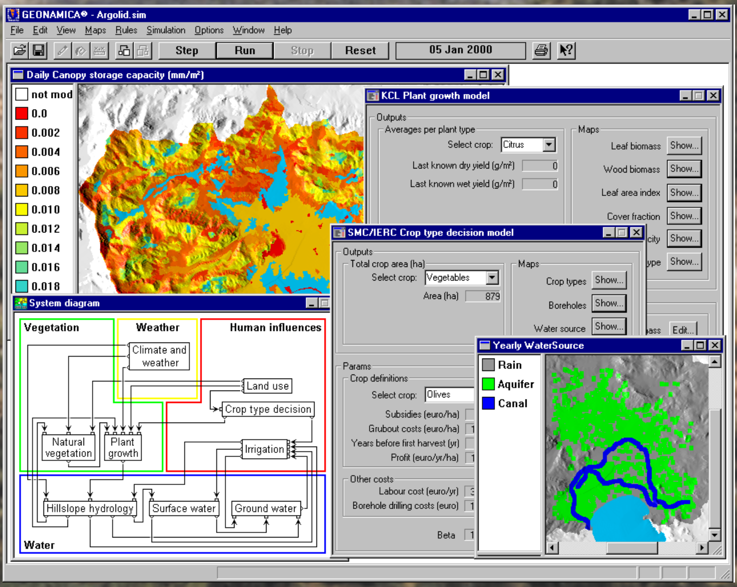
MODULUS

A SPATIAL MODELLING TOOL FOR INTEGRATED ENVIRONMENTAL DECISION-MAKING

Synthesis



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05 Jan 2000

Select crop: Citrus

Last known dry yield (g/m²) 0

Last known wet yield (g/m²) 0

Select crop: Vegetables

Area (ha) 879

Select crop: Olives

Final Report
Contract ENV4-CT97-0685
Submitted to the Commission of the European Union
Directorate General XII
Environment (IV) Framework
Climatology and Natural Hazards Programme
Brussels, Belgium

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TABLE OF CONTENTS

SYNTHESIS

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MODULUS, A SYNTHESIS

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Abstract

An important amount of new knowledge and research material has been obtained from the many projects carried out in the EU-DG12 Environment and Climate Programme. However, little effort has gone into making this scientific material available as part of practical planning or management tools for regional spatial planners or public policy makers. In a two-year project, MODULUS developed a generic spatial Decision Support System (DSS) intended for integrated environmental policy-making at the regional level. Models and scientific material from 4 past or ongoing EU-projects were integrated that represent the physical, economic and social aspects of land degradation and desertification in the Northern Mediterranean. The individual models operate at very different temporal and geographical scales. At the most detailed temporal scale, processes taking few minutes are represented, and, at the most detailed geographical scale dynamic models running on top of raster-GIS layers are implemented. The MODULUS DSS is developed into a very interactive, transparent and (geo)graphical instrument. It runs on PC machines under Windows 98/NT and makes extensive use of the ActiveX/COM Component Technology to integrate component sub-models. In order to demonstrate its generic applicability the MODULUS DSS is applied to two pilot regions: the Argolida (Greece) and the Marina Baixa (Spain). While MODULUS succeeded in developing the information system described, it was less successful in uncovering its potential end-users and involve them in the application of the tool in both case regions.

1. Methodological Approach

In the past decade, as part of its successive Framework Programmes, the European Union has sponsored major research efforts in the domain of land degradation and desertification. This research has generated large amounts of data, methodologies and models, which have been instrumental in getting a much better understanding of both the physical and human causes and effects of these phenomena in Southern Europe. Based on the work carried out, many of the research projects made ‘scientifically based’ suggestions and recommendations, on ways to slow down, stop or reverse the process of land degradation. However few of the measures and interventions proposed found their way through the policy making process and got to be implemented. Thus, and from a practical policy making point of view, little use was made of the studies carried out. This is mostly due to the fact that much of the research was carried out for pure scientific reasons and with the purpose of better understanding the processes causing or caused by land degradation. This type of research tends to be very sectorial and in depth, rather than integral and multi-faceted in nature. It may produce output, which is extremely valuable in its narrow discipline, but overly specific and fragmented for the policy maker who needs a broader societal view on the problems in need of solutions.

With a view to boast the policy use of material developed for scientific purposes, the MODULUS project posed the following scientific question: *Can existing scientific material, obtained from different complementary research projects, be integrated and made useful to policy makers?* MODULUS did not intend to answer this question in a universal manner, rather it set out to tackle this subject in a very practical, even pragmatic manner, and build and apply a spatial Decision Support System aimed at integrated socio-economic and environmental policy preparation in the domains of Land Degradation, Desertification and Sustainable Water Management in the Northern Mediterranean. In order to achieve this aim, the following guidelines and activities were listed at the beginning of the project:

- To make use, to the extent possible, of existing scientific knowledge, methods, models and databases available from recent 'EU Environment Programme' projects. In particular, scientific material developed in EFEDA, ERMES, ModMED and ARCHAEOMEDES, and to a lesser extent MEDALUS was assessed for integration.
- To review existing models dealing with physical, ecological and socio-economic aspects of land degradation and adapt them in view of their integration into a multi-scale, multi-temporal dynamic modelling framework and decision support instrument aimed at better understanding and mitigating the processes of land degradation and desertification in Europe.
- To involve from the start and for the duration of the exercise, potential end-users of the intended DSS-system from local planning and decision-making authorities, to explore the wider range of issues that preoccupy them, and to include in the models those policy indicators and variables that they consider relevant for their practical policy preparation work.

It was the explicit aim of MODULUS, to build a Decision Support System with a high level of flexibility and generic applicability enabling the end-user to gain access to state of the art knowledge about the processes causing and caused by land degradation, and providing appropriate tools for the design and evaluation of policy options in an integral, interactive, transparent and user friendly manner. In order to focus the research and development activities, the system and its integrated models were to be applied and tested in the Argolida (Greece), and Marina Baixa (Spain) regions as part of a collaborative effort involving local policy makers and researchers that previously worked in these regions as part of EU Environment and Climate projects. MODULUS principally built upon the research results obtained in 4 projects: EFEDA, ERMES, ModMED, and ARCHAEOMEDES, and to a lesser extent MEDALUS. These projects have been selected among those carried out in the DG 12 Climate and Environment Programme because of the complementary nature of the research carried out.

1.1 The EFEDA project

The EFEDA project (see for example: Burke et al., 1998) examined the interaction between types of land surface and hydrological change associated with desertification and meso-scale climatic impacts. EFEDA developed methods and models to investigate the interaction between the land surface and climate processes within the context of changing surface properties. One of the main outputs of research was the PATTERN ecosystem model, developed to investigate the impact of climatic variability and climatic change on surface and subsurface hydrology and plant ecology (Mulligan, 1996, 1998a). The model is a tightly coupled hydrology and plant growth model developed for semi-arid environments. It incorporates all of the major hydrological fluxes as well as ecological processes of germination, growth, biomass partitioning, death and competition for up to three plant functional types at any one time. It includes a rainfall, storm and weather generator in addition to the tightly coupled hydrology and growth model that forms its core. The model was originally designed as a cellular slope model applied at the $100m^2$ scale. It was later coupled with a GIS and applied to the whole Guadiana catchment (Castilla La Mancha, central Spain) for analysis of the impact of land use and climatic change on groundwater recharge.

1.2 The ERMES Project

As part of the ERMES project (see for example: Oxley et al., 1998) multi-scale models have been developed concerning the effect of changing land-use patterns on vegetation cover, erosion risks, water run-off and infiltration, changes in ground water and channel flows, and evapotranspiration. The models developed capture the effects of various processes of water flow and storage as a function of biological activity that operate in the system. These are very small-scale processes involving the water storage capacity and permeability of the soils as a function of the vegetation cover, slope, soil type, aspect and detailed spatial and temporal patterns of rainfall. This allows to represent at more aggregate levels the behaviour of successive scales of sub-basins within a catchment, and to represent the complex impacts of land-use on the channel flows at local and large scales, as well as on the recharge rates for ground water, and the stability and fertility of soils within the catchment.

1.3 The ModMED Project

The focus of the ModMED project (see for example: Legg et al., 1998; ModMED, 1998) is on the study and modelling of natural vegetation dynamics, thus, on the biological and ecological processes characterising land covered by freely colonising and growing plant species. However, there is also awareness that the space available to natural vegetation enabling the recovery of spontaneous plant cover is largely dependent on socio-economic dynamics. Where human pressure is increasing, loss of biodiversity and the complete destruction of habitats occur, but, where old types of land-use practices are abandoned, new re-colonization and succession takes place restoring the dominance by shrubs and eventually forest species. In turn, the latter may lead to the loss of some ancient communities of grass- and shrub-land vegetation with a high biodiversity and conservation value. Although these processes are increasingly understood, the timing of the related landscape changes and the biological mechanisms behind such changes (species dissemination, establishment and competition) still need to be studied to a more satisfactory extent. ModMED addresses these problems by integrating three different levels of ecosystem analysis: individual plant, plant community, and landscape. A modelling environment has been developed consisting of hierarchically nested modules operating at different spatial and temporal scales.

1.4 The ARCHAEOMEDES Project

The ARCHAEOMEDES Project (see for example: Leeuw, 1998) investigated how the changing socio-natural dynamics of Southern Europe (urbanisation, agro-industry, infrastructure) relate to the problems of degradation and desertification in the area. Its central themes were: (1) the definition of the various levels of structuration which drive the dynamics involved, (2) the investigation of the ways in which the dynamics at these various levels articulate, (3) the development of decision support models of these dynamics which facilitate the investigation of alternative scenarios for the future, and (4) the development of ways in which to map these dynamics in geographical time-space. The project used a combination of fieldwork, analysis, interpretation and modelling focussed on the relationship between the social dynamics responsible for perception, decision-making and action and the natural dynamics, which sometimes are subject to human action, and at other times, trigger and constrain it. The phenomena are investigated at four spatial scales, each representing the interaction between two levels of structuration ranging from the European scale to the scale of the individual.

1.5 Outline of an integration

From these short project descriptions, it may be clear that there is both complementarity and overlap between the projects selected. The complementarity permitted to come to an integrated model covering the essential physical, ecological, economic and social processes related to degradation, while the overlap permitted to select the most appropriate and compatible model-components among the alternatives available.

The incorporation of EFEDA's PATTERN model within MODULUS provides mechanisms for analysing the spatially variable sensitivity of landscapes and water resources to land use change within a variable climatic regime. There is a certain degree of overlap between EFEDA and ERMES as far as the study of biophysical processes is concerned, however, while EFEDA studies the processes on the micro-geographical scale only, ERMES aggregates such micro-results in order to represent processes that are active at the level of sub-catchments as well as the complete catchment. Moreover, ERMES not only models hydrological processes such as run-off, infiltration, and channel flows at the surface, but also those at the sub-surface level, involving replenishment, depletion and pollution of the aquifer. In order to create a tool with which decision makers interested in strategic planning can perform exploratory exercises concerning possible economic developments, land degradation, waste management, and water use and re-use, the biophysical processes studied and modelled in ERMES and EFEDA need to be linked to the human decision making concerning land-use and economic demand which is modelled in the ARCHAEOMEDES project. The linked soil parameters, climatic and physical conditions, and characteristics of potential crops lead to a detailed pattern of expected yield. Expected yields together with perceived opportunities and risks determine the farmers' decision making and thus the patterns of actual land use and resource demands, inputs and impacts. In turn, the demands for land and resources will affect the physical parameters of the environment. Not in the least, as modelled in ModMED, it will have an affect on the natural vegetation: the immediate disappearance of natural land use when human activities expand, and the very gradual recovery of species, communities and finally natural landscapes when land is no longer used for intensive human activities.

2. Choice of the Pilot Regions

MODULUS is to develop models and a Decision Support System with a high level of generic applicability in the Northern Mediterranean region. Applying the system to two pilot regions will test the adaptability and transferability of the system. From the onset of the project, the Marina Baixa (Spain) and the Argolida (Greece) were selected based on the following scientific and practical considerations:

1. *Policy relevance.* Both regions are coastal watersheds, some 40 by 40 km in size. They are predominantly limestone systems with a rugged, mountainous landscape and elevations ranging from sea level till +/-1500m. The socio-economic activities are concentrated in the semi-arid, coastal, lowlands suitable for the practice of Mediterranean rain fed poly-culture (olives, vines and cereals). However, the traditional agricultural has been largely replaced by mono-culture and intensive fruit cultivation, based on irrigation: citrus in the Argolida and medlar in the Marina Baixa. Both are valuable but delicate cash crops, which demand capital-intensive cultivation and cause a lot of stress on the limited drinking water supplies. In the Argolida more than in the Marina Baixa the income generated in the agricultural sector depends on European export subsidies, a system that is not sustainable in the long run. In the Marina Baixa, the rising importance of the tourism industry generates ever-increasing demands for water and conflicts

with the farmers are an emergent issue. Thus, in both regions selected, there are non-trivial problems of land degradation and depletion of drinking water that require integrated assessment and urgent policy intervention.

2. *Focus.* MODULUS promotes a dynamic and integrated approach to water management, desertification and land degradation. From the many sites where EU Environment Programme projects have been carried out, we selected two where physical, natural, and socio-economic processes have been studied by the research teams participating in MODULUS. Sites also, were the consequences of human practices (crop rotation schemes, irrigation, abandonment of agricultural land, return of natural vegetation cover) on slope dynamics and on the aquifer (depletion, pollution, salt intrusion) has been documented and modelled.
3. *Data availability.* MODULUS did not include an intensive data acquisition programme, rather it proposed to work to the extent possible with existing data. For both regions selected, data of sufficient quality, including GIS data, were readily available to calibrate and run the integrated models.
4. *Model availability.* MODULUS integrates existing models, methods and knowledge. It allowed for the reformulation (aggregation and simplification) of existing models. But, as little as possible new models were to be developed. Both sites have been selected because ERMES and ARCHAEOMEDES carried out combined research in these regions in an effort to pool up to date understanding of the linked natural and socio-economic dynamics. EFEDA and ModMED had been involved in predominantly natural dynamics, and had, as a consequence, been able to come up with more easily 'portable' insights and models.

3. Policy makers

The development of a Decision Support System is an expensive and a time consuming venture, only to be undertaken in cases where problems exist that need a lasting surveillance of a complex system and where interventions, aimed at keeping this system on course, need to be assessed. But, DSS are sophisticated technical instruments with a logic of their own. Irrespective of their level of sophistication, they provide, through their models and tools, a partial representation of the real world system. In order to assure their effective use for policy and planning exercises, the way in which they represent the real world system should be understood and supported by the intended end-users. To that effect, the latter should partake in the development of the DSS. From the start, they should get the feeling that the end-product is useful in solving their problems in ways that make intuitive sense to them (see for example: Holtzman, 1989).

In MODULUS the intended end-users are regional planners and policy makers, defined as: *high-level technicians actively involved in the design and evaluation of regional public policies. They perform policy work of a formal/analytic nature in support of the administrator or politically appointed person responsible for taking the actual decision and starting the actual policy implementation.* Thus, this policy maker is not a politician; rather, he is a technician. He is not setting the agenda; rather the latter is set by his superior, the public, and more and more the media. Most often, the policy maker will work under a lot of stress due to time constraints and rapid changes in the emphasis and relevance of the policy work itself.

It was one of the aims of MODULUS to involve the intended end-users from both pilot regions in the project right from the start, but this caused more problems than expected which forced us into rethinking the practical implementation of this aim. In retrospect, some of the problems encountered reflect rather naïve visions on the true differences between the world of the researcher and that of the policy maker. Nevertheless, some of the lessons learned are very valuable in case we ever will want to equip policy makers with state of the art research material. We met with problems that find their origin in the research activities carried out, as well as in the policy-making organisations that we aimed to work with (see Chapter 2).

1. In both pilot regions selected, as would have been the case in most other pilot regions, the scientific work carried out in the past, had been carried out for pure research purposes, and not for policy making strictly speaking. Hence, local and regional policy makers had never been involved in this work. Nor was there a network of potentially interested institutions or persons. As a result, MODULUS had to find and contact potential end-users and convince them of the usefulness of yet another research project. This process was slow and tedious more so, because at the beginning of the project there was not much to be shown to the end-users. In fact, most of the models considered useful for integration, were still under development as part of the projects that initiated their development. Thus, they could not be demonstrated in a running version. It was only in month 18 of the project that a reasonable demonstrator was available which could convince the end-users of its usefulness. This was close to 12 months later than what was required and originally expected.
2. As will be explained in Paragraph 4 of this chapter, there are great differences between policy models and research models. These differences are not accidental; rather are deeply embedded in the minds of the researchers that produce the models. Thus, it is a very hard bargain for a developer to simplify his model. While developing an integrated model, the process of simplification and aggregation is an iterative one, as step by step a model is tuned to its place and role within a larger entity, at an appropriate temporal and spatial resolution. This takes time, and, none of this is trivial, certainly not when this process takes place before or while the original research model is finished. Thus, the modeling materials available in MODULUS, as well as the model developers, were not necessarily and entirely ready for the exercise. This caused more delays in producing a version of the MODULUS DSS that could have been demonstrated to the potential end-users.
3. In the Argolida, it was reasonable to assume that the institution, benefiting most from the MODULUS DSS would be the Prefecture, as the pilot region is fully encompassed within the jurisdiction of the Prefecture. Moreover, the Prefecture is an institution deciding on land use, agricultural and water management policies, hence, the domains that are dealt with by the MODULUS DSS. However, in the Marina Baixa, it was less clear which policy-making institution should take ownership of the MODULUS DSS, because it is a less self-contained administrative or policy-making entity. Potential end-users could be found either in the larger municipalities that are part of the Marina Baixa region, such as: Benidorm, Altea, or Callosa, or in administrative entities that are larger than the Marina Baixa, such as: the Province of Alicante, or the Comunidad Valenciana. In the Marina Baixa, none of these institutional bodies expressed much interest. More positive reactions were obtained from stakeholder organizations, such as the water companies and the farmers' cooperatives (see Chapter 2, Part 1, Section 2).
4. In some West European countries there exists a long tradition of involving scientifically trained technicians in the policy preparation process. Other countries are still in a phase of setting up the institutional frameworks within which these people are or will become active. In Greece and for the Argolida for example (see Chapter 2, Part 1, Section 3), regional agricultural policy preparation takes place at the level of the District and the Prefecture. This institutional structure is very new: the level of the district exists since 1997, while the level of the prefecture is in place since 1994. For both institutions, the intended technical staffs have not been hired yet. Precisely these technicians are the prototypical end-users of the MODULUS system. Thus, MODULUS departed from a very technocratic West European view on policy-making and intended to implement it in regions where the infrastructure and the people to support it are not present. Thus it was extremely difficult to find in the pilot regions even a few people that would be end-users of the system developed.
5. Another problem is to name the exact person within the policy-making organisation that should be the user of the DSS. Although it is well understood in a scientific context that problems of land degradation and water management need to be addressed in an integrated manner, policy-making institutions are still organized in a strictly sectorial manner. Hence, the technicians within these are often more interested in the analysis of 'sectorial management solutions' rather than 'integrated policy options'. Thus the MODULUS DSS does not always offer them the

level of detail that they find suitable; instead it offers them a level of complexity that they find confusing.

6. Only at the end of the project (month 21) did we finally get through to a few potential end users. There were limited contacts only. Insufficient and too late to change anything substantial in the system. Mostly they got to see the prototype system developed in a few demonstrations and in a workshop organized in both case regions. The results of these workshops were in general positive. They are discussed at great length in Chapter 2, Part two, Sections 2 and 3.

In the absence of real policy makers in the early stages of the project, and in order not to slow down the technical work, the project team decided to define a 'virtual' policy maker and 'typical' policy problems. The intention was to replace these by 'real' policy makers and their 'real' policy problems later in the project. We only got to this stage at the very end of the MODULUS project. We have met with our intended end-users, we heard their reactions to the system demonstrated and have listened to their problems and concerns. If MODULUS would have continued for another year, much of this could have been incorporated into the DSS. But, it did not.

4. 'Research Models' versus 'Models to support Policy Making'

Despite the fact that the terms 'integrated' or 'integral' model are widespread in the scientific literature, and despite the fact that the use of integrated models is strongly advocated in 'disciplines' such as Integrated Assessment (see for example: Gough et al., 1998), very few recipes or procedures for model integration are available from the literature. Hence, model integration seems more an art than a science at this moment.

The integration of models is clearly a multi-criteria and multi-objective problem as problems need to be solved that deal with the *end-use*, *scientific*, and *technical* aspects of the integration. Although we treat them here separately, it is clearly understood that this sub-division is rather artificial:

- *End-use integration* deals with the end-use and the end-user of the model. It seeks an answer to the questions: what is useful to be integrated with a particular end-use in mind and what are the needs, expectations and constraints of the end-user. Public policy problems are very often 'complex problems' rather than 'complicated problems' in the sense that although the problems touch the near complete system, they could be given an adequate answer if a limited formal description of the whole system would be available to support the search for solutions. The development of the integral MODULUS model involved foremost a simplification and aggregation effort with minimal loss of content and accuracy in order to enable policy use of models that were originally developed for research purposes.
- *Scientific integration* is about what can and what cannot be integrated from a scientific point of view. It involves constraints on the type of models (for example: qualitative vs. quantitative, dynamic vs. static, equilibrium vs. non-equilibrium, etc.) on the temporal dynamics and time scales, on the spatial dynamics and spatial resolutions, on the details that matter, and on rigorous methods for aggregation and simplification. Once sub-models have been selected and integrated, a thorough analysis of the resulting product is required in order to find out whether the component models are correctly and sufficiently coupled, whether their synchronization and information passing is correctly handled, and whether the integrated model is an appropriately complete and correct representation of the real world system. Such analysis should bring about the missing elements and processes in the representation.
- *Technical integration* deals with the ways in which existing models, their software representation, databases, user-interfaces, input and output devices can be coupled into a single system, running on the end-user's computer platform. In the computer sciences, technical

integration has been given a lot of attention in the last decade. It has become much easier, at the least for the software technicians among us, with the venue of object oriented and component based development methods and frameworks.

The approach taken in MODULUS was clearly bottom-up: based on a reasonable understanding of the characteristic processes and problems typifying the pilot regions (and many similar Mediterranean regions) and based on a fair amount of complementary modelling material, an integrated model was designed and constructed. On the basis of information available before the start of the project, the decision was taken to limit the amount of models considered for integration to those developed as part of the 4 projects described earlier in this chapter. These projects where deliberately selected on the basis of the complementary nature of the research carried out: from a preliminary analysis it was concluded that the potential for integration was real. This decision limited from the start greatly the number of models to be analysed and evaluated with a view of their integration in the MODULUS model. But, this does not exclude that other models, from other EU-Environment and Climate projects, could have been integrated and could have resulted in a much better DSS than what is available today. As a matter of facts this is quite likely the case. At the end of MODULUS however, we are much better equipped to consider the possibility for exchanging MODULUS-models against more appropriate ones or complement them with additional ones selected from any of the other EU-funded projects. At this moment, unlike in the beginning of the project, it is much better understood what the precise role of 'other' models would be within MODULUS and why this role is insufficiently covered by the actual MODULUS model. The factual possibility for extensions or modifications of this kind is one of the virtues of the open architecture of the MODULUS system.

4.1 End-use integration

Models are '*a simplified representation of a system (or process or theory) intended to enhance our ability to understand, predict, and possibly control the behaviour of the system*' (Neelamkavil, 1988, p.29). However, there are important differences between 'Research' models and 'Policy' models.

Research models are strongly process oriented. Their temporal scales, their spatial scales, but also their level of complexity is determined by the characteristics of the process that is the subject of the modelling exercise. The model is mostly mono-sectorial. The model developer aims at a representation that is as accurate as possible. He uses the model to test hypotheses and push the level of understanding with an eventual aim to enable 'prediction'. In his endeavour, he is encouraged to make use of scientifically innovative techniques and he will develop a model that is as complex as required. Often this will pose difficulties in validating the resulting model. But, in a quest for new knowledge, the development of the model is a purpose of its own right as it raises new questions that help in furthering and deepening the level of knowledge. In the process, new data needed for the model will be gathered as required from field sites or other sources. The processing speed and the interactivity of the model are not considered a criterion. Nor are the transparency of the model and its user-friendliness, as the model developer is usually the only user of the model.

Policy models are foremost problem oriented. The policy problems that are in need of solutions determine the time horizon of the calculations performed as well as the temporal and the spatial resolution at which processes are represented. The levels of detail, complexity and spatial resolution are most often determined by the availability of data. Policy models are only interesting because they deliver usable output. In order to achieve this, robust, extensively tested, and proven methodologies will preferentially be applied to perform the mathematical operations. The policy model might be complex, but it is kept as simple as possible. Quite often it is superficial, but addresses the problem in an integrated manner. The processing speed and the interactivity of the model are determining factors for its success, mostly so if the model is used in participatory and exploratory exercises involving policy makers and/or stakeholders. Also the transparency and the user-friendliness of the system are crucial factors. And, as the model is very much problem oriented, the involvement of the problem owner during its development is very dear.

In his review of the models developed as part of projects in the field of desertification under EU framework III and IV, hence including the material used in MODULUS, Mulligan (1998b) describes these differences in more detail (see also Chapter 4). He reinforces the point that research models are not automatically useful for policy purposes; rather that important adaptations are often required.

In the selection of component sub-models for the integrated MODULUS model, the following list of key *end-user requirements* was taken as a guideline (see Chapter 4, Section 1):

(a) *All processes.* The MODULUS model should adequately represent all the important processes necessary to provide the required policy outputs.

(b) *Scientifically proven.* The process descriptions within the MODULUS model should be well understood and scientifically proven. A well understood, proven but crude process description is preferred above an innovative but poorly documented and less proven one. The model results should be as robust, reliable and accurate as possible.

(c) *Scale.* The MODULUS model should be spatial and operate at a regional scale. It should provide information at a sufficient level of spatial resolution to reflect the scale of variation in the most important physical, environmental and socio-economic variables. A spatial resolution also at which policy problems occur and can be addressed in public policies.

(d) *Time horizon.* The MODULUS model should be dynamic and operate at time scales and temporal resolutions representing realistically the autonomous dynamics of the system modelled. A time horizon also which is relevant for policy design, implementation and assessment.

(e) *Routine data.* The MODULUS model should be sufficiently simple to run as much as possible from routinely measured data. Routinely available data may include data collected by government or intergovernmental agencies such as the EU.

(f) *Scenario based.* The MODULUS model should provide easy to understand scenarios that the user can be taken through. These may be for environmental changes, anthropic impacts, and management options;

(g) *Output centred.* The MODULUS model should be output centred. It will be judged mostly upon the quality of its output and less upon its scientific or technical innovative character. It should provide appropriate results using indicators or variables that directly interface with the policy implementation process rather than more abstract scientific or technical variables;

(h) *Interactive.* The MODULUS model should be fast, responsive and interactive and should cater for a very short attention span. A response time of 15-60 minutes per simulation-run covering a period of 20-30 years should be aimed for. Clever models, fast algorithms, and efficient code are required to achieve this.

4.2 Scientific integration

From the 4 projects, models were available in different stages of development: some where fully finished and had been tested and validated against real world data, while others were still in an early development phase, some of them were barely past the conceptual phase. The models were evaluated on the basis of an informal evaluation of their content and their conceptual, paradigmatic, spatial, dynamic, and technical characteristics using agreed criteria (see Chapter 3). A more profound scientific evaluation would also have considered the performance of the models in terms of their capacity of generating validatable output. However, most of the models available from the 4 projects where not sufficiently operational to permit this kind of analysis.

As a result, the evaluation focused strongly on the role models could fulfil as component sub-models of the integrated MODULUS model. The following criteria where taken into consideration for their selection and evaluation:

- *Time scales and temporal dynamics.* Only dynamic models are considered. Models have to span a strategic time horizon (10-20 years) and operate at appropriate (simulation) time steps reflecting the real world processes and decision-making time frame (1day-1year). With a view of simplifying or aggregating the model, the effect of increasing or decreasing the time step on the performance of the model is a criterion;
- *Spatial resolution and spatial dynamics.* Only spatial models or models that can be spatialised are considered. Models need to be applicable to a relatively large regional entity and operate at an appropriate spatial resolution reflecting realistically the real world processes, the spatial variability across the region, and the individual geographical entities subject to decision and policy making (1ha-1000km^2). With a view of simplifying or aggregating the model, the effect of increasing or decreasing the spatial resolution on the performance of the model is a criterion;
- *Compatibility of scientific paradigms.* Models are considered that from a scientific/operational point of view can be integrated. Thus, the basic assumptions and constraints on which the models are developed are evaluated. Most of the models selected in MODULUS are spatial, dynamic, non-equilibrium or quasi-equilibrium models that are solved by means of simulation. Hence, little problems with clashing scientific paradigms were detected;
- *Models that fit the total integration scheme.* Models were considered that fulfilled a task within the MODULUS integration scheme which was not dealt with by any other (sub-)model. They compute a subset of the total set of state-variables and exchange the necessary information among one another at the right temporal and spatial scales during the calculation;
- *Level of sophistication.* The models selected for integration are in most cases simplified versions of 'the ultimate' or 'the best available' models. In order to fit the integrated scheme, and to work at the right level of abstraction, models need to be simplified and striped of details that are not directly relevant in the process represented, the pilot regions and/or the problems studied. The value of the integral model is as good as the weakest element in the web of linked sub-models. Hence, it is better to improve this weakest element rather than to add details to the other sub-models.

From the model descriptions provided by the developers at the beginning of the project, Tables 1 and 2 were compiled. In both tables, black cells indicate the time and space resolution at which the models appropriately represent the processes modelled. Non-spatial models, such as the RBCLM2 model, or spatial models running on irregular geographical spaces, such as the Catchment model, or running at variable time steps, such as the PATTERN Weather & Storms model, are represented by means of a blue cell in the appropriate columns. If however such model gets a black cell in one or more columns, then it can be spatialised or made to run at a fixed time step.

Name of Model	**Project**	**Non-spatial**	**irregular**	**Spatial resolution (in meters)**			
				1 < 10	10 < 100	100 < 1000	> 1000
Constrained cellular automata	RIKS				■	■	
Forest fire model(*)	ModMED				■		
Grazing Model(*)	ModMED				■		
Seed dispersal (**)	ModMED				■		
Community model (RBCLM2)	ModMED	1 < 100			■		
Catchment model	ERMES		> 1000				■
Slope model (*)	ERMES			■	■	■	
Aquifer model (IERC)	Archaeomedes					■	
Aquifer model (AUA)	Archaeomedes					■	
Decision making model	Archaeomedes			■	■	■	
PATTERN Weather & Storms	EFEDA	■					
PATTERN Hydrology Model	EFEDA	.001-100000		■	■	■	■
PATTERN Plant Growth Model	EFEDA	.001-100000		■	■	■	■

Table 1: *Models considered for integration in MODULUS; spatial resolution as specified by the developers. (*) refers to models useful for integration, but not integrated as yet. (**) this model has been re-implemented entirely.*

These tables helped in defining a set of minimum requirements for the integrated product in relation to the temporal and the spatial resolution at which it is to run and enabled the modellers to get a better view on the effort required to narrow down the differences in temporal and spatial resolution of the component sub-models. Finally, from the tables an estimate could be made on the type and resolution of data required to run the integrated product.

Name of Model	Project	Temporal resolution					
		non-dynamic	Time step				
			variable	hours	days	months	years
Constrained cellular automata	GEONAMICA					■	■
Forest fire model(*)	ModMED				■		
Grazing Model(*)	ModMED					■	■
Seed dispersal (**)	ModMED					■	
Community model (RBCLM2)	ModMED					■	■
Catchment model	ERMES				■	■	■
Slope model (*)	ERMES				■		
Aquifer model (IERC)	Archaeomedes				■		
Aquifer model (AUA)	Archaeomedes				■		
Decision making model	Archaeomedes					■	■
PATTERN Weather & Storms	EFEDA		🟦		■		
PATTERN Hydrology Model	EFEDA			■	■		
PATTERN Plant Growth Model	EFEDA			■	■		

Table 2: *Models considered for integration in MODULUS; temporal resolution as specified by the developers. (*) refers to models useful for integration, but not integrated as yet. (**) this model has been re-implemented entirely.*

The analysis of the two tables lead us to conclude at first that an integrated MODULUS model consisting of the models mentioned, would be a grid based model running at a spatial resolution of 1 ha (100 by 100 meters) and at a temporal resolution in the order of 1 week to 1 month. The output generated with this model would suffice for most relevant policy questions in both case regions. A spatial resolution of 1 ha would be appropriate for the majority of the processes represented, and a large amount of GIS data is available at this resolution. Also, this spatial resolution allows for the inclusion of models running on irregular (administrative) areas if the borders of these are redrawn to coincide with the edges of cells. The errors thus made are minimal.

However, the choice of a monthly or weekly time-step was not appropriate for a number of the models. In particular, KCL's PATTERN model (see for more details Chapter 4) requires a much finer time step (bucket tip times, minutes or hours). As a result, the decision was made to develop the MODULUS model, running at an hourly time step. While the simulation is stepping through time, sub-models are invoked as required and the information, which is exchanged between them, is aggregated over days, weeks or months as need be.

4.3 Straightforward integration, adaptation, rebuild

The key trade-offs in the selection process were very much between accuracy (of the data and of the model process representation) and simplicity (of models and of data). The resulting model needed to have sufficient spatial and temporal detail and sufficient model complexity to accurately represent the processes but needed to achieve this over large areas in a fast and responsive manner with a minimum of data. From the Paragraphs 4.1 and 4.2 it will be clear that this is not automatically achieved; rather that important adaptations to the research models were required before they were effectively integrated.

In this respect, MODULUS has developed solutions at three levels (see Chapter 4):

- *straightforward integration* when the model represents the process adequately and efficiently, and when the interactions with other component models is possible;
- models are *adapted* if only minor repairs or reformulations of the model, its algorithms or code are required to have it perform its tasks more appropriately;

- finally *rebuilding* is considered when the model need major repair and adaptation in order for it to fit in the modelling scheme.

Clearly, the more a model has been designed and developed with a generic purpose in mind, the more a straightforward integration is possible. However, the rebuild solution is often the only one that will meet all the user-requirements fully. In MODULUS we have gained experience with all 3 levels of integration: the land-use model (see Chapter 5), and the AUA Aquifer model (see Chapter 6) were integrated as they are; the Farmer Decision Making model (see Chapter 6), the Natural Vegetation (see Chapter 4, Section 3) model and the Watershed model (see Chapter 6) have undergone adaptations, and the Weather, Hydrology and Plant Growth models (see Chapter 4, Section 2) have basically been rebuild.

4.5 Technical Integration

As all of the models discussed so far are also computer models, the problem of technical integration is very much a hard- and software problem: how can we efficiently link pieces of executable code so that they together perform the operations specified in the integrated model at the right time and so that data is exchanged in a way that is consistent with the temporal and spatial logic of the model? And, is it possible to do this in a manner that enables reconfiguring the model in a straightforward manner?

Clearly, the typical user of a modelling shell or Decision Support System (DSS) would be served best if he could compose, exchange and re-arrange sub-models as easily as Lego building blocks and develop his model from a set of exchangeable and interchangeable *Model Building Blocks* (MBB). Such Model Building Blocks represent a part of a model: an action or process. They can be more or less complete models varying from simple mathematical operators to nearly complete models consisting of coupled mathematical equations performing large numbers of sophisticated calculations. The concept of MBB is not new, it has been implemented in different forms as part of many simulation and modelling frameworks.

But, in MODULUS the question of re-use was clearly posed: from different EU projects partners have their existing models, written as monolithic applications in whatever programming language they master. Most often, this application is their model: they have worked on the code for a long time, have tested it and trust it. Rather than re-coding this material in yet another programming language to develop yet another monolithic application, MODULUS has chosen to try and integrate the material on the basis of a state of the art component technology. The constraints of time and budget, the availability of ready to use modelling material, as well as the objective to produce a running system applied to two pilot regions made us decide to tackle the problem from a rather practical angle. With a view to present at the end of the project a tangible answer whether component-based development is a usable methodology to develop a DSS for environmental policy making, the focus of the work carried out under the heading ‘technical integration’ therefore was on the evaluation of the usability of the existing component technologies, rather than on the development of new standards, functional specifications and technical designs. Thus we realise that MODULUS will not develop the ultimate modelling environment nor a full library containing a set of easily pluggable Model Building Blocks. More development time would be required to achieve this goal.

Software components are pieces of software that are designed for re-use: *‘a coherent package of software artefacts that can be independently developed and delivered as a unit and that can be composed, unchanged, with the other components to build something larger’* (D’Souza and Wills, 1999*)*. The ideal software-component is platform independent and can be plugged into a software system like a plug into a socket. In the last decades, several software component technologies have been developed; some of which are platform independent. For MODULUS, we have chosen the COM/ActiveX technology developed and supported by Microsoft. The following criteria were conclusive:

- COM is actually the market leader, hence has the largest set of existing components;
- It is technically stable and has a good performance;
- The programming language independence has a high priority in MODULUS, while the platform independence has not, because all the models are developed for the PC platform, but they are written in different languages;
- There exists a bridge to the other technologies: CORBA and Enterprise Javabeans, hence, the inclusion of CORBA or Javabeans components is possible if this would be required in the future.

In the course of MODULUS, GEONAMICA has been partly redesigned and extended to make extensive use of the COM/ActiveX technology. GEONAMICA is a spatial modelling environment and Decision Support System Generator developed on the Windows (NT/95/98) platform by RIKS bv. GEONAMICA enables the development of integrated dynamic models, operating at multiple time scales and spatial resolutions. These models are supplemented with state of the art analysis, presentation and decision support tools and become available as part of dedicated, transparent, interactive and easy to use spatial Decision Support Systems (Uljee et al., 1996; Huizing et al., 1998; White et al., 1997). As is explained at length in Chapter 5, different architectures enabling the incorporation of models as components into the GEONAMICA framework have been tried out. With a view to change the software code of the existing models as little as possible, the sub-models are ‘wrapped’ into a piece of intermediate software code (called ‘wrapper’), which makes them look like ActiveX Model Components (see Chapter 5, Paragraph 3.3) from the outside (see figure 1).

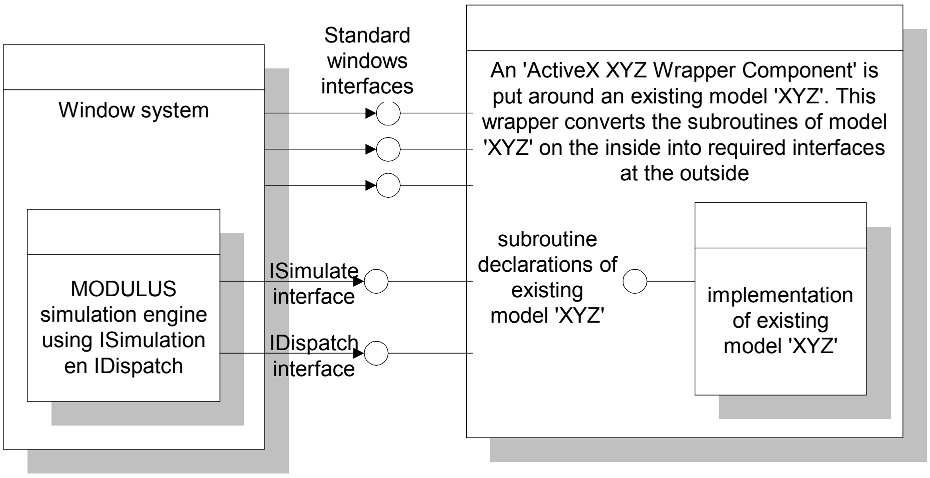


***Figure 1**: The MODULUS simulation engine works with ActiveX Model Components. Existing models are encapsulated in ‘wrappers’ that make them look like ActiveX Model Components from the outside.*

The key element in component technologies is the existence of a set of standard interfaces enabling the exchange of information between the different components, as well as the possibility of exchanging one component against another in a straightforward manner. In MODULUS, (see Chapter 5) an ActiveX Model Building Block implements at this moment 21 different interfaces. Most of these are standard COM interfaces. The custom interface **ISimulate**, enables the simulation engine to start and run MBB’s with different time steps synchronously. The standard **IDispatch** interface retrieves all the input and output specifications of the MBB’s. The simulation engine then ‘connects’ outputs of the one MBB to the inputs of the other, thereby establishing the correct dataflows in the combined simulation model.

5 The integrated MODULUS model

Screening the available models against the *End-use integration* and *Scientific integration* criteria enabled to decide on a preliminary scheme for an integrated MODULUS model, consisting of linked sub-models. For some of the sub-models, such as the slope model, alternative models were available for integration, which were ranked from most to least adequate (see Figure 2). The models ranked first were implemented first. This resulted in a reasonably adequate model, but other integration schemes could have been considered for implementation. This also resulted in ‘white spots’ for which no models were available in the integration scheme. More in particular the choice of the PATTERN Hydrology & Slopes model rather than the ERMES Slope model resulted in the need for an additional model called the Pumping model (see Chapter 6). The latter was developed and added to the model base.

This preliminary integration scheme had the great merit of covering an important part of both the natural and the socio-economic system. From an extensive analyses it was concluded that sufficient data were available in both pilot regions to run the integrated model, and that the sub-models produce and exchange the appropriate information required in the integration scheme (see Chapter 6). This in itself is a remarkable result, since each of the models had been developed within different research contexts and with different purposes in mind. However, one should not generalise this to mean that model integration is a straightforward and easy process. On the contrary, it requires a very careful examination of every aspect of every sub-model that is affected by the integration: the inputs needed, the outputs generated, the time steps taken, the synchronisation of the processes, the units of measurement, etc. It may be clear that this is the work of specialists working in a team, and it is to wonder whether this process can ever be made into an operational procedure not requiring the involvement of the model developers.

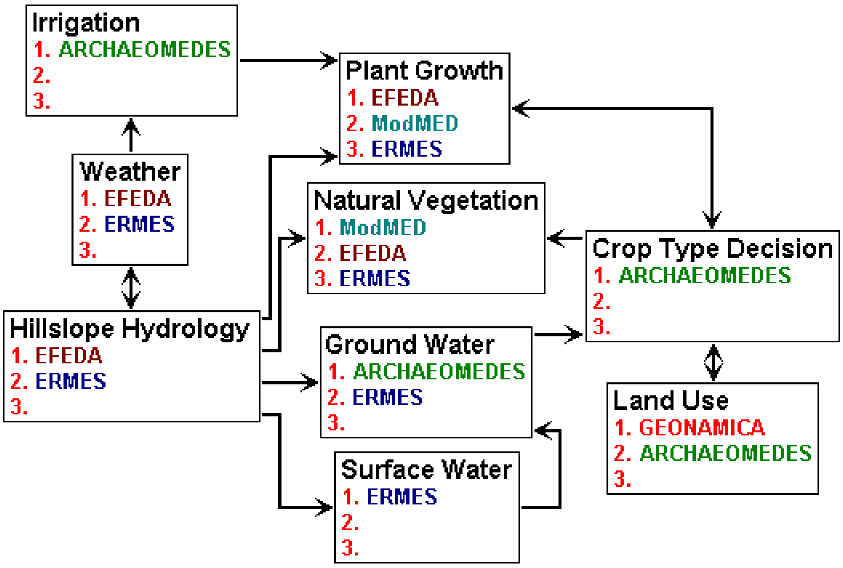


Figure 2: *The MODULUS model integrates a number of sub-models (shown as boxes). Each sub-models is a model developed as part of EFEDA, ERMES, ModMED or ARCHAEOMEDES. For each of the boxes, the available models, named after the projects that generated them, have been ranked from most to least adequate. After a very thorough analysis, the models ranked first were implemented. The arrows in the scheme represent the main conceptual linkages between the sub-models only.*

However, the fact that the integration exercise led to a *Scientifically* acceptable model did not mean that the *End-use* of the integral instrument was automatically guaranteed. The first tests performed showed that a single run of the integrated model for the entire Argolida region, consisting of nearly 240000 cells of 1ha each, took nearly 12 days. In this test the sub-models were running at the appropriate time step (1 minute – 1 year), for a period of 30 years, and at the spatial resolution, which is considered minimally required for the soil and slope models (namely the 100 m grid). It goes without saying that a model, which takes more than 10 days to perform a single simulation run, is not a very practical tool for policy preparation. It quickly looses all of its capabilities as a tool for analysis, for explorative learning as well as for communication. Hence, a lot of effort was put into reducing the execution time of this MODULUS model.

The performance of the models was improved in one of three ways. *First,* more efficient ways of performing the calculations were tried out and faster algorithms were implemented (see the calculation of temperature in PATTERN^{LITE} in Chapter 4). *Second,* the levels of detail, spatial, and temporal resolution applied in the models were re-evaluated against the problems that they were to solve and the data material available to run them (see the IERC-Aquifer model in chapter 6). *Third,* and only when the previous two failed, models were simplified at the level of the process representation and the modelling methodology itself (see PATTERN^{LITE} in Chapter 4).

We could add to this a *fourth* way of boosting the performance, which consists in switching off particular sub-models in a simulation exercise if such sub-models are not very relevant to the policy problem. This feature has been build into the MODULUS model, but it should be invoked with the greatest care only, as the sub-models that are switched off, are simply replaced by default input data on which the model will run fine, but fully isolated from the processes that generate these data. However, for the purpose of testing and calibrating individual or combined models, this feature has been a great help and a valued time saver during the project.

While raising the performance of the MODULUS model, we refrained as much as possible from rebuilding and reprogramming the existing material. As a matter of facts, and as is discussed in Chapter 5, reprogramming the entire model would most likely increase its performance and its technical transparency a great deal. As it stands at the end of the project, the final version of the system will take, depending on the pilot region and the exact set of models activated, some 45 minutes for the same 12 day-run mentioned earlier. The full model will only run on PC's equipped with a minimum of 256 Mb internal memory.

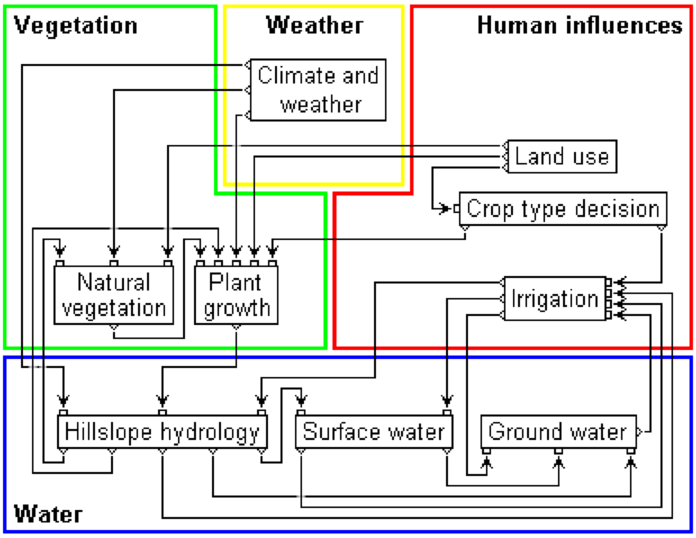


Figure 3: *The MODULUS model integrates physical, ecological, environmental, social and economic processes each running at the appropriate temporal scale and spatial resolutions.*

In its definite version, the integrated model is represented, also in the user-interface of the MODULUS DSS, as depicted in figure 3. Each of the models included in the scheme is dynamic and spatial. The typical spatial resolution at which the integrated model runs is the 1ha grid. The role of the individual models in the connection scheme can be summarised as follows:

- *Climate and weather:* (EFEDA, PATTERN Weather & Storms model, available as a C++ software model, resolution 1ha, see Chapter 4, Section 2). This model runs daily. It calculates for each day the time of sunrise and sunset and the average solar radiation map at the top of the atmosphere between sunrise and sunset. The average solar radiation is then corrected for cloudiness and the slope and aspect of each cell. The average temperature per cell is updated monthly. Further the model generates for the day a detailed time series (expressed as a fixed amount of rain per variable amount of time, called bucket-tip time) for precipitation for the study areas based on data from at the least 1 AWS weather station. Both temperature and precipitation for the future are corrected for climate change affecting the pilot regions as calculated by the HADCM2, GFDL or ECHAM Global Circulation Models

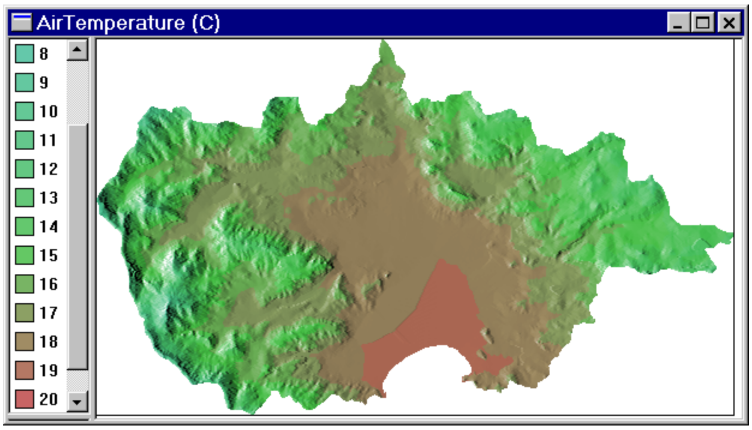


Figure 4: *Air temperature in the Argolida. The mean monthly temperature at sea level is derived from a 30-year climate scenario. It is spatialised and corrected for altitude and local deviation from the mean temperature as measured by local weather stations.*

- *Hillslope hydrology:* (EFEDA, PATTERN Hydrology & Slope processes model, available as a C++ software model, resolution 1ha, see Chapter 4, Section 2). This model runs daily, but integrates internally over bucket-tip times. It deals with the soil hydraulic properties and calculates the water budget: interception, infiltration, soil moisture, transpiration, soil evaporation, overland flow, surface recharge, and erosion.

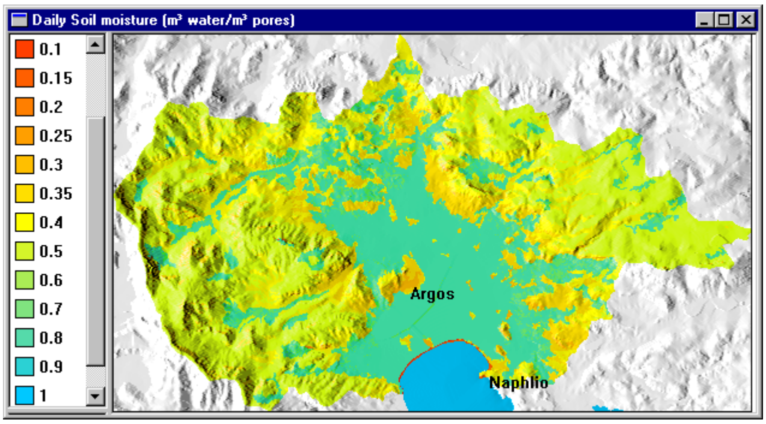


Figure 5: *Soil moisture in the Argolida in January*

- *Natural vegetation:* (ModMED, RBCLM2 Community model, available as a PROLOG software model, resolution 25ha, see Chapter 4, Section 3). This model runs once a month. It represents the processes of growth, succession and decline of the natural vegetation at the community level. It calculates the leaf area index, the vegetation cover fraction, and the rooting depth. The natural vegetation model is a rule-based model, applied to each individual 25ha cell of the case regions. It is supplemented with a cellular seed diffusion model, which produces a seed biomass map and thus links the community level cells at the landscape level, a C++ software model.

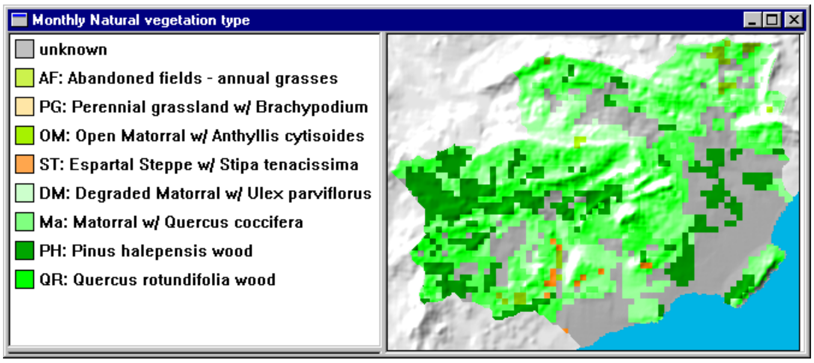


Figure 6: *Natural vegetation types in the Marina Baixa, modelled on a 500 meter grid.*

- *Plant Growth:* (EFEDA, PATTERN Plant Growth model, available as a C++ software model, resolution 1ha, see Chapter 4, Section 2). This model runs daily. It represents the processes of growth of commercial crops and natural species and calculates the leaf biomass, root biomass, leaf area index and the vegetation cover fraction.

- *Ground water:* (ARCHAEOAMEDES, 2 versions of the aquifer model are retained: the (Agricultural University of Athens) AUA-ModFlow model and the IERC-Aquifer model. The ModFlow model is available as a FORTRAN software model, while the IERC model is available as a POWER BASIC software model, see Chapter 6). Due to the very complex and discontinuous nature of the aquifer in the Marina Baixa, the aquifer model is only applied in the Argolida region. This model represents the depletion, recharge and pollution of the aquifer. It calculates the aquifer water height, salt concentration and the fluxes between cells. The ModFlow-aquifer model runs monthly and on a spatial resolution of 500 by 500 m. The IERC-Aquifer model is developed to run on daily time steps and on a 1ha resolution, however for computational reasons and due to the lack of sufficient data, it is installed to run, like the AUA-Modflow model, on a monthly time step and on a 25ha resolution.

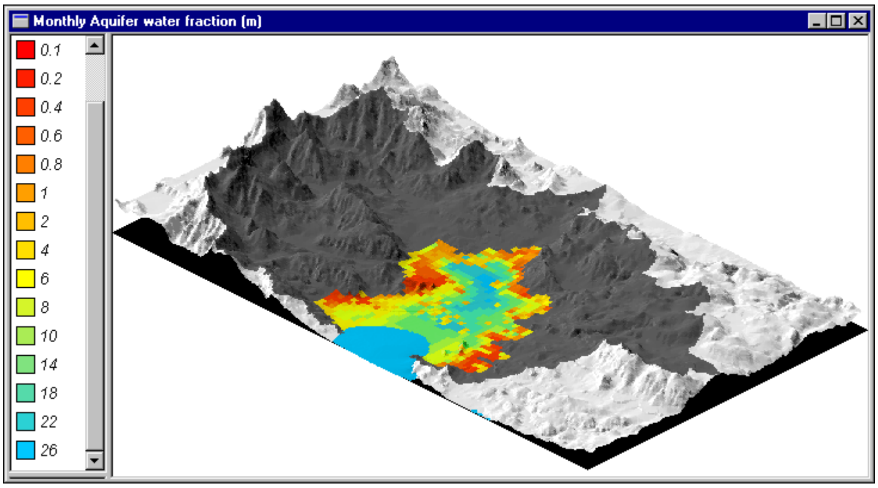


***Figure** 7: The main watershed modelled in the Argolida and the location of the Aquifer within it. The Aquifer is modelled on a 500 by 500m grid and using monthly time steps. The water fraction of the aquifer in a month of April is represented.*

- *Surface water:* (ERMES, Catchment model, available as a POWER BASIC software model, see Chapter 6). This model runs on a daily basis. It represents the river, canal, and water reservoir system, and the water quality of the surface water. It calculates the river flows per stream order, the sinkhole flows, the catchment recharge flows, and the river PO_4 and NO_3. The model runs on irregular shaped, natural defined areas: the catchments and sub-catchments.

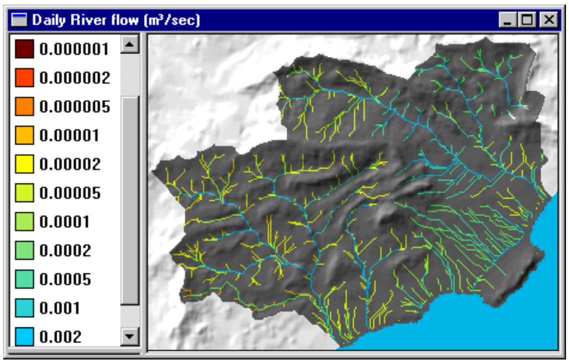


Figure 8: *Daily river flow in the Marina Baixa for a day in January.*

- *Crop type decision:* (ARCHAEOMEDES, Decision making model, available as a POWER BASIC software model, resolution 1ha, see Chapter 4). This model runs on a yearly basis. It is a rule-based model representing the crop-choices made by farmers as a function of changing physical, socio-economic and institutional conditions and circumstances. It is applied to each 1ha cell and calculates the crop type, crop water requirements, water source, presence of boreholes, borehole depth, pumping capacity, air mixer deployment and the total yearly long term exploitation costs.

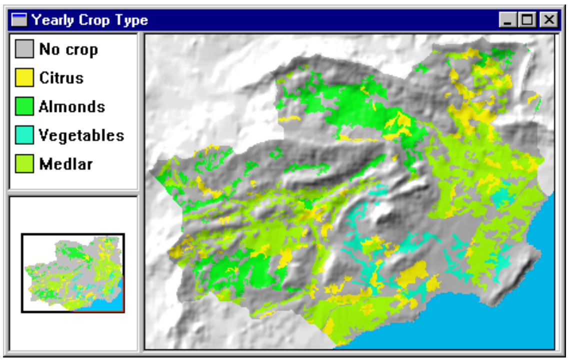


Figure 9: *Crop types in the Marina Baixa.*

- *Irrigation:* (Extracted from work done in ARCHAEOMEDES by IERC, available as a POWER BASIC software model, resolution 1ha, see Chapter 6). This model runs twice daily. It is a rule-based model representing the farmers' decisions to switch on the water pumps and start the irrigation. It is applied to each 1ha cell and calculates the pump status, volume to be pumped, and extraction from the canal, volume of frost water, frost water salt concentration, irrigation water volume, irrigation water salt concentration, and the total yearly short-term exploitation costs.

- *Land Use*: (GEONAMICA Constrained Cellular Automata model, available as a C++ software model, see Chapter 5, Section 2). This model runs yearly. It is a cellular automata based models which allocates in a detailed manner (1ha grid) the land claims resulting from demographic changes, as well as the dynamics in the agricultural and non-agricultural part of the economy. The allocation methodology takes into consideration the activity specific attractivity of cells in terms of their suitability, zoning regulations and accessibility to the road transportation infrastructure.

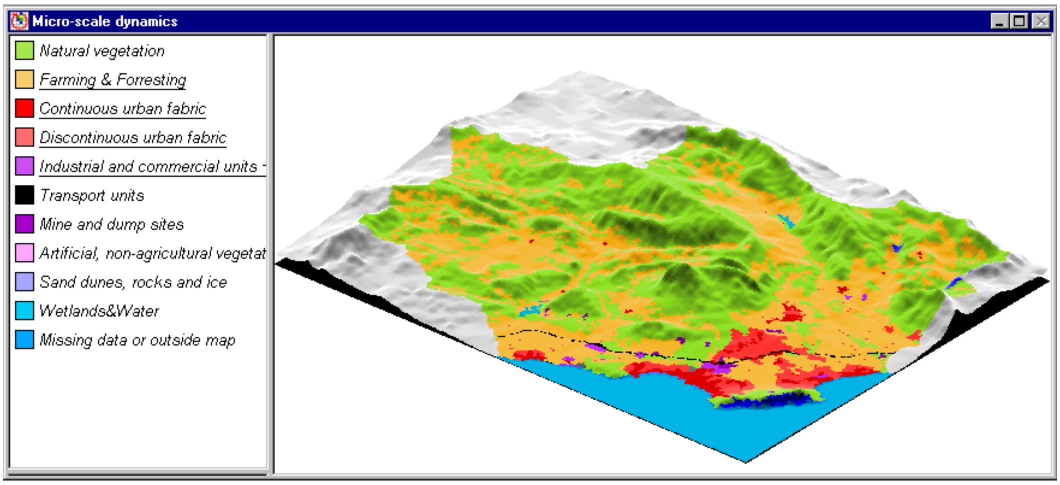


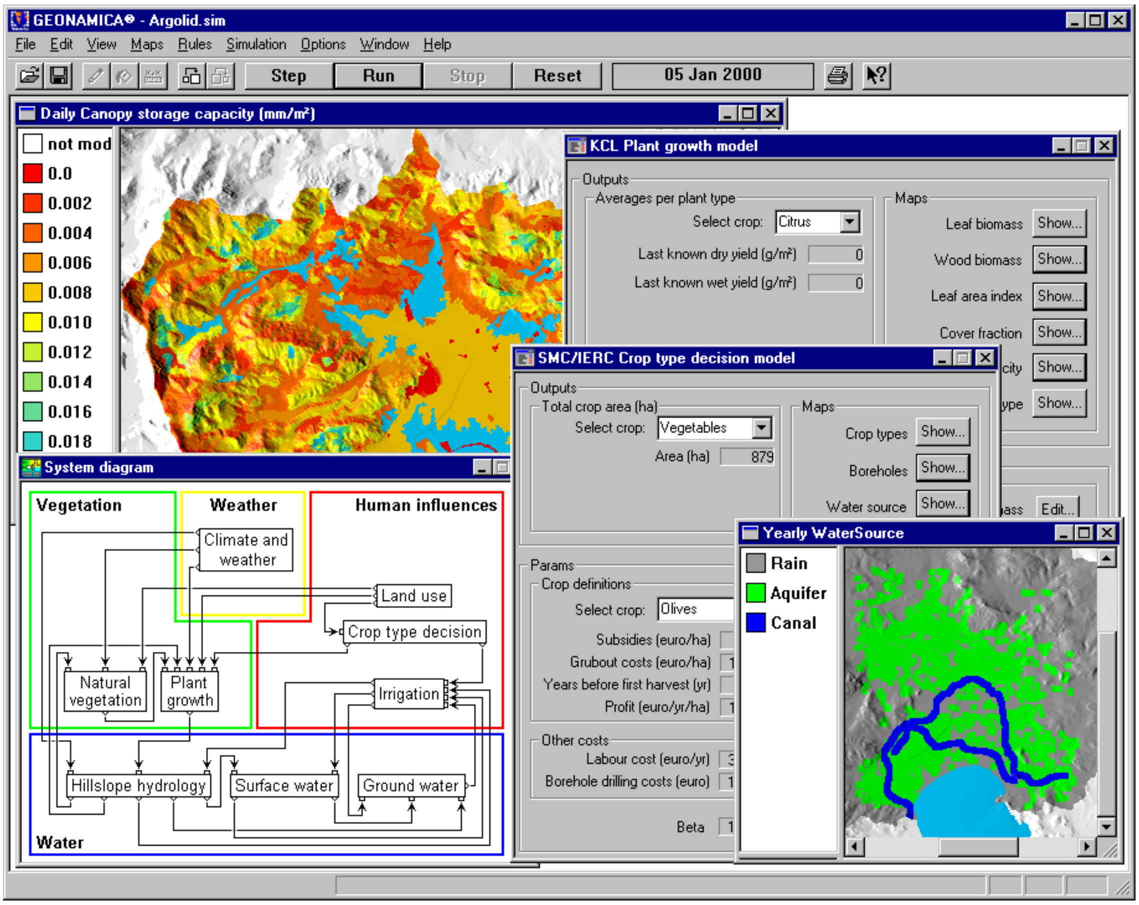
Figure10: *Land use in the Marina Baixa in 2030*

The model presented heavily relies on GIS data. As an input it requires some 25 GIS layers (raster maps, mostly at 100 meter resolution), and it updates at every simulation time step some 50 output maps. All the output maps are simultaneously available to the user. Hence, during the simulation he can watch the evolution of the modelled region by means of any combination of the mapped variables. Some of the output maps represent a final output variable of the integrated model, but most maps are generated or updated by a model to serve as an input to another model.

6. Using the MODULUS model and Decision Support System

The use, role and usefulness of models and Decision Support Systems in policy making has been the subject of a rich scientific debate and literature, and extreme views have their advocates. In this chapter we do not have the room to dwell on this discussion. However, inherent in the aims of the MODULUS project, is the somewhat positivistic view that the use of scientific models can improve the policy making process. More in particular, MODULUS adheres to the view that *better* informed policy makers are *better* equipped to make *better* policies that bring the systems they are to manage on a path towards sustainability. Thus, the prime role of the models and the Decision Support Systems is awareness building and education, rather than the decision-making act itself. The models therefore should give an adequate and truthful representation of the real world system, and the policy maker should be enabled to work with the models in a well-structured, well-guided and flexible manner. To this effect, the system has been equipped with a graphical user-interface, enabling to gain access to the models, the data and the maps by invoking menu commands or selecting interface objects on the screen. The same interface increases the transparency of the model by enabling access to context-sensitive on-line model documentation: at any point in time, the user can gain access (by pushing the F1-key) to the technical background information required to understand the processes modelled and the numbers they require and generate. Without this information, the models would remain black boxes and no learning would take place.

In the Decision Support System, the real world system is represented by means of the integrated MODULUS model. The user can try out *policy interventions* by changing policy relevant parameter values in one or more models. He can test the robustness of the system and his policy interventions if the system is subjected to *scenarios*, defined by other parameters, representing mostly exogenous elements. Finally, he can see how his policy interventions and/or scenarios affect the system in terms of policy relevant variables or *indicators*. In this way the impact of interventions can be tested and tuned in an interactive session between the policy-maker and the modelled system and catastrophes can perhaps be avoided in the real world system.



Select crop: Citrus
Last known dry yield (g/m²) 0
Last known wet yield (g/m²) 0

Select crop: Vegetables
Area (ha) 879

Select crop: Olives
Subsidies (euro/ha)
Grubout costs (euro/ha) 1
Years before first harvest (yr)
Profit (euro/yr/ha) 1
Labour cost (euro/yr) 3
Borehole drilling costs (euro) 1
Beta 1

Figure 11: *User-interface of the MODULUS system. The user gets access to the individual sub-models (Model Building Blocks) by clicking the boxes in the systems diagram (shown in bottom left). He can run simulations and open any combination of (dynamically updated) maps on the display*

For other Decision Support Systems, we (Uljee et al., 1996; Engelen et al., 1999) have implemented user-interfaces in which the parameters and variables of the constituting models are organised in a manner that clearly reflects their adherence to one or the other of the following categories: policy parameters, scenario parameters, and indicator variables. This would have been possible for MODULUS too if there would have been a better involvement of the end users of the system and if the model developers in MODULUS would have had more experience with the development of policy models generally. In a similar manner, a more adequate set of policy relevant indicators could have been developed and implemented in the DSS. Indicators will make phenomena perceptible that are not easily or immediately detectable. They would generally simplify in order to make the complex phenomena, represented in scientific terms in our research models, quantifiable in such a manner that the technician, the policy-maker or the layperson would better understand them. Early in the project we drafted a list of policy indicators, which we considered useful in evaluating intended policies in terms of the environmental, social and economic functions of the regions but never could agree on the formal representations or the algorithms to implement them.

The DSS takes as an input data in standard readable formats, .TXT for simple data, and .IMG IDRISI, or ARC/INFO grid .ASC for the GIS maps. A number of dedicated editors: text editors, graph editors, map editors, and formula editors are available to the user for entering data and setting the specifics of a simulation exercise. While a simulation is running data are written into a MS Excel Workbook, which is opened and linked dynamically to a simulation if and when this option is invoked. In a similar manner, dynamic map output can be stored in so-called .LOG files for future analysis and visualisation by means of a dedicated ANALYSE-Tool. Or it can be animated and visualised in the form of .GIF movies. Thus, the dynamic output of a simulation exercise is available to the end-user for further analysis and interpretation.

The individual models in the DSS have been validated and tested to both case regions to some degree: for the AUA Aquifer model, the validation has been very elaborate and in detail, while for other, such as the Land use model, it has been rather partial and limited to ensuring that the results are sensible and appropriate to the environment and conditions in the pilot regions. The integrated MODULUS model has been run and tested under a wide range of conditions by the different model developers in isolation or as part of 'test drive teams'. These tests revealed a considerable number of problems in the constituting sub-models or the integrated model that never showed up before, in the assumptions underlying the models, the formulation and implementation of the models, the coupling and synchronisation of the models, and the exchanges of data, both the actual numbers and the units of measurement. However, at the end of the project we can only conclude that more time and effort will be required for the validation of the integrated MODULUS model in a systematic manner. Such validation however should go hand in hand with, or come after, a critical review of the integrated model and its constituting sub-models. For instance, we know that there are possibilities for intensifying the linkages between the constituting sub-models. In some cases this requires only minor changes, relative to the improvement in the representation of the process. In other cases we should work much more on some constituting sub-models to improve them drastically, or consider finding replacements.

Only a very limited number of exercises have been carried out with the integrated model. These were mostly for demonstration purposes and dealt with among others water management and irrigation issues in the Marina Baixa (see Chapter 6). The results of these exercises show the usefulness of the system developed: its interactive, integrated, spatial and dynamic approach. The results produced are easy to visualise and communicate to the end-users. Notwithstanding this, it is a fact that the DSS remains a relatively cumbersome instrument, which produces output that is of more interest to the researcher than the policy maker. For instance, the failure or success of a cropping season is expressed in leaf biomass, rather than Euro or tons of fruits, hence clearly not a kind of indicator that makes intuitive sense to the farmers in the regions.

In spite of all the reservations made, the MODULUS DSS can be useful in the design and the assessment of a large number of policy relevant matters. The list provided is not intended to be complete. It only is a record of exercises already worked out, and the descriptions are fragments of what can be read at great length elsewhere in this report:

1. *Zoning regulations, land use and land cover policies, urbanization schemes.* Among others the Land Use model features zoning maps for different types of land uses and which can be drawn, imported, or changed interactively by the user. The effects of zoning regulations on the system as a whole or on particular land uses or linked variables can thus be analysed.
2. *Location of crops or other activities.* As the crop growth is linked right through to the soil properties, the soil moisture and the proximity of irrigation waters, the potential for alternative types or other combinations of crops can be tried out in an explicit geographical and dynamic manner.
3. *Irrigation systems.* Irrigation puts a lot of stress on the availability of drinking water for household use or use in the industrial and tourism sector. Dedicated parameters in the model enable to simulate the application of alternative irrigation technologies and to analyse the consequences of these on the aquifers and other water users.
4. *Types of crops, mono- and multi cropping systems.* The change from traditional rain fed multi-cropping to irrigated mono-cropping systems has brought a lot of wealth to both pilot regions studied. However, it also has caused stress on the traditional life style and social cohesion in the regions. More so, it caused severe land degradation and economic dependency on one or a few staple crops. The potential for a partial restoration of the multi-cropping system could be evaluated. The MODULUS model will have nothing to say about the effects on the return of traditions and life styles, but it will enable to assess the best locations for these activities and

value alternatives in terms of output generated, water consumed, number of farmers employed and families involved.

5. *Climate and weather scenarios.* With the PATTERN^{LITE} model, the weather in both pilot regions will be generated. This is done within the general trends set by a changing climate as forecasted by one of three General Circulation Models. The far-reaching consequences of these changing weather patterns on the physical environment, the vegetation, the commercial crops and the surface and sub-surface hydrology is calculated throughout the entire MODULUS model.
6. *Artificial recharge of aquifers.* In the Argolida the artificial replenishment is tried out in an experimental set-up. The potential for this technique seems real. In MODULUS, and in particular by means of the Aquifer sub-model, it is possible to estimate the consequences of this practice: the volumes required to replenish, the state of the aquifer through the years and the effects on the existing salination, and potential new pollution of the ground water. Further to this, other sub-models enable estimating the benefits of this technical solution.
7. Creation of storage lakes. In the Marina Baixa, where aquifers are small, heavily fragmented, and affected by salt intrusion, most of the drinking water is obtained from storage lakes. The latter store water pumped in from outside the region or from local springs. The Catchment sub-model enables to experiment with alternative configurations and different numbers of storage lakes in different locations. The consequences of the availability of this water can be analysed.
8. *Alternative EU policies and regulations, subsidies.* In their cost benefit calculation and crop decision-making, farmers are influenced by subsidies and other regulations at the regional, national or European level. Changes in these will have immediate consequences in the crop choices and through these on other aspects modelled.
9. *Alternative employment and economic activities.* If water scarcity would threaten employment in the agricultural sector, then the potential and need for alternative forms of employment and the location of such activities need to be assessed, as are the consequences of these regarding land degradation.

7. Conclusions

At the end of this project and this particular chapter, we formulate some general conclusions relative to the work carried out and the lessons learned. These we would like to formulate under three headings:

1. ***The end users and MODULUS***

   As is explained in great length in Chapter 2, MODULUS had great difficulties in defining and locating the end-users of the Decision Support System that it intended to create. The problems encountered are briefly mentioned in this chapter (see Paragraph 3): lack of the appropriate network, insufficient knowledge of the institutional organisation and the policy-making culture in the pilot regions, and not in the least, lack of good demonstration material to convince potential end-users of the benefits which they were to get from the project and the final product.

   Two months before the end of the project, two major workshops, one in Argos (Greece) and one in Alicante (Spain), were organised, in which the system was demonstrated to, and discussed with, a group of some 80 interested and potential end-users, consisting of: politicians (including the Prefects of the Argolida and Corinth region) technicians, stakeholders from industry, water companies, farming organisations, and researchers. Technically speaking, these workshops came at the right time in the project: we had finally gotten through to the right kind of policy-people, and we had a working system to show, capable of demonstrating the use of this kind of instruments in the region of the end-users and on real problems and examples. However, from a management point of view, these workshops should have been organised 12 months earlier. As it happened, they came too late in the project to have the impact on the activities, which they deserved to have.

In general the product demonstrated, the MODULUS DSS, generated good discussions and got a reasonably good response. There was agreement that there is a match between the models and the problems in the case regions. Hence, that this system has a great deal of potential. But, and at the same time, it was also obvious that there is still a great mismatch in between the policy questions that need straightforward answers and the outputs generated by the model. This is more than a mismatch in terminology only, rather points at 'white spots' in the model: aspects and processes not incorporated as yet. One good example of this is the absence of a module taking care of the accounting of policy alternatives: what are the costs and what are the benefits, now and in the future *'and in Euro if possible'*. Some questions raised and comments made touched upon very fundamental technical aspects too, such as the operational status and usability of the system, its integrated nature, its data-hunger, its correctness and accurateness, its ability for upgrading to new situations, new problems, changing world views and knowledge. These made us realise that the product developed so far is more the beginning than the end of a development cycle, which will take a while before it will come to an end. However it was also a stimulus for the developers, in that many of the problems raised could be solved with little effort: a change in terminology, the incorporation of for instance 10 commercial crops rather than 6 in our models, or, an extra equation here or there.

Other points raised are not unique to MODULUS; rather they are typical for the kind of systems and models like MODULUS. *'Is this a management system or a policy support system?'* Although we build these instruments for policy makers with a view to enable them to explore and fine tune their policies in a long term, integrated context, they mostly end up being viewed as management systems and evaluated on their sectorial and short term forecasting capabilities. Also, *'is this a system for analysis, for training and education, or for communication?'* Again, we build them for the purpose of analysis, which automatically includes some form of education, yet they often end-up being used as tools for communication. *'Is this a database or is it a knowledge base?'* Although the emphasis is very much on the knowledge embedded in these systems in an operational form, users will often look at them as instruments containing data on related topics, thus devaluating the system to an ill-designed and very incomplete database.

Finally comments are made relative to the way in which these systems can be made useful in the organisation of the policy maker. This is a very fundamental issue that is very often overlooked, certainly by the scientists who's role it is to build the models. Systems like MODULUS attain a very high level of sophistication. Hence they cannot be handed to the end-user on a simple CD-Rom with user manual. Rather they require guidance and in most cases, an intensive training programme. In the Argolida, for instance, the prototypical end user of MODULUS does not have a PC on his desk, let alone the state of the art PC required. Further this user is not very proficient in English, hence would need to get a system and documentation in the local language. Once the organisation would take the system on board as a tool for policy assessment, procedures need to be developed that give it a clear institutional position and role in the organisation and the assignments of its employees. None of the above are trivial problems to tackle. Moreover they require the involvement of specialists with skills that are not typically present in a group of scientists involved in EU-Environment and Climate research projects.

2. *The Integration carried out in MODULUS*

While we interpreted 'integrating existing material' rather loosely while carrying out the scientific and the end-use evaluation, thus permitting models to be adapted or rebuild for the purpose of MODULUS, we took this expression much more factually while carrying out the technical integration. This was not accidental, rather we wanted to find out what state of the art component technology has to offer to consortia like ours involved in the joint development of an integrated model and encompassing decision support framework. Thus the true story about integration of the models in MODULUS is to be found in Chapter 5. Two rather conflicting views on integration come to the surface. On the one hand the technological solutions offered by today's component technologies, put in the hands of very able software developers, are very promising and indeed enabled the integration of material that was never designed to be coupled before. On the other hand the same chapter will demonstrate the impossibilities and discuss the many quick and dirty solutions that are needed to construct such a technically instrument which after all should remain a 'scientific' instrument. MODULUS shows, and other projects have demonstrated the same, that the methodology applied enables to do the piping work from a technical point of view. This requires skillful people spending a lot of time and effort on work-arounds that are not nice, not efficient and that can not really improve the bad performance of the constituting components. The same technicians, with much less effort, can design much better software products with the same or better 'modelling' functionality. And the scientists can most likely develop models with the same functionality as the MODULUS model in a scientifically much nicer, much more reliable manner. However, the key element in this is that before any of this can happen, an exercise like the one carried out in MODULUS is required to bring these scientists together, to cut the odd corners of the individual models, to find ways in which they can be simplified, spatialised and aggregated in manners that make them fit in a linking scheme defined with a particular end-use in mind. To our opinion, this is where the true value of the MODULUS methodology lies: it plays its role in an intermediate stage, a 'bottom-up' phase as it is called in Chapter 3. A stage in which existing material is gathered, and where a synthesis needs to be made. A stage in which this material is selected and evaluated in a new context, with other end-users in mind, and for applications in other regions with other problems. A stage as well where specialist from different disciplines get together to construct an end-product from semi-finished products. This is where component technology is useful, because it enables different parties to work at a distance, to come to agree on the tasks and functionalities of models, tools and final products, and work on it in an environment (both physical and software) that is theirs. From the MODULUS project we can conclude that this works, that a tool can be developed within reasonable constraints relative to budget, human resources and development time. This phase however is not the final one in a development path of a Decision Support System for practical regional policy making. On the contrary, it needs to be followed by an in depth evaluation of the integrated model and its constituting sub-models, the way in which it covers the decision domain(s), the way in which it links the sub-systems within the domain(s), the way in which the spatial and temporal dynamics are dealt with. Also an evaluation of the DSS by the end users is pertinent. How do they think their decision domain has been represented. Does the system speak their language? Does it work in the way that they find useful and pleasant? With the answers to these questions a more or less major redesign of the DSS is possible and a 'top-down' development phase can start. In the latter, and with a view to improve both the functionality and the performance of the system, each of the components needs to be worked on very seriously and all the elements that do not fulfill the performance or the functionality criteria should be considered for major repair or re-implementation. Also at this stage, component technology has a lot to offer in that it enables to compartmentalise the system, develop it in a distributed manner, and keep much better track of the advancement of the work in progress.

3. ***The ideal team for carrying out similar work in the future***

   In the previous two bullets of this list we have commented on our successes and failures relative to our end-users and the methodology applied. This last bullet addresses the human resources required to carry out similar exercises in the future. Indeed, building a MODULUS-like system is an undertaking that holds the middle between a typical research project and the development of a custom defined (software) product. A team carrying out this kind of projects should therefore have specialists of both kinds too.

   From this report it will be clear that the development of a DSS with this level of complexity is teamwork. A team consisting of the right kind and the right number of specialists, with experience in this kind of business, is as essential as a good division of tasks and responsibilities, and a clear but stringent project schedule. As to the number of people, we would like to make a case for reasonably small teams. For the development of a DSS like MODULUS, teams exceeding a dozen people, working simultaneously, are to be avoided. The work would be hampered by overlap between the team members and disciplines represented, and the management would become time consuming. As to the disciplines and skills represented we believe that the following kind of people are required:

- *Motivated and visionary end-users*
  Decision Support Systems are to be used in situations where ill-structured problems need to be solved. The involvement in the project team of the problem owner is therefore a prerequisite. But, the development and application of integrated models and DSS for policy making, spatial planning and the analysis of socio-environmental systems is a very new activity. Hence, successful projects are those that find motivated and visionary end-users interested to work on a new breed of tools. End-users that are aware of the fact that this kind of work is novel and difficult. End-users also, that are able to communicate very well with the development team and bring across their needs, working methods, policy problems, criteria, constraints, policy levers and policy options.

- *'Trans-discipline' and 'trans-role' domain specialists / scientists / model developers*
  Land degradation, desertification, water management and most other problems related to socio-environmental systems are set in very complex systems. These systems can only be understood in their truly multi-disciplinary setting. Few will argue this statement. However, science is still very much structured in strictly divided disciplines and the career opportunities of a scientist depend very much on whether he can excel in one of these. Yet what is needed most in order to develop effective instruments are scientists and model developers that are interested in interdisciplinary work, interested in looking into the domain of the other and building knowledge-bridges between the domains. Scientists also, with the flexibility to imagine the position of the others involved in the exercise. In most cases, to take the role of the end-user and thus understanding much better his exact needs. Finally, we would like to add, that it is essential to have domain experts and modellers working in the team that have a good knowledge about the geographical region for which the models and the DSS are developed. In MODULUS we were blessed with such people, but this is not always the case.

- *An architect of the integrated model or the model base of the DSS*
  It is not enough to bring together a bulk of 'good' sub-models in order to construct an integrated model. This is one of the lessons learned from MODULUS. On the contrary, a lot of adaptation and rebuilding is required. It is not enough to bring together a group of 'good' model builders either. In a project team somebody will need to take the role of the 'architect' of the integrated model. He keeps an eye on the overall functionality of the integrated model and on the role that each of the sub-models is to perform in this. He assists the model developers in reformulating and adapting their models. Individual model developers are most often proficient in their domain and the models that they developed. Some are not interested in going much beyond this and build bridges with others. The architect however is more of a generalist yet has a very good understanding of the pitfalls of modelling in general.

- *Flexible and skilful software system designers and developers*
  Decision Support Systems are complex information systems that require a non-traditional development cycle. Iterative and evolutionary design methods are much more effective than the typical waterfall development method. In this kind of development process, re-implementation cannot be avoided. A well-designed system and an appropriate development strategy however, will minimise the amount of 'lost' implementation effort. Yet, the software developers should be aware of the fact that some of their hard work might be thrown away in the next version of the system. Some will find this very frustrating and hard to take.

- *A professional 'communication' specialist (a mediator, or facilitator)*
  The expertise and working methods of policy-makers and scientists are often worlds apart. Hence, when they are to work together on a complex product like a DSS, it is not uncommon that the communication and exchange of information is very difficult or non-existing. Yet, this communication is very essential indeed. The participation of a communication professional, a mediator or facilitator, in a project team can be very effective. In MODULUS for instance such person could have found his way much more easily to the end-users and could possibly have involved them in the project earlier and to the benefit of all involved.

- *Project manager.*
  A DSS is a very sophisticated information system. Its development is hard work as very many little details matter and need to be taken care of in order to deliver a product that is foolproof and free of bugs. A strict management of this kind of project is essential. This is not only so because more than a few people are involved in it, but also because the work is organised in clearly sequenced tasks: a model needs to be past the conceptual phase before it can be implemented and before it can be tested, validated and run. Once many such models become integral parts of much more encompassing DSS systems, then the synchronisation and sequencing of the tasks becomes paramount. An agreed schedule, clearly defined tasks and milestones need to keep the project on track. If not the delivery of the system will be endangered and the costs will rise in a disproportional manner.

Given its financial and human resources and given also its short lifetime, MODULUS embarked in a very ambitious endeavour. Those of us that did not believe this at the beginning of the project learned it in the process. We succeeded nevertheless in bringing together and re-using research material in a new context, a context for which it was not really developed. We succeeded also in developing an integrated model and encompassing Decision Support System and applied it in two case regions. This model has only been partly validated and has not been used in real policy exercises by its intended users. We would have wanted to do this with real policy-makers and planners, but for the reasons explained were not able to do this as originally planned. Our greatest enemy was time. We learned that it takes more than 24 months to go though the full development cycle of a DSS of this complexity. We strongly believe that a third year would have been the year in which the 'odd ends' would have been cleaned up and a much better product would have surfaced. However, we believe that we have produced a tangible product, something rather unique to show and that we may conclude that MODULUS, in all its modesty, took part in *'furthering the scientific foundations and practical tools for sustainable management of land resources in parts of the Northern Mediterranean region that are subject to land degradation and desertification*'.

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