Towards to a system analytical and modelling approach for integration of ecological, hydrological, economical and social components of disturbed regions

K. Bellmann

Chair of Soil Protection and Recultivation, Potsdam Institute of Climate Impact Research, Brandenburg Technical University of Cottbus (BTUC), P.O. Box 101344, D-03013 Cottbus, Germany

Abstract

As a consequence of surface coal mining, past landscapes within the Lusatian coal mining region were disturbed (land cover, forest, agro- and other ecosystems, geological material, hydrology), paralleled by strongly changed economic and socio-economic conditions (unemployment, emigration due to slowing down of mining activity in the region). The task is to restore the landscape and to improve the present state of the economic and socio-economic conditions, as well. Consented goal states for both the ecological and economic system in the region and consistent planning and management options (PMO) for such economic sectors, which are linked to natural resources (terrestrial, hydrological), are to be designed. They must be ecologically and economically evaluated, assessed and selected for real implementation.

In order to handle such a complex problem, a comprehensive analysis of the whole system with subsequent multiscaled modelling efforts is needed. The final aim is to establish an interactive, effective, sufficiently simple decision support system for the actors in the disturbed region.

The future responses of the landscape variables and the economical and social characteristics as an answer to economic sector PMO (e.g. PMO for control in agriculture, forestry, hydrology a.o.) can be approximately calculated, and subsequently evaluated and assessed by such an appropriately tailored simulation and decision support tool.

In this study, the complex problem and the ecologic and economic system with its components are analysed and structured. Based on this, principles of stepwise model building and its usage (e.g. in if-then-simulation experiments as scenario analyses of the effects under changing non-modelled political and economical boundary conditions) toward an integrated approach are proposed.

In this study, the present state of the disturbed region is described briefly (Section 1), and a rough scheme of the ecological and socio-economic structure of the region (Section 2) as well as of the structure of the problem, which must be solved (Section 3) and the role of the models in decision support (Section 4) is outlined. In Section 5, the tasks of analysing and modelling of the components in the Lusatian coal mining region are derived, and in Section 6, the main steps in module building and its usage are briefly described. Finally, some conclusions are drawn. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Ecological– economical systems; Modelling; Simulation; Systems analysis; Complex dynamic analysis; Disturbed regions; Regional planning; Decision support; Hydrology; Forestry; Agriculture; Socio-economics

1 Formerly at Potsdam Institute of Climate Impact Research.
1. Present state

Presently in the disturbed Lusatian mining region, the consequences of the long term open-pit mining are dramatic, concerning the landscape, the economic sectors and the social system as well (see Hüttl et al., this volume).

1. The structure of the landscape is strongly altered due to large wasted areas which are characterised by terrestrial and hydrological anomalies, mainly by strong decrease of groundwater table and the presence of desert lands with only sparse vegetation.

2. After dumping, the physical and chemical state of the disturbed substrate is completely different from the undisturbed one (unstable structure, pyrite weathering).

3. The economic sectors, forestry and agriculture, which rely on intact soils as well as water resources in the landscape, are strongly influenced by the former industrial use. Presently, forest stands on recultivated sites cannot yet be considered as being sustainable ones with respect to their ecosystem dynamics. As far as agriculture is concerned, the soil fertility of recultivated sites may be strongly reduced, leading to unsatisfactory crop yields.

4. Further, the socio-economic characteristics of this mining region are drastically modified. The strong reduction of coal mining induced a drastic increase of unemployment. An increasing emigration out of the region and decreasing population density can be observed.

Like in technical systems, in the beginning, the following should be carried out.

1. Analyse the system and define its components, the system borders, links between components, possible management facilities and other driving forces as well as the response characteristics.

2. Analyse available data sets and the present degree of process knowledge.

2. A first rough schema of the regional components

Considering the dependencies between the changes of: (i) the socio-economic state; (ii) the landscape structure; (iii) the states of the managed and unmanaged ecosystems; (iv) the economic situation of forestry and agriculture, the following scheme gives a rough overview of the key components and their links and feedbacks between the key components in the region and their links and feedbacks (Fig. 1).

Two main components in the region should be distinguished.

1. The landscape with its hydrological and terrestrial (i.e. ecological and geological) characteristics.

2. The economic and socio-economic system of the region.

Obviously, the landscape component includes three levels.

1. The (abiotic) basic level: physico-chemical processes within the geological material, linked with hydrological processes as well as with fluxes within this material and fluxes from and to neighboured water bodies (vertical fluxes and horizontal flows).

2. The (biotic) ecological level: processes of the flora and fauna, their growth, reproduction, spatial distribution in terrestrial and aquatic ecosystems especially in (managed) forest and agro-ecosystems.

3. The regional landscape level: with its higher level characteristics like
   - the land–water relation;
   - structures and functions of the water ways;
   - water and matter balances;
   - vegetation patterns and
   - perception of landscape, ‘beauty’.

The economic and socio-economic components are linked to the landscape component by

- transfer of information from the landscape level to the economic sectors forestry and agriculture and possibly to other economic sectors relying on natural resources (e.g. tourism, open cast mining).

This is bottom up information about local ecological, hydrological, soil, and landscape characteristics, which is needed to calculate economic and socio-economic key processes by

- transfer of information from the regional economic level and/or the macro-economic and socio-eco-
The socio-economic component can be handled at two levels.

1. **Regional economic level** (related to the spatial dimension of the landscape):
   1.1. regional economic and structures of the different production and service sectors in the region, each linked with ecological and terrestrial resources (agriculture, forestry, tourism, open cut mining, industries, hydrology with drinking water supply), sector nature conservation and
   1.2. socio-economic level (partly related to the spatial dimension of the landscape).

2. **Macro economic and socio-economic level** (not related to the spatial dimension of the landscape):
the processes of the production and service sectors determine macro-economic and social processes and structures (and vice versa).

As the macro level processes depend on political, economic, and other external driving forces or circumstances, these conditions have to be considered in analysing the whole system and its dynamics, i.e. further informational interactions (information fluxes) between the sectoral actors and their corresponding regional and sector-specific planning and management authorities and related institutions (e.g. mining authorities, ministry of agriculture and forestry) are to be considered.

Forestry and agriculture and other economic sectors link the socio-economic and the landscape component within the region under study.

The production of the economic sectors ‘agriculture’ and ‘forestry’ depends strongly on the ecological and water resources of the landscape, i.e. they are imbedded in the ecological and hydrological system of the landscape. Simultaneously, these sectors are part of the economic and socio-economic systems. Thus, there are many dependencies between the dynamic processes of the two important components.

Further links are given by the sector ‘tourism/recreation industry’ with its broad utilisation of natural resources determining the benefits of such sectors.

3. The structure of the problem

Systems analysis starts with problem analysis. Considering the strong links between the above mentioned components, the restoration of disturbed landscapes can only be achieved by building up a cooperation between the different actors and stakeholders.

Thus, only the implementation of restoration programs leading to both ecologically and socio-economically sustainable developments within the regional context will be successful.

From an ecological point of view, goal states and PMO are required, which support the given natural potentials of self-repairing autonomous processes in the nature. It can be expected that the same is true for socio-economic goals and control options. Options, which do not inhibit the self-organising processes of the socio-economic and economic system should be favoured.

There seems to be no conflict in defining general goals. Each of the involved agencies, authorities and lobbies really want a sustainable development

- of the essential economic and socio-economic components (economic welfare) and
- of the landscape structure (i.e. land use, etc.) and its functions, biotope diversity, species diversity, and ecological performances (environmental welfare).

Such general goals seem to be generally accepted. This is not true in the case of more detailed, sector-specific goals, because different actors have different visions about the ‘best’ development of their own specific sector. Thus, each actor has his own specific goals to realise.

The complications may arise by sector-specific reactions to political, economic and social driving forces from outside the region. Mostly, the aim and the way of sectional specific adaptation options to these forces are different, so that compromises between the sectoral actors have to be found. If not, non-sustainable development can be expected and limited resources (material, financial support) are often ineffectively used.

Often ‘egoistically’ oriented visions exist about the further development of the own sector. Singular possibilities and different ways of design and evaluation of PMO are used, since the actors have access to different financial and natural resources as well as they are supported by their specific lobbies.

When trying to find sustainable development lines for the whole region, the following has to be considered.

- Controversial ideas about the future utilisation of landscape units and the derived policy guide lines.
- The only weakly developed abilities of the actors will agree to renounce some of their egoistic sectoral goals, i.e. to tolerate decreasing own benefits in favour of desired developments in other sectors.

In order to come to a consensus with respect to the specifically focused goals, the responsible person for each component or sector should be able to negotiate with those who are closely linked to the own sector.
The challenge for the different interested actors is to find a broad consensus in the decision about sector-specific goals and the PMO, which should be selected and implemented within a given future time interval (multi-criterial optimisation problem).

Compromises between goals and PMO of the different actors have to be found. If not, non-sustainable development can be expected and limited resources often might be used ineffectively.

The success of such consensus-negotiations depends on sufficient information about possible conflict potentials due to ecological and socio-economic goals and long-termed PMO being not yet consistent.

The complex effect of the PMO has to become more transparent, i.e. information about the short and long term ecological and socio-economic consequences of the implementation of ‘egoistic’ versus ‘consented’ sectional PMO are essential.

4. Problem solving by a simulation approach

4.1. Software tools for the support of regional decisions

The needed information may be supplied by appropriate data bases with a link to data processing units (software system, regional model) for dynamic simulation experiments, that give insights in complex reactions of the socio-economic system as well as the ecological and other systems of the landscape, because a complex answer of the region’s components to an ensemble of differently aimed but well selected PMO of the actors with a subsequent evaluation and an impact assessment is wanted.

It is obvious that this kind of problems can only be handled if an appropriate and easily usable software tool is supplied, including the necessary component models and appropriate simulation facilities.

This integrated software instrumentarium should consist of component models for the different system levels (see Fig. 2) in order to help the analyses of causal key relations within the integrated economic/socio-economic/ecological system.

To overcome the complexity given by a nearly untreatable network of the causal relations, it seems to be recommended to use techniques to make the causal chains shorter without losing essential information (Becker et al., 1999). This could be done by the introduction of aggregated indicators (indices), used as link variables between the qualitatively different components within the system.

In the frame of solving regional development problems, a concept for a metamodel of integrated environmental and socio-economic aspects, and, based on this concept, a basic version of a software tool for the support of regional multi-criterial development activities was developed by Becker et al. (1999). Presently,
a case study about environmental evaluation (hydrological, ecological) of management regimes within a region is under study.

By ‘if-then experiments’ for each actor with subsequent multi-criterial analyses, it will be possible to study the regional consequences for both the actor’s own sector and for the other sectors under study in the region and to find consented goals and PMO.

Simulation experiments with such an appropriate landscape regional model support a better understanding of the whole system, of goal definitions as well as design, evaluation and assessment of PMO (see Fig. 2).

4.2. Stepwise utilisation of simulation models

It seems recommended to follow a two-step procedure.

4.2.1. First step

Find for each sector such a set of options that meet the ‘egoistic’ goal of this sector (after a given number of years), independently of what would happen in the other sectors (under management as usual) as a response to the implementation of such an ‘egoistically’ aimed PMO.

The results of such a first step should be compared with the most interested actors. It can be expected that using data sets of neighboured sectors combined with results of simulation experiments would lead to a more complex understanding of the whole system’s behaviour. This would already result in an extraordinary progress in handling such complex problems.

4.2.2. Second step

This step is aimed to find any lasting consensus in goal definitions and the designing procedures to meet this goals.

The task is to find for each sector a set of such PMO, which lead to the common sense goals. Both the sectional common sense goals and the ‘optimal’ (compromises) section-specific PMO have to be designed and evaluated.

5. Tasks in order to specify the software environment

For further specifications of the software tool, it is necessary to formulate somewhat more detailed tasks that must be solved in using such a software instrument and in its further specification.

The software system must be effective in supporting decision making processes. Therefore, its structures and facilities must stringently depend on (i) the kind of problems to be solved; (ii) the information given about the main processes and their interactions and (iii) the available data. Together with measurement and data gathering programs the tool should support the following tasks.

5.1. Socio-economic block

- Analysis and modelling of the regional economic and socio-economic infrastructure of the producing and service sectors (micro analysis).
- Analysis and modelling of the economic and socio-economic macro processes that determine the labour market, the population structure and migration of the region.
- Definition of the sector-specific goals and their dependencies.
- Analysis and evaluation of the public behaviour concerning environmental goods and its dependencies on political and social driving forces.
- Design of PMO for the control of these processes.
- Analysis and evaluation of the socio-economic, ecological and hydrological consequences of each designed PMO.

The findings and a broad spectrum of simulation results support decision making in planning and management as well as the definition of appropriate goals, especially concerning the reduction of unemployment and emigration.

5.2. Forestry and agriculture block

Among the production sectors of the region, ‘forestry’ and ‘agriculture’ have to be considered specifically as they are intensely linked to the ecological resources in the landscape.

- Analysis and modelling of the dynamics of the economic and natural key characteristics (income, benefits, market output) for the farms and forestry-linked companies leading to the results of economic sectors, ‘forestry’ and ‘agriculture’ of the region.
• Re-definition of the sectional goals as an adaption reaction to possible changes of political and economic driving forces from outside as well as specifications for a special farms and forestry-based companies (e.g. energy crops, Agenda, 2000).
• Design and evaluation of PMO for meeting these goals, especially planning of appropriate and effective production structures and management policies, in order to prevent negative effects of soil degradation, groundwater dynamics, market changes, prize developments, etc.

5.3. Landscape block

• Analysis and modelling of the dynamics of the landscape’s main characteristics, such as land use, land cover, land–water relation and others.
• Definition of the goals that should be reached to satisfy simultaneously the demands of the different landscape users (human population, all industries that depend on the natural resources, energy production, nature conservation).
• Design and broad evaluation of planning guidelines for the aimed landscape structures, and for special use patterns.
• Design and broad evaluation of water management options (flooding options) in conversion areas as a key element for further regional landscape development and the ecological processes, growth and succession.

Solving these tasks provide support in sustainable development and improvement of environmental quality as evaluated by the human population.

5.4. Soil block

Analysis and modelling of

• soil development on mine spoils and humus accumulation;
• dynamics of (unstable) soil characteristics as a consequence of different land use impacts;
• dynamics of physical, chemical, and biological soil processes in the unsaturated zone, depending on water supply (precipitation, groundwater level) and on the characteristics of the geological material;
• soil/plant interactions and
• matter and water balances by coupled vegetation and soil processes.

5.5. Hydrology block

• Analysis and modelling of quantitative and qualitative processes in the watersheds of the region with large-scaled hydrologically disturbed landscape units, depending on land use and climate.
• Definition of the final regional hydrological goals that should be reached in consensus with the regional development authorities’ aims, mainly focused on a stable water balance as a base for the desired development of the ecosystems.
• Design and hydrological, ecological, and economical evaluation of alternative management options for control of natural and artificial water fluxes by the water management agency.

5.6. Forest ecosystem block

• Analysis and modelling of the dynamics of the physical, chemical, physiological key processes in forest ecosystems, depending on the physico-chemical and biological characteristics of the geological materials and on the soil quality of the stands.
• Definition of ecologically possible goal states of the forest ecosystems.
• Elaboration and assessment of management options, that should lead to increased soil fertility (melioration, fertilisation, change of forest structure) and stable growth of forest stands (tree species exchange, fertilisation). Such options are focused on the maintenance of stand and yield stability, even for rising groundwater levels and for dramatically changing soil moisture a.o., depending physico-chemical soil processes.

5.7. Agro-ecosystem block

• Analysis and modelling of crop growth and yield processes on recultivated soils with low soil fertility.
• Definition of the possible goals for yield capacity, depending on management, climate (mainly precipitation), and groundwater level.
• Design of management options and their evaluation in the case of further decrease or increase of groundwater level in landscape units of a certain watershed.

5.8. Unmanaged ecosystem block
• Analysis and definition of the dynamics of the natural flora and fauna (successions) in damaged or disturbed key landscape units, depending on the chemical and physical characteristics of the disturbed geological material, on climate (mainly wind and precipitation), and on small-scaled hydrological features due to hydrological changes.

Modelling of the consequences of policies on landscape development for biotopes and nature conservation.

6. Steps in building the model

Independent of the real chances are always possible and necessary to model the dynamic processes of the region for a logic system analytical approach. As a first result, it yields comprehensive insights into the structure of the total system and, by this, an increase of knowledge about problem-relevant gaps. Obviously, this is a helpful support (necessary, but yet lacking) to plan experiments, monitoring programs and data collections.

In system design, the following system elements are necessary to define.

1. The set of system components \( (C) \), their state variable \( (z) \), the set of processes \( (P) \) within each \( C \) and the links between them within \( C \) and between processes of other \( C \)'s.

2. Driving force variables
   2.1. The (naturally given) driving forces \( (x) \), not controllable by man (climate). Nevertheless, scenarios of assumed climate change may be used as driving force.

   2.2. The scenario-variables \( (v) \) which are very important to the system’s dynamic, but not intended or without any chance to be modelled (marginal conditions that are assumed as scenario, e.g. energy policy, agrar policy, political and economical developments with importance for land use change). For each simulation run these \( v \) can be hypothetically assumed. Often, complex situation scenarios are defined by more than a single (marginal) scenario variable.

3. Human-caused management variable (control time series) \( (u) \), e.g. water flux control options, harvesting options in forestry, fertilisation in agriculture.

4. Ex ante input variable \( (w_{ij}) \) for a process of a certain component \( C_i \). The input time series \( w_{ij}(t) \) is identical with the output time series of a process of another certain component \( C_j \) (ex ilante \( j \) time series \( (w_{ij}(t)) \)). Without supply of \( w_{ij}(t) \) for each time step \( t \) by \( C_i \) the linked process of \( C_j \) cannot be calculated.

   If the \( C_i \)-process and the \( C_j \)-process are coupled with feedback both \( w_{ij} \) and \( w_{ji} \) are needed for calculating the dynamics of the two components. The best modelling option is to include both components in the same model (on-line linkage, see Fig. 3).

   Unfortunately, in some cases an on-line link within the same code is not yet possible, i.e. there exist two separated submodels, each producing an output time series that can be used as the input time series for the other one (off-line linkage, see Fig. 4).

   The stored output of \( C_i \) or an estimated time series \( w_{ij}(t) \) can be used as a driving force for \( C_j \), and vice versa. This estimation can be based on approximations from measurement data or may be defined as a scenario (see Fig. 4).

5. Output variables \( (y) \) as a function of state variables or as a state variables itself.

   In order to support the understanding, it seems recommended to define aggregated output variables (complex indices) that describe system states in such a way that it can be understood and received (on-line or off-line) by quite different system components.

6. Linkage matrix \( (L) \) with the existing linkages between the processes within a single component (single component case), and additional to this with the existing linkages between processes of different components (multi-component case, see the \( w_{ij} \) and \( w_{ji} \) mentioned above).

7. The characteristic time step \( dt \) of each process (e.g. day or year) as the characteristic naturally given time step for the calculation of changes of
Fig. 3. Principle of a multi-component model (on-line linked).

Fig. 4. Principle of a multi-component model (off-line linked).
the state variable which is controlled by the process (Eigenzeit).

By the three types of variables (state variables, driving force variables and output variables), the linkages and feedbacks between the processes within each component and between different components (in the case of multi-component systems), and the characteristic time steps of a process, a modeller is guided in building a single component model and a more or less complex model.

By such a general systems approach, any types of components can be formalised (soil, succession, changes of fauna, forest and agro-ecosystems, economic and social systems). Following the scheme, one gets for each component a description which is consistent with any other one.

This guideline is a sine qua non presupposition for coupling very different components of a complete system, even in the case of comprehensive considerations of a region with ecological, economic and social components.

As seen from Fig. 1, differently scaled and detailed component models are needed. An overview is given in Fig. 5.

6.1. Mathematical description of processes of component model

The designed system serves as a skeleton for component model building in the narrow sense, i.e. for the formulation of the process equations and their links that describe the changes of the state variables for each time step. These equations are mainly based on the experimental and monitoring results as well as existing data from literature and other sources.

The type of these equations may be difference or differential equations, often with discrete terms. The formal process descriptions can be also fuzzy system descriptions.
Simplifying, a model $M_i$ of a single component $C_i$ is characterised by

\[ M_i = (A_i, P_i, L_i, z_i, x_i, u_i, v_i, p_i, z_{0i}, T_i) \]

where $A_i$ is complex algorithm for dynamic calculations, i.e. for running the model, $P_i$ set of all processes, $L_i$ linkage matrix with the coupling variables between processes within the component, $z_i$ vector of state variables, $x_i$ vector of driving force variables (naturally given, no chance options by man), $u_i$ vector of management variables (with change options by man), $v_i$ vector of marginal variables (with chance options by man, scenario variables), $T_i$ set of the Eigenzeit for each process, $z_{0i}$ vector of initial value for each state variable at initial time step and $p_i$ vector of process parameters needed for the process equation.

In the case of a multi-component model, the above expression must be extended by $w_{ij}$ and $w_{ji}$ vector of between component coupling variables, i.e. the ex-ante variables being essential for on-line or off-line calculations in the frame of the multi-component approach.

Following such a formalism, a pool of consistent (i.e. linkable) component models can be built.

In the modelling of a certain set of components, in an early phase, the single component behaviour can be studied using auxiliary ex-ante time series and $w_{ij}(t)$ and $w_{ji}(t)$ (see Fig. 4). Later on, a shift to an on-line more component system (see Fig. 3) and, depending on the further progress, to a multi-component system might be possible.

### 6.2. Model aggregation for bottom up use

First of all, together with system-based experimental research programs for each block (analysis), the modelling efforts will enlarge the detailed knowledge about the physical, chemical, and biological basic processes at a given representative patch site. Usually, the corresponding mechanistic models become more and more extended ones with high demands for initial values and parameters, which are often not completely available at the landscape scale.

Therefore, such knowledge models will be (i) reduced in their parameter demands and (ii) aggregated in their output variables so that they become better applicable for a broad set of ecosystem types and landscape types. This leads to more appropriate (better tailored) information supply to linked components (e.g. link between an ecosystem component and economic forestry sector, or between a hydrological component and the economic agriculture sector).

Often, such an output aggregation in the form of indices or verbal expressions is essential for bottom up transfer of information from a more basic component (natural vegetation) to a higher level component (tourism). In such cases, especially in ecological evaluation of PMO of a certain socio-economic component, it seems recommended to introduce ecological, hydrological, soil and other indices (see Wenzel, 1996; Becker et al., 1999) in order to give the actor a feedback about the consequences in the landscape.

In Fig. 5, the utilisation of a reduced model is shown, concerning design, evaluation and assessment of PMO.

### 6.3. Examples for regional modelling

The recent analysing, modelling and developing software instruments (tools) for (i) large scale regional landscape systems (Becker et al., 1999; Cohen, 1997; Krysanova et al., 1999; Easterling et al., 1993) and for (ii) the supply of additional tools for regional impact assessment of land use changes on ecology, hydrology, and economy (Wenzel, 1996; Schellnhuber and Wenzel, 1988) are developing rapidly.

Erhard and Flechsig (1998) describe a landscape model approach for studying stability and productivity of forest ecosystems under extreme reduction of air pollutants. Within the study region of about 450 km² a process based pine forest model was applied to about 5000 forest patches under regional climate and immersion scenarios.

Especially an increase in regional studies about linked dynamics of socio-economic, landscape and ecological characteristics under changing political, social, and demographical boundary conditions (as scenarios) during the last 10 years can be observed.

Comprehensive and complex model approaches for the analysis and management of socio-economic systems were developed with first priority in modelling hydrological systems on a regional and landscape level.

Examples are HSFP (Flynn et al., 1995), ELM, CELLS (Wolff, 1995), RHSSYS (Band et al.,

Further examples for complex approaches in integrated modelling for the support of decision making and management, even in the case of simultaneous consideration of dynamic processes in the ecological, landscape, and socio-economic components under changing political, demographic and other external conditions are: LEDNES, (Harms, 1995) for analysis of driven landscape dynamics, NELUP, NERC/ESRC (O’Callaghan, 1995) for decision support in landscape planning, IMAGE 2.0 (Alcamo, 1994) for integrated system analysis in order to evaluate of cost–benefit relations in industrial development (costs) and the advantages for the terrestrial/atmospheric/oceanic system, LUC (Fischer, 1995) for the analysis and control of land use and land changes in Europe and Northern Asia, CLUE (Veldcamp and Fresco, 1996), a conceptual framework to study the conversion of land use and its effects, and NOS (Bork et al., 1995) for analysis and evaluation of changes in agriculture land use options in NE Germany, due to deep changes of the political and economic conditions in East Germany. An overview about methods and results of regional modelling (claims and reality) is given by Wenkel et al. (1997).

Running research programmes in this field are, e.g. Landnutzungskonzepte für periphere Regionen (Frede, 1998), Regionalmodelle zur nachhaltig umweltgerechten Nutzung von Agrarlandschaften (Dabbert, 1998), mweltentlastende Landnutzung unter den Bedingungen des globalen Wandels (Wechsung, 1999).

The experiences accumulated in this kind of studies may help to establish future programmes for analysis and understanding the different linked processes in disturbed landscapes as a whole, and for design and complex evaluation of such management options, which lead to sustainable reconstruction and future use of these regions, being presently far from an ecological and economic equilibrium.

7. Conclusions

1. The knowledge about the structures and essential ecological and economic process within the specific region must be increased (chemistry, hydrology, biology, economy, socio-economy).
2. The tasks in basic and applied research and in modelling must be derived from the desired and possible aims in sustainable development of characteristics of landscapes, hydrological systems and the economy and socio-economy in the region under study.
3. The experimental analyses and monitoring programmes should be closely linked to the development of knowledge models for better understanding and prognosis of the behaviour of the subsystems.
4. In order to find a way to a comprehensive regional model (landscape, ecological and hydrological components linked with the economic and socio-economic components) the specific component models must be horizontally and vertically linkable.
5. For such a complex task of regional modelling, a commonly accepted system structure (frame, components, links, driving forces) must be designed, in cooperation with decision making authorities of the region. The involved research teams should feel obliged to this system concept.
6. Therefore, the research programmes and teams should be structured in such a way, that the cooperation within and between the different ecological and hydrological groups and the economic and socio-economic groups will develop more until the needed and satisfying level is reached.
7. Following such a principle of cooperative disciplinary research, which is based on systems theory and which is using advanced tools, it should be possible to develop an instrument for evaluation and assessment of ecologically, economically, and socio-economically oriented PMO. Finally, it is to be expected that such a simulation and data processing tool can in be used in order to select the optimal PMO.

References


