# Integrated Modelling and Decision Support Tools: A Mediterranean example

T. Oxley

N. Winder

Brian McIntosh

M. Mulligan

Guy Engelen

# Integrated Modelling & Decision Support Tools: A Mediterranean example

T.Oxley[1], N.Winder[2], B.McIntosh[3], M.Mulligan[4] & G.Engelen[5]

[1]*EMMA, Imperial College, Prince Consort Road, London SW7 2BP, UK (t.oxley@ic.ac.uk)*
[2]*Spatial Modelling Centre, Umeå Universitet, Box 839, SE-981 28 Kiruna, Sweden*
[3]*School of Water Sciences, Cranfield University, Bedford MK43 0AL, UK*
[4]*Department of Geography, King's College London, The Strand, London WC2R 2LS, UK*
[5]*RIKS bv, PO Box 463, 6200 AL Maastricht, The Netherlands*

**Abstract:** A great deal of new knowledge and research material has been generated from research carried out under the auspices of the EU. However, only a small amount has been made available as practical policy-support tools. In this paper we describe how EU funded research models and understanding has been integrated into an interactive Decision Support System addressing physical, economic and social aspects of land degradation in the Mediterranean. We summarise the 10 constituent models that simulate hydrology, human influences, crops, natural vegetation and climatic conditions. The models operate on very different spatial and temporal scales and utilise different modelling techniques and implementation languages. Many scientific, modelling and technical issues were encountered during the transformation of 'research' models into 'policy' models. We highlight the differences between each type of model and discuss some of the ontological and technical problems in re-using research models for policy-support, including resolving differences in temporal scale and some of the software engineering aspects of model integration. The involvement of policy-makers, 'stakeholders' and other end-users is essential for the specification of relevant decision-making issues and the development of useful interactive support tools. We discuss the problems of identifying both the decision-makers and the issues they perceive as important, their receptivity to such tools, and their roles in the policy-making process. Finally, we note the lessons learned, the resources needed, and the types of end-users, scientists and mediators required to ensure effective communication, technical development and exploitation of spatial modelling tools for integrated environmental decision-making.

***Keywords:*** Modulus, Decision Support Systems, Integrated Modelling, Policy-Support

## 1. INTRODUCTION

The MODULUS Project set out to build a Decision Support System (DSS) with a high level of flexibility and generic applicability enabling the end-user to understand the processes causing and caused by land degradation, and to provide appropriate tools for the design and evaluation of policy options. The system and its models were applied and tested in the Argolida (Greece) and Marina Baixa (Spain) regions in collaboration with local policy makers and researchers with experience of these regions. The project was designed to build upon the results obtained in the EU funded EFEDA, ERMES, ModMED, ARCHAEOMEDES, EPPM, and MEDALUS projects.

Modulus succeeded in bringing together and re-using research material and models in a new context by developing an integrated model embedded within a tailor-made DSS. We learned that it takes more than the 24 months allocated to the project to go though the full development cycle for a DSS of this complexity. However, we believe that we produced something rather unique, and conclude that the MODULUS DSS represents a 'Proof of Concept' system demonstrating the feasibility of integrating diverse research models for policy-support. There are two main purposes of this paper:

i. To highlight the complex scientific, modelling and technical issues involved in the development and exploitation of spatial modelling tools for integrated environmental decision-support; and
ii. To discuss the problems of identifying decision-makers and the issues they perceive as important, their receptivity to model-based decision-support tools, and the role of such tools in the policy-making process.

## 2. RESEARCH OR POLICY MODELS

There are important differences between 'Research' models and 'Policy' models. *Research models* are strongly process oriented. Their temporal and spatial scales and level of complexity are solely determined by the characteristics of the process being examined. Such models are often mono-sectorial. The research model developer aims at a representation that is as accurate as possible, uses the model to test hypotheses and further understanding of the world and tends to make use of scientifically innovative techniques to develop a model that is as complex as required. Often this will pose difficulties in validating the resulting model, but in the quest for new knowledge the development of the model can be a goal in its own right. 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 typically considered, nor is model transparency or user-friendliness, as the model developer is usually the only user of the model.

*Policy models* are foremost oriented towards addressing practical policy problems. The problems addressed determine the temporal and the spatial resolution at which processes are represented. The level of detail and degree of complexity are often determined by the availability of data. Policy models are only interesting because they deliver practically useful output. To achieve this, robust, extensively tested methodologies will preferentially be used. The policy model might be complex, but generally is kept as simple as possible. Policy models are not designed to further understanding of processes but to help explore the possible effects of policies. Processing speed and model interactivity are determining factors for success, particularly if the model is used in participatory exercises involving stakeholders. In addition, transparency and user-friendliness are crucial factors, along with the involvement of the problem owner during model development.

## 3. THE MODULUS SUB-MODELS

There are 9 sub-models integrated into the Modulus DSS (see the system diagram in Figure 1). Details of these models are provided elsewhere [Engelen, 2000; Oxley *et al.*, 2000]. For each model we identify the source project, the language it is written in, the spatial and temporal resolution, and the processes modelled.

<u>*Climate & weather*</u>*:* (Efeda, Pattern$^{LITE}$ Weather model, C++, 1ha). This model runs daily, calculating the time of sunrise and sunset and the average solar radiation. The temperature per cell is updated monthly. The model generates detailed daily time series for precipitation using a dynamic ('bucket-tip') timestep. Temperature and precipitation are corrected for climate change [Mulligan, 1996; Mulligan & Reaney, 2000].

<u>*Hillslope hydrology*</u>*:* (Efeda, Pattern$^{LITE}$ Hillslope model, C++, 1ha). This model runs daily, but integrates internally over bucket-tip timesteps. It deals with soil hydraulic properties and calculates the water budget. [Mulligan, 1994, 1996, 1998; Burke *et al.*, 1998; Reaney & Mulligan, 1999]

<u>*Plant Growth*</u>*:* (Efeda, Pattern$^{LITE}$ Plant model, C++, 1ha). This model runs daily. It represents the processes of growth of commercial crops and natural species and calculates the leaf biomass, root biomass, LAI and the vegetation cover fraction. [Mulligan & Reaney, 2000]

<u>*Natural vegetation*</u>*:* (Modmed, RBCLM2 model, Prolog, 25ha). This model runs monthly. It represents community-level processes of natural vegetation change. This model is rule-based, applied to each cell, supplemented with a cellular seed diffusion model (C++), which produces a seed biomass map and links the

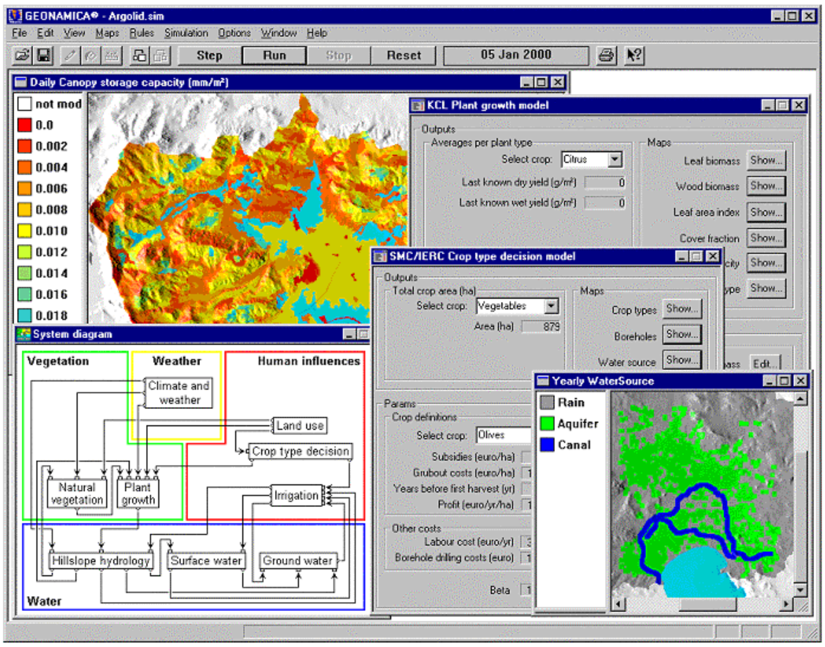


**Figure 1**: The MODULUS DSS graphical user interface, including the system diagram highlighting the constituent sub-models

community level cells at the landscape level [Mazzoleni *et al*., 1998; McIntosh *et al.*, 2001].

*Ground water:* (Archaeomedes, 2 user-selectable models: the AUA-ModFlow model (Fortran, 25ha) and the IERC-Aquifer model (in Power Basic, 1 ha)). These models address the depletion, recharge and pollution of the aquifer. ModFlow runs monthly [Poulovassilis & Giannoulopoulos, 1999] and the IERC model [Robinson, 1999] runs daily.

*Surface water:* (Ermes, Catchment model, Power Basic). This model runs daily and represents the river, canal, and water reservoir system, and the water quality of the surface water. The model runs on irregular shaped, natural defined areas: the catchments and sub-catchments. [Billen, 1992; Allen *et al*., 1996].

*Crop choice:* (Archaeomedes/EPPM, Decision making model, Power Basic, 1ha). This model runs annually. 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. [Winder *et al.*, 1998; Oxley *et al.*, 2002]

*Irrigation:* (Archaeomedes, Power Basic, 1ha). 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. [Oxley *et al.*, 2000]

*Land-Use*: (Constrained Cellular Automata model, GEONAMICA®, C++, 1ha). This model runs annually. It allocates the land use dynamics resulting from demographic changes, as well as the dynamics in the agricultural and non-agricultural part of the economy. [Engelen *et al.,* 1997; White & Engelen, 1997].

These models are integrated by means of information flows as detailed in Oxley *et al* (2000) and McIntosh *et al.* (2000). Maintaining the flows is crucial for the integrity of the DSS; they must for example be retained when the user only selects a subset of the available models for a simulation.

A variety of simulation scenarios can be explored using the DSS. Selections of these scenarios are documented in Engelen *et al*. (2000) and Oxley *et al*. (2000), but potentially can include water management practices, crop choice and subsidy change, climate change, economic policy and urban development. Other problems such as planning and land suitability mapping, tourism and water stress, environmental impact assessment, natural vegetation dynamics, desertification and aquifer recharge can also be addressed.

## 4. MODELLING & TECHNICAL ISSUES

The MODULUS DSS integrated EU funded research models and gave them a visual interface; a dynamic map in which hydrological, biological and agronomic landscapes evolve on the screen in real time. Initial calculations suggested that a single run of all the models to be integrated would probably require tens and quite possibly hundreds of processor hours. Simplifications and adaptations were therefore unavoidable.

Two critical issues had to be addressed. The first relates to time steps and the second relates to spatial self-organisation. Both issues bear on the dynamic sensitivities of the composite system. All of the component models have definite time steps that determine the simulated times at which system variables are updated. Aquifer levels, for example, are updated relatively infrequently though water enters the soil in definite precipitation events and may move through the soil very rapidly. Thus the surface hydrology 'wants' to give water to the aquifer on an hour-by-hour basis while the sub-surface aquifer can only accept it on a much longer time step. The effect of this is that water may appear to be delivered to the aquifer in enormous and unnatural torrents with potentially significant dynamic impacts. Water abstraction poses similar problems in that irrigation decisions are made on a much shorter time frame than aquifer level changes. Aquifers can therefore build up huge 'irrigation debts' which are paid off instantly at the beginning of a hydrological step. Prigogine (1978) has shown that periodic disturbances of this sort can result in spontaneous self-organisation with the development of complex spatial patterns that would show up on our distribution maps.

Reducing time steps to bring every model into step with the others is not an option because the increased computational load would increase run-time to an unacceptable level. Increasing time steps is similarly unacceptable because fine time-scale phenomena like single storm events can have very significant effects. One response to such problems is to use interpolation and this provided a workable compromise, at least in the hydrological domain. Mulligan and Reaney (2000) developed a simplified version of PATTERN using a novel 'bucket-tip' technique such that timesteps responded dynamically to rainfall events. It was not clear however that there existed any generic 'off the shelf' solution to problems of scale difference between models. Rather, the adaptations made to each model were primarily made in model and domain-specific ways.

In terms of implementation two basic problems were encountered – integrating models written in different languages (eg. Power-Basic vs. Prolog) and controlling the order in which variable values are computed across component models. The DSS was built as an integrated model composed of a number of ActiveX components called Model Building Blocks, each MBB corresponding to one of the sub-models detailed above.

The integration of existing models was achieved without having to completely re-code through the use of a *wrapping* technique, whereby each sub-model was transformed from its native code into an ActiveX MBB – a more or less complete model with a predefined set of inputs and outputs. The wrapping process was tailored to each component model, involving some minor recoding.

The spatial modelling environment GEONAMICA developed by RIKS bv. was used as the core simulation engine and platform for integration. Standard interface definitions, the hallmark of ActiveX, were used to integrate each MBB with the GEONAMICA system and the Windows OS. The development and use of standard interfaces enables models implemented in different languages to exchange information and also facilitates model re-use - different MBBs can be exchanged free from compatibility concerns. A standard interface was defined to permit the simulation engine to run models with different time-steps at the same time and to control variable computation order. Another standard interface was defined to retrieve each MBB's input and output specification thereby allowing the simulation engine to 'connect' one MBB to another in terms of information flow.

## 5. POLICY-MAKERS & END-USERS

The view that many scientists have about policies and policy-making in the environmental field is often overly simplistic. Frequently researchers refer to a rational 'decision-maker' as some autonomous individual located at some higher level in an administrative hierarchy. In reality, policy formulation and decision-making are complex processes involving many individuals and many different forms of knowledge, and it is difficult, if at all possible, to pinpoint the moment at which, or the people by which, a decision is arrived at. This oversimplification on the scientists' side is representative of a more fundamental source of tension, which resides in the fact that the two communities function in qualitatively different contexts. Most scientists are concerned about single issues or phenomena and, correspondingly, the idea of 'solutions'. The policy world, on the other hand, exists in a multiple-issue and multiple-constituency world where the agenda is constantly changing and where an environmental issue is only one of many competing for attention. Moreover, scientists and people involved in making and administering policies are subject to different kinds of peer and contextual pressure, they have different time horizons, they speak in many ways a different language. These differences complicate communication between the two groups, but simultaneously make such communication essential if one is to focus research on a community of policy-making end-users.

There is a widespread assumption, not least among ourselves at the start of Modulus, that transparent communication between all the stakeholders involved in environmental problems is necessary. It is worth questioning whether this is in fact always the case and under what circumstances there is anything worthwhile communicating. For example, a local farmer may be more concerned about crop yield than water consumption. In order to be effective, communication between the farmer and a hydrologist working on problems of desertification may not require discussing the effects of excessive water consumption so much as crop choices that do not use so much water. Yet the hydrologist is a specialist on water, not crop choices. Thus the communication that is needed is not between the hydrologist and the farmer, but between the farmer and an agronomist. In turn, the agronomist need only know that he should advise farmers on crops that require less water consumption; he does not need to know the details of the hydrological science. In other words, much depends on the agendas of the participants. The agenda for scientists may be somewhat different to the policy issues at different scales. In turn policy issues at, say, a national scale may not be the same as those at a regional or local level.

There is an additional problem of diagnosis. Scientists and other environmental specialists tend to simplify from complex situations in a way that enables them to apply their knowledge. We have come across numerous situations where the interpretation of the symptoms of an environmental disorder have been specified as very different 'problems' by politicians and specialists, and between specialists. An example is a situation where more water is being consumed than can be sustained in a local environment: in one domain, the problem may be perceived as excessive water use, but in another, it may be perceived as insufficient supply. The policy implications of the two perceptions are dramatically different, in that the first would recommend a policy instrument to reduce water consumption, whereas the second would recommend a technical solution that would increase water supply. This mismatch of agendas and ‘problem’ identifications can result in inappropriate research, not at a suitable scale or not easily connected to decision issues.

The knowledge of any individual, group of individuals (at various levels) or institution is derived, negotiated and shared in a particular context. As a result, there are often relatively invisible differences that can lead to serious misunderstandings. One of the areas in which this affects us here, is the hampering of communication between people who have, as part of their (formal) education acquired ‘institutional’ knowledge, and people who have, on the other hand, acquired their knowledge informally, as part of their everyday activities in the area where they live. Such knowledge is often termed ‘local knowledge’.

The way in which knowledge is translated into effective use varies at different scales. ‘Institutional’ science tends to address supra-regional, and often supra-national, agendas. There is a codification of knowledge in the form of standards and procedures. For instance, water quality standards for potable and recycled water are set on the basis of research commissioned at the national or EU level (and sometimes at a wider international level). At a local and regional level this knowledge is received in the form of technical standards rather than specific local policy. The ‘communication’ takes place at the institutional level. This creates problems as local issues drive a need for local access to local knowledge. Many of the ‘communication’ issues we have seen at a local and regional scale arise because environmental issues are often unanticipated and highly specific to local circumstances. Institutional knowledge has not been developed with these situations in mind, potentially resulting in a lack of relevant understanding. Sometimes local and regional specialists can be hired to help fill the gap. There is still, however, the difficulty of how scientists interpret situations as problems at this local scale.

In addition there can be very important differences between local and regional areas in terms of effectiveness of communication between scientists and policy-makers. Among the factors influencing local communication effectiveness are the extent to which environmental issues are a priority among different constituencies, the social and cultural nature of local networks and the alignment between local politicians and issues.

One of the core problems of an exercise like Modulus is that the same information can mean different things to different people. Communication between participants presumes a certain degree of alignment of objectives and perceptions. Such alignment is a very slow and complex process of learning, which, even at the best of times, cannot be accommodated very easily in a project-based agenda where time is limited and the implicit design objective is one of ‘experts’ giving advice to the ‘non-experts’.

During the Modulus project workshops were held with the aim of directly involving the regional and local policy stakeholders in the DSS design process. In order to better understand the nature of the reasons why the stakeholders expressed interest in the project, we asked a number of the workshop participants their reasons for being there. Three main reasons were identified by the end-users: prestige, personal or institutional self-interest, and access to a reliable source of EU information.

One of the most informative comments arising from the workshops regarding the motivation and involvement of potential end-users was: to quote one key workshop participant *“Finally, we stop being the aboriginals that are studied by civilised people, and from now on we will start collaborating with them at the same level.”* [Filippucci *et al.*, 2000]. This is a crucial point that we feel bears strongly on the way in which we, as scientists, need to structure our approach to providing practical policy-support.

Indeed, with respect to the building and maintenance of relationships between researchers and end-users, one of the principal problems was the need to transform an initial relationship based on the ‘commoditisation’ of each group by the other for its internal consumption, into a relationship of mutual trust and respect based on content. In that process, it is essential that contact is frequent, personal and relaxed as well as productive. However, as we saw in the Argolida, the time-frame of researchers and policy-makers is very different, making the relationship building process more difficult.

## 6. CONCLUSIONS

Re-using and applying models and experience gained in scientific research to providing policy support is not a trivial problem. There are a number of potentially very serious ontological and technical issues to be solved when integrating different models. During the Modulus project we encountered and addressed many such problems but importantly we do not claim to have determined the best methods for tackling them. Many issues remain but the Modulus DSS demonstrates that, at least in principle, the tasks are not insurmountable.

In addition to the various scientific problems encountered we addressed the needs and concerns of effective communication with the policy problem-owners and stakeholders. We determined that a team consisting of the right kind and the right number of specialists with suitable experience is as essential as a clear, well-planned project design and schedule. We believe that the following types of people are required in such a team:

- Motivated and visionary policy end-users.
- ‘Trans-discipline’ and ‘trans-role’ domain specialists / scientists / model developers.
- An architect for the integrated model or DSS model base.
- Flexible, highly skilled software system developers.
- A professional ‘communication’ specialist.
- An experienced project manager.

## 7. ACKNOWLEDGEMENTS

This research was supported by the Commission of the European Union DG-XII Environment (IV) Framework Climatology and Natural Hazards Programme contract ENV4- CT97-0685.

## 8. REFERENCES

Allen, P., T. Oxley, & M. Strathern, A dynamic spatial model of water quality in the Rhone Valley, In: Mouchel, J.M. (ed.), (EU-DGXII, EV5V-CT94-0547), 1996.

Billen, G., The Phison River System: a conceptual model of C, N and P transformations in the aquatic continuum from land to sea, In: NATO ARW on interactions of C, N, P & S biogeochemical cycles, 1992.

Burke, S., M. Mulligan, & J.B. Thornes, Key parameters that control recharge at a catchment scale: using sensitivity analysis and path analysis to define homogenous recharge classes, In: Wheater, H.S. & C. Kirby, *Hydrology in a changing Environment. Vol II*. Wiley, Chichester, 229-243, 1998.

Engelen, G., R. White, & I. Uljee, Integrating constrained cellular automata models, GIS and decision support tools for urban planning and policy making, In: Timmermans, H. (ed.), *Decision Support Systems in Urban planning*, Chapman & Hall, 1997.

Engelen, G. (ed.), MODULUS: A Spatial Modelling Tool for Integrated Environmental Decision Making, (ENV4-CT97-0685), 2000. http://www.riks.nl/RiksGeo/proj_mod.htm

Filippucci, P., M. Mata-Porras, & S. van der Leeuw, The Alicante Experience, Vol1, Ch2, 87-95, In: Engelen, G. 2000.

Mazzoleni, S., C. Legg, S. Strumia, & A. Migliozzi, (eds.), ModMED, Modelling Vegetation Dynamics and Degradation in Mediterranean Ecosystems, (EU-DGXII, ENV4-CT95-0139), 1998.

McIntosh, B.S., S. Mazzoleni, & A. Coppola, Selection and Evaluation of Models, In: Engelen, G. (ed.) 2000.

McIntosh, B.S., C.J. Legg, P. Csontos, M. Arianoutsou, & S. Mazzoleni, Rule-Based Modelling, In: Mazzoleni, S. & C.J. Legg, (eds.), ModMED: Modelling Mediterranean Ecosystem Dynamics, ModMED III Project, (EU-DGXII, ENV4-CT97-0680), 2001.

Mulligan, M., Modelling the hydrology of dryland vegetation competition, *Annales Geophysicae, Vol. 12*, 1994.

Mulligan, M., Modelling the complexity of landscape response to climatic variability in semi arid environments, In: Anderson, M.G.A. & Brooks, S.M. (eds.), *Advances in Hillslope Processes*, Wiley, 1099-1149, 1996.

Mulligan, M., Modelling the geomorphological impact of climatic variability and extreme events in a semi-arid environment, *Geomorphology, 24:1*, 59-89, 1998.

Mulligan, M. & S. Reaney, Pattern$^{LITE}$, a policy relevant version of Pattern for Modulus, Vol.1, Ch.4, Sec.2, 145-200, In: Engelen, G. 2000.

Oxley, T., B. McIntosh, M. Mulligan, & R. de Roode, Adaptation, integration and application of an Integrative Modelling Framework, In: Engelen, G. 2000.

Oxley, T., P. Jeffrey & M. Lemon, Policy relevant modelling: relationships between water, land use and farmer decision processes, *Journal of Integrated Assessment (in press.)*, 2002.

Prigogine, I., Time, Structure and Fluctuations, *Science* 201:4358 777-785, 1978.

Poulovassilis, A. & P. Giannoulopoulos, Groundwater modelling in the plain of Argos, Agricultural University of Athens, (EU-DGXII, ENV4-CT95-0159), 1999.

Reaney, S., & M. Mulligan, Modelling storms from historic and GCM monthly rainfall data for climate impact studies, *Geophysical Research Abstracts Vol 1 No 2.*, pg 293, 1999.

Robinson, A.V., Integrated Systems Modelling of the interaction between Water Resources and Agriculture, PhD Thesis, Cranfield, 1999.

White, R. & G. Engelen, Cellular Automata as the Basis of Integrated Dynamic Regional Modelling, *Environment and Planning B, 24,* 235-246, 1997.

Winder, N., P. Jeffrey & M. Lemon, Simulation of crop choice dynamics: an application of nested Master-Equation models, *Etudes et Recherches sur les Systemes Agraire et le Developpment, 31*:175-189, 1998.