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Desertification and land degradation in Mediterranean Areas: From science to integrated policy making

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Fondazione Eni Enrico Mattei

**Desertification and Land
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Mediterranean Areas:
from Science to Integrated
Policy Making**

Guy Engelen*

NOTA DI LAVORO 15.2001

JANUARY 2001

CLIM – Climate Change Modelling and Policy

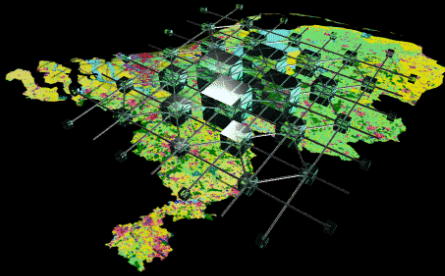
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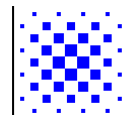


Desertification and Land Degradation in Mediterranean Areas: from Science to Policy-making

Paper presented at the workshop:

‘The Impacts of Climate Change on the Mediterranean Area: Regional Scenarios and Vulnerability Assessment’

in Venice, Italy, December 9th – 10th, 1999



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Desertification and Land Degradation in Mediterranean Areas: from Science to Integrated Policy making

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Abstract

In the domain of desertification and climate change 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, so far little effort has gone into making this scientific material available as part of practical planning or management tools for regional public policy makers. In this presentation, we will dwell on the experiences gathered in developing a generic spatial Decision Support System for integrated environmental policy-making at the regional level. The experiences are taken from a two year EC-project, MODULUS. In this project models and scientific material from 4 past EU-projects are integrated that represent the climatological, 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 as a very interactive, transparent and (geo)graphical instrument. It runs on PC machines under Windows NT and makes extensive use of Active X and component technology. In order to demonstrate its generic applicability the MODULUS DSS is applied to two case regions: the Argolid (Greece) and the Marina Baixa (Spain). In the presentation we will dwell on the practical and scientific lessons learned from the project, and more in particular on the difficulties involved in adapting scientific material to the needs of integrated policy-making.

Introduction

In the past decade, as part of its successive Framework Programmes, the EC 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 problems 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. Hence, from a practical policy making point of view, little use was made of the studies carried out. This is in part due to the fact that much of the research was carried out for scientific reasons and with the purpose of better understanding the processes causing the problems. 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 too specific and disconnected for the policy maker who needs a broader view on the problems that need to be solved. With a view to boost the policy use of material developed for scientific purposes, the MODULUS project poses the following scientific question: *Can existing scientific material, obtained from different complementary research projects, be integrated and made useful to policy makers ?*

Methodological Approach

The methodological approach of MODULUS is clearly focussed on the integration of research material that is or will become available from other EU Environment Programme Research Projects. The guiding principle in this integration effort is the fact that the resulting model should be useful for environmental decision and policy making in the Northern Mediterranean generally and in two pilot regions in particular. To that end MODULUS principally builds upon the research results obtained in 4 on-going or past projects: EFEDA, ERMES, ModMED and ARCHAEMEDES, 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 complementarity of the research carried out.

The EFEDA project

The EFEDA project (See for example: Burke et al., 1998) examined the interaction between the 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 100m² 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.

The ERMES Project

As part of the ERMES project (See for example; Oxley et al., 1998) multi-scalar 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 pattern 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.

The ModMED Project

Although 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; hence on the biological and ecological processes characterising land covered by freely colonising and growing plant species, there is 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 occurs, 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, this can 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.

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 to the individual scale.

From the above short project descriptions, it may be clear that there is both complementarity and overlap between the projects selected: the complementarity should permit to come to an integral model covering the essential physical, ecological, economic and social processes related to degradation, while the overlap should permit selecting the most appropriate and compatible model-components among the alternatives available.

MODULUS: a Spatial Modelling Tool for Integrated Environmental Policy-making

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. Early in the project, the Marina Baixa (Spain) and the Argolid (Greece) were selected based on the following scientific and pragmatic considerations:

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

Policy makers

The development of DSS systems is an expensive and time consuming exercise, only to be undertaken if real problems exist that require a lasting surveillance of the system and regular interventions in order to bring it back on course. The only way to assure that the DSS will be effectively used for policy and planning exercises is to involve the end-users during its development. 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 whose role it is to implement policies.*

MODULUS intended to involve the end-users in the project right from the start, but, we ran into two problems, which forced us into rethinking the practical implementation of this aim:

1. In both pilot regions selected, as would have been the case in most other pilot regions, the past scientific work has been carried out for research purposes and not for policy making strictly speaking. Hence, little attention has been paid to involve local or regional policy makers in the work. As a result, MODULUS needed to find and contact its own end-users and convince them of the usefulness of yet another research project. This process took more time and effort than expected.
2. In some northern EU-countries a long tradition exists of involving scientifically trained technicians in the policy preparation phase. Other countries are still in a phase of setting up the institutional frameworks within which these people are or will become active.

As a consequence, and in order not to slow down the technical work, we decided to define temporarily a 'virtual' policy maker and 'typical' policy problems, to be replaced by real policy makers and their policy problems at a later stage. At the same time extra effort was put into the search for 'life' policy makers.

Policy problems, policy levers, and policy indicators

From the fieldwork carried out in the pilot regions as part of ARCHAEOEMEDS and ERMES, a preliminary list of policy issues --policy problems, policy levers, policy indicators and policy criteria-- has been established. This list has been helpful in selecting and adapting the models considered useful for integration and in focussing the discussions with the actual policy makers. However, the policy issues mentioned in the preliminary lists very strongly focus on the short term: the actual economic activities, production practices, and immediate water management problems. It is precisely the strength of model based systems to explore the decision space and search for development alternatives that are beyond the immediate concerns and imagination of stakeholders, politicians and planners. Although most of these alternatives might turn out to be totally unacceptable or undesirable, some will be worth further analysis and evaluation, and all of them are calculated on the basis of a coherent set of assumptions, represented in the same equations and rules of the models. Hence, if we work from

the assumption that 'good' socio-environmental policies are to be evaluated from a broader perspective and that they have to increase the level of sustainability of the region, then, we should define indicators and criteria that fit in broad categories including for instance: *environmental quality, human welfare, resource availability* and *cost of policy implementation*.

'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. We believe that 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

In his review of the models developed as part of projects in the field of desertification under EU framework III and IV, hence, including all of the projects concerned in MODULUS, Mulligan (1998b) discusses a number of important differences between 'Research' models and 'Policy models'. Both are foremost tools developed to simplify reality in order to understand it better. The former are developed to push ahead scientific understanding. They are process oriented, and are developed to build, test and extend research hypotheses. The latter are output oriented and meant to explore, understand, and anticipate the consequences of policy interventions in complex 'real world' systems. As to their use there should not be a difference between both types of models, and policy makers should be able to work with the most up to date knowledge about the way systems work. However, there are a number of practical considerations that differentiate them. Mulligan mentions among others:

- Research models are mostly complicated models which are computationally demanding and hence are much more time consuming than what is wanted for interactive, explorative policy exercises;
- Research models are often developed to understand processes that take place at geographical and temporal scales that are not relevant to policy makers. Policy makers will typically be interested in time scales expressed in years, not in seconds or centuries, and spatial scales covering a typical political, administrative, or management unit;
- Research models are typically data demanding. Often they will require field data specifically collected to run the model. Policy models can usually not afford this time and resource consuming luxury and should run on the basis of existing data material;
- Research models are models for experts, generating a type of output that is of immediate interest to the expert. The output is not compatible with the language and concepts that are of concern to the policy maker. Often, minor adaptations to the output generated by the models and a state of the art graphical user interface could bridge part of this gap, but they are rarely being applied;
- Research models are difficult to validate. This reflects their level of sophistication. Validation is a prerequisite for models if they are to be used in a policy context.

This list reinforces the point made earlier that research models are not automatically usable for policy purposes, and that often important adaptations need to be made to research models in order to use them for policy purposes. For MODULUS, the key end-user requirements of the Decision Support System and its integral model can be summarised as follows (see Chapter 4 by Mulligan and Reaney in Engelen et al., 1999):

- (a) *All processes*. The MODULUS model must adequately represent all of the important processes necessary to provide the required output;
- (b) *Scientifically proven*. The process descriptions within the MODULUS model should be well known and scientifically proven. It is better to have a well understood, proven but crude process description than an innovative but poorly documented and less proven description. The model results have to be robust, reliable and accurate;
- (c) *Scale*. The MODULUS model must operate at a regional scale and must provide information at a sufficient level of spatial detail (resolution) to reflect the scale of variation in the most important environmental and human variables;
- (d) *Time horizon*. The MODULUS model must be a dynamic model, operating at time scales and temporal resolutions which are relevant to the policy end-user. It should realistically represent the autonomous dynamics of the system modelled as well as the time scales involved in the policy preparation and implementation phases;

- (e) *Routine data.* The MODULUS model must be sufficiently simple to run 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 which the user can be taken through. These may be for environmental changes, anthropic impacts, and management options;
- (g) *Output centered.* The MODULUS model must be output centered. 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 must 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 will be required to achieve this.

The key trade-offs are between accuracy (of the data and of the model process representation) and simplicity (of models and of data). The model must have sufficient spatial and temporal detail and sufficient model complexity to accurately represent the processes but must achieve this over large areas in a fast and responsive manner with a minimum of data. From the above, it will be clear that this is not automatically achieved on the basis of research models, rather that important adaptations to the models are required before they are effectively integrated. In this respect, MODULUS has developed solutions at three levels: 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 to 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.

Scientific integration

The 4 projects described earlier in this paper were deliberately selected on the basis of the complementarity of the research carried out. And, from a preliminary analysis it was concluded that the potential for integration was real. From the 4 projects models were available in different stages of development: some models were fully finished and had been validated and tested against real world data, while others were still in an early development phase. The models were evaluated on their conceptual and technical merits as well as their scientific novelty. A 'typical' scientific evaluation would also have considered the performance of the models in terms of realistically representing the processes for which they are developed, and their capacity of generating validatable output. However, most of the models available from the 4 projects were not sufficiently operational to permit the latter type of analysis.

As a result most of the evaluation has been focussed on the role models could fulfil as component sub-models in the integrated context of the MODULUS model. The following criteria were taken into consideration for the 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 have 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-1000km²). 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 available in MODULUS are spatial, dynamic, non-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 are considered that fulfil a task within the MODULUS integration scheme which is 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 scale during the calculation;
- *Level of sophistication.* The models considered are in most cases simplified version of 'the ultimate' or 'the best available' models. In order to fit in the integrated scheme, and to be at the right level of abstraction, models need to be simplified and need to be stripped of details that are not directly relevant to the problems at

stake. 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.

The analysis of the models against the selection criteria lead us to conclude that an integral 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. A large amount of GIS data are available at this resolution, and it allows for the inclusion of models running on irregular (administrative) areas if the borders of these areas are redrawn to coincide with the edges of cells. The errors thus made are minimal. As for the temporal resolution, the choice of a monthly or weekly time-step is not appropriate for a number of the models. In particular, KCL's PATTERN model (see for more details Chapter 4 by Mulligan and Reaney in Engelen et al., 1999) requires a much finer time step (minutes or hours). As a result, the decision was made to develop a model running at an hourly time step. While the simulation is stepping through time, sub-models are invoked as required. Information that needs to be exchanged is aggregated over days, weeks or months as required.

Technical Integration

As most research models nowadays are also computer models, the problem of technical integration is very much a hard- and software problem. From a computer science point of view, integration of models has become very much a problem of *software component* integration. Software components are pieces of software that are designed for re-use: *'a coherent package of software artifacts 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.

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 can be more or less complete models varying from simple mathematical operators, such as Multipliers or Adders, to rather sophisticated and nearly complete models consisting of coupled mathematical equations performing a number of sophisticated calculations. A Model Building Block represents a part of a model: an action or process. MBB's may simply represent sources of information (i.e. entered from file or by the user), other will transform information as it passes through them, and still other will simply serve to communicate, in a synthetic manner, the outputs of the model to the user.

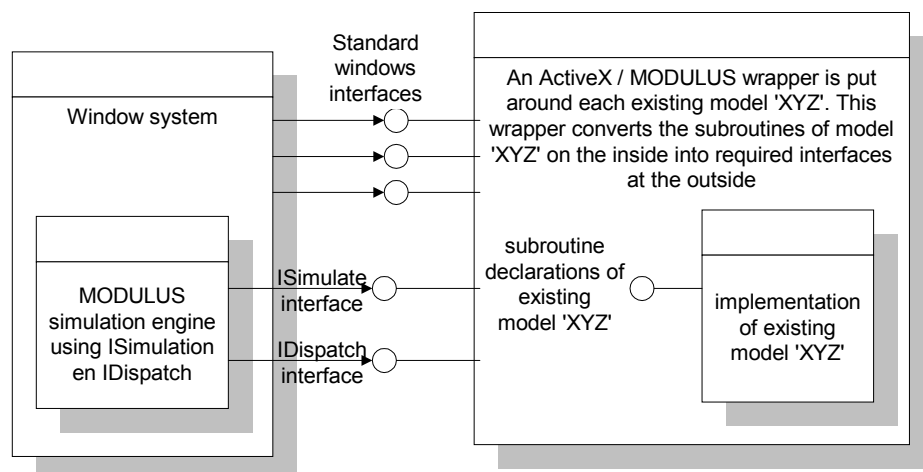


Figure 1: The MODULUS simulation engine works with standard COM ActiveX/MODULUS components. Each of the existing models is encapsulated in a 'wrapper' which makes them look like ActiveX/MODULUS software components. For more details see Chapter 5 by Engelen et al. in Engelen et al., 1999.

We realise that MODULUS will not develop the ultimate methodology or library containing a set of easily pluggable Model Building Blocks. More development time would be required to achieve this goal. But in MODULUS the question of re-use is posed: from different EC projects partners have their existing models,

written as monolithic applications in whatever programming language they master. Rather than re-coding this material in yet another programming language to develop yet another monolithic application, MODULUS has chosen to 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 case regions made us decide to attack the problem from a rather practical angle. The focus of the work carried out under the heading ‘technical integration’ therefore is on the evaluation of the usability of the existing component technologies, rather than on the development of new standards, functional specifications and technical designs.

The Preliminary MODULUS model

Screening the available models against the *End-use integration* and *Scientific integration* criteria has allowed deciding on a preliminary scheme for an integral MODULUS model, consisting of component sub-models (see Figure 2). This integration scheme has the great merit of covering an important part of both the natural and the socio-economic system. From an initial analyses it was concluded that sufficient data are available in both pilot regions to run the integral model, and that the sub-models produce and exchange the appropriate information required in the integration scheme. This in itself is a remarkable result, since each of the models has been developed within different research contexts and with different purposes in mind. However, one should not interpret 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. 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.

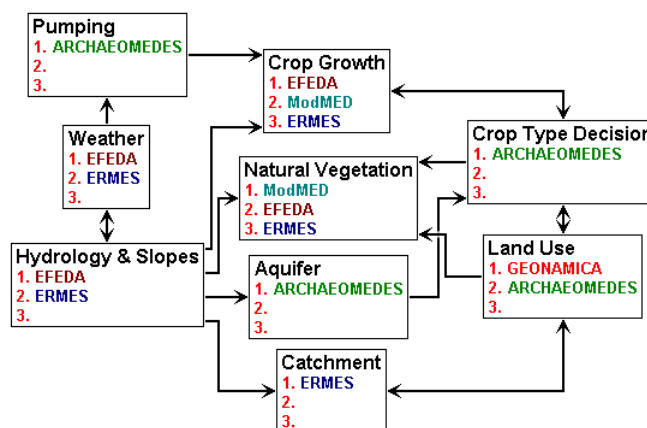


Figure 2: The MODULUS model integrates a number of components (shown as boxes). Each component consists of a model developed as part of EFEDA, ERMES, ModMED or ARCHAEOEDES. For each component the available models (named after the projects they have been developed in) have been ranked. The models ranked first have been implemented first. The arrows in the scheme represent the main links between the sub-models only.

Each of the models included in the scheme is dynamic and spatial. The typical spatial resolution at which the integral model runs is the 1ha grid. The role of the individual models in the connection scheme can be summarised as follows:

- *Weather:* (EFEDA, PATTERN Weather & Storms model, available as a C++ MBB). 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 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 in minutes and bucket-tip times) for precipitation for the study areas based on data from at the least 1 AWS weather station.

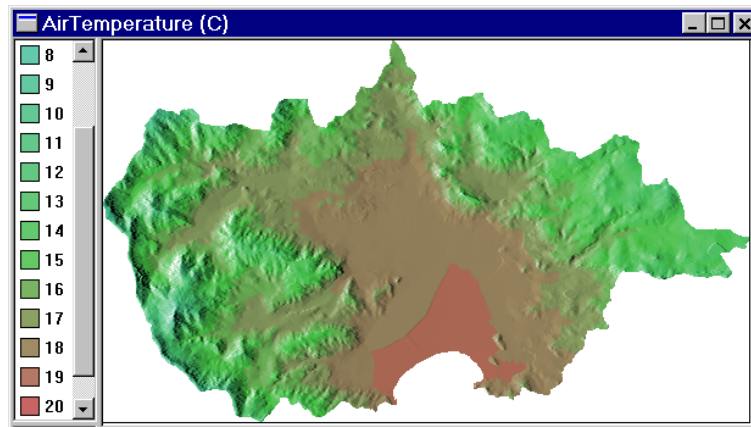


Figure 3: Air temperature in the Argolid at ground level. The mean monthly temperature at sea level is derived from a 30-year climate scenario. It is spatialised and corrected for altitude and local deviation from the mean temperature as measured by local weather stations.

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

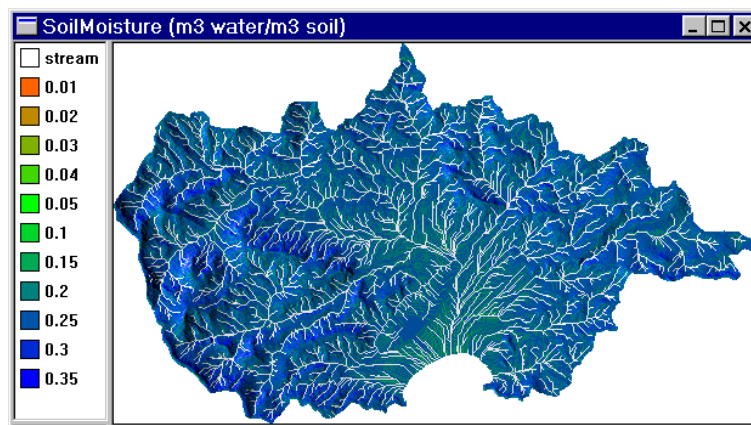


Figure 4: Soil moisture in the Argolid in the winter (end of December)

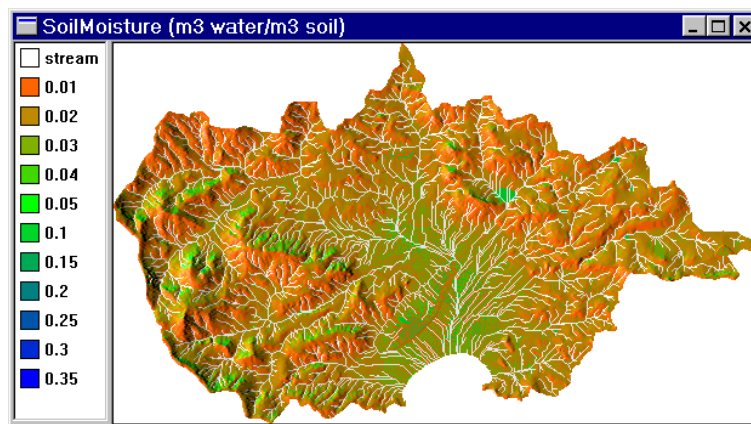


Figure 5: Soil moisture in the Argolid in the summer (beginning of September)

- **Natural vegetation:** (ModMED, RBCLM2 Community model, available as a PROLOG MBB). 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 cell of the case regions. It is supplemented with a cellular seed diffusion model, which produces a seed biomass maps, which links the community level cells at the landscape level.

- *Crop Growth:* (EFEDA, PATTERN Plant Growth model, available as a C++ MBB). This model runs daily. It represents the processes of growth of commercial crops and calculates the leaf biomass, root biomass, leaf area index and the vegetation cover fraction.
- *Aquifer:* (ARCHAEOAMEDES, 2 versions of the aquifer model are retained: the Agricultural University of Athens-ModFlow model and the IERC-Aquifer model. The ModFlow model is available as a FORTRAN MBB, while the IERC model is available as a POWER BASIC MBB). Due to the very complex and discontinuous nature of the aquifer in the Marina Baixa, the aquifer model is only applied in the Argolid 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 intended to run daily on a 1ha or 1km resolution.

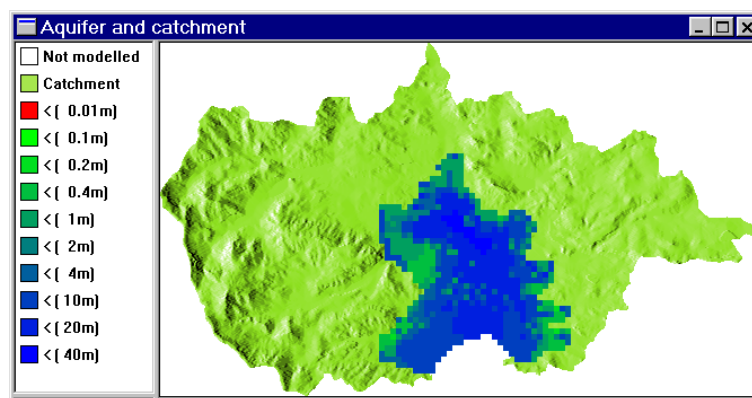


Figure 6: The main watershed modelled in the Argolid and the location of the Aquifer within. The Aquifer is modelled by means of a ModFlow model at a 500 by 500m grid, which runs on a monthly basis. The volume of the aquifer is represented.

- *Catchment:* (ERMES, Catchment model, available as a POWER BASIC MBB) 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 PO₄ and NO₃. The model runs on irregular shaped, natural defined areas –the catchments and sub-catchments.

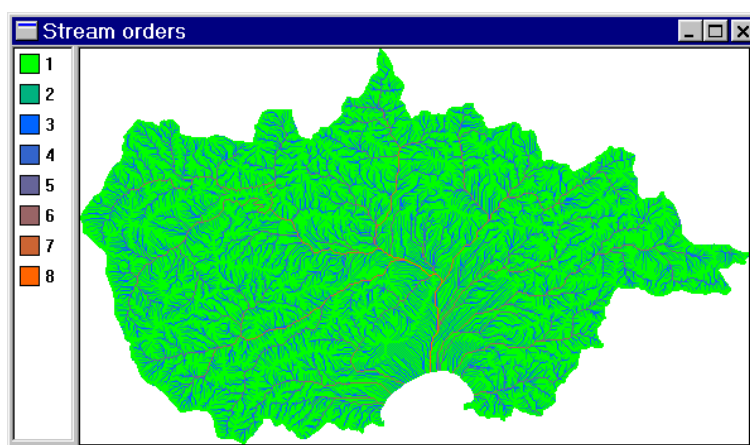


Figure 7: Catchment stream orders for the Argolid watershed.

- *Crop type decision:* (ARCHAEOAMEDES, Decision making model, available as a POWER BASIC MBB). 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.

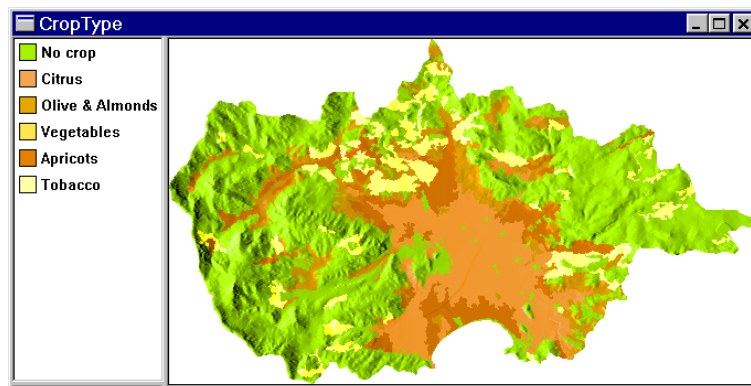


Figure 8: Crop types in the Argolid.

- **Pumping:** (Extracted from work done in ARCHAEOEMEDS by IERC, available as a POWER BASIC MBB). This model runs twice daily. It is a rule based model representing the farmers decision 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, 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.

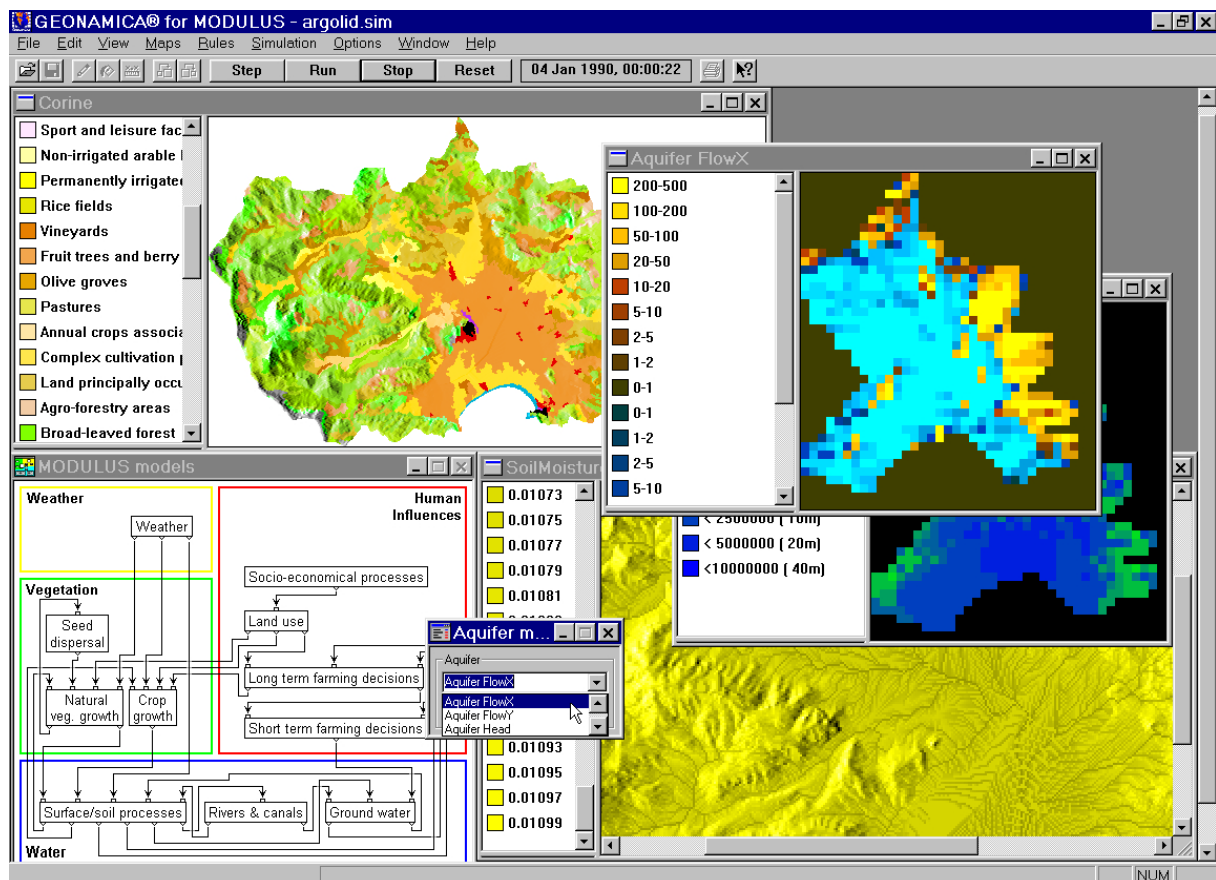


Figure 9: User-interface of the MODULUS system. The user gets access to the individual sub-models (Model Building Blocks) by means of the systems diagram (shown in bottom left). He can run simulations and select any combination of maps on the display

- *Land Use*: (GEONAMICA Constrained Cellular Automata model, available as a C++ MBB). This model runs yearly. It is a cellular automata based model 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 will take into consideration the activity specific attractivity of cells in terms of their suitability, zoning regulations and accessibility to the road transportation infrastructure.

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 50 mapped variables. Some of the output maps represent a final output variable of the integral model, but most maps are generated or updated by an MBB to serve as an input to another MBB.

Although it is expected that the integration will eventually lead to a *Scientifically* acceptable model, this does not mean that the *End-use* usability of the integral instrument is automatically guaranteed. The first tests performed showed that a single run of the integral model for the entire Argolid region, consisting of 239385 * 1ha cells, 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 this much time to perform a single simulation run is not a very practical tool for policy making. It loses all of its explorative capabilities as well as its role as a communication tool. Since then, a lot of effort has been put into reducing the execution time. A simulation run now takes some 2 hours.

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 paper 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. A well-designed user-friendly interface should enable to structure the policy exercises carried out with the model. The same interface should increase the transparency of the model and the DSS as much as possible: at any point in time, the user should have access to the background information required to understand the processes in the model he is working with and the numbers they generate. Without this information, the model becomes a black box and no learning takes place. The user can try out *policy interventions* in his system (which he selects from a predefined Policy Options Window). He can test the robustness of the system and his policy interventions if the system is subjected to *scenarios* (which he can select from a predefined Scenarios Window). Finally, he can see how his policy interventions and/or scenarios in terms of indicators (which are shown in an Indicator Window) affect the system. 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 system. Such an explorative approach, we believe, contributes to the design of actions to pilot the system past the worst and hopefully towards the most desirable future possible.

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