# Socio-Economic Implications of Land Use Change Modelling on a Regional Scale

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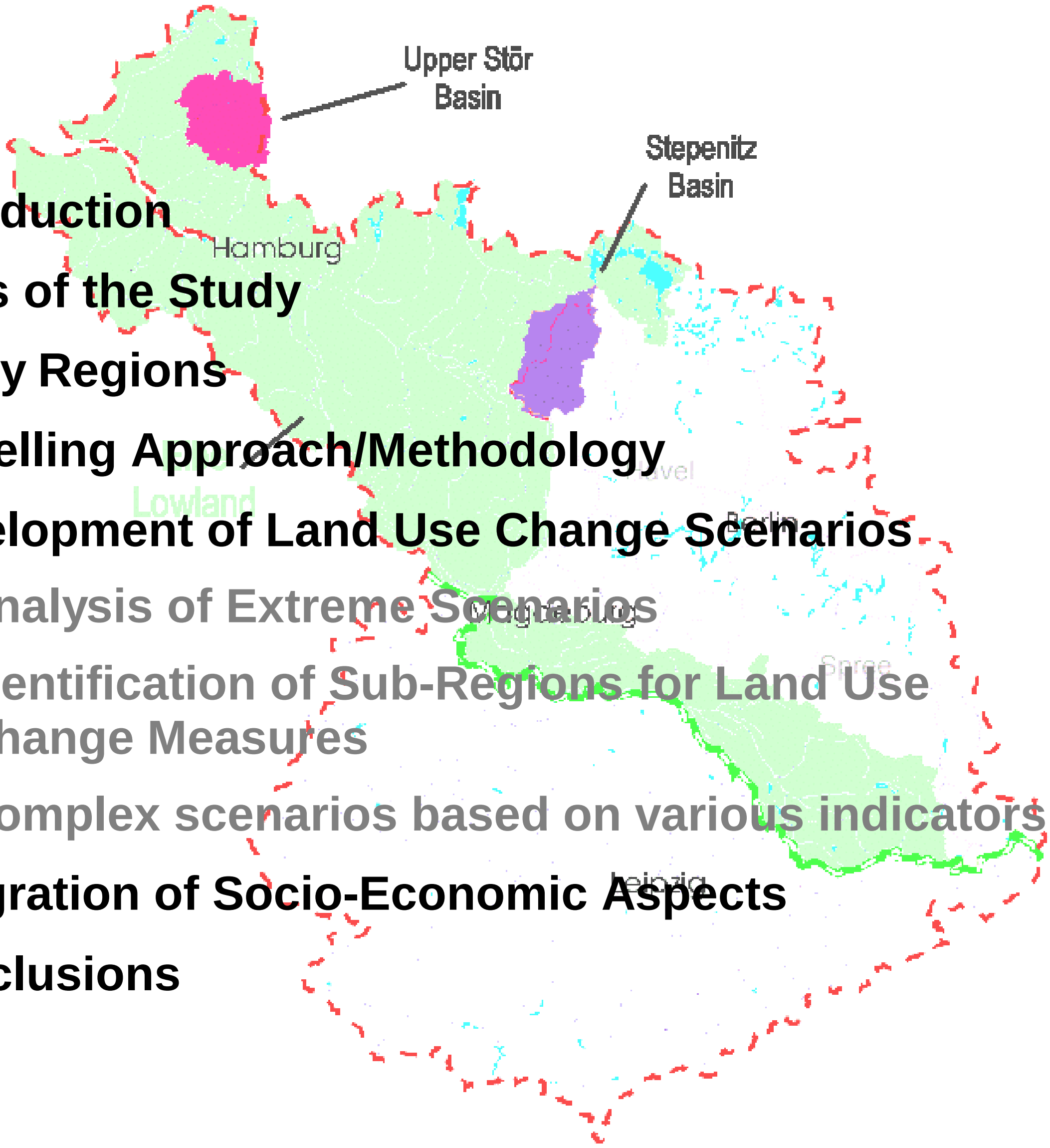


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# INTRODUCTION

- The study of **human impacts on the hydrological cycle** plays a growing role in today's hydrological research.
- Global change phenomena must be investigated at all spatial scales (from local to global), but it is the **regional scale** that is crucial for an improved understanding of the different causes of global change and its impacts on the environment and society.

*Therefore, stronger research efforts are needed at this scale where the most important sources and drivers of global change are located.*

- **River basins** are the preferred land surface units for water-related regional-scale studies because their drainage areas represent *natural spatial integrators or accumulators* of water and associated material transports and thus allow to investigate *cumulative effects of human activities* on the environment.
- **Land use** is one of the main boundary conditions which directly or indirectly influences many hydrological processes.
- In the present study a **concept** is described, which allows to assess the impacts of land use changes (as an important aspect of global change) on the regional water cycle.

# AIMS OF THE STUDY

- The results are part of the **WaStor** (*water and material retention in the Elbe river lowland*) project, a regional sub-project of the interdisciplinary research project '**Elbe-Ecology**' funded by the German Ministry for Education and Research (BMBF).

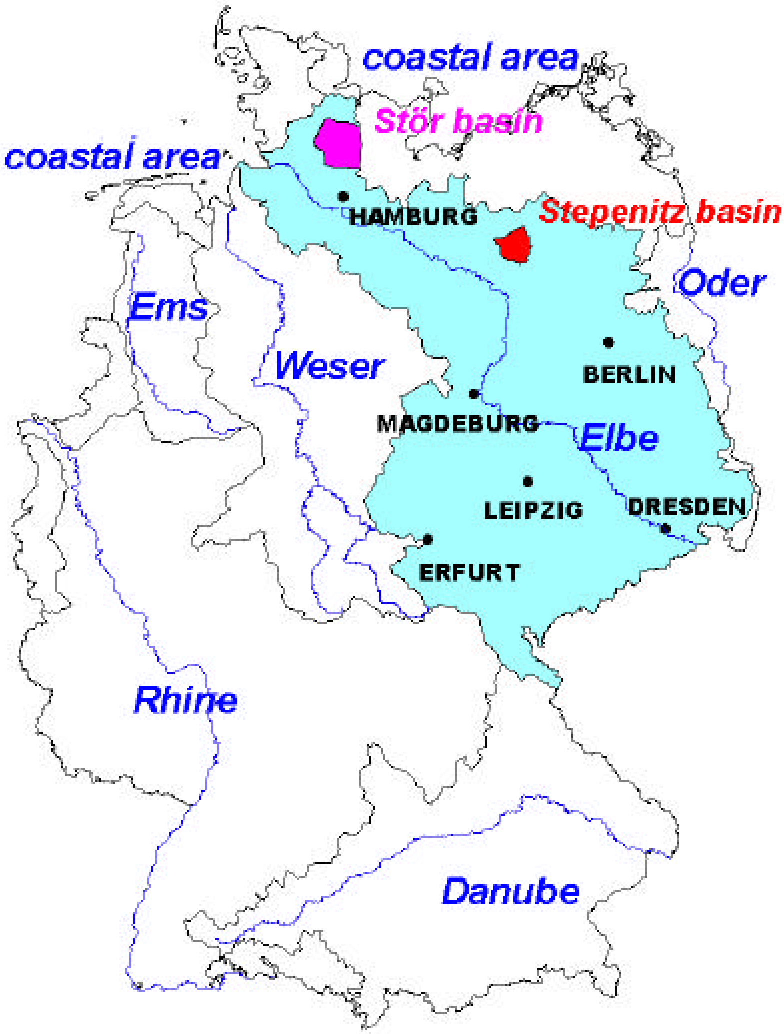
The **aims of this project** are

- to study the influence of various measures of **land use change** on the regional water balance and the river runoff (especially for arable land)
- to analyse possible contributions of **economic and ecological land use management forms** for water retention and flood protection in the Elbe lowland
- to derive methods for the **adaptation to socio-economic conditions**, which will result in a changed land use in the next years
- to derive adequate ('realistic') **scenarios** of land use change (especially for vulnerable and conflict regions) and strategies for a sustainable development in the region.

- **First results** of modelling land use changes are presented for a meso-scale tributary basin of the Elbe river basin, which - due to the changing political and economic conditions after 1989/1990 - is confronted with considerable socio-economic problems.
- The definition of land use change scenarios must, therefore, include **socio-economic aspects** evolving from the regional, national and European legislation (i.e. **Agenda 2000**).
- In the end, the scenarios should result in recommendations which can be used, e.g. by political stake holders.

# STUDY REGIONS

- The primary scale of the 'Elbe-Ecology' project is the **entire German part of the Elbe basin**.
- Special studies are performed in **vulnerable sub-regions** where more detailed data are available.
- Two of these sub-regions are the **Stepenitz** (575 km²) and the **Stör** (1.100 km²) sub-basins.
- Both basins are part of the **pleistocene Elbe lowland** which is representative for (semi) humid landscapes in Europe.
- The **Stepenitz river basin** (situated in the state of Brandenburg) is characterized by a series of complex hydrological and ecological problems.
- These problems result mainly from the **intensive agricultural practices** in almost 80 % of the total basin area and **measures** like melioration, river-bed alignments, and drainage of natural wetlands, which resulted in a considerable loss of natural retention areas in the past.

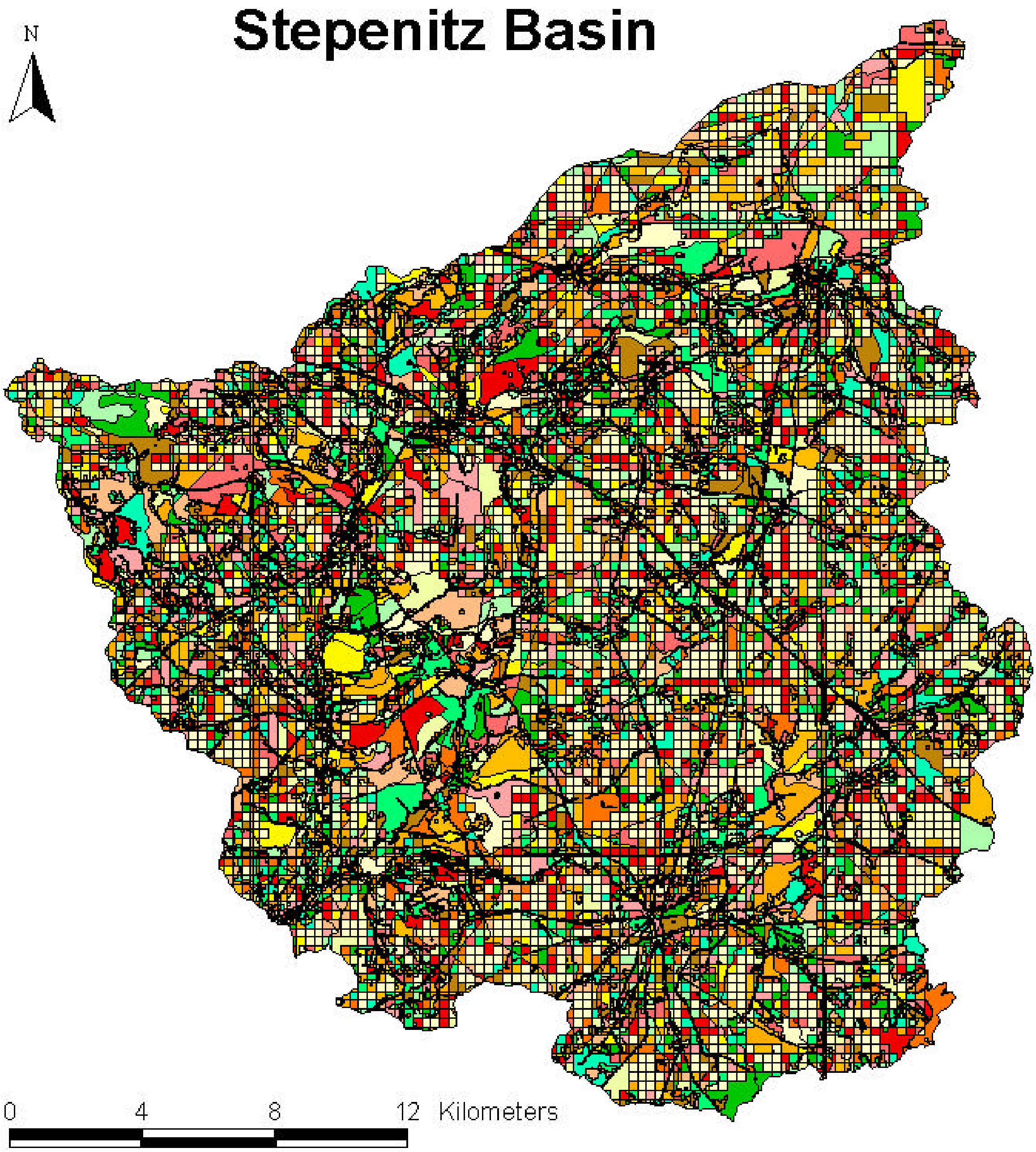



- In addition, large areas are dominated by rather **poor sandy soils** with low agricultural productivity.

# METHODOLOGY

- In order to study the impacts of climate and/or landuse changes on the hydrological cycle, **high resolution data** and **appropriate models** are necessary.
- These models must enable studies, which in detail describe both the natural **spatial variabilities** and the **anthropogenic impacts** at various temporal and spatial scales.
- The present study applies methods of a GIS-based modelling approach, which has been applied from the **mesoscale** up to the **macroscale** (German part of the Elbe river basin, 100.000 $km^2$).
- The approach is based on **variable spatial aggregation and disaggregation techniques**, which allow an effective simulation of the regional hydrological cycle.
- It allows to take into account any type of land surface units, from **biotopes** or **hydrotopes** (patches with the same or similar type of vegetation, land use, hydrological behaviour etc.) up to various aggregated landscape types, which offers the opportunity to correlate biophysical and socio-economic factors.
- **Problems** in assessing these impacts on the mesoscale generally arise from the available data, which due to insufficient resolution (time step, classification etc.) strongly influence the modelling approaches to be used and often inhibit a detailed analysis.

## SPATIAL DISAGGREGATION




**Elementary unit map** of the Stepenitz basin

- resulting from a GIS-based pre-processing of various spatial maps (landuse, soil, groundwater table depth, topography, sub-basin structure)
- comprising 30.176 homogeneous polygons
- basis for modelling.

# DEVELOPMENT OF LAND USE CHANGE SCENARIOS (1)

- The analysis of land use changes in a region is a rather **complex task**, since many different aspects must be taken into account.

- Which areas of the actual land use should be converted into which other type depends both on the **physical properties** of the specific location and on various **socio-economic factors**.

- **In principle**, agricultural land should be converted where areas are used unprofitably and the existing natural conditions (soil, slope, climate etc.) do not fit the actual use.

- **In general**, the form of the scenarios developed for a region strongly depends on

(a) the **specific aims** of the investigation (ecosystem protection, water balance studies, flood protection, etc.),

(b) the **model** used (kind and extent of physical and non-physical boundary conditions that can be taken into account, model sensitivity),

(c) the **spatial scale** (resolution of the available temporal and spatial data) and

(d) the specific **natural and socio-economic characteristics** and constraints of the study region itself.

# DEVELOPMENT OF LAND USE CHANGE SCENARIOS (2)

- In the present study the development of land use change scenarios is performed according to the following **steps**:

1. Comprehensive hydrological modelling and **analysis of the current state** of the river basin, as a basis for the quantitative assessment of influences of various land use alternatives
2. Development and analysis of the impacts of **extreme land use changes**
3. **Identification of sub-regions** which – due to various landscape characteristics – are primary candidates for a possible land use change
4. Development and analysis of **more complex scenarios** (based on several natural indicators)
5. **Inclusion of socio-economic aspects** like management planning of the local government, concerns of various stakeholders and interest groups, and projections of the national and international legislation.

- Based on these steps, a **catalogue** of land use change scenarios is developed and applied, which covers a considerable range of alternatives induced by the natural and economic-ecological constraints of the region.

- One basic aim of the simulation calculations is to investigate whether and how land use changes or alternative management practices may induce positive effects on the **regional water balance**.

# ANALYSIS OF EXTREME SCENARIOS

- One important step in studying the effects of a changed land use on the regional water cycle is the development and analysis of extreme scenarios which

(1) cover the thinkable **width** of hydrological basin response and
(2) demonstrate the **sensitivity** limits of the used model.

- One of the **shortcomings** of such simple scenarios is that they are generally far from being realistic.

- To analyse the effects of land use changes on various regional water balance terms, **two scenarios** were developed and applied in the Stepenitz river basin:

**Scenario 1** assumes the complete conversion of agricultural land (about 66.4 % of the total area) into forest

**Scenario 2** assumes an increase in the degree of sealing for urbanized areas (e.g. settlements) from moderate, i.e. 20% (present state), to complete (100%). This concerns just 2.23 % of the total basin area.

The **results** can be shortly summarized as follows:

- The modelling approach is **sensitive** enough to study the influences of land use changes on the regional water cycle.
- Even land use changes restricted to relatively **small** fractional areas can be modelled.
- The results underline the hydrological importance of **forested areas**, which due to their high evapotranspiration and percolation show a higher water retention potential than arable land, resulting in a considerable reduction of flood runoff.
- Changes in river runoff as induced by scenario 1 would have considerable **consequences** for the regional water budget and the availability of drinking water.

# IDENTIFICATION OF SUB-REGIONS FOR LAND USE CHANGE MEASURES

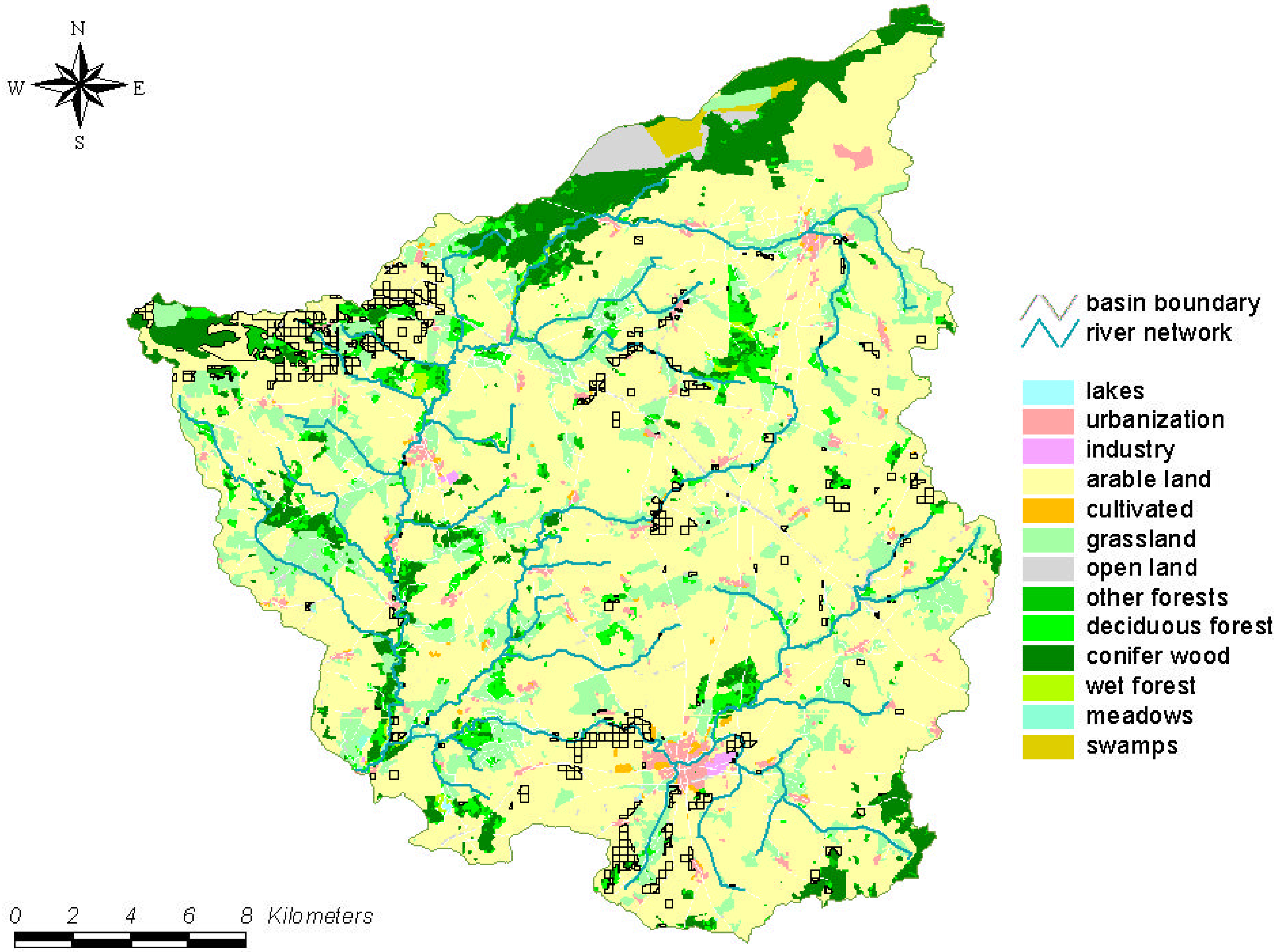
- The identification of areas which are **primary candidates for a possible land use change** is based on **statistical analyses** of various landscape characteristics. They use **correlations** between the actual land use and various natural properties ('indicators') which strongly determine the actual land use:

> - **Soil** properties are the primary key for farming, as they determine the qualification of an area for a specific cultivation and the maximum reachable yield.
> - The **slope** plays an important role only in mountainous regions, as it enlarges the costs of farming.
> - The **ground water table depth** (GWTD) is another important local characteristic defining the agricultural use of an area. Many cultivations require GWTDs between ~0.8 m and ~1.5 m (dependent on the soil type). On the other hand, pasture-land requires GWTDs between ~0.4 m and ~0.8 m and, therefore is restricted to wetland or riperian areas.

- The **multi-criterial analyses** can identify areas that for various reasons are not (or less) suited for the actual land use. Moreover, they can reveal shortcomings in the basic maps, which prevent the generation of detailed land use change scenarios.
- Following **general conclusions** can be drawn from the statistical analyses:

1. **Forests** are usually pushed back into areas where topography, surface conditions or soil quality are unfavourable for agricultural use.
2. **Topography** does not play a dominant role in the Stepenitz basin, but can be used to identify areas which may be converted to e.g. (unmanaged) grassland.
3. Insufficient **resolution** or **class differentiation** of the used spatial maps must be properly taken into account in generating complex land use change scenarios.

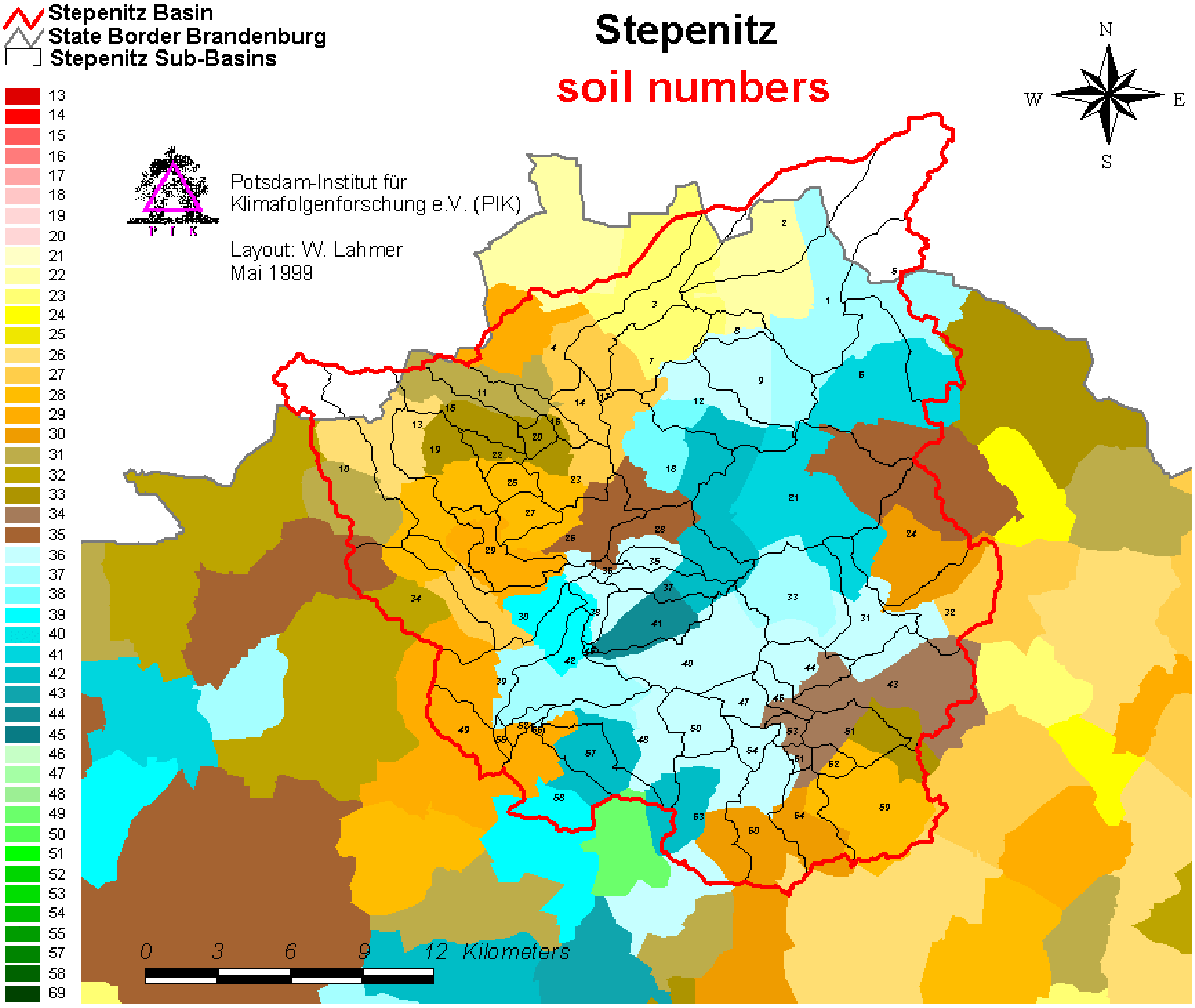
# Identification of sub-regions as primary areas for a possible landuse change




**Agricultural areas** in the Stepenitz basin characterized by a **slope > 4%** (black outlined areas), which might be converted into dry pasture land. The small fractional area demonstrates that topography does not play a dominant role in the Stepenitz basin.

# Soil number as additional indicators

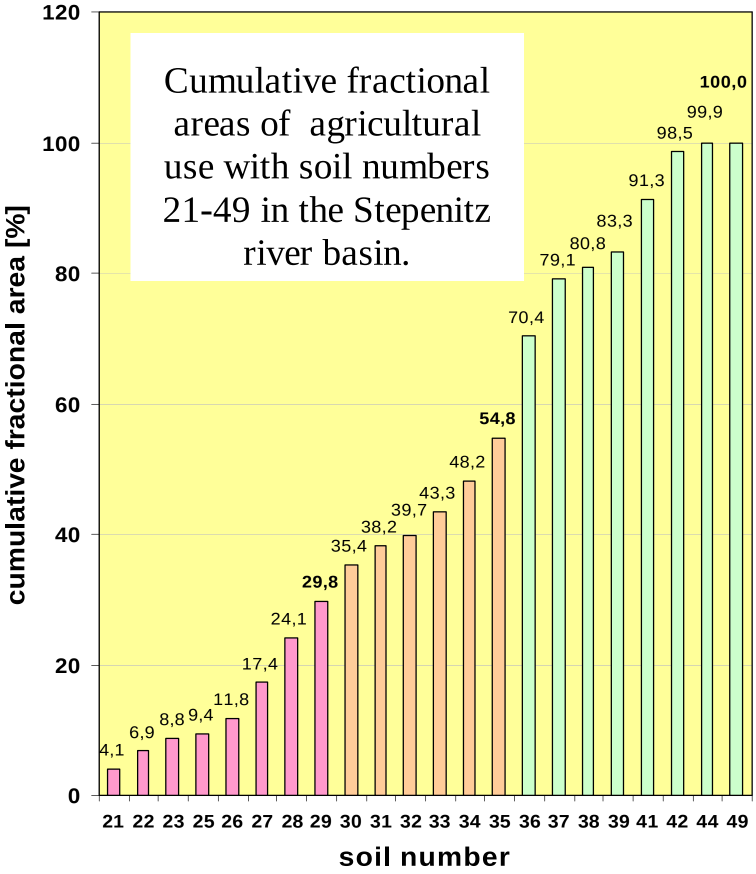
Besides the physical parameters already mentioned, also the so called '**soil number**' is used in identifying areas which – under pure natural constraints – are preferred areas for a change of the actual land use.




Spatial distribution of SN in the Stepenitz river basin, ranging from 21 (bad agricultural conditions) to 49 (relatively good conditions).

- Though this **indicator for soil quality** is based on rather old investigations (1934) and is relevant only for a few cultivation types, it represents an important additional indicator for the derivation of more complex and realistic scenarios.
- Therefore, it should be used as additional selection criterion in simulating the regional hydrological cycle for a changed land use.

# Landuse change scenarios including the indicator ‘soil number’



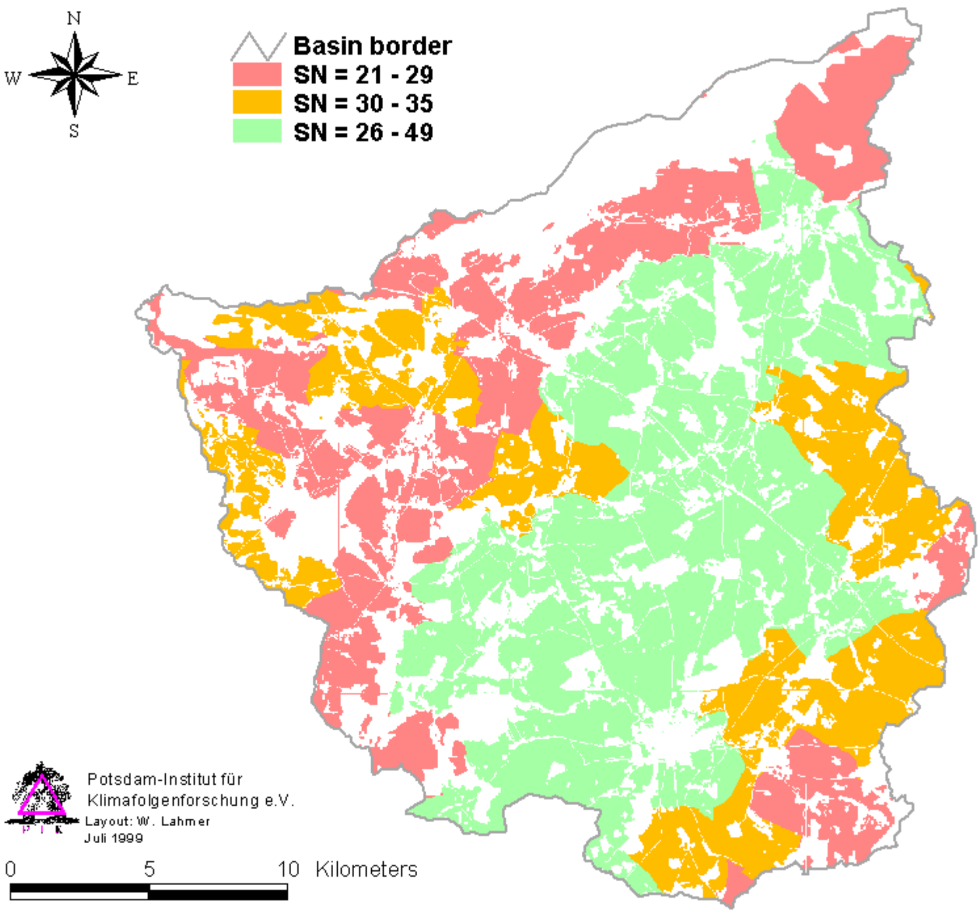

- Based on the cumulated fractional areas of actual agricultural use corresponding to the soil numbers SN=21-49 in the basin, **arable land was changed into bare land** for

  SN = 29 (***scenario 1***),

  SN = 35 (***scenario 2***), and

  SN = 49 (***scenario 3***).

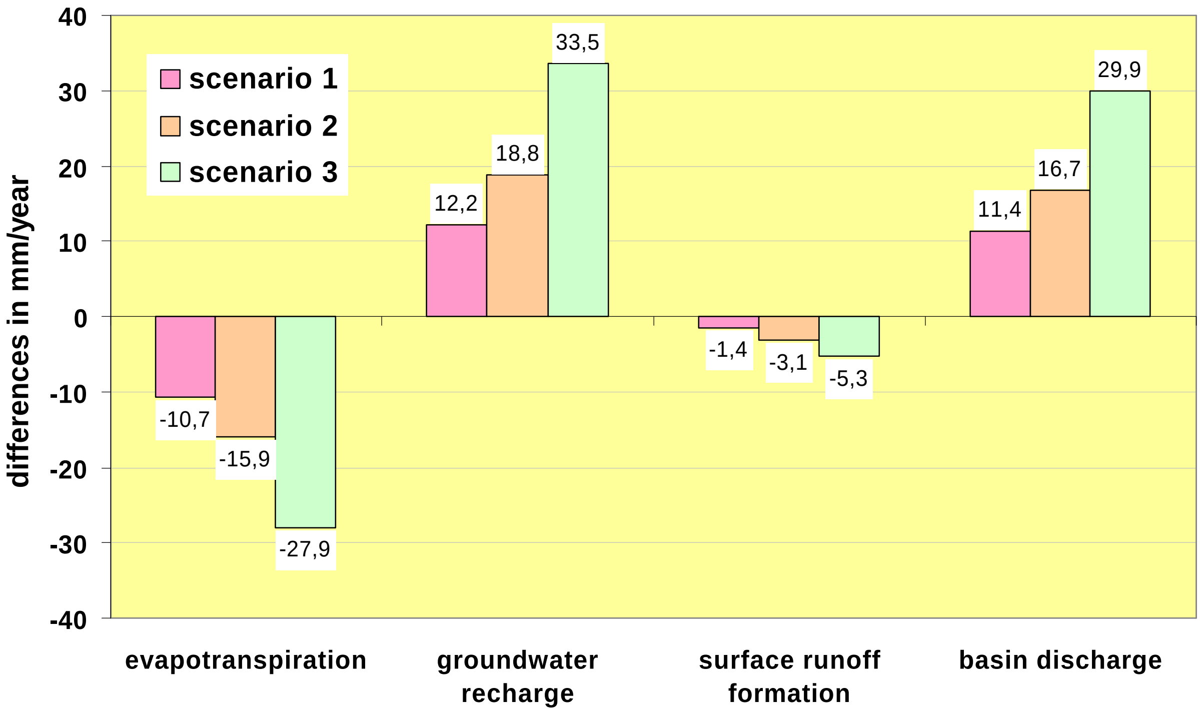
- These scenarios correspond to a conversion of 29.8%, 54.8% and 100% of the actual agricultural area in the basin, or to 19.7%, 36.2%, and 66.0% of the whole basin area.




Agricultural areas with soil numbers = 29, = 35 and = 49 (all areas) in the Stepenitz basin, which were converted into bare land.

# Simulation results
# including the indicator ‘soil number’

- **Water balance calculations** on a daily time step were performed for the reference scenario (actual land use) and the three land use change scenarios for the period 1981 to 1993.




Changes of the mean annual sums of various water balance components calculated for the period 1981-1993 in case of converting arable into bare land.

- Basin **evapotranspiration** decreases by 2.2%, 3.4%, and 5.9% with increasing conversion rate as compared to the actual land use.
- The mean annual **groundwater recharge** increases by 15.0%, 23.4%, and 40.9% for the three scenarios.
- The changes of **surface runoff** are rather small.
- Basin **discharge** increases by 7.1%, 10.7%, and 19.1% for the 3 scenarios, due to the decrease of evapotranspiration and the increase of groundwater recharge.

⇨ These results can be considered ‚realistic‘ only if the soil number is an appropriate indicator for the suitability of agricultural use of a region.

⇨ **Correlation analyses** between the SN map and the other basic maps used for modelling show, however, that clear correlations between the soil number and other landscape characteristics are more or less restricted to the actual land use.

⇨ An alternative ‘quality indicator’ should be derived.

# Definition of more complex land use change scenarios

*Importance of various conversion modes for arable land in the Stepenitz river basin as function of different local conditions defined by the groundwater table depth (GWTD), topography (slope) and productivity (soil number SN).*

| conversion of arable land into | local conditions | parameters/ indicators |
|---|---|---|
| **bare land** | low productivity/bad soils<br>high landscape heterogeneity | SN = 20<br>local mosaic patterns |
| **grassland** | topography<br>medium to deep groundwater table | slope = 4%<br>GWTD = 2m |
| **forest** | low productivity/bad soils<br>deep groundwater table | SN = 30<br>GWTD = 5m |

**GENERAL PRINCIPLES:**

- Unprofitable areas (bad soils, pronounced topography, high landscape heterogeneity etc.) should be abandoned in favour of an intensive use of good quality areas, either totally (without any further management) or in the form of, e.g. unmanaged grassland.
- Due to the bad sandy soils, the **conversion of arable land into bare land** is the favoured conversion type in the state of Brandenburg, especially for heterogeneous or low productivity areas, which should be completely taken out of management.
- The **conversion of arable land into grassland** (‚dry pasture‘) is favoured on areas with larger GWTD and considerable slope (erosion protection).
- The **forestation of arable land** is the preferred land use change mode on areas with deep GWTD and bad soils (small soil numbers).

| local condition | extensive use on | |
|---|---|---|
| | arable land | pasture |
| deep GWTD | ++ | - |
| medium GWTD | +(+) | + |
| shallow GWTD | - | ++ |

(legend: - not relevant, 0 almost no effect, + relevant/positive effect, ++ very positive effect

## Extensive use

Instead of changing the land use type, agricultural areas may be less intensively used as well.

- The **‚extensivation‘ of arable land** represents an alternative to forestation on areas with deep GWD, as long as the soils are of reasonable quality.
- On the other hand, **pasture** should be extensively used on areas with shallow GWD (due to nutrient reduction).

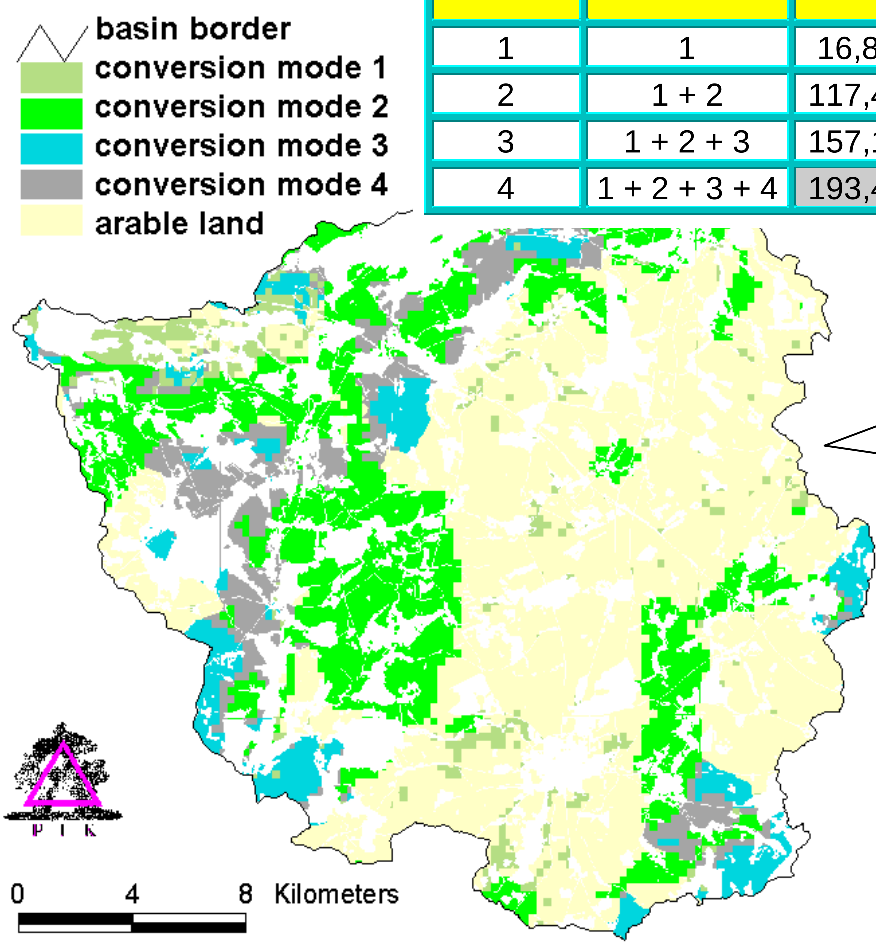
# Conversion of bare land into 4 other land use types

- Example for more complex landuse change scenarios
- **4** more or less 'realistic' **conversion modes** based on the indicators groundwater table depth (GWTD), topography (slope) and productivity (soil number SN)

| conversion mode | description of landuse change mode | area [km²] | percentage of arable land [%] | percentage of catchment area [%] |
|---|---|---|---|---|
| 1 | arable land -> dry pasture for slope >= 4% | 16,8 | 4,4 | 2,9 |
| 2 | arable land -> meadow for GWTD <= 0.75m | 100,6 | 26,5 | 17,5 |
| 3 | arable land -> forest for GWTD >=4.5m and SN <=29 | 39,7 | 10,5 | 6,9 |
| 4 | arable land -> open land for 0.75m < GWTD < 4.5m and SN <=29 | 36,3 | 9,6 | 6,3 |
| | | 193,4 | 50,9 | 33,6 |

*From the 4 conversion modes the following **4 scenarios** were derived (including more and more affected areas):*

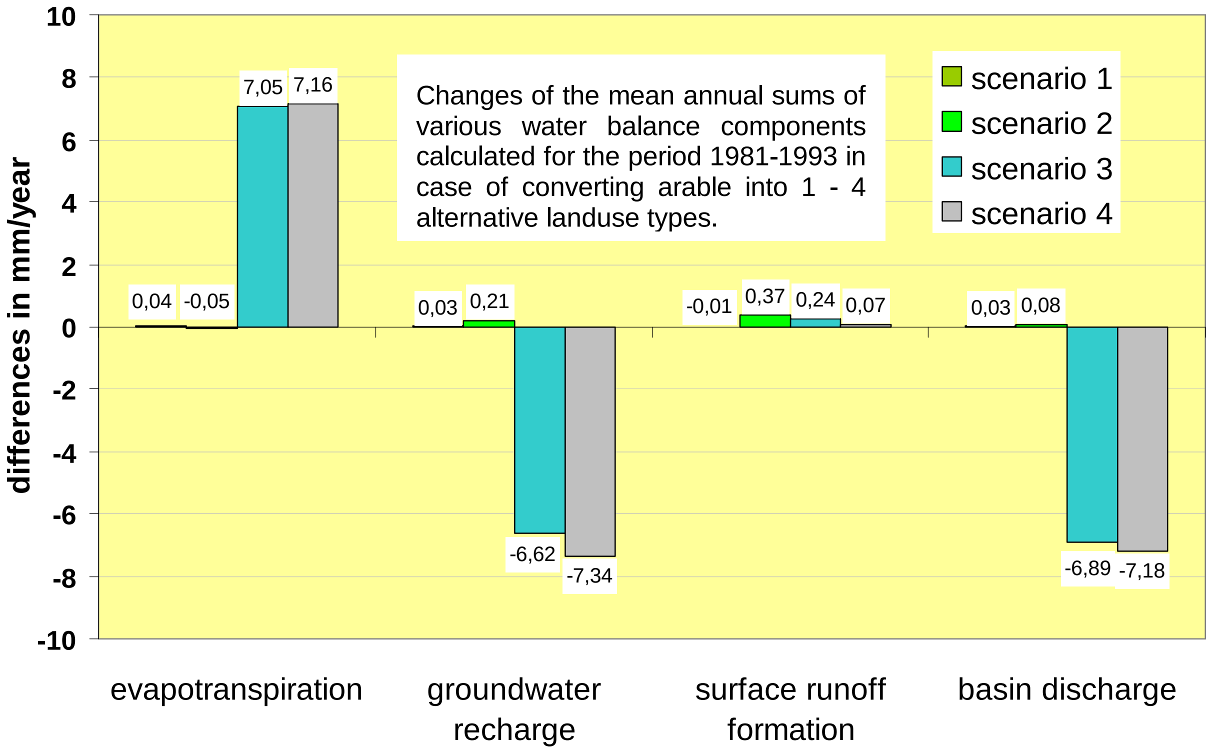
| scenario | conversion modes | area [km²] | Percentage of arable land [%] | Percentage of catchment area [%] |
|---|---|---|---|---|
| 1 | 1 | 16,82 | 4,43 | 2,93 |
| 2 | 1 + 2 | 117,42 | 30,93 | 20,42 |
| 3 | 1 + 2 + 3 | 157,14 | 41,39 | 27,33 |
| 4 | 1 + 2 + 3 + 4 | 193,43 | 50,95 | 33,65 |




The selected areas are concentrated in the western and eastern part of the basin, whereas the central part (which is better suited for agricultural use) is more or less unchanged.

# Simulation results for the complex scenarios

- **Water balance calculations** on a daily time step were performed for the reference scenario (actual land use) and the 4 land use change scenarios for the period 1981 to 1993.




- The conversion of arable land into **dry pasture** (conversion mode 1), **meadows** (CM 2) or **open land** (CM 4) does not result in considerable changes of the water balance components, due to the small fractional areas or a small sensitivity against these types of landuse change.
- Larger changes result from the conversion of arable land into **forests** (CM 3), which dominates the scenarios 3 and 4.
- Influences on the surface runoff are generally small, since non of the considered landuse types is characterized by high surface runoff formation.

## CONCLUSIONS

- ❖ **Moderate changes** of the actual landuse result in relatively small changes of the annual water balance components. The changes calculated for scenario 4 are +1.50%, -7.31%, 0.12% and -4.15% as compared to the actual landuse.
- ❖ This means a reduction from 3.44 $m^3/s$ to 3.31 $m^3/s$, i.e. 0.13 $m^3/s$ of the mean annual **basin discharge**, mainly due to forestation.
- ❖ Larger reductions of the basin discharge (increase of the basin water retention potential) are possible only by **forestation** of larger areas. This, however, seems to be questionable in view of the already existing water deficit in the region.

# INTEGRATION OF SOCIO-ECONOMIC ASPECTS

The identification of areas for a changed land use based on **natural indicators** must be extended by **socio-economic aspects**.

The corresponding **catalogue** should include the

- management planning of the **local government**,
- concerns of various stakeholders and **interest groups** and
- projections of the **national and international legislation**.

*Especially the still outstanding reforms of the agriculture policy of the European Union (EU) (**Agenda 2000**) will induce far-reaching structural changes in the New German Countries.*

What and how many agricultural areas will be affected by these reforms depends on many details like

- the concrete **regulations**,
- **price** developments (also on the global market),
- the **structure** and **intensity** of the actual land use,
- the **amount of areas** to be taken out of management or into extensive use,
- the **financial support** for forestation or new sustainable management forms paid to the farmers and
- the **adaptability** of the farmers themselves.

- However, land use change measures can be successfully implemented only, if a reasonable **long-term economic situation** and a high **employment rate** of the main users (farmers) is guaranteed. !
- The **opposition** to the implementation of land use and management changes will be the higher the better the actual economic situation and the lower the adaptation potential. !
- The changes will induce relatively **small effects** in regions with an already high rate of extensive agricultural practices.
- In order to quantify both the specific regional economic conditions and the potential effects of outstanding land use change measures, r**epresentative farms** in pre-selected areas will be analysed on the basis of the actual land management and use.
- Besides the various natural conditions, these analyses will include the **assessment of structural data** like the size of the farms, areas used for agriculture and livestock, agricultural practices, and management intensity (conventional, extensive, ecological).
- Based on these analyses, **'realistic' land use change scenarios** will be generated and analysed.

# The AGENDA 2000

- Defined as a **strategic political concept** of the European Commission
- Hints on the **strengthening** (economic growth, competitiveness, employment) and **expansion** of the EU (eastern countries) in the first decade of the 21th century.
- The **reform of the common agricultural policy** represents an important part of this concept, in order
  - ❖ to secure a competitive agriculture and a sustainable production of high quality food
  - ❖ and to preserve multiform agricultural practices.
- To achieve these aims, **prices of important products** are going to be reduced in favour of a higher **direct financial support** of the farmers.
- According to a study of Braun et al. (1998) dealing with the influences of this reform on the state of **Brandenburg**, the following **problems** are to be expected:
  1. The **competitiveness** of the agricultural companies will not be adequately supported,
  2. the **income** of the farmers will decrease by more than 10%, and
  3. the **administrative expenses** will rise.

# Conclusions

⇨ First results of simulating land use changes on the meso-scale demonstrate the quality of the applied **GIS-based modelling concept**, which

- directly uses **model parameters** derived from generally available spatial data and
- provides **spatial and temporal results** of various water balance components.

⇨ The **disaggregation** of the study area into homogeneous areal units (*elementary units*), followed by an **aggregation** of areas with equal or similar hydrological behaviour (*hydro-topes*) has turned out to be an effective method to study long-term impacts of land use (or climate) changes.

⇨ **Multi-criterial analyses** show that high resolution spatial data are needed to study human impacts on the hydrological cycle in a river basin.

⇨ The modelling approach has turned out to be **sensitive** enough to cope with land use changes restricted to small fractional areas.

⇨ One of the key tasks is the development of more **sophisti-cated land use change scenarios** which fit all (or at least the most important) conditions and constraints of the region under study.

⇨ A reasonable increase of the basin's water retention capacity seems to be possible only by **forestation** of larger areas. This, however, is contradictory to the already existing water deficit in the region.

⇨ Besides the physical processes and parameters that must be taken into account in long-term transient land use change scenario calculations, the implementation of **socio-economic aspects** represents one of the major challenges in this type of hydrological modelling.