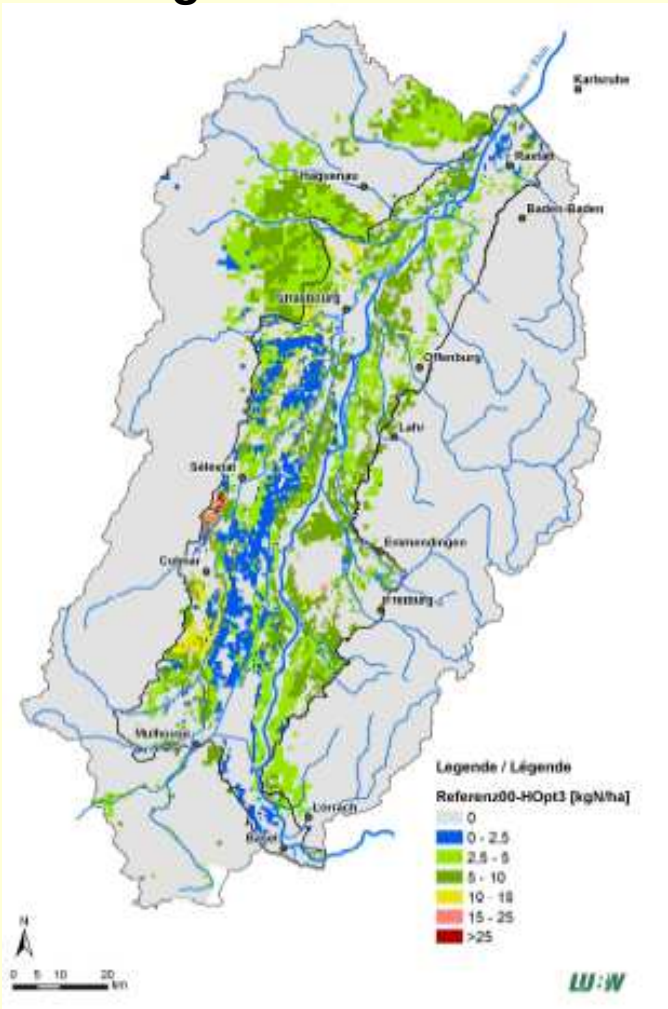
M1 option for action fertilization:

Reduction of N emission compared to the Referenz (N emission 2000) in kg N/ha

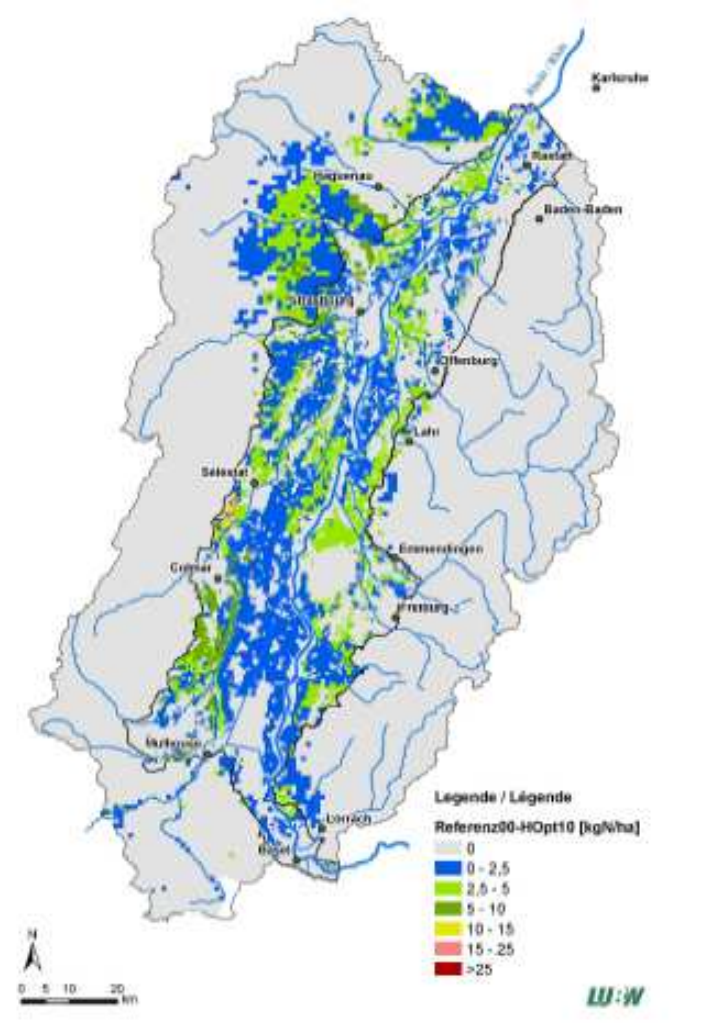
M 1a = fertilization of grain maize according to legal requirements



M 1b = further 20% reduced fertilization of grain maize



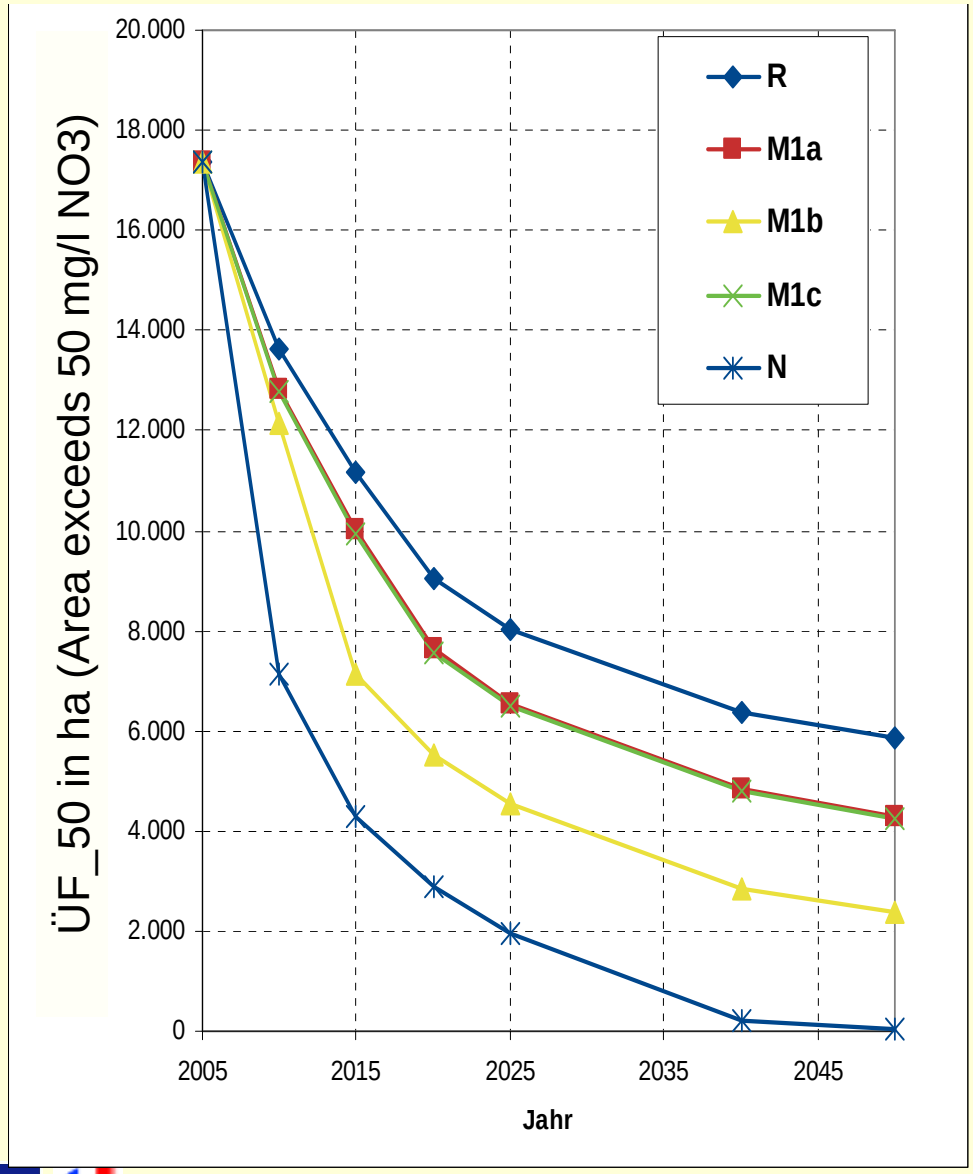
M 1c = fertilization of grain maize and winter wheat according to legal requirements

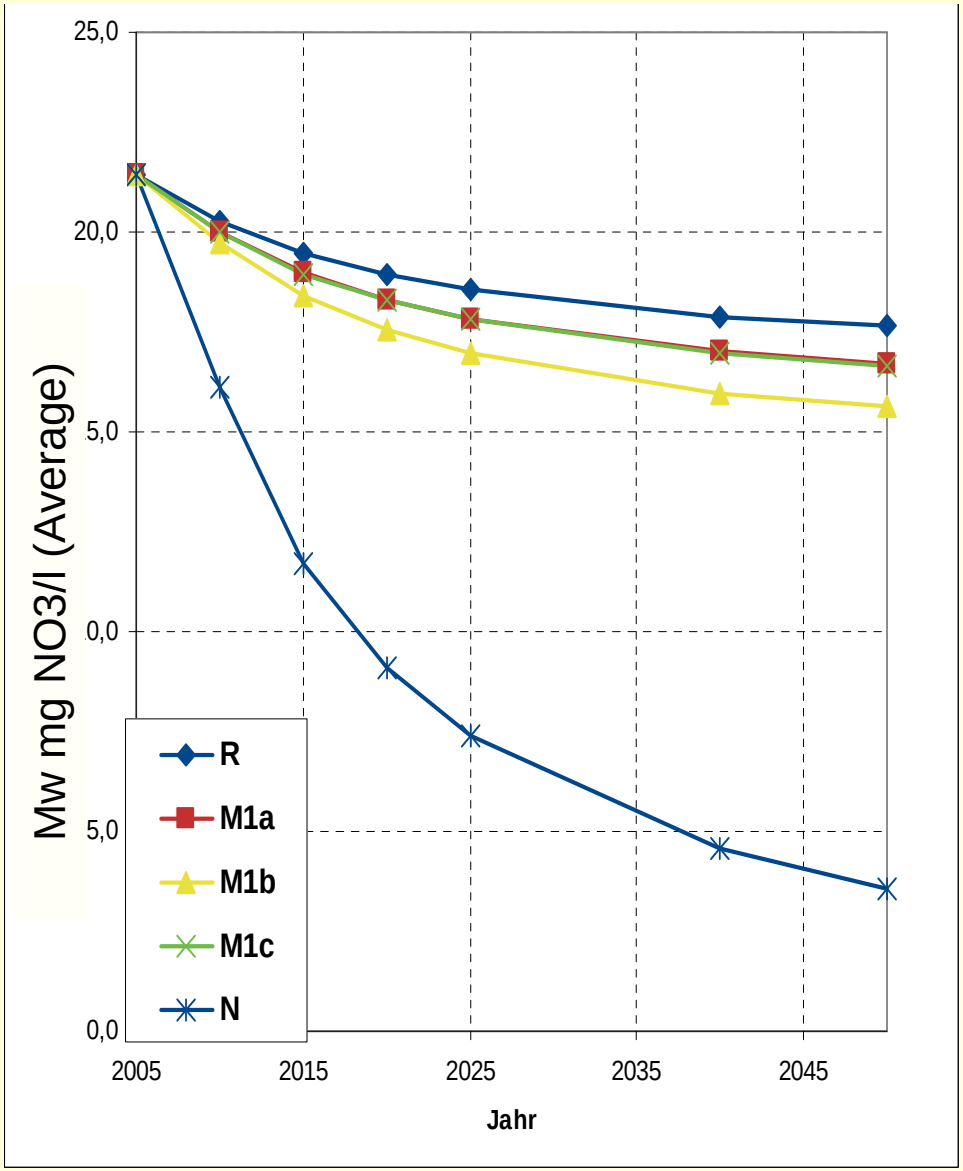


Groundwater: Option fertilization

R: N-immission from 2000 remains constant until 2050

N: N-immission stopps directly and completely from 2006 on





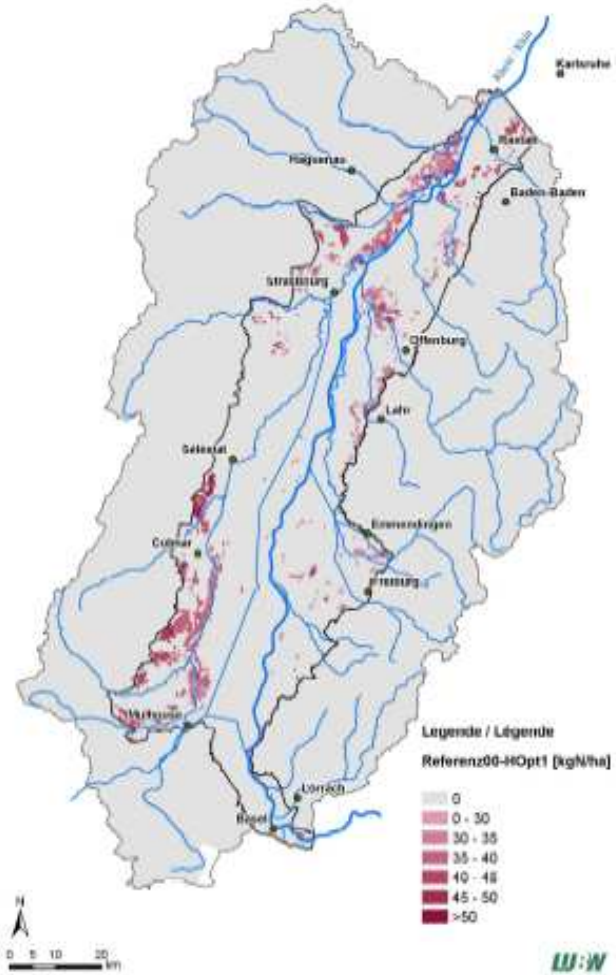
Option for action M3:
Conversion of arable land into grassland

- Effectivity considered as high, feasibility considered as low
- So far only realized in a few options for action (F: CAD (Contrat d'Agriculture Durable)
  Mostly the area is bought by water supply companies
- Since 2005: Duty to keep the amount of grassland constant in the scope of the cross-compliance obligations

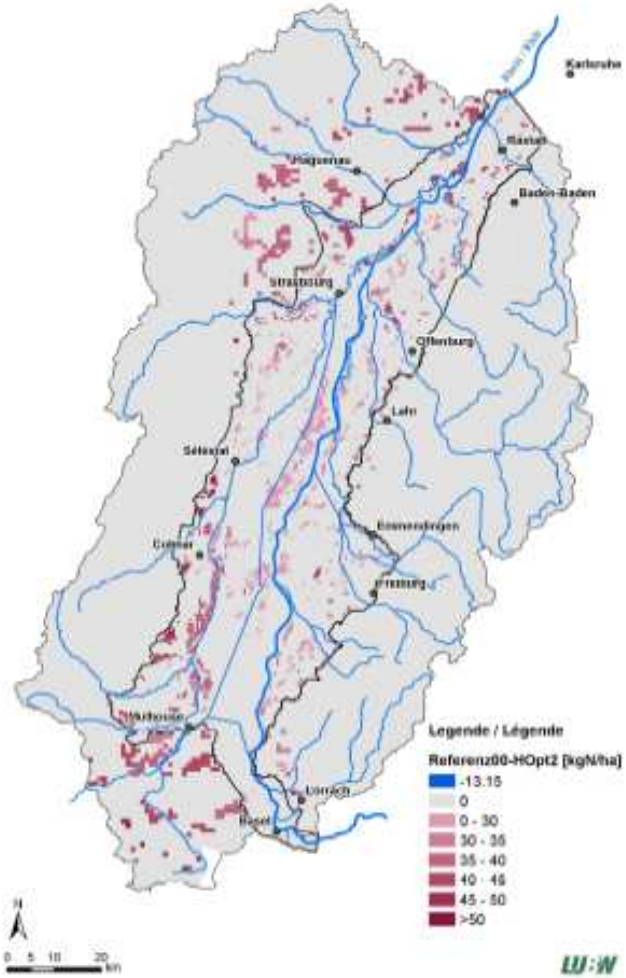
Option for action M3: Conversion arable land into grassland

Reduction of N-emission in comparison to reference run (N emission 2000) in kg N/ha

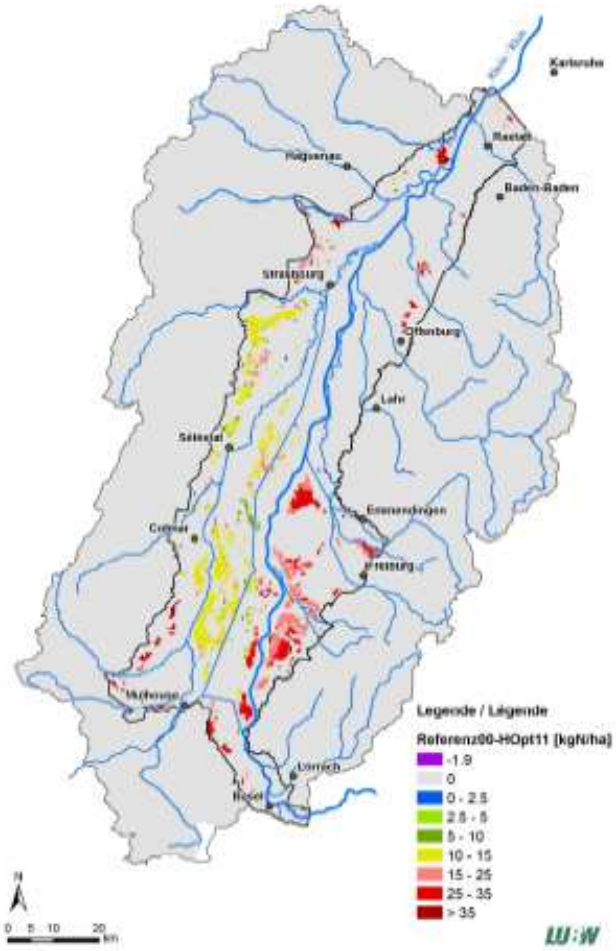
M 3a = 20% of the arable land with the highest N emission in the IPA



M 3b = 20% of the arable land with the highest N emission per municipality

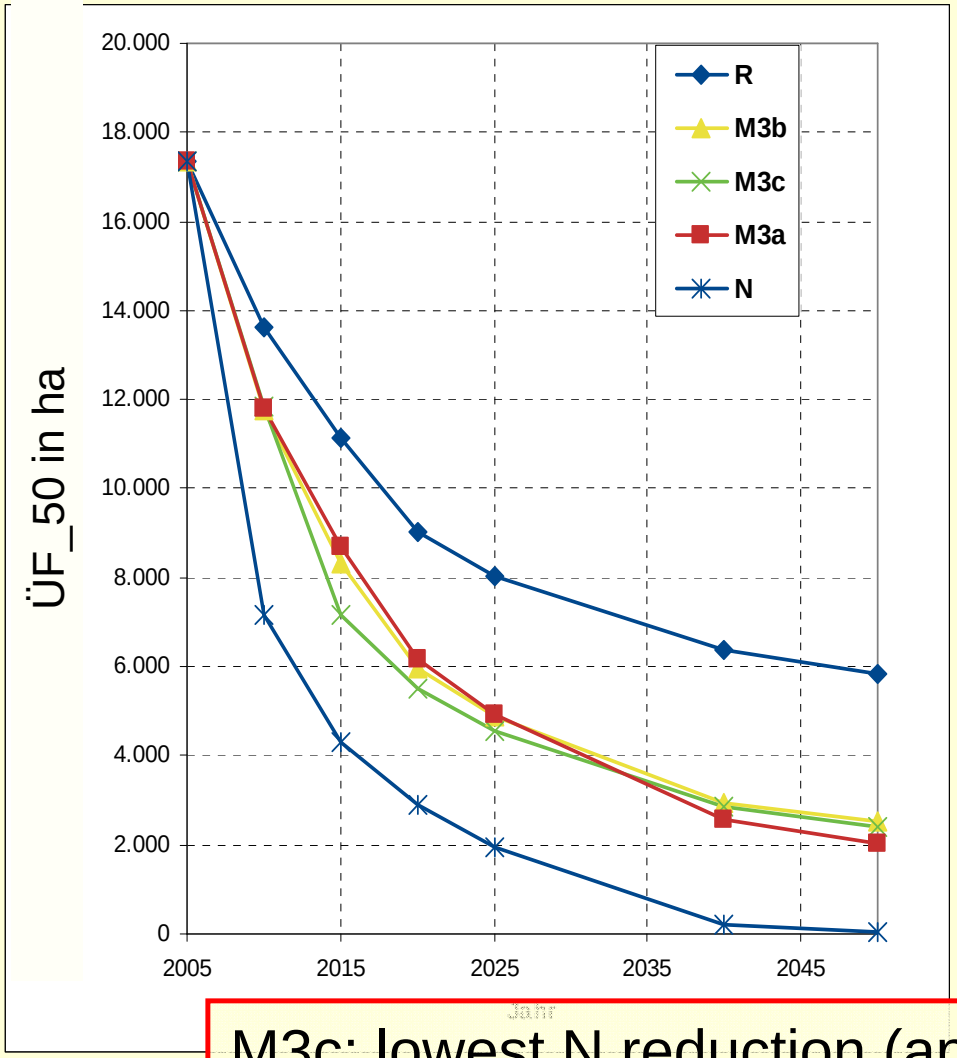


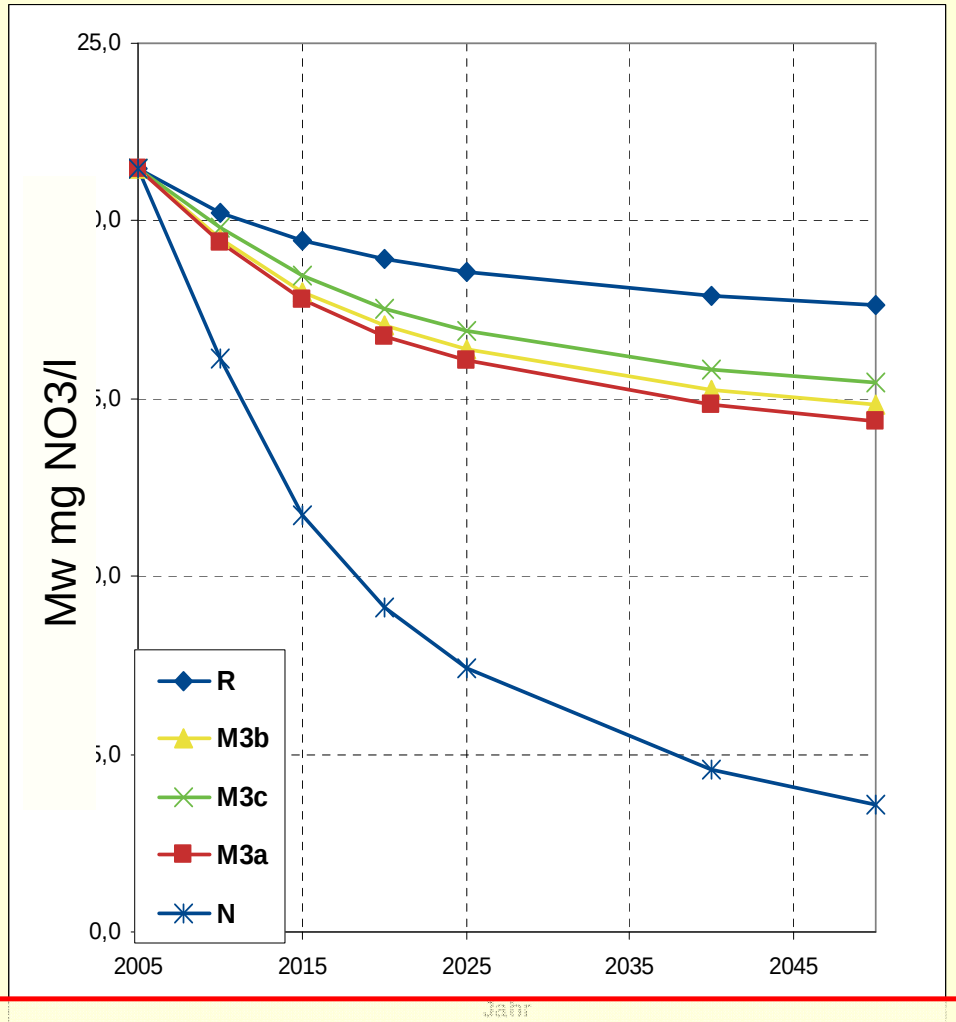
M 3c = 20% of the arable land with unfavorable site characteristics



Groundwater: arable land → grassland

Reduction of N-input$_{A+G}$	R	M3a	M3b	M3c
Averages [kg N/(ha a)], (%)	25,4	19,1 (-25%)	19,9 (-22%)	22,0 (-13%)





M3c: lowest N reduction (approx. = “effort"), but nearly the same effect as M3a and M3b => preferably use of this option!

Further options of action

M2: Maximum amount of intercropping

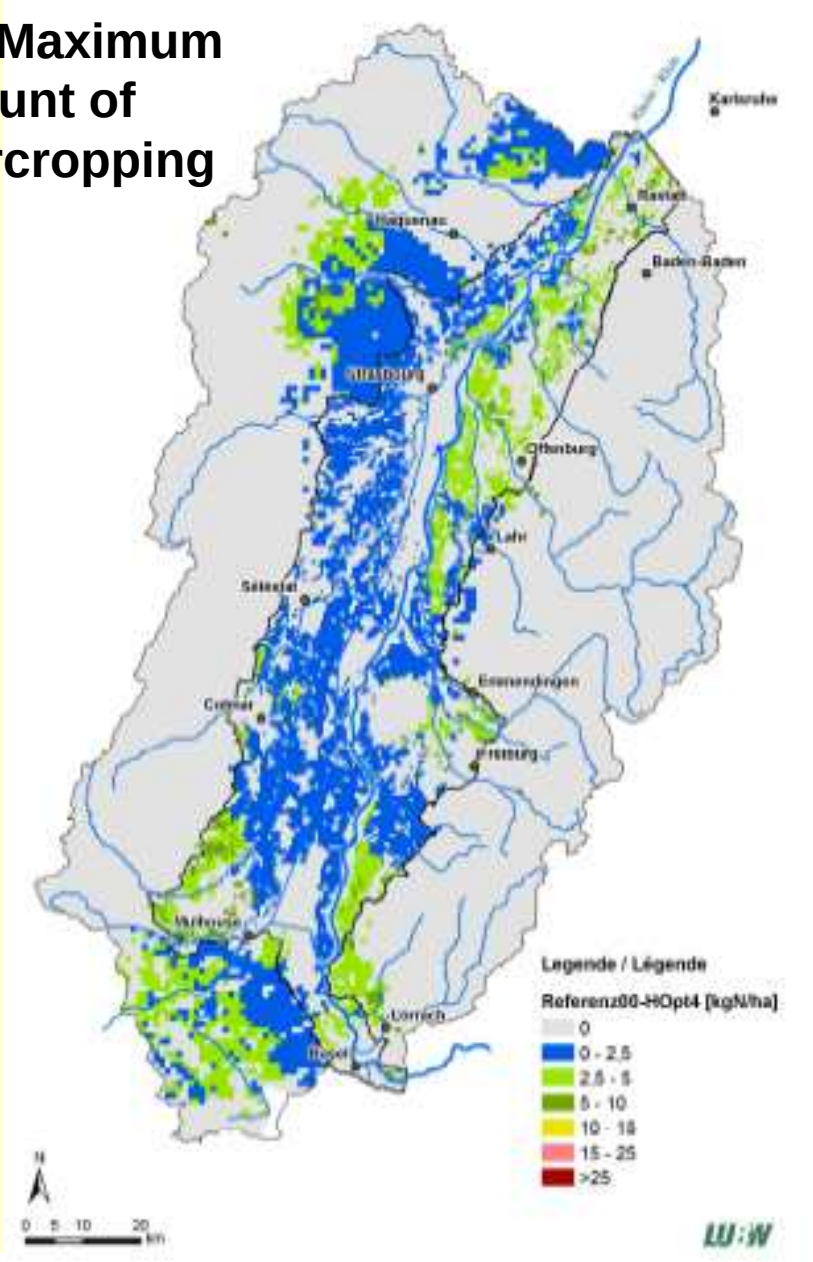
- is demanded by the EU Nitrates-Directive
- is less practiced: e.g in Alsace in the winter wheat cultivation only 9.000 from 40.000 ha
- problem: intercropping is not possible with grain maize cultivation; undersown crops instead (governmental aid in Germany: MEKA; in France: AdERM) only accessed for 2 % of the acreage (2.300 ha)
- model-technical implementation: On the basis of surveys with STICS (Poitou-Charentes) the N surplus of the preceding crop was reduced by 70 %.

- **M4**: Combination of arrangements
- M1a - fertilization according to the legal requirements (grain maize) +
  M2 - maximum intercropping +
  M3a - conversion from 20% of the arable land into grassland in the IPA

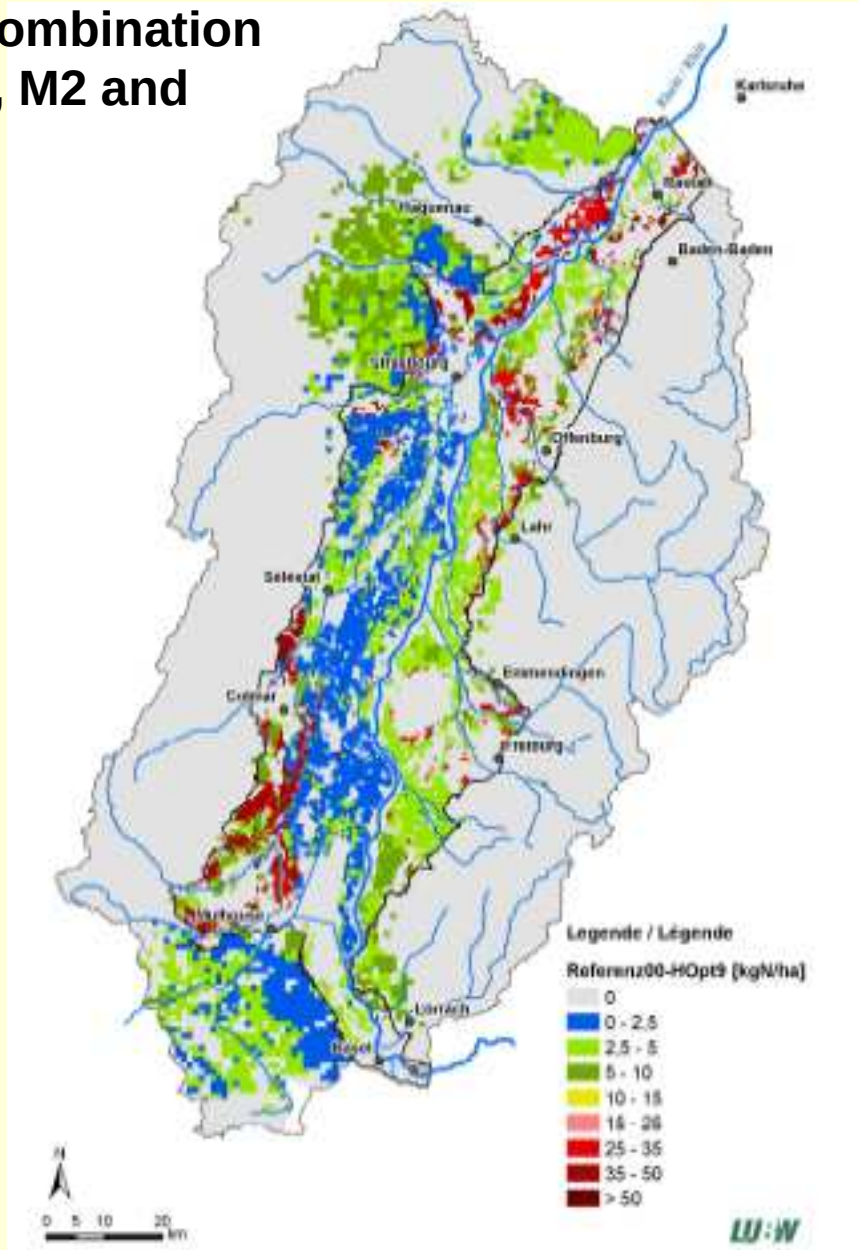
Options for action M2 and M4

Reduction of N emission compared to the Referenz (N emission 2000) in kg N/ha

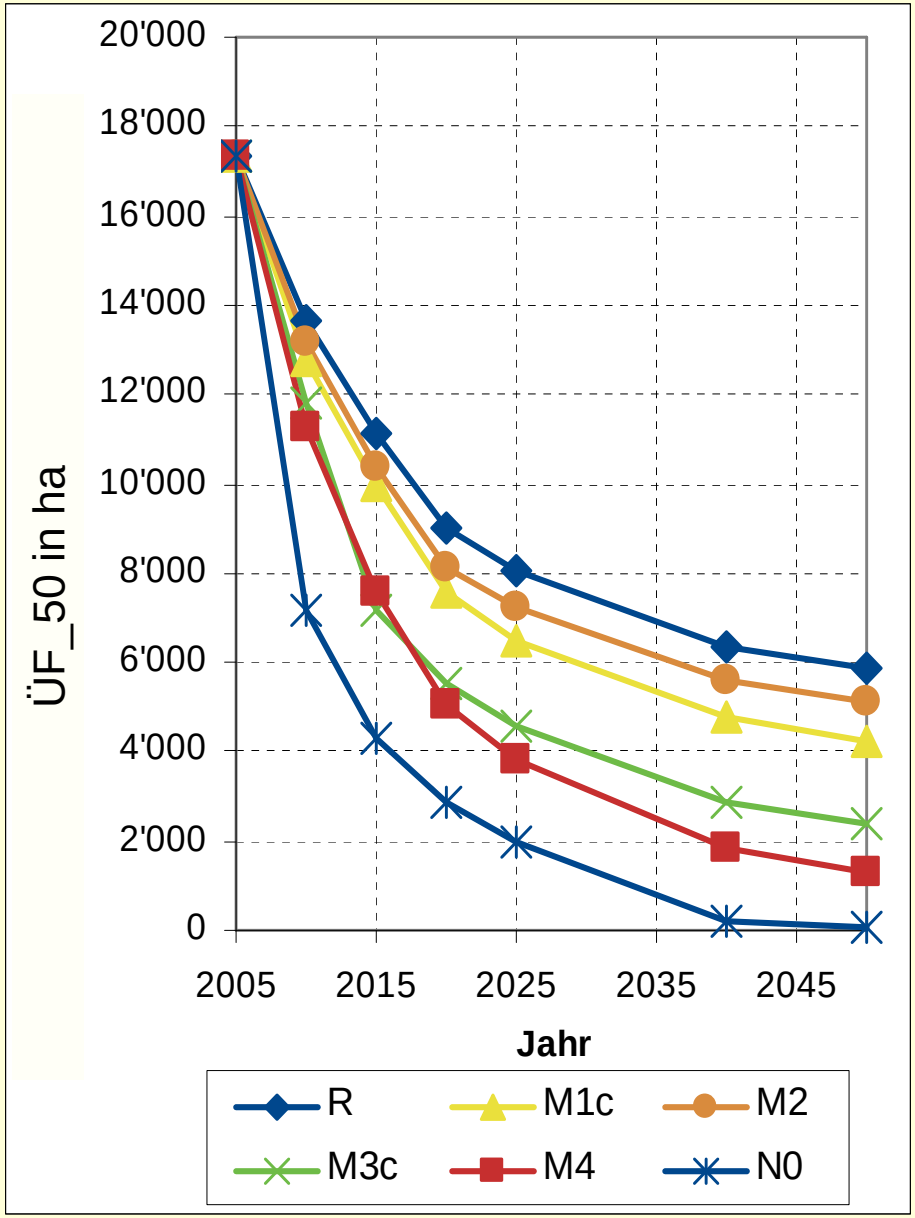
M2: Maximum amount of intercropping

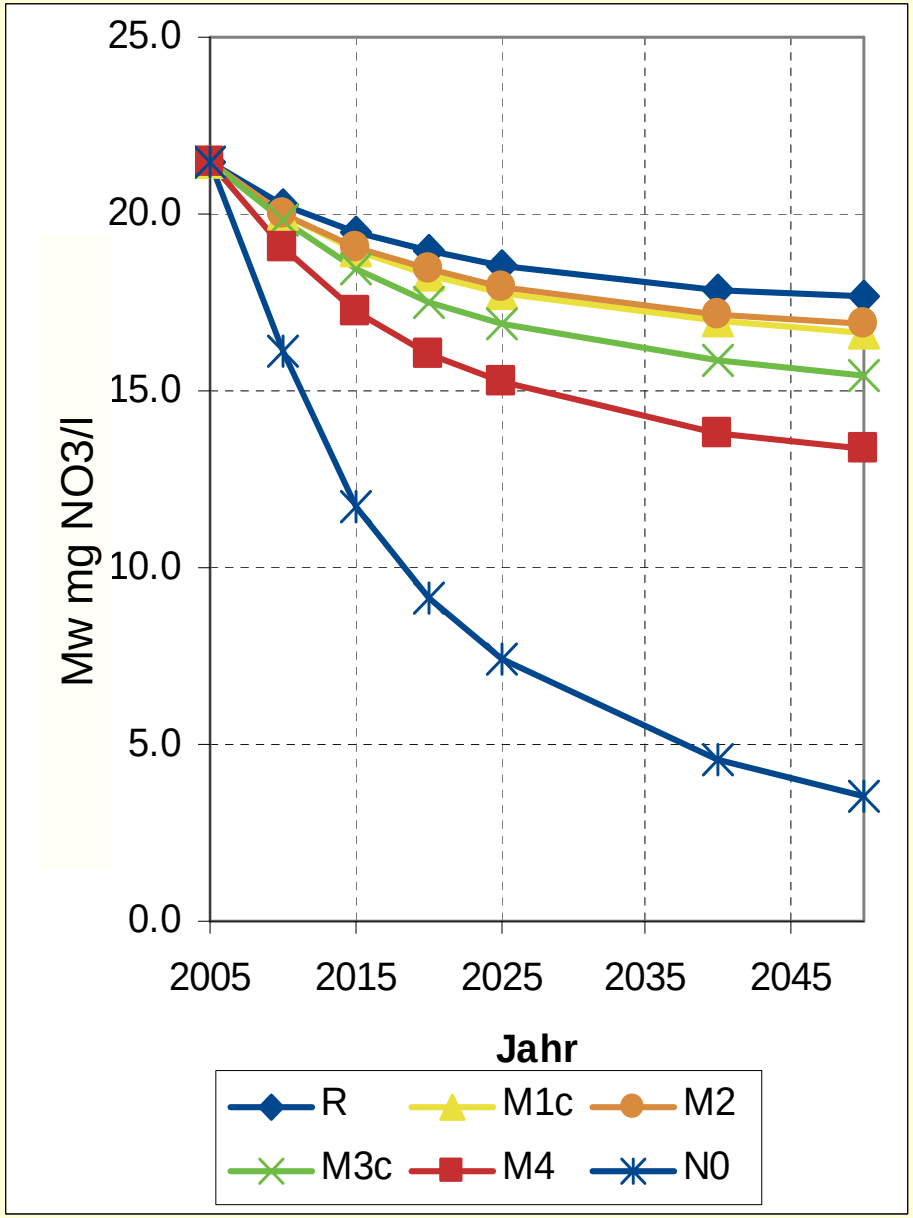


M4 = Combination of M1a, M2 and M3a



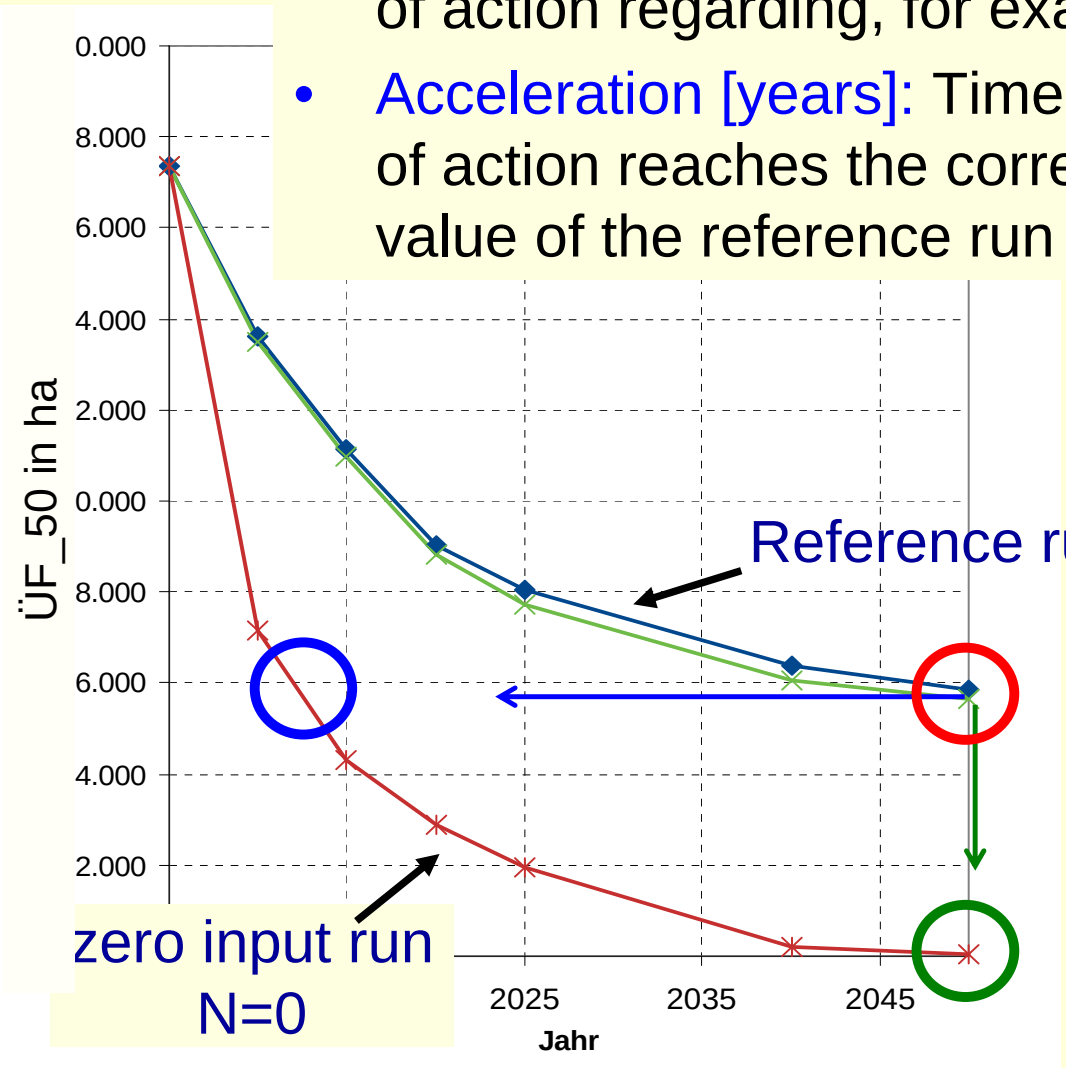
4 remedial actions
Indicators exceeding area (ÜF50) and average (Mw)





Criteria to compare the options of action

- Effectivity [%]: Relative difference (in the year 2050) between the reference run and the run of a specific option of action regarding, for example, the indicator ÜF_50
- Acceleration [years]: Time period in which a specific option of action reaches the corresponding value faster than the value of the reference run in the year 2050

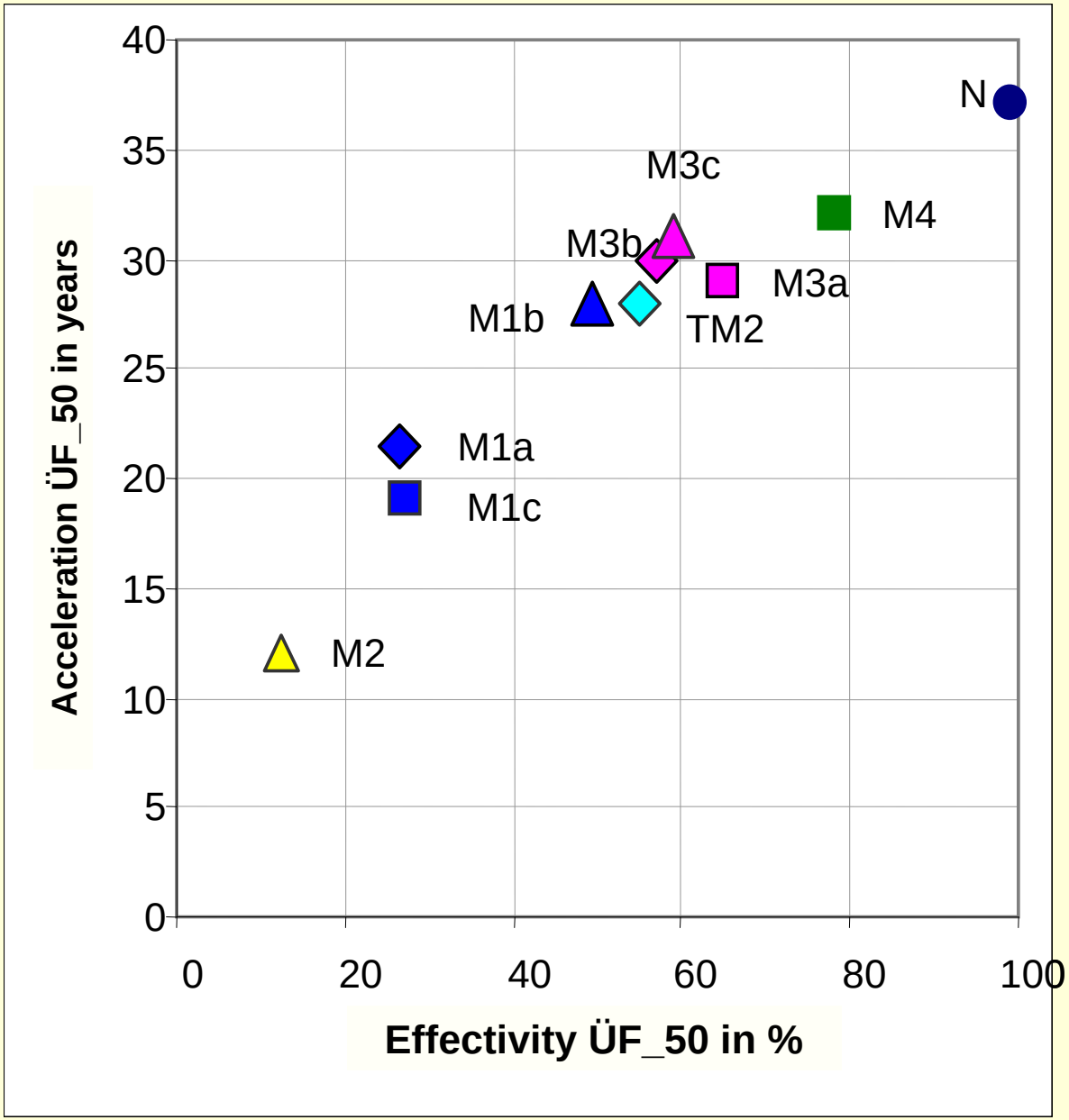


Example zero run:

Acceleration: 38 years

Effectivity: 100%

Overall evaluation of the remedial actions



Relative diminuation of ÜF_50 versus Referenz R

TM2 = Maximum intercropping with cropping pattern as in the trend scenario

Concluding remark

The developed model system MoNit works

a) Magnitude and spatial distribution of the current nitrate load in the groundwater as well as the trend show a satisfactory agreement.

➡ The model can be used for prognosis.

b) Agri-economic scenarios have been worked out and their impact on nitrate leaching and nitrate concentration in the groundwater has been evaluated

c) Mitigation options have been evaluated by local experts. On this basis 8 cultivation measures, relevant for the project area, have been modelled and the impact on nitrate leaching and nitrate concentration in the groundwater comparatively evaluated

The models are run by staff of the institutions LUBW, LTZ and BRGM in order to be able to model current issues.

Publications

Grimm-Strele, J. et al.: Der Modellverbund MoNit zur Simulation der Grundwasser-belastung durch Nitrat im Oberrheingraben. In: Wasserwirtschaft 98 (2008)

Grimm-Strele, J. et al.: Prognose der Nitratbelastung des Grundwassers im Oberrheingraben mit dem Modellverbund MoNit. In: Wasserwirtschaft 98 (2008)

Projektberichte:

- MoNit: Entwicklung von Prognosewerkzeugen (Zwischenpräsentation) / MoNit: Développement des outils de prévision (présentation intermédiaire), 2005
- Hydrogeologischer Bau und hydraulische Eigenschaften / Structure hydrogéologique et caractéristiques hydrauliques, 2006
- Grundwasserströmung und Nitrattransport / Modélisation hydrodynamique et transport des nitrates, 2006
- Fluss-Grundwasser-Interaktion / Interactions nappe-rivière, 2006
- Nitratherkunft im Bodenwasser und Grundwasser / Origine des nitrates dans l'eau du sol et les eaux souterraines, 2006
- Prognosen zur Entwicklung der Nitratbelastung / Perspectives d'evolution de la pollution par les nitrates, 2006

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Thanks a lot for your attention!