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Long-Term Integrated Water Management in the German Elbe River Basin

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ABSTRACT: A general Integration Methodology and Approach (IMA) has been developed to investigate multipurpose management in large river basins. Main steps of the approach are:

1. Problem description and goals definition
2. Conceptualisation
3. Scenario definition and alternative management design
4. Simulation and estimation of effects/impacts
5. Evaluation
6. Comparison and negotiation.

Stakeholders and decision makers are involved in all steps of the approach. The approach is now applied in the whole Elbe river basin covering the Czech Republic and Germany (148000 km^2, about 1/3 Czech, 2/3 Germany). Results will be presented next year. To illustrate how the approach works selected results from an earlier study in a German tributary river basin, the Spree-Havel basin (24000 km^2), in particular the Spree river basin upstream Berlin (6171 km^2), will be presented here. In this river basin, the following critical conditions are given:

- limited water availability, in particular in the vegetation season (summer)
- increasing water demand in urban areas and industrial regions
- insufficient nature protection in many wetlands
- irregular winter floods
- complex water management conditions.

Basis for the detailed analysis has been a complex water balance and management model containing 190 users (industries, municipalities, wetlands, etc.), 122 balance points, 14 reservoirs, 50 dynamical elements (modules) representing special elements and functions in the basin (e.g. water transfers, open pit mines) and about 200 reference points where results can be registered to evaluate the investigated scenarios. In the end, a control strategy for the reservoirs, water transfers and water uses is selected, that fulfils best over time the demands throughout the basin. As an example, it should be mentioned that a sufficient water supply for the Berlin area could only be achieved by constructing a new reservoir in the upper Spree basin and by operating the system on a continuous basis considering the water demands of all users in the basin. A general conclusions from the study is that in dry periods (summers) special measures are required to provide enough water for the surface water system of Berlin, to the wetlands of the Spreewald and in the upper Spree for the refilling of the open pit mines to act against their acidification.

INTRODUCTION

In many parts of the world, water demand is increasing while in parallel the availability and quality of water resources are decreasing, mainly due to the growing world population, ongoing urbanization, industrialization and the intensification of agriculture. This development is often associated with general reductions in environmental quality and it endangers sustainable development. Integrated approaches are required to analyze such systems and allow sustainable systems to be designed:

- An attempt in this direction has been made in the Elbe river basin, focusing on the availability and quality of water resources and changes to these caused by ongoing Global Change processes and human activities and their impacts, and on application of regional Integrated Water Resources Management (IWRM). The main reasons for focusing on the regional scale and a river basin as a working unit are: River basins represent natural spatial integrators of the effects of many forces, including climate, land use, changing use and management of water resources, and resulting water and associated material fluxes (from point and nonpoint sources). The hierarchical structure and natural boundaries (water divides) of river basins allow water and other material budgets to be established for defined land surface areas (river basin and sub-basin areas) and they can serve for large-scale modeling, model validation, global change and environmental impact studies, and ultimately for the afore mentioned design of sustainable systems. For this reason, the Water Framework Directive of the European Union has defined river basins as primary working units (WFD 2000).

- It is mainly at these scales (10^4 to 10^6 km^2) that political and technical measures and regulations can be taken in order to ensure sustainable regional development and avoid or mitigate negative effects due to, for example, changes in climate, land use / land cover, water management and other human activities, impacts and waste releases from industry, communities, traffic and agriculture.

To support integrative interdisciplinary research in river basins, the German government has launched a new research program on "Global Change in the Hydrological Cycle" (GLOWA: GSF 2002), which takes into account the interaction between the environment and society and integrates research in the fields of social and natural sciences, considering social, political, economic, ecological, hydrological, climate, land and water use and management and associated aspects. One of the funded projects within the GLOWA Program is GLOWA-Elbe, which is related to the German part of the Elbe river basin (Figure 1).

After a brief description of the Integration Methodology and Approach (IMA) developed for GLOWA-Elbe and for the solution of some other problems in the Elbe river basin, selected results of studies in one of the largest German Elbe tributary river basins, namely in the Spree/Havel basin (see Figure 1) is presented and briefly discussed.

Fig. 1: The Elbe river basin in the Czech Republic and Germany

INTEGRATION METHODOLOGY AND APPROACH (IMA)

An essential component of any integration across social, natural and engineering sciences is communication and negotiation between decision-makers (actors), politicians and their representatives (responsible governmental authorities and institutions, subcontractors…), Environmental Protection Agencies (EPAs), Non-Governmental Organizations (NGOs), land owners, scientists and the public or interest groups of citizens and others concerned (stakeholder participation in the widest sense). It is required in particular in the analysis of systems under pressure, such as a region, country, district or river basin where measures and strategies for action are needed to ensure or support sustainable development.

The pressures might be external (e.g. climate change, global market developments….) and/or internal (human activities within the unit as driving forces/drivers). Both result in changes of states and in subsequent impacts which often require a response by society. This sequence from **D**rivers to **P**ressures, **S**tates, **I**mpacts and ultimately **R**esponses defines the well-known **DPSIR** framework in Figure 2 of the European Environment Agencies (OECD 1994, UNCSD 1996), which represents the basis of the IMA.

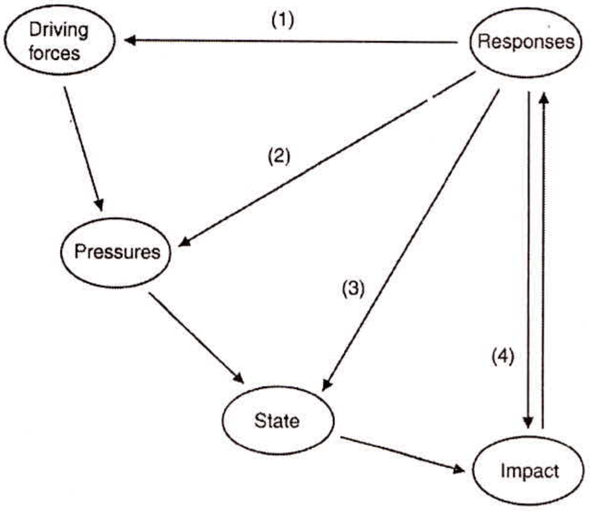

Fig. 2: The DPSIR Approach

Drivers are first of all human beings and societies and their activities. These drivers also have views or visions about desirable states of the environment (e.g. "Leitbilder" for sustainable development), and about critical thresholds for important environmental characteristics, which should not be exceeded (cf. water quality criteria, required or acceptable minimum or maximum discharges….). These criteria need to be defined by the responsible authorities and institutions and accepted by the people concerned, including the public at large, i.e. by representatives of the "drivers community" (stakeholders). They are needed first to identify, measure and analyze existing or possible **P**ressures to the environment and societies by comparing the observed or expected (predicted) **S**tates (measured by indicators) against the predefined criteria. If the indicators of states exceed the defined criteria (accepted range of states), **I**mpacts occur (in terms of undesired or unacceptable states). To avoid or mitigate such impacts, **R**esponses (in terms of measures and actions) are required, which again need to be discussed and accepted by people, i.e. the society or their representatives (stakeholders). This means that stakeholders represent a crucial component in any integrated analysis technique and integration approach (like DPSIR or IMA).

The developed integration approach IMA tries to achieve this. It represents a kind of transformation of the DPSIR framework into a well structured, manageable analysis technique supporting stakeholder-based planning and decision processes. It is based on earlier ideas and suggestions of Wenzel (1999, 2001) and Messner *et al.* (2001), which have been combined and synthesized in GLOWA-Elbe into the form of the IMA as illustrated in Figure 3 (Becker *et al.*, 2002). The general scheme in Figure 3 shows the main components and steps of the IMA, which are explained in more detail in another publication (Wechsung *et al.*, 2005) and in brief in the following.

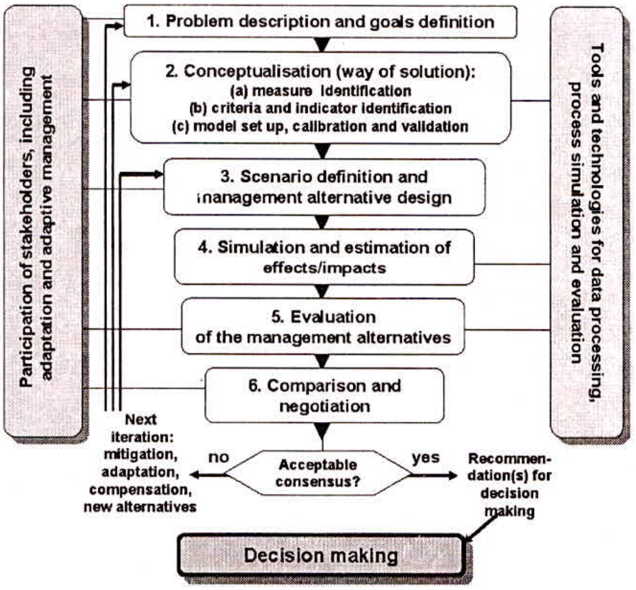

Fig. 3: Planning framework for integrated water resources management

Step 1 and 2: Problem Description and Goals Definition

Step 1 includes a number of preparatory steps for setting the task in the IMA application, namely:

(a) Problem and conflict analysis.
(b) Institutional and stakeholder analysis.
(c) Formulation of goals and targets (1 in Figure 3).
(d) Definition of criteria to specify and, if possible, express the goals and targets in quantitative terms.
(e) Specification of indicators, which measure whether the criteria according to (d) are or can be reached (and the goals and targets fulfilled, 2 in Figure 3). Later on, they serve as a basis for the evaluation of the results of the analyses (step 4).

As has been mentioned stakeholders need to be involved in all these activities, as is indicated by the left block in Figure 3. Sub-steps (a) to (c) above are self-explanatory. Well-known and generally applied criteria to be specified under (d) are, for example:

- required minimum discharges or groundwater levels,
- bankfull discharges below which no flood damage occurs,
- thresholds of water quality or environmental conditions which should not be exceeded (defined, e.g., by international bodies such as bodies of the EU, governments, EPOs,….),
- ecological criteria such as crop yield,
- biomass production and biodiversity,
- socio-economic criteria such as net primary production, acceptable investment and operation costs, employment rate, and others.

These indicators are measurable quantities, which can be compared with the criteria defined under d) to measure the success of actions and measures tested in the impact analysis (steps 2 and 3). If all these questions and tasks have been clarified, the "way of solution" can be conceptualized (step 2 in Figure 3).

Step 3: Scenarios for Future Development

In Figure 4, major system characteristics and management alternatives of the river basin of interest are indicated in the recent past (as observed, left hand), and for the future (right side). In the future, two components are important:

(a) *External driving forces*, which cannot be directly controlled in the system, such as precipitation, climate change and associated atmospheric forcing (predictions and projections for the coming fifty or hundred years), global market developments, in particular food markets, and other global economic trends as well as expectations, international agreements, conventions or treaties which need to be fulfilled (see Figure 4, upper part).
(b) *Internal driving* forces in terms of internally driven developments and options for action in the considered land surface area (areal unit), e.g. river basin. These options may include:
    - changes in land and water use and management, including ecological farming.
    - new technologies, e.g. for water supply, waste water treatment and recycling, and for industrial water use.
    - the construction of reservoirs and other control facilities for water management, e.g. channels and weirs for water diversions, and the like.

In this step again, the direct involvement of stakeholders is essential since funding resources are required for new constructions and technologies, and since resulting effects and consequences must be accepted by the stakeholders concerned. In the initial phase of all studies stakeholders should have equal rights to express their needs and desires and make suggestions for the scenarios to be investigated, problem solutions, and actions which can be implemented (Figure 4, lower part: management alternatives).

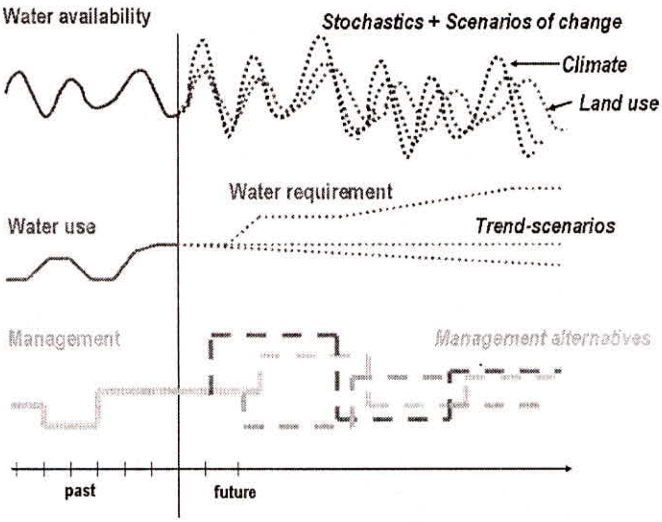

Fig. 4: Scenarios for planning water management

STEP 4: Multidisciplinary Impact Analyses

These analyses of impacts of Global Change and human activities on the environment and society within study regions (river basins) represent a core activity in the integration process. Scientific expertise, comprehensive and coupled modeling and software systems are required to link to each other the various system inputs (driving forces, cf. climate characteristics, global market developments and pressures, human activities in terms of land and water use and management and changes to these) as included in the developed future scenarios, and the resulting outputs (indicators such as water resources availability and quality, evaporation and transpiration, plant growth, biomass production including crop yield, waste water and other wastes). This modeling must take into account the features and control behavior of land surface systems (natural as well as managed systems, for example, arable irrigated or non-irrigated land, controlled river systems, urban systems, other human settlements).

Various types of models and modeling systems are available to describe the responses of these systems to given inputs, including their interaction with the atmosphere and with society (ecological, hydrological, atmospheric, socio-economic and other models; see Figure 5).

The adaptation of models to a land surface unit (grid area or polygon, small or large river basin, region or others) generally requires considerable effort, data and experience. The general philosophy and concept for the modeling is to start from hydrotopes, i.e. homogenous or nearly homogenous land surface units with equal or similar hydrological behaviour, as is illustrated in Figure 6.

The hydrotope based modeling is then aggregated in larger areal units such as river basins (or sub-basins) according to Figure 7.

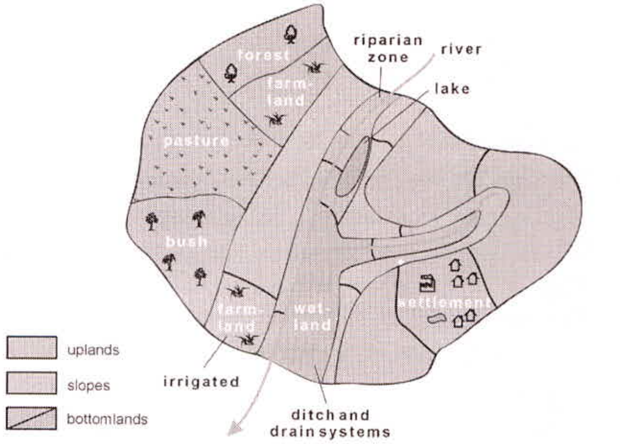

Fig. 6: Hydrotope

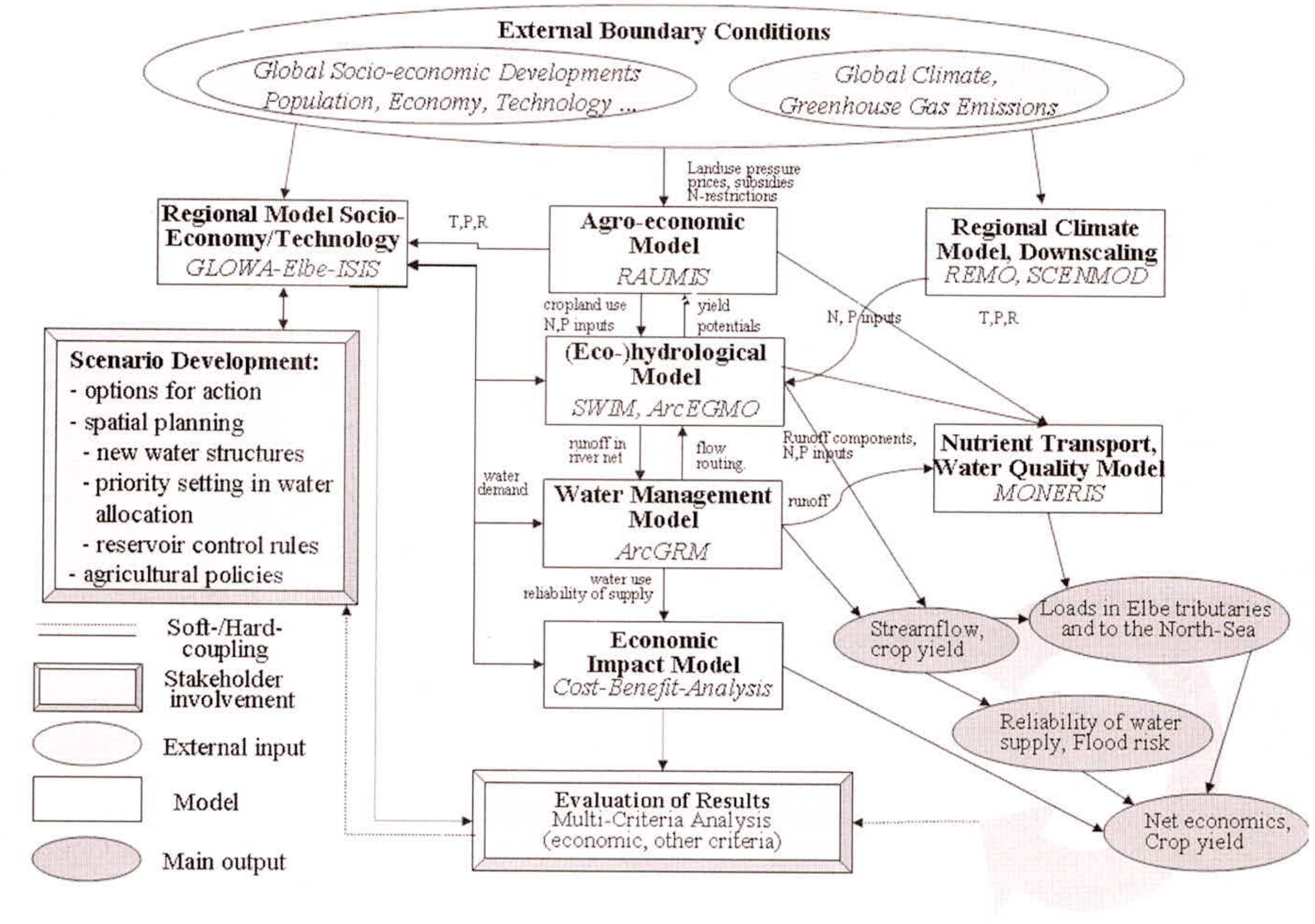

Fig. 5: Structural scheme for the system of river basin modelling

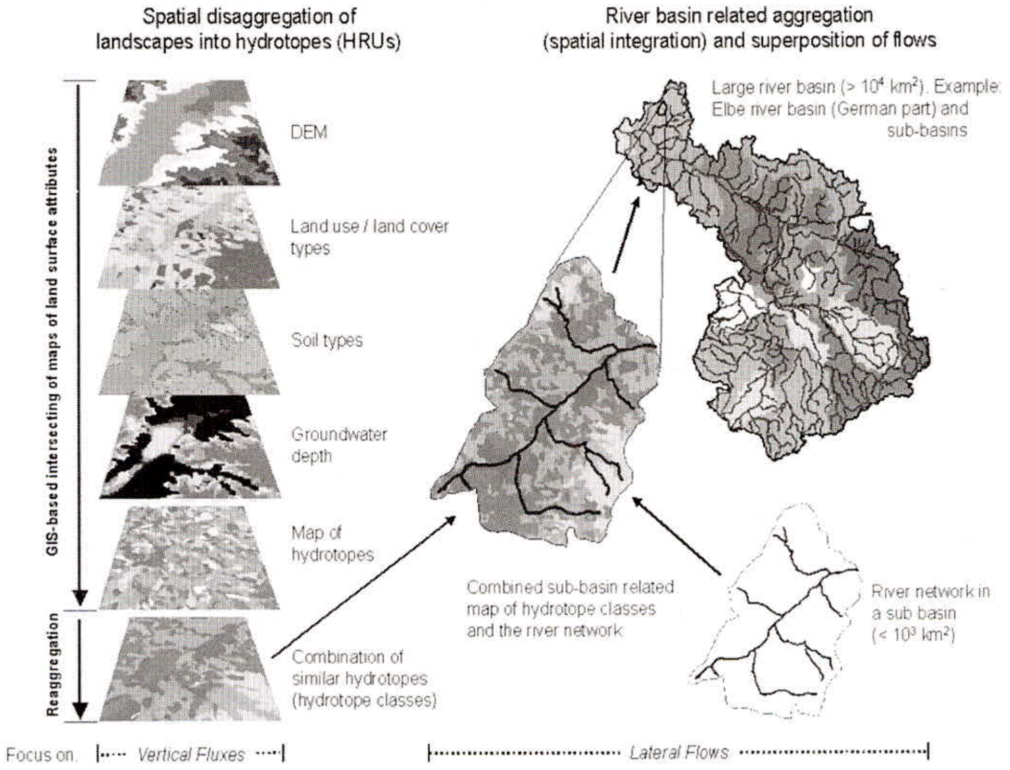

Fig. 7: Spatial disaggregation and aggregation

So, in principle, models are adapted or developed to describe the complex interrelations and interactions between the relevant processes in the area of interest (river basin, country, region). These models then need to be validated with reference to past and recent observations and to monitoring activities, and for the conditions given in the validation period in the study area (step 2c in Figure 3, control runs). After that, the models can be used to simulate the impacts of Global Change on the environment and the society for the coming 20 to 50 years for given "scenarios of change" distinguishing:

- "external" driving forces such as climate, global market developments etc. (not directly controllable from inside the system).
- measures and actions within the area under study (action alternatives) to ensure sustainable development in terms of water availability, food production, environmental quality, human welfare etc. and to avoid or mitigate as far as possible damages and losses due to extreme and hazardous events such as droughts, floods, landslides…

Based on results, the appropriate policies and strategies, measures and action programmes can be developed in communication with policy makers, investors, the public, land owners, EPAs, NGOs and others concerned in the area under study (stakeholder participation in the widest sense (steps 4 and 5).

In Figure 8, a structural scheme of the modeling system, which was developed and applied in the Spree-Havel river basin according to the IMA, is presented. Selected models will briefly be introduced below and examples of their application presented.

Step 5 and 6: Evaluation of Results and Comparison and Negotiation

As far as benefits and costs can be calculated in the frame of the impact analyses they can be expressed in monetary units, which allow a simple and direct evaluation. Therefore cost-benefit analyses are widely used in the evaluation and form the basis for decision-making. However, in general, other (non-monetary) criteria and indicators need to be taken into account additionally, for example, ecological criteria (in particular hydrological criteria in terms of water availability and quality), social indicators and others. Some of these indicators can be expressed in monetary units by use of established relations such as, for example, costs for damage and losses in dependence on the degree of exceedance of given thresholds for hydrological indicators, such as required minimum discharge and water quality, or bankfull discharge. Such indicators can then also be directly included in the cost-benefit analysis.

Nevertheless, various indicators remain, e.g. ecological ones such as biodiversity, and social ones such as employment rates, which cannot or can hardly be expressed in monetary units. All these numbers and indicators, in addition to the monetary ones, are arranged in a so-called multi-criteria matrix, which serves a multi-criteria decision analysis using, for example, NAIADE (Munda 1995) or PROMETHEE (Brans *et al.,* 1986) in combination with an outranking approach, which can take into account uncertainties.

The subsequent evaluation again requires the participation of the stakeholders to identify those scenarios of development which they consider most beneficial or at least most acceptable, and thus favor implementation. In many cases, a "straightforward solution" cannot be achieved at once but is reached through repeated iterations with alternative options for action suggested as result of the communicative evaluation (comparison) and negotiation (bottom blocks in Figure 3). Whenever serious conflicts between stakeholders and different interest groups occur, an equity analysis can additionally be applied to identify possible compromise solutions (O'Connor 2000).

PILOT APPLICATION OF THE IMA IN THE SPREE-HAVEL RIVER BASIN IN EASTERN GERMANY

The Elbe river basin is the 12th largest in Europe. It covers an area of nearly 150,000 km^2 in Central Europe, about 1/3 in the Czech Republic and 2/3 in eastern Germany (see Figure 1), with middle mountain ranges in the Czech Republic, the Erzgebirge, Thuringian Forest and Harz mountains in Germany and large areas of hills or lowlands in the rest of the basin (central, northern and eastern German part). The basin provides a variety of environmental and socio-economic conditions and a number of socio-economic and ecological problems, including water availability and quality problems and water use conflicts, some of which were amplified by the political and economic changes connected with the German reunification in 1990.

A first preparatory step for the IMA application was the establishment of a comprehensive data base consisting of GIS-based spatial data (DEM, land use/land cover, soils, hydrogeology, river network and related sub-basin boundaries; Figure 7, left side) and time series data (meteorological, hydrological, etc.) for the Elbe basin as well as crop yield data for sub-regions. These data served for the adaptation and validation of available models and also as reference for the results of the impact analyses using various development scenarios.

Within the German part of the basin (nearly 100,000 km^2 in area) the most problematic region is the Spree/Havel river basin (24,000 km^2) covering mainly the federal state of Brandenburg, including the German capital Berlin (easternmost part of the Elbe basin, see Figure 1 and 8), and eastern Saxony (Sachsen in Figure 1 and 8). Main problems and conflicts in the basin are:

- water shortage during summer and other dry periods, expressed by standing water, no or backward flows in some lowland downstream river reaches in and around Berlin.
- several associated water quality problems, especially in 3 subregions (see Figure 8):
  - the mining area of lower Lusatia (within the lower blue circle),
  - the wetland area and Biosphere Reserve of the Spreewald (dashed areas in the middle part),
  - the distributed surface water system with many lakes and connecting lowland rivers and channels in the Berlin area, most of them dependent on sufficient in- and through-flow.

It is tried to explain the application of the IMA to this tributary basin of the Elbe.

Large parts of the Spree/Havel river basin are characterized by rather low natural water yield and water availability due to the relatively small amounts of precipitation (long-term annual average 500–600 mm/year).

Moreover, the extensive and intensive open-pit lignite mining activities in lower Lusatia (within the blue circle in Figure 8, around the border between the federal states of Saxony and Brandenburg) caused a large-scale lowering of the groundwater table across an area of about 2000 km^2, where no natural groundwater outflow into the rivers can be generated until the groundwater levels get back to their earlier state. Before 1990, this lacking inflow was more than compensated by the groundwater pumped from the open-pit mines into the river system. Following the German reunification, the mining activities were drastically reduced, and the afore mentioned additional inflow to the rivers greatly reduced. Therefore, additional water deficiencies and a number of associated water quality problems and water use conflicts occur, in particular during dry periods. Compensatory measures and actions in water management are required to fulfill water demands and support sustainable development. A general scheme of the water management in this basin is illustrated in Figure 9.

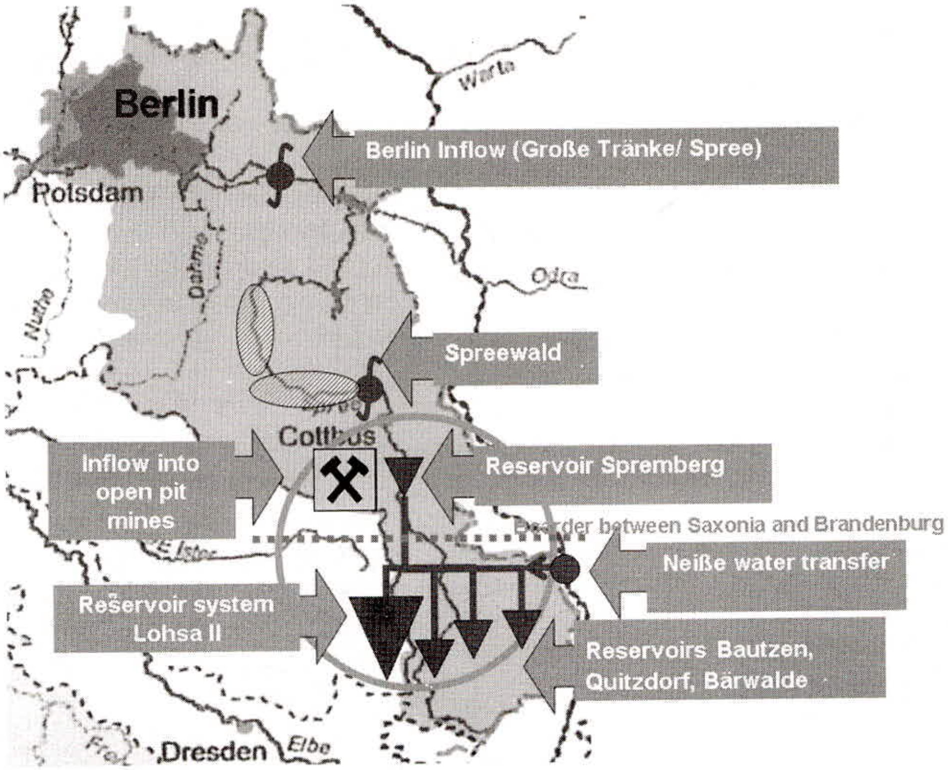

Fig. 8: Spree river basin

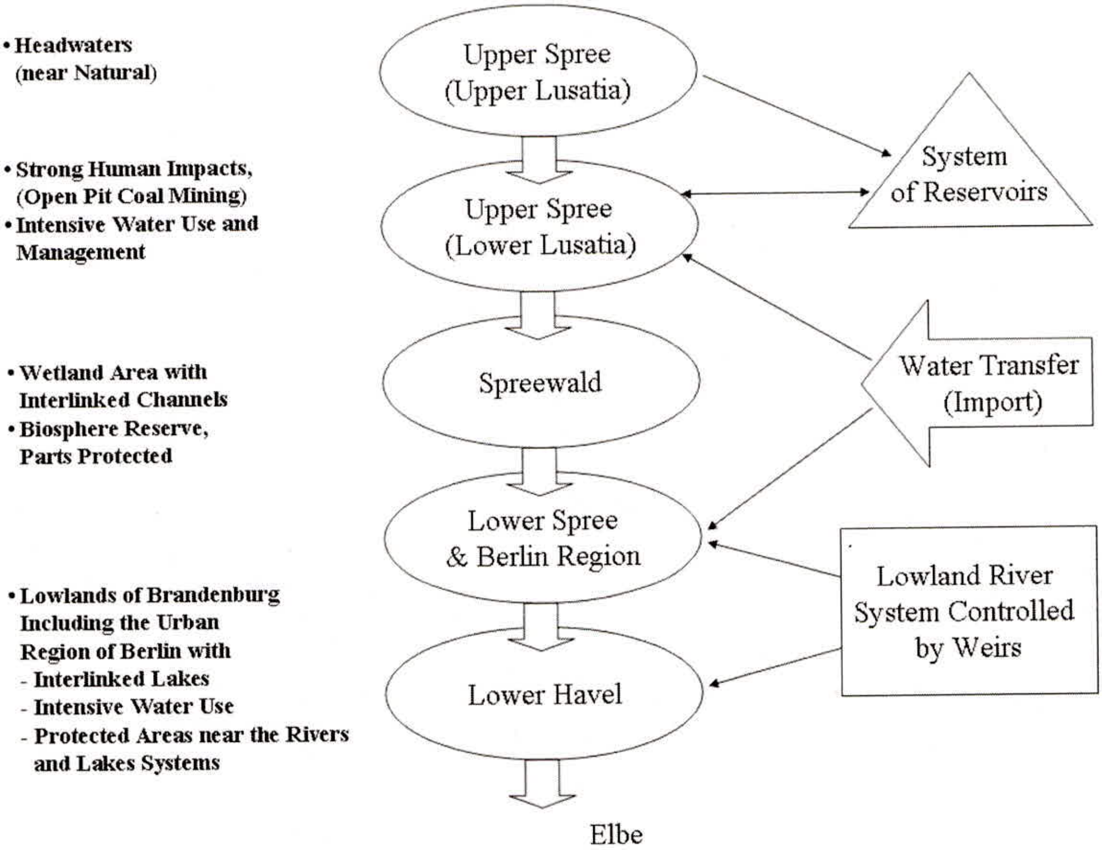

Fig. 9: General scheme of water management in the Spree river basin

Primary task and sub-tasks are here:

- to determine the long-term water availability on the large (regional) scale and provide sufficient water in all the three sub-regions (basic condition for improv-ing also water quality and ecological status).

Subtasks:

- assessment of available water resources in their spatial and temporal variability (status quo) from available hydrological records (water levels and discharges),
- estimation of future changes of water availability due to expected climate change (precipitation and temperature change),
- using hydrological models (N-A-models) to estimate changes in runoff and river discharge in the entire basin,
- using these predicted inputs in a detailed regional scale water balance and management model to fulfill the demands as far as possible and to register statistically the deficiencies (demand minus supply) on a monthly basis,
- find out better options of managing the available system to fulfill best the demands (perhaps with additional control structures and measures, planning studies).

Taking this into account, primary emphasis in this regional pilot application of the IMA had to be on water quantity issues (Grünewald *et al.*, 2002, Kaltofen *et al.*, 2002). Water quality aspects and problems were investigated in an off-line coupled mode in "nested" studies in sub-regions, where they occur and need to be analysed:

(A) Upper Spree with the mining area in lower Lusatia

- 800 km^2 mining area, influenced by open pit mines (+180 km^2),
- 2100 km^2 extension of groundwater depression cone (13 Mio m^2 groundwater deficiency),
- acidification of lakes in the refilling open pit mines. Surface flow demanded;

(B) Spreewald (wetland, protected area, biosphere reserve):

- stable inflow of about 5–7 m^2 required,
- keeping groundwater levels high enough;

(C) Berlin (lower Spree, urban agglomeration):

- further reduction of waste water inflow (from upstream 265 t/a, from treatment of plants 112 t/a, from canalization 38 t/a),
- ensuring required minimum monthly flows and water quality limits (avoiding O_2-breakdowns, trying to keep bathing water quality).

For the detailed long-term simulation of water availability, the comprehensive water balance model as mentioned before was used. Its output became input into the overall water management system for the Spree river basin, schematically represented in Figures 8 and 9. This system is rather complex and includes within the Spree river basin itself 110 water users (U), 66 balance points (B: river cross-sections), 8 reservoirs (R) and 11 managed lakes (L) in former open pits. Additional users, balance points and elements are in neighbouring river basins, namely the Schwarze Elster (60 U, 50 B, 6 R, 3 L) and the Neisse river basin (20 U, 6 B, 1 L). There are also streamflow control structures for water transfer between (see Figure 8).

- the Schwarze Elster and upper Spree (left green-coloured basin),
- the Neisse and the upper Spree (right border river),
- the Odra and the lower Spree (right of Berlin).

The entire system covers parts of four German federal states (Sachsen, Brandenburg and Berlin, Sachsen-Anhalt) and two major water divides with the neighbouring river basins and sub-basins, namely on the eastern side the Odra river basin with its tributary, the Neisse, and to the west the Schwarze Elster (tributary of the Elbe river).

The primary task of the system is to manage and allocate the available, often very limited and thus insufficient water resources in such a way that the water demand of the existing 190 water users (in total) can best or adequately be fulfilled. Accordingly the primary objectives of this study are:

- To assess at the regional scale of this river basin the available water resources and their variability in space and time, taking into account the impacts of human activities and the potential impacts of climate change until about the year 2050.
- To analyse the performance capabilities of the existing water management system as characterized above by developing and applying the existing earlier developed management strategies and control regulations for the existing 14 reservoirs, control structures for streamflow, cf. water diversions, water transfers etc.
- To investigate the potential effects of new structures requiring investments, in combination with new alternative management strategies to fulfill water demands and ensure or support sustainable development in the river basin(s) (again IMA-Step 2/B/, but now with new options and alternatives for investment and management).

The simplified annotated scheme of the regional water management system to be modelled is represented in Figure 9. Near natural runoff generation conditions are only given in the uppermost part of the Spree river basin, upper Lusatia, and in the upper Havel, as well as in headwater sub-basins of various other tributaries of the Spree and Havel. The second part of the upper Spree basin is the strongly affected and modified lower Lusatia (blue circle in Figure 8), where the open pit mines and most reservoirs are concentrated. Downstream of this region follows the Spreewald, a famous wetland area with a dense interlinked channel system, forests and arable land, parts of which are protected as a Nature Reserve and even as a UNESCO Biosphere Reserve (dashed areas in the middle of Figure 8). Further downstream after an intermediate, loosely populated, near natural area, including the Dahme tributary river basin, follows the urban agglomeration of the German capital Berlin, where a number of water users are located and a minimum inflow of 8 m³/s from the Spree river into the surface water system in Berlin is required to keep the water flowing and ensure an ecologically adequate water quality. The last part of the "chain" is the lower Havel downstream of Berlin where minimum water levels and flows need to be maintained (Figures 1 and 8).

The large-scale interdependencies between upstream and downstream availability and demand for water resources explain why a coordinated and integrated management and modelling of the entire water resources system in the Spree/Havel and Schwarze Elster river basins is necessary to solve the given complex water availability problems and the resulting allocation conflicts.

SPECIFICATIONS OF THE WATER MANAGEMENT SYSTEM

An inter-governmental working group was established for this purpose, where in addition to the governments of the involved three German federal states (Saxony, Brandenburg, Berlin) the LMBV enterprise mining company, responsible for the restoration and development of the affected mining region in lower Lusatia, was involved. Man tasks to be solved were:

- Which solution to be selected?
- Where to do investments?
- How to finance it?
- How to operate?

An earlier version of the regional scale, long-term water management model (called ArcGRM Spree/Schwarze Elster) was taken first for the investigations. Later, the improved modelling system ArcGRM-GLOWA was used, which fulfills the special requirements of the IMA application (Kaden *et al.*, 2002). The new requirements were in particular the possibility to perform various scenario analyses with different inputs and routines to be applied according to Figure 4:

- numerous stochastically generated realizations (at least 100) of possible future climate (climate change scenarios) for the coming 50 years to allow the analysis of uncertainty and risk in the simulation results even for changing climate
- scenarios for projected or expected changes in land and water use and management
- various alternatives for designing and managing the complex water resources system in the entire reference river basin, here Spree and Havel
- economic transfer functions serving for the economic evaluation of the results of the impact analyses
- generalized routines for the integrated (aggregated) statistical and probabilistic analysis and interpretation of the various results of the simulations.

After completion of the improved ArcGRM-GLOWA modelling system, it was applied in the Spree /Havel river basin according to the IMA with the following working steps (see Figure 3 and 8):

Step 1 and 2: Definition and Specification of Criteria and Indicators

As was mentioned in this case, primary interest was in water demand, i.e. required minimum discharges for various users at all reference and balance points (river cross-sections) within the river basin. They were defined in direct consultation and close cooperation with stakeholders in the region (participation). Related indicators are the simulated streamflows (river discharges).

A number of other criteria such as thresholds for water quality related to these discharges were also defined but only on a sub-regional basis, where the earlier mentioned nested studies were performed (upper Spree, Spreewald, and the Berlin region).

Step 3(A): Scenario Development for Unmanaged Conditions

Here two global greenhouse gas emission scenarios and related climate scenarios were considered, namely A1 and B2 (IPCC 2001).

- (A1)—"business as usual" = strong growth, globalisation, rapid transfer of technology, equalization of regional incomes and generals conditions, "moderate" environmental policy,

- (B2)—ecologically oriented policy ("Eco-prioritization") = stronger and more focused regional environmental policy, higher intensity and degree of innovation in environmental protection and ecological engineering, slower general growth.

Regional climate scenarios were developed for the Elbe river basin by applying (1) a statistical model based on a cluster analysis algorithm, (2) a regional climate model (REMO) combined with a statistical model.

Both approaches were used for the stochastic generation of 100 realizations of the two climate scenarios A1 and B2 (step 3 in Figure 3), which then served as input for the hydrological or eco-hydrological models.

Step 3(B): Scenario Development for Managed Conditions

Here management alternatives were derived in agreement with the stakeholders concerned considering all options for action as suggested, discussed and accepted by them. They may include a number of different control strategies and alternatives for the reservoirs, water transfers and diversions, technologies of water use, a priority ranking for water allocation in water deficiency situations (e.g. during droughts).

Step 4(A): Impact Analyses for Unmanaged Sub-basins and Management Conditions as Applied in the Past

In a first step, the generated 100 realizations of time series of meteorological inputs, (i.e. precipitation, air temperature, humidity, ...) for each considered climate scenario are used to simulate time series of the resulting run-off and discharge over the coming 50 years for all sub-basins not influenced by the above mentioned users and control structures (so-called "unmanaged water yield"; first implementation of step 3 of the IMA). For this purpose the hydrological model ArcEGMO was used, which had already been applied successfully in earlier studies in the basin. From the results (100 realizations of simulated river flows) frequency distributions can be drawn for all reference points. As an example, Figure 10 shows the distribution functions of expected monthly mean river discharges for the upper Havel river (gauging station Borgsdorf). These distribution curves allow the frequencies of occurrence of these discharges to be estimated (long-term average monthly mean and extremes for all months of the year) and thus the risks and uncertainties caused by the stochastic character and the uncertainties in the simulated climate scenarios can be assessed.

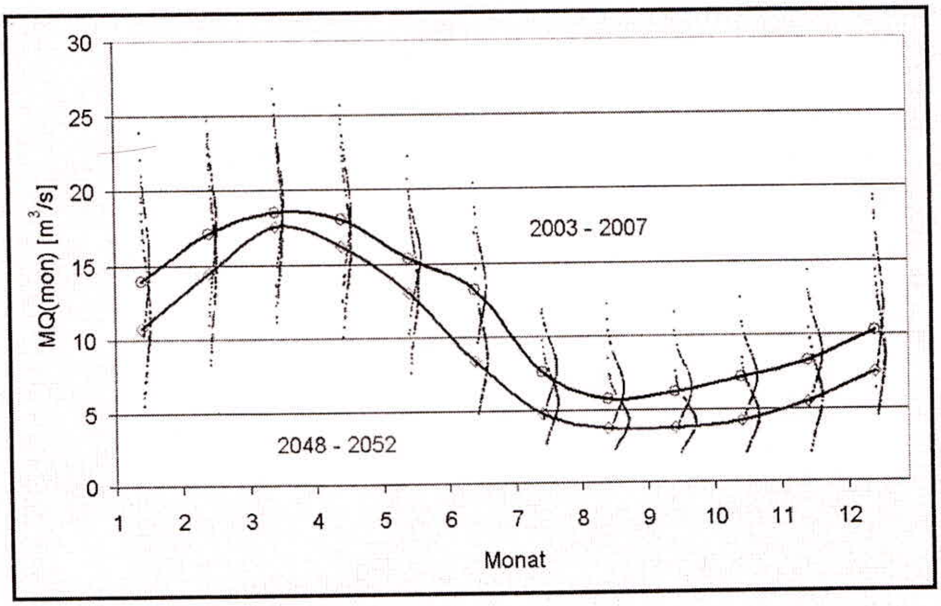

Fig. 10: Distribution functions for simulated individual and mean monthly discharges at the gauge station Borgsdorf/Havel

Step 4(B): Impact Analyses for Managed Conditions Considering the Predefined Management Alternatives

The generated time series of water yield (discharges from "unmanaged sub-basins") serve as input to the water management model, the core of the ArcGRM, which allows all water uses (or demands and water yields at the user and balance points in the entire river basin as assessed in the model) to be balanced precisely and in a detailed way (i.e. time and geo-referenced). Where there are water deficiencies, additional water is allocated from the reservoirs according to defined operation rules and priority ranking of water users. This is done first for the present unchanged conditions (as reference), afterwards for changed management conditions applying the management alternatives defined in step 3(B) above.

At the end of steps 4(A) and (B) a user-friendly representation of the simulation results is performed for interpretation, evaluation, negotiation and decision support (Figure 10). A very informative and well accepted form of presenting the results of the simulations are probability distributions as represented in Figures 11 and 12.

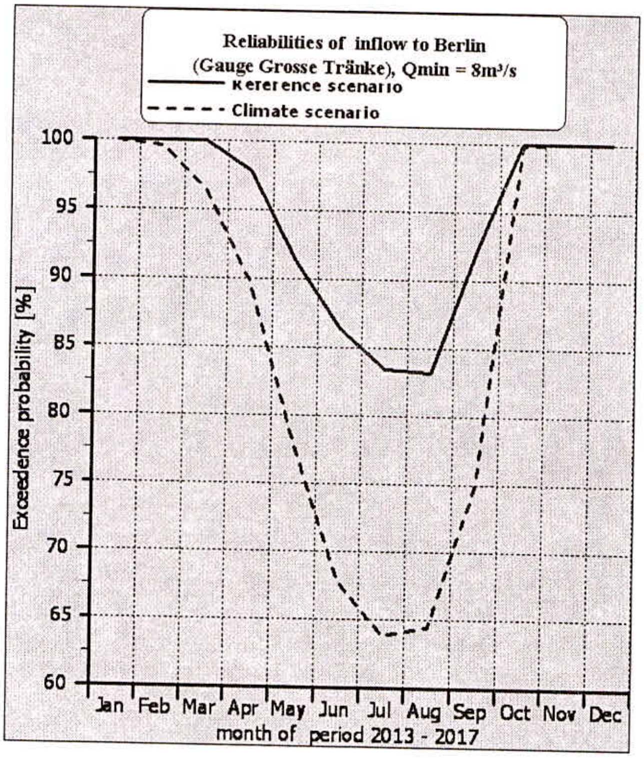

Fig. 11: Reliabilities of inflow to Berlin with changing climate (*Source:* Grünewald *et al.*, 2001)

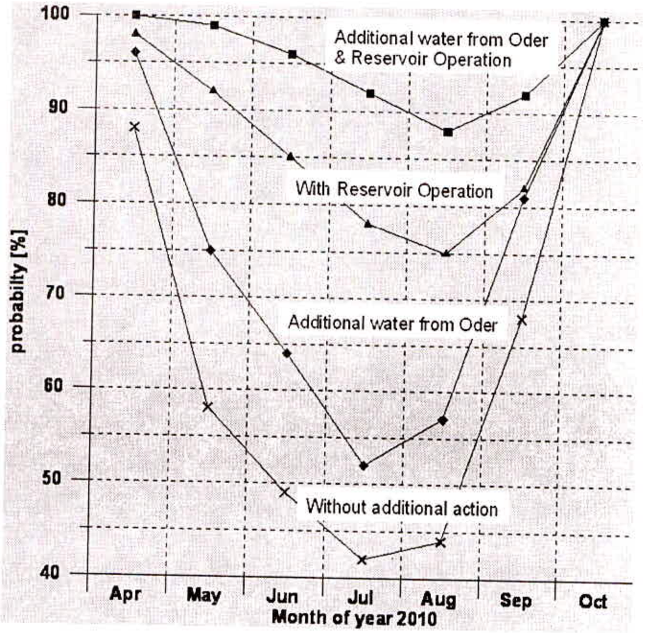

Fig. 12: Reliabilities of inflow to Berlin with different management options (*Source:* Grünewald *et al.*, 2001)

In Figure 11, the probabilities of exceedance of the required minimum Spree river inflow to the surface water system of Berlin (gauge Große Tränke) are represented for the critical vegetation period (spring and summer) when significant water deficiencies often occur two curves are shown—for the given climate conditions—for projected climate change.

Steps 5 and 6: Multicriteria Evaluation, Comparison and Negotiation

Figure 12 is for the given climate and different management options. The curves show that without additional management, i.e. with the available reservoir system only and the applied operation rules, water demand is only fulfilled during the winter period (October-March). In the summer period, serious water deficiencies occur down to about 40% exceedance probability (lowest curve in Figure 12). The situation can only be improved by including a new reservoir in the management, or/and by transferring water from neighbouring river basins, in this case from the Odra river. The three upper curves in Figure 12 illustrate how the situation can be improved and water deficiencies reduced if the two additional options (management alternatives) are realized. The Figure directly served the negotiations for the decision making of the established intergovernmental working group.

Finally, after negotiation it has been agreed to build a new reservoir in the upper Spree river basin in Saxony (since appropriate locations for a reservoir exist only there, see Figure 8) and to share the investment costs between the different partners (stakeholders) in the three German federal states Saxony, Brandenburg and Berlin, across the boarders of these states. This can be considered as an example of a "transboundary collective decision-making process" involving various stakeholders.

As already mentioned, several other criteria are also of interest in an integrated river basin analysis and decision-making process such as economical, social, ecological and other environmental criteria. In the Spree and Havel river basin, especially in its critical subregions, this concerns, in addition to streamflow and water availability (on which all other criteria are dependent):

- in the upper part of the Spree basin: acidity in the developing open-pit mine lakes in lower Lusatia in the course of their refilling due to the regional re-rising of the groundwater table and the resulting exfiltration of very acid ground water into about 9 of the lakes (Kaltofen *et al.*, 2002),
- in the wetland region of the Spreewald: a set of ecological parameters characterising the status of the wetland, in particular of the protected parts (including the biosphere reserve), as well as agricultural productivity in terms of, for example, yields of special crops (vegetables like cucumber, reddish) serving for special, well known and widely exported products, which represent an essential source for income in this region (Dietrich *et al.*, 2002 Wessolek *et al.*, 2002), (see Figure 13).

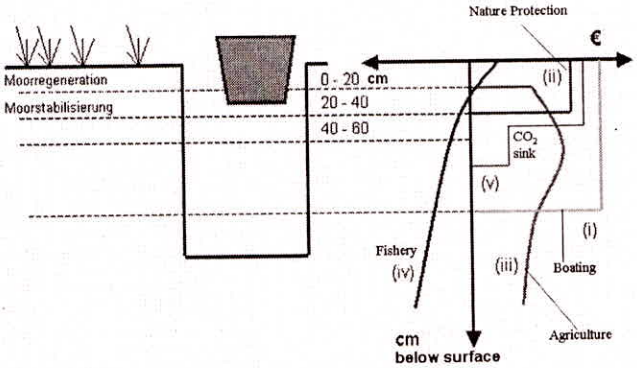

Fig. 13: Soil moisture conditions and associated cost functions in wetlands

- in the Berlin region and the surrounding lower part of the Spree basin: various parameters controlling water quality and aquatic eco-system parameters in the surface water system, including eutrophication, fish mortality, water quality at swimming places and the like (Oppermann *et al.*, 2002).

These aspects and the results of the recent studies will soon be published or presented in special separate reports. All results have confirmed the IMA as an appropriate concept for integrated river basin water management.

CONCLUSIONS

The main and most important conclusion of the study is that the suggested Integration Approach and Methodology (IMA) has been proven as well-suited for the planning of sustainable development and management in river basins, taking into account the impacts on the environment and society of Global Change and human activities within the basin. This was shown particularly in the pilot case study in the Spree/Havel river basin, the second largest German tributary river basin of the Elbe river. The modelling approaches and systems applied in both case studies can serve for other similar and even more complex studies in larger river basins. Such a study is planned next in the entire Elbe river basin.

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