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Decision support system for desertification mitigation in the Agri basin, southern Italy

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Abstract

As a contribution to understanding the interaction between the factors which influence desertification, a decision support system (DSS) is developed for the 1700-km^2 Agri basin in southern Italy. This integrates the SHETRAN physically based hydrological and sediment yield model, a simple socio-economic model (in which farmers select those crops which give the highest income relative to cost of production), a database (containing climate, physical and socio-economic data according to a range of future scenarios) and existing desertification management experience into a single tool to aid decision-making in desertification mitigation. It provides a means of examining the effect of climate change and land management on desertification, allowing for feedback between the physical conditions and land use as determined by farmer decisions and government or EU agricultural policy (especially crop subsidies). Typical issues which the DSS can address include: what are the desertification consequences of specified climate scenarios, within a context of fixed agricultural policy?; and, given a climate scenario, is a specified land use or agricultural policy sustainable?

Keywords: Agri basin; Decision support system; Graphical user interface; Model integration; River basin management; Socio-economic model; Software development

1. Introduction

Desertification, or dryland degradation, is today recognized as an important environmental problem which may seriously compromise the sustainable development of the Mediterranean area (Ghazi, 1999). Its spread is the result of climatic, social and economic trends, including a move away from the practices of traditional rural culture to land uses which are more concerned with financial profit than their long term (or even short term) environmental impacts. Of course, no-one has made a direct decision to increase desertification but the collective effect of the policies and forces of the last few decades is that subsidies, tax concessions and financial return have come to outweigh considerations of sustainability and environmental protection. Concern about the consequences has prompted the European Commission (EC) to support through its Environment Programme a programme of investigation to identify, understand and mitigate the effects of desertification in southern Europe (e.g. Fantechi et al., 1995; Balabanis et al., 1999; Enne et al., 2001). One aspect of the resulting research has been the development of models and decision support systems (DSS), intended to integrate available knowledge and data and provide the strongest basis for making decisions on land management to mitigate desertification. As part of this research, the EC-funded MEDALUS (Mediterranean Desertification and Land Use) project developed in its third phase (1996–99) a DSS for one of its target areas, the 1700-km^2 Agri basin in southern Italy. This DSS integrates hydrological, soil erosion, vegetation growth and socio-economic models, a database containing climate, physical and socio-economic data according to a range of future scenarios, and existing desertification management experience into a single tool to aid decision-making. At its core is a feedback loop linking crop subsidies, farmer crop choice and physical environmental response (e.g. runoff, soil erosion and crop yield). The novelty of the DSS resides in its integration of the physical

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environmental and socio-economic aspects, thereby providing a new means of investigating the interaction of complex physical and socio-economic systems and their impact on the development of desertification at the basin scale. In this respect it provides an advance over the study of desertification from the purely physical or socio-economic viewpoints.

Development of the DSS (at the Water Resource Systems Research Laboratory, University of Newcastle upon Tyne) builds firmly on the experience of DSS construction at the University of Newcastle in the form of NELUP (Natural Environment Research Council/Economic and Social Research Council Land Use Programme) (O'Callaghan, 1995) and the Waterware DSS for river basin planning developed under the Eureka EU 487 programme (Jamieson and Fedra, 1996). It also draws upon the extensive research at the University of Basilicata into farmer response models (Bove and Quaranta, 2002). The work complements other Mediterranean DSS programmes with different target areas and issues but with the same overall aim of supporting sustainable land and water management (e.g. Andreu et al., 1996; Allen et al., 1999; Mira da Silva et al., 2001).

This paper describes the farming-related environment of the Agri basin and shows how this is represented in the DSS. It then presents the DSS design, including the component models, database, data requirements and data output options, finishing with a typical application procedure.

2. The Agri basin

2.1. Description

The Agri basin, 1700-km^2 in area, is located in the Region of Basilicata in southern Italy. Economically and socially it is one of the less favoured areas of Europe and, especially in its middle reaches, suffers from badlands erosion arising from poorly controlled land use, seasonal extremes of climate and its geological characteristics. It is a climatically marginal region, parts of which have already experienced desertification and parts of which are threatened by land abandonment and the potential results of global warming. For this reason it was selected as one of the MEDALUS project's target areas (Mairota et al., 1998; Geeson et al., 2002).

Unemployment and rural depopulation have persisted for some decades. In the 1980s, changes in the sources of agricultural subsidies and in the enforcement of relevant legislations prompted changes in land use which could encourage desertification. A trend towards intensification of agriculture and expansion of irrigation is clear in the middle and lower parts of the basin whereas, in the upper part, agricultural activities complement other sources of income (Mairota et al., 1998). Away from the irrigated areas, durum wheat is now widely grown, often with little regard for environmental consequences or indeed the crop yield, because of a favourable subsidy level. A crucial objective for the future must be to identify a sustainable programme of land use which reduces land degradation and avoids the marginalisation, and eventual abandonment, of agricultural land.

2.2. Farmer response

Surveys carried out by the University of Basilicata (Bove and Quaranta, 2002) have shown that farmers select their crops on the basis of short term considerations. Profit (strongly related to crop subsidies) is far more important than soil physical conditions. Farmers therefore continue to grow the same crops even if yields decrease. They may try to compensate by using more fertilizers but in the long term this disregard for the physical conditions may lead to soil degradation. Crop subsidy, on the other hand, can be altered according to government and EU policy, to support soil conservation. The price system may thus be changed in response to developing land degradation. The long term farmer response to deteriorating physical conditions might therefore actually be a response to a policy decision by government or EU, which itself is a direct response to the physical conditions. In other words, the feedback loop by which land use changes as a function of physical conditions is unlikely to be through a direct farmer response but could include government or EU policy.

3. DSS general capability and aims

The Agri DSS integrates a physically based hydrological, sediment yield and vegetation growth model, a socio-economic model and a database (containing climate, physical and socio-economic data) for the Agri basin (Fig. 1). Through this integration it provides a new means for examining the effect of climate change and land management on desertification, allowing for feedback between the physical conditions and land use as determined by farmer decisions and government or EU agricultural policy. In addition to providing information on the evolution of physical conditions, such as soil moisture deficit and soil erosion, it provides simple economic indicators in the form of crop types and crop yields. An important feature of the DSS is its use of physically based models (rather than, for example, simpler regression models) which enables it to be used predictively. In other words, the impacts of different land management strategies under possible future climatic conditions can be explored, and the optimum strategy selected, before any strategy is implemented in practice.

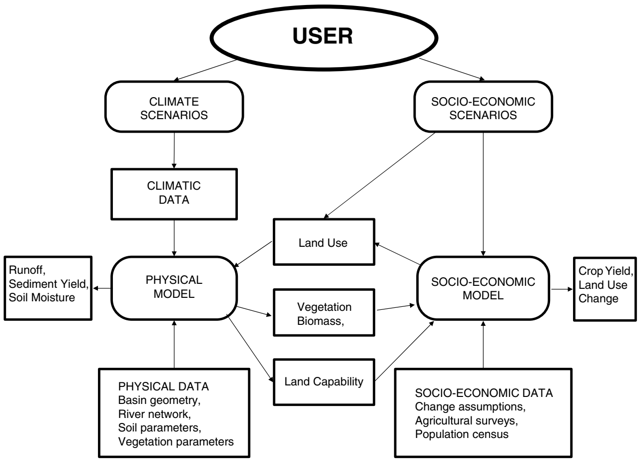

Fig. 1. The Agri DSS: data flow and model connections.

Within the development timeframe it was not possible to obtain sufficient socio-economic data to develop and implement a sophisticated socio-economic model. The emphasis of the DSS is therefore on the occurrence of desertification and the impacts of desertification on physical conditions and crop yield. Feedback loops associated with wider socio-economic issues such as land values, population changes and farmer and regional income are not modelled.

Overall the DSS will support decision-making in such fundamental areas as allocating funds to the best advantage to mitigate desertification. Typical issues which it will address include:

(i) What are the desertification consequences of specified climate scenarios, within a context of fixed agricultural policy (especially crop subsidies)?
(ii) Given a climate scenario, is a specified land use or agricultural policy sustainable? What form of agriculture is sustainable? How do policies (in the form of crop subsidies, which affect crop choice) mitigate desertification?

Question (i) concerns the potential severity of the future desertification problem and might indicate, for example, declining crop yields or changes of crop in the face of a worsening climate. Question (ii) concerns policy testing and might indicate, for example, the feasibility and cost of supporting certain choices or of reducing desertification levels by specified amounts.

4. DSS design

Important aspects of the DSS design include the physical and socio-economic models, the database, the data flow system, the model connections and the screen display or graphical user interface (GUI).

4.1. Physical models

The core of the DSS is the physical model or the model of the catchment physical conditions, i.e. the fluxes and storages of water and sediment. The physical model output feeds the vegetation growth model and forms the basis of desertification indicators such as soil moisture deficit and soil erosion. It is also the means by which the impacts of farmer choice of crop are demonstrated. Without the physical model the DSS would lose its dynamic nature and its basis for predicting the impacts of future climate and land use change on crop yield.

The principal physical model is currently SHETRAN, a physically based, spatially distributed catchment modelling system for water flow, sediment transport and contaminant transport (Ewen et al., 2000). This has been widely described elsewhere and an earlier application in a desertification study is reported in Bathurst et al. (1996). Given a time series of rainfall and evaporation data and property data describing the catchment, SHETRAN produces time series of all relevant hydrological and transport quantities, including surface and subsurface responses. Spatial variability across the catchment is represented by a grid system. Validation of SHETRAN for simulating water flow and sediment transport in the Agri is described in Bathurst et al. (2002).

Provision is also made for an alternative model, MEDRUSH (Kirkby et al., 2002). This has not yet been validated for the Agri basin but it can be used to simulate larger basins than can SHETRAN (up to 5000 km^2), for periods of up to 100 years. It provides scenarios of vegetation growth and the distribution of vegetation functional types, water runoff and sediment yield, and the ways in which these evolve in response to short term sequences of storms, seasonal/annual variations in climate, and long term trends in climate and land use.

4.2. Vegetation model

Predictions of economic yield (in the form of biomass) for a range of crops are required as input to the socio-economic model. However, SHETRAN does not have a dynamic vegetation component allowing the vegetation (especially crops) to respond to the varying physical conditions, such as soil moisture content. Therefore, to support SHETRAN use in the DSS, the US Department of Agriculture's EPIC (Erosion-Productivity Impact Calculator) model (Williams, 1995) was adapted to provide biomass predictions. This model can simulate crop growth and economic yields for a range of crops under a variety of management options, including crop rotations, irrigation, tillage and pesticide application. In the DSS it takes inputs of net rainfall, evaporation and soil moisture from SHETRAN and provides crop yield for the socio-economic model.

For the MEDRUSH option, a vegetation growth model is already included, allowing direct predictions of biomass to be made.

4.3. Agricultural management system

Agricultural practice (e.g. planting and harvest dates, tillage methods, the application and level of irrigation and fertiliser and the spatial distribution of land use, crops and crop rotation schemes) effectively determines several physical model parameters, including overland flow resistance, soil erosion characteristics and soil hydraulic properties. An agricultural management system linking land use with agricultural practice was therefore coded, as a set of look-up tables (LUT). These form the link between the DSS graphical user interface and the model input files. Through the GUI the user can alter the entries in the tables to simulate different agricultural practice scenarios. The altered practice data are converted to model parameter values via the LUT.

4.4. Agri socio-economic model (ASEM)

A simple socio-economic model relevant to the Agri basin was developed to determine change in land cover resulting from farmer behaviour (in terms of crop selection), as a feedback to the physical modelling. To achieve its aim it provides farmer response to price system, crop yield and the availability of subsidies, assuming current technology and soil fertility. Crops are selected which give the highest income relative to cost of production according to the ratio

$$\frac{(\text{Price} \times \text{yield}) + \text{subsidy}}{\text{cost}}.$$

The model determines the ratio for the actual crop at each location in the basin, through the simulation. In order to determine whether another crop would give a higher ratio, it calculates comparison ratios for other relevant crops in the Agri basin, using a standard set of values for yields, prices and production costs. These standard values were prepared by the University of Basilicata from local information and are shown in Table 1. They provide default inputs to the model and shape the model response functions. For each major crop (durum wheat, pasture, olives and grapes), the characteristic income, subsidy and cost are given as functions of crop yield. A range of yields is provided, from a "bad year" to a "good year". The standard for the table is durum wheat, so that the yields for the other crops are scaled on the wheat yields. Thus in a bad year the wheat yield is 0.5 t ha^{-1} and the other yields are then typically 1 (pasture), 0.3 (olives) and 10 t ha^{-1} (grapes).

4.5. Integration of core models into the DSS

As the various core models have different designs, each has its own interface with the DSS. This forms a

Table 1
Standard values for yields, prices and production costs for relevant crops in the Agri catchment (data for the late 1990s)

Cover (%)	Crop	Data type	Typical min.				Typical max.
60	Wheat	Yield, t/ha	0.5	1.0	1.5	2.0	2.5
		Market revenue, Euro/ha	87.5	175	262.5	350	437.5
		Subsidy, Euro/ha	375	375	375	375	375
		Total revenue, Euro/ha	462.5	550	637.5	725	812.5
		Cost, Euro/ha	485.84	485.84	485.84	485.84	485.84
30	Pasture	Yield, t/ha	1	2	3	4	5
		Market revenue, Euro/ha	50	100	150	200	250
		Subsidy, Euro/ha	100	100	100	100	100
		Total revenue, Euro/ha	150	200	250	300	350
		Cost, Euro/ha	50	66.67	83.33	100	116.67
2	Olives	Yield, t/ha	0.3	0.5	0.7	0.9	1.1
		Market revenue, Euro/ha	120	200	280	360	440
		Subsidy, Euro/ha	360	600	840	1080	1320
		Total revenue, Euro/ha	480	800	1120	1440	1760
		Cost, Euro/ha	281	281	281	281	281
2	Grapes	Yield, t/ha	10	15	25	35	40
		Market revenue, Euro/ha	15,000	22,500	37,500	52,500	60,000
		Subsidy, Euro/ha	0	0	0	0	0
		Total revenue, Euro/ha	15,000	22,500	37,500	52,500	60,000
		Cost, Euro/ha	13,000	16,000	22,000	28,000	31,000
6	Other crops						

Costs represents only the variable costs; they not consider the fixed costs, that are in any case independent of yield.

shell around the model for providing the correct data exchange with the other models and data stores, including setting up the input files, controlling the model simulation, and processing and storing the output data. For example, at model set-up, map data and model parameters specified by the user through the graphical user interface are converted by the model interface into model input files. Time series inputs of rainfall and potential evapotranspiration are extracted from the DSS database and converted into model specific formats. Similarly, feedback inputs from other models are converted into input file parameters. After the simulation is complete, output is processed by the interface and stored in the correct formats for input to other models and DSS display. In addition, outputs are generated from the basic model output data that give an overall picture of the simulation, indicating trends and providing summary statistics of various quantities. These include spatial averages, accumulated values, temporal totals and averages and frequency distributions.

4.6. Database

The database stores and manipulates the various types of data required and produced by the DSS. The data in the database are fixed and represent a particular catchment state or scenario condition (e.g. the validated SHETRAN files of property data for the current state of the Agri basin). Data are extracted from the database, modified and displayed or used for model input. Model output data are also stored in the database.

4.7. Data flow system

A controlled flow of data is essential to operation of the DSS. The DSS must be able to communicate with both the database and the models, while the models must be able to communicate with each other. The models use information passed to them by an interface to retrieve data from the database, run simulations, exchange data between themselves and put new data into the database. The new data can then be retrieved from the database and displayed in a variety of ways.

A central task of the DSS is to run the physical and socio-economic models concurrently and provide feedback between them. The models must therefore exchange data at discrete timesteps, a process which is achieved using text files, thus ensuring portability across computing platforms (e.g. from UNIX systems to PCs). Control of the running of the core models and the flow of data between the models, the user and the DSS itself is handled by a separate module. The socio-economic model effectively runs as a subroutine for the physical model. The user defines the timestep for exchange and the models are run in series for each timestep, so that one is running while the other is stopped. This method offers full control of the core models and exchange data and allows user interaction, all with little cost in terms of overall simulation time and data movement overheads.

4.8. Model connections

The principal connection between the physical and the socio-economic models concerns land cover (e.g. Fig. 1). The exact exchanges depend on the requirements and outputs of the models and on the nature of the data in the database.

The socio-economic model requires inputs from the physical model to predict farmer response to physical changes in the environment. The physical model supplies to the socio-economic model biomass at a specified date and the current (simulated) land use. These data are available as spatial distributions at the monthly to seasonal timescale.

The physical model takes as input from the socio-economic model the physical consequences of farmer behaviour in terms of land cover (e.g. crop choice or land abandonment). The input consists of a distributed map of land use for a specified future period (e.g. the next crop season). Agricultural practice (e.g. tillage methods, crop density, sowing dates and crop rotation schemes) can also be supplied, not directly from the socio-economic model but through the look-up tables which link agricultural practice to land use classes.

The timestep for data exchanges is dictated by the extent of the agricultural season, so that land use changes would normally be transferred to the physical model at a fixed harvest date. However, the variety of crops in the Agri basin may involve a range of harvesting and sowing dates, which may also vary through time under the effect of a changing climate. The nature of the socio-economic predictions (whether they are to be implemented immediately or spread over time) and the sensitivity of the farmer behaviour model affect the timing of data exchanges. Possible further development of the socio-economic model to include additional processes, such as irrigation applications, may require feedback between the models to occur at other times of the year. The exchange timestep is therefore small, perhaps one month, so that the flexibility exists to exchange data at any time of the year.

For the case of historical simulations, time series of rainfall and potential evapotranspiration are available for direct input to the physical model. For future conditions, climate scenarios are generated independently of the DSS to give the relevant time series of data. In both cases the time series are stored in the DSS database.

4.9. Screen display

Interaction between the user and the DSS is solely via a graphical user interface. This allows the user to access, set up and run the models and to access and display information held in the database. The GUI has been designed to be user friendly and to encourage users to interact with the DSS. Extensive use is therefore made of such facilities as colour graphics, windows, icons, menus, buttons and sliders. Through a "context-sensitive" help system, highlighting a feature or item at any point on the screen results in a response relevant to that feature or item.

The GUI consists of a hierarchy of windows which provide the user with the tools to view data, build and run scenarios and analyze scenario output. As an example, Fig. 2 shows the output data display windows. An important innovative feature is the provision of a user interaction capability. When a scenario is created, the user can select an option for stopping the scenario at specified intervals, e.g. every five simulation years, view the current data, make any changes that are required and re-start the scenario. In this way the user can intervene in a similar manner to real-world managers and planners in response to changing conditions.

5. DSS data provision and output

5.1. Data provision

Data requirements for SHETRAN (and MEDRUSH) are well defined: they comprise meteorological input data and topographic, soil and vegetation property data, all spatially distributed. The requirements for the socio-economic model ASEM are satisfied by the data on standard values in Table 1. EPIC comes with its own standard data sets for a variety of crops.

Rainfall and potential evaporation time series data are needed to drive the physical model. For historical simulations, measured records are available. For future climates, scenario data can be generated outside the DSS from General Circulation Model (GCM) data. Currently the most realistic GCM dataset is provided by the UK Hadley Centre Climate Model 2 (HADCM2). This incorporates the effects of greenhouse gases and sulphates and represents transient conditions through the 21st century, with atmospheric CO_2 levels predicted to reach double the levels of the pre-industrial period sometime between 2050 and 2100. As an illustration of capability, Fig. 3 shows average monthly rainfall generated for the Agri basin using HADCM2 data for

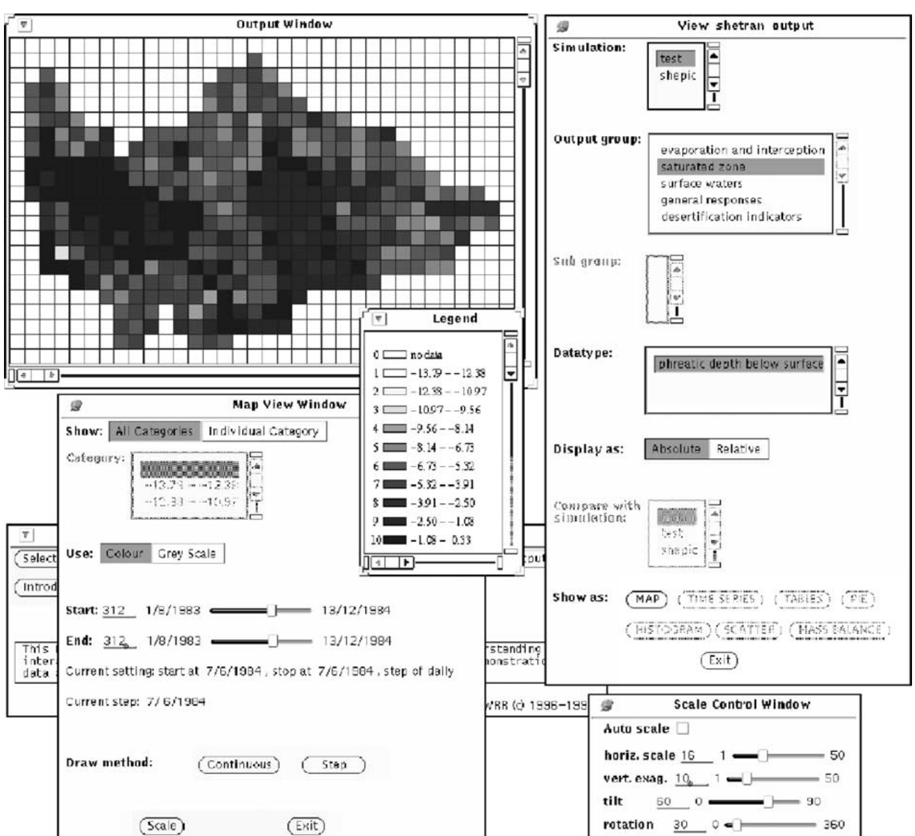

Fig. 2. Example of the graphical user interface window hierarchy, showing the output data windows, including a SHETRAN map of phreatic elevation depth taken from an animated sequence.

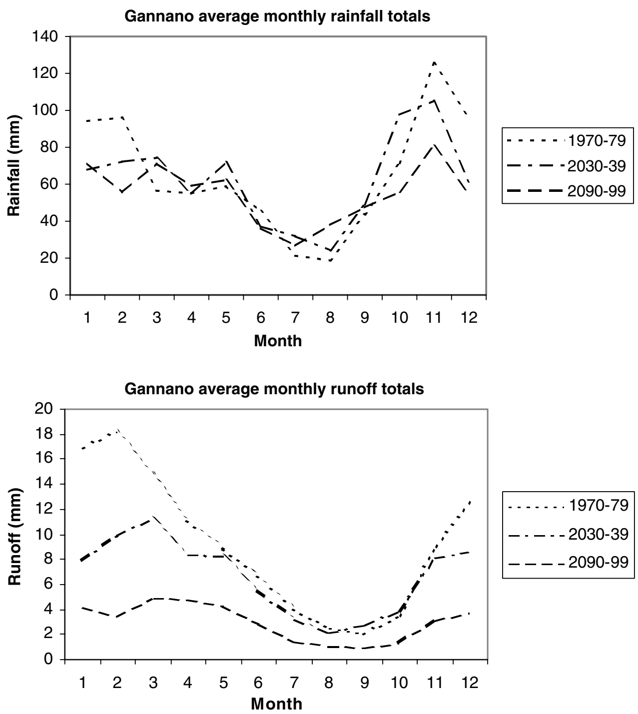

Fig. 3. Average monthly rainfall and simulated runoff totals for the Agri basin to the Gannano barrage (upstream area 1532-km^2) for the scenario periods 1970–79, 2030–39 and 2090–99.

1970–79 (current conditions), 2030–39 (a relevant planning horizon) and 2090–99 (for a full global warming effect). Also shown are the corresponding monthly runoff totals simulated by SHETRAN (in this case outside the DSS). A clear decline in runoff, especially in the winter, is predicted.

5.2. DSS output

The principal use of the DSS will be to examine the effects of climate change and land management on desertification, allowing for feedback between the physical and socio-economic environments. The emphasis in the DSS output is therefore on the physical characteristics associated with desertification. Such output includes (but is not limited to) the following:

- Basic model output such as distributed runoff, sediment yield, soil moisture, phreatic surface elevation, evapotranspiration, vegetation biomass and land use;
- Derived output such as catchment runoff and sediment yield, cumulative erosion/deposition distributions, soil moisture deficit distribution, comparisons of different hydrological and sediment conditions, crop economic yields and changes in land use;
- Desertification indicators such as patterns and levels of soil erosion, changes in soil moisture deficit and changes in crop yields;
- Warning flags such as soil moisture deficit too high for crop growth, low vegetation biomass indicating crop failure and increased winter flooding.

6. Application

As noted earlier, the need for the Agri basin is to identify a sustainable programme of land use which reduces land degradation and avoids the marginalisation, and eventual abandonment, of agricultural land. The DSS could contribute to this process as follows. First, it could be run for a series of land uses and climate scenarios to indicate which forms of agriculture are likely to be sustainable under future conditions. It would do this by showing the impact of each scenario on such indicators as soil moisture deficit, runoff, soil erosion and crop yield. In addition, the socio-economic model would monitor the trend in the income to cost ratio for the given crop but would not at this stage provide feedback in terms of a change in crop. The resulting information could be provided on a spatially and temporally distributed basis, showing which parts of the catchment are most vulnerable to degradation and monitoring the rate of increase of any land degradation. The overall results could at this stage be presented to local farmers and planners as a set of land management options and their impacts, providing guidelines for selecting sustainable land uses. However, given that farmers are likely to respond more to profit than to land degradation, they might continue an apparently unsustainable land use as long as the subsidies for that use are favourable. The DSS could therefore be used further to explore the changes in subsidy needed to steer farmers towards more sustainable forms of agriculture. This application would employ the full feedback capabilities between the physical and socio-economic models. The physical models would simulate changes in runoff, soil moisture deficit, soil erosion and crop yield as a function of climate and land use. As signs of land degradation develop, the user could specify different levels of crop subsidy, favouring the more sustainable land uses. Through a series of runs, the socio-economic model would indicate the level at which the farmer would respond by switching crops in the desired way. The change in land use would feed back to the physical model and continued running of the DSS would indicate whether the new land use was indeed sustainable or whether subsidy levels would need to be changed to support a different crop type.

Through the above applications, the DSS could be used to identify sustainable forms of agriculture for future climatic conditions, to highlight those parts of the Agri basin which need most attention, to predict the rate of increase of land degradation, to develop land use policies which support soil conservation and to provide guidelines on sustainable land use for local farmers, planners and other end-users. Particularly important is its ability to explore programmes of land use predictively (enabling the optimum programmes to be selected before any programme is implemented on the ground) and at the scale of the full basin (presenting an integrated picture at a scale of interest to planners).

7. Conclusions

The DSS provides a new means of investigating, in a predictive manner for future conditions, the interaction of complex physical and socio-economic systems and the impact on the development of desertification at the basin scale. It does this most notably through the integration of physical and socio-economic models at the large basin scale and through the development of a flexible, user-friendly management tool. More specifically, its development for the Agri basin demonstrates a formal, scientifically based methodology for supporting in a rational manner the making of decisions concerned with land management in areas affected by desertification.

In developing the DSS, considerable emphasis was placed on ensuring relevance to desertification issues through careful specification and on designing an efficient software framework for integrating models and datasets. The DSS is therefore a powerful means of examining strategies for basin management under a range of scenario conditions, relevant at a spatial scale of interest to planners and for various planning horizons. It is an important step towards making expertise available to non-experts and towards the development of a tool to be used within the EU for managing desertification problems. In this context it is now being applied in the EC MEDACTION project (Policies for Land Use to Combat Desertification, 2001–2003) to develop guidelines on, and to contribute towards policy formulation for, land management in the Agri basin and in a further target area, the 700-km^2 Cobres basin in Portugal.

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References

Allen, P.M., Lemon, M., Seaton, R., 1999. Sustainable water use in the Argolid: a sub-project of ARCHAEOMEDES. In: Balabanis, P., Peter, D., Ghazi, A., Tsogas, M. (Eds.), Mediterranean Desertification: Research Results and Policy Implications. EUR 19303, vol. 1. Office for Official Publications of the European Communities, Luxembourg, pp. 423–429.

Andreu, J., Capilla, J., Sanchís, E., 1996. AQUATOOL, a generalized decision-support system for water-resources planning and operational management. J. Hydrol. 177, 269–291.

Balabanis, P., Peter, D., Ghazi, A., Tsogas, M., 1999. Mediterranean Desertification: Research Results and Policy Implications. EUR 19303, vols 1 and 2. Office for Official Publications of the European Communities, Luxembourg.

Bathurst, J.C., Kilsby, C., White, S., 1996. Modelling the impacts of climate and land-use change on basin hydrology and soil erosion in Mediterranean Europe. In: Brandt, C.J., Thornes, J.B. (Eds.), Mediterranean Desertification and Land Use. Wiley, Chichester, UK, pp. 355–387.

Bathurst, J.C., Sheffield, J., Vicente, C., White, S.M., Romano, N., 2002. Modelling large basin hydrology and sediment yield with sparse data: the Agri basin, southern Italy. In: Geeson, N.A., Brandt, C.J., Thornes, J.B. (Eds.), Mediterranean Desertification: A Mosaic of Processes and Responses. Wiley, Chichester, UK.

Bove, E., Quaranta, G., 2002. Social and economic conditions of development in the Agri valley. In: Geeson, N.A., Brandt, C.J., Thornes, J.B. (Eds.), Mediterranean Desertification: A Mosaic of Processes and Responses. Wiley, Chichester, UK.

Enne, G., Peter, D., Pottier, D., 2001. Desertification Convention: Data and Information Requirements for Interdisciplinary Research. EUR 19496. Office for Official Publications of the European Communities, Luxembourg, 374 pp.

Ewen, J., Parkin, G., O'Connell, P.E., 2000. SHETRAN: distributed river basin flow and transport modeling system. Proc. Am. Soc. Civ. Engrs, J. Hydrol. Eng. 5 (3), 250–258.

Fantechi, R., Peter, D., Balabanis, P., Rubio, J.L. 1995. Desertification in a European Context: Physical and Socio-economic Aspects. EUR 15415EN. Office for Official Publications of the European Communities, Luxembourg, 635 pp.

Geeson, N.A., Brandt, C.J., Thornes, J.B. (Eds.), 2002. Mediterranean Desertification: A Mosaic of Processes and Responses. Wiley, Chichester, UK.

Ghazi, A., 1999. Opening address. In: Balabanis, P., Peter, D., Ghazi, A., Tsogas, M., (Eds.), Mediterranean Desertification: Research Results and Policy Implications. EUR 19303, vol. 1. Office for

Official Publications of the European Communities, Luxembourg, pp. 5–8.

Jamieson, D.G., Fedra, K., 1996. The 'Waterware' decision-support system for river-basin planning. 1. Conceptual design. J. Hydrol. 177, 163–175.

Kirkby, M., Abrahart, R.J., Bathurst, J.C., Kilsby, C.G., McMahon, M.L., Osborne, C.P., Thornes, J.B., Woodward, F.I., 2002. MEDRUSH, A basin scale physically-based model for forecasting runoff and sediment yield. In: Geeson, N.A., Brandt, C.J., Thornes, J.B. (Eds.), Mediterranean Desertification: A Mosaic of Processes and Responses. Wiley, Chichester, UK.

Mairota, P., Thornes, J.B., Geeson, N., 1998. Atlas of Mediterranean Environments in Europe: The Desertification Context. Wiley, Chichester, UK. 205 pp.

Mira da Silva, L., Park, J.R., Keatinge, J.D.H., Pinto, P.A., 2001. I. A decision support system to improve planning and management in large irrigation schemes. Agri. Water Manage. 51 (3), 187–201.

O'Callaghan, J.R., 1995. NELUP: an introduction. J. Environ. Plann. Manage. 38 (1), 5–20.

Williams, J.R., 1995. The EPIC model. In: Singh, V.P. (Ed.), Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, Colorado, USA, pp. 909–1000.