DeSurvey

A Surveillance System for Assessing and Monitoring Desertification

Module 1.4. GROUND-BASED LAND CONDITION ASSESSMENT
WP 1.4.2. Fine scale ground-based land condition (LC) assessment

Principal contributors of the report:
Mark Mulligan (1), Gemma Dunjó (1), Didier Leibovici (2), Segaier Mongi (3), Mohamed Ouessar (3), Maud Loireau (2), Eric Delaitre (2), (2
(1) King’s College London (KCL), Department of Geography, London, United Kingdom
(2) IRD US166, Maison de la Teledetection, Montpellier, France
(3) Institut des Regions Arides (IRA), Médenine, Tunisia

other contributors : see WP list participants

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Protocol for coupled LEIS-PATTERN model and report outlining data availability for application, calibration and validation of the coupled model along with a strategy for the collection of the necessary data

Website: **http://www.desurvey.net**

Work Package 1.4.2: Fine scale modelling of land condition changes

One of the objectives of DESURVEY WP 1.4.2 is to adapt the standalone PCRaster version of the PATTERN model, i.e. the biophysical components of the MedAction model for application to the particular conditions and issues of land degradation that are important in the North-African context and to couple the model (offline) with the LEIS (Local Environmental Information System) model of IRD/ROSELT to achieve integrated environmental and socio-economic modelling of landscapes threatened by desertification.

1. THE PATTERN MODEL

The PATTERN model is a fine-scale, spatially distributed, biophysical model, which simulates the dynamics of land condition in order to assess land degradation and desertification in the Mediterranean region. The model has been subject to several adaptations and improvements accounting for the particular purposes of each of the projects in which it has previously participated (e.g. MODULUS, MedAction).

PATTERN was developed in PCRaster Environmental Software (version 2.0), based on the incorporation of a script modelling language component to a GIS, allowing the generation of scenario outcomes (Van Deursen and Wesseling, 1997). The PATTERN model is dynamic and can operate at time scales and temporal resolutions representing realistically the autonomous dynamics of the system modelled. Moreover, it is sufficiently simple to run to a large extent from routinely measured data.

The model is based on the integration of a series of scientific, process-based and simple models which incorporate a wide range of desertification processes in a spatially complex and process-holistic manner (Mulligan, 2003). In this context, PATTERN adequately represents all the important processes and descriptions within the model are well understood and scientifically proven. The main models are: climate and weather, hydrology and plant growth. In addition, sedimentation and salinisation are also modelled within PATTERN (Figure 1).

Most of the process descriptions in pattern are low level and thus of generic application to a wide range of environments (with suitable parameterization)

1.1. Climate and weather module

The climate and weather model is a stochastic weather generator calibrated on information available from weather stations, which simulates different aspects of the weather in three different sub-models: rainfall, temperature and solar radiation. The rainfall sub-model produces spatially-distributed, sub-hourly rainfall storms with a variable time step, based on historic rainfall and parameters describing the nature of the climate and its spatial variability. The temperature sub-model calculates spatially distributed monthly average air temperatures, based on historic temperature data and parameters describing the nature of the climate and its spatial variability. The solar radiation sub-model calculates for each day the time of sunrise and sunset as well as the solar radiation during that day corrected for cloudiness and slope and aspect of each cell. The model can operates within the 100m spatial grid, but like the hydrological model, is capable of aggregating some of the dynamics across larger spatial areas, and it generates baseline meteorological and climatic data over long time periods but at high temporal resolution.

Climate and weather takes no inputs from other models, only from field data or from scenario. The weather module also outputs directly to the end user. The storm data is used by the hydrology module to partition rainfall between subsurface and surface water. Temperature is used by the plant growth model as a determinant of production and as a basis of rules for community change. Solar radiation is converted to photosynthetically active radiation (PAR) and drives the process of photosynthesis in the plant growth module. Solar radiation also drives the process of evapotranspiration in the hydrology module. Sunrise and sunset also determine the timestep for integration of the plant growth module.

This model is the simplest of all the submodels when viewed from the perspective of its linkages with other models, since there are no inputs required from other models, only the raw empirical data required for the definition of climate scenarios and the determination of the spatialisation of rainfall, temperature, solar radiation, etc. across the study area. The output linkages become relevant to most of the other models, but often indirectly. The direct linkages involve the rainfall, which is required by the hydrology model for determining the slope and soil hydrology, and the temperature and sunshine dynamics which are required by the plant growth model.

1.2. Hydrology module

The hydrology model calculates the soil hydraulic properties and the water budget by simulating a number of different hydrological processes. Each process is described in a different sub-module: precipitation and irrigation, interception, evapotranspiration, runoff, soil sealing, infiltration, soil moisture, recharge, erosion and deposition, and are computed depending on the climate and weather model (solar radiation, temperature and rain) and the plant growth model (cover fraction, leaf area index).

This model operates upon the 100m resolution spatial grid, but with the capacity to derive some of the hydrological dynamics in an aggregated form across larger areas. The hydrology model runs on sub-daily time steps to represent the processes as realistically as possible. Each time step has a state and a duration, and is determined based on the time of sunset and sunrise and the time and duration of the rainfall storms, calculated in the climate and weather module.

1.3. Plant growth module

The dynamic Plant Growth module represents the process of growth of crops and natural vegetation and produces figures for biomass, leaf area index (LAI), vegetation cover and yield. It runs daily and calculates an optimum growth based on a theoretical maximum radiation use efficiency applied to the photosynthetically active radiation (PAR) which is absorbed by the plant leaves present. The radiation use efficiency is reduced to account for the impact of soil moisture (affected by soil erosion/deposition, changes in soil properties) and salinity. Growth and maintenance respiration are subtracted from this gross production to give net production (dependent upon temperature and the living biomass of the plant). Net production is partitioned between leaves, roots, shoots, woody and reproductive (fruits and flowers) biomass. The biomass of leaves in turn affects intercepted PAR and soil evaporation versus transpiration. The biomass of roots has an impact on water availability (but also a significant impact on the plants maintenance costs). The model operates and is parameterised for both 'natural' vegetation and the main Mediterranean crops in which sow/harvest/cropping cycles are represented and affect the plant biomass accordingly.

In landscapes, which have been subject to desertification processes, the existence and type of natural vegetation is very important since it influences both the soil moisture and surface runoff, as well as erosion rates. Regarding the linkages with other models, it requires information relating to the vegetation cover and soil moisture from the hydrology model, and solar radiation from the climate model. Likewise, the outputs from the model are for providing the hydrology model with information about LAI, canopy capacity and vegetation cover, and for providing the end user with spatialised information about crop yield.

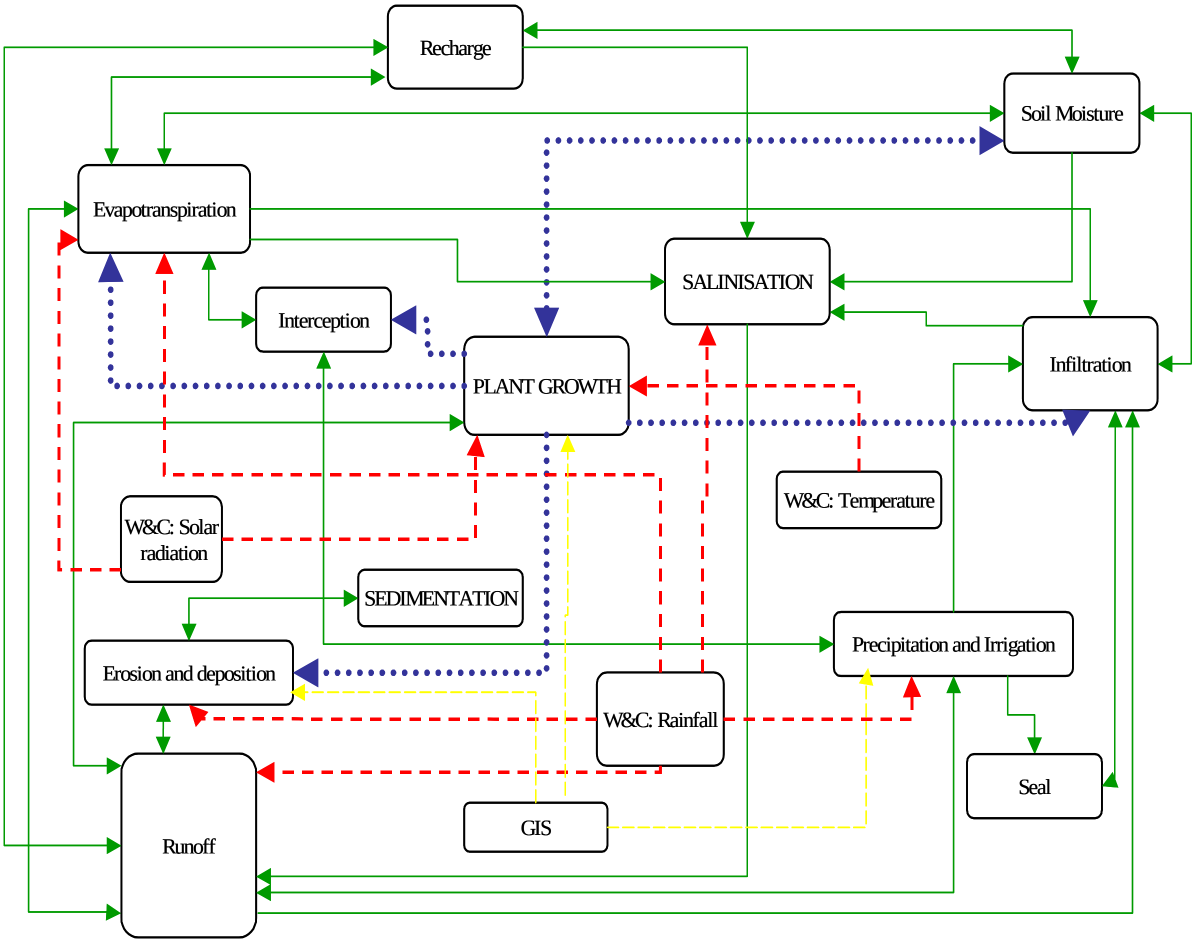

Figure 1. Summary of the processes and interactions in the PATTERN biophysical model

1.4. Sedimentation module

The objective of this module is the calculation of the transport and deposition of eroded sediment in order to calculate (a) net erosion and its agricultural impacts and (b) the sedimentation of reservoirs and rivers in order to calculate the economic cost of sedimentation prevention/mitigation measures (checkdams and dredging)

1.5. Salinisation module

This model calculates the salinity of the soil and the aquifer. The soil salinity can increase by infiltration of saline water. The origin of this saline water can be irrigation or soil salt from upstream areas that is picked up by runoff and transported to downstream areas. The amount of salt in the soil is calculated as the amount of salt already present in the soil plus the amount from irrigation and runoff minus the wash out of salt through recharge.

2. THE LEIS MODEL

In Africa and particularly in the circum-Saharian zone there is a need in useful information for decision making focused on improving natural resource management at a local level in order to slow down the desertification process. For that purpose within the ROSELT/OSS program (ROSELT/OSS, 2004), the LEIS (Local Environmental Information System), has been developed as an original tool coupling GIS and models for establishing a complete diagnostic of natural resource use allowing prediction of future evolutions. It is issued from a close working attitude and procedure between methodological research, modelling, computing and information system conceptions, and applications in 9 observatories of 9 circum-Saharian countries, involving numerous researchers from the north and from the south.

The Observatory Network for Long-Term Ecological Monitoring (ROSELT) is a program set up by the Sahara and Sahel Observatory (OSS). It is made up of a number of observatories, which operate in a network at regional level in Africa, in the geographical zone of the OSS. This zone comprises three sub regions: North Africa, West Africa and East Africa. Its purpose is to organize scientific monitoring of the environment in order to characterize the causes and effects of land degradation, and to have a better understanding of the mechanisms which lead to desertification. ROSELT aims at providing reliable data on land degradation in arid areas and pertinent biophysical and socio-economic indicators of desertification, as well as to assess the state of the environment within the OSS zone.

The global methodology of the LEIS is to combine biophysical data and socio-economic data together using an integrated spatial approach. To be able to distinguish in the landscape the respective impacts of factors coming from the above mentioned domains, the spatial approach considers intersecting two planes of distinct information, one linked to land use (CPU see further) and the other one to natural resources (LU see further), to define Spatial References Units (SRU) (Loireau, 1998). Multi-use balances (availability minus extraction of natural vegetation) and anthropogenic pressure indices computations are based and output on this functional mosaic description of the landscape. The modelling done at a defined period leading to the SRU map and the balances maps resulting on them constitute the diagnostic. The plane of resources expression is built using classical GIS methods with a range of different layers, while the plane of uses comes from spatialisation of models of exploitation practices. These models encompass the originality together with the prediction ability of the tool. From an established diagnosis, scenarios of evolution of the main driving parameters such as population and production (depending on “climate parameters”) allow scenarios to be made leading to new balances maps based possibly on new SRU. It is the model-building set of choices and parameters establishing the diagnostic at a given period which allows scenario analysis, so validation of the obtained diagnostic model is essential to provide good predictions. Before being communicated to local or national authorities, as useful information for a better evaluation of desertification risks, balance maps can be aggregated according to administrative units or to some biophysical units depending on a specific interest.

Implemented under the same GIS software platform, the LEIS tool couples a as a geographic database and spatialised models. The geographic database is organized as a relational database management system; its structure was formalized using UML (Booch et al., 1999) to conceptualize and represent the spatial area-resource-usage interactions at local scale. Despite the friendly general user interface LEIS is a tool dedicated to scientists of the domain.

3. SYSTEM DIAGRAM FOR THE LEIS MODEL

Figure 2 shows the conceptual diagram of the LEIS methodology. The goal of this conceptual framework is to give the necessary elements needed for the development of LEIS in each observatory, using common specifications (data models, manipulation, system architecture, etc.).

The LEIS is together a database system and a set of models gathered to work as a GIS tool within ArcMAP™ (one of the applications packaged with ARGIS 8.3™ by ESRI). The models have been implemented within Visual Basic 6 from Microsoft. The LEIS tool as an extension for ARCGIS and is deliverable as a dll.

The necessary database to make LEIS work has been derived from an UML diagram explaining the different objects interacting to describe the “functioning of the system” useful to fulfil the objectives of the LEIS.

The Observatory is modelled for a given in which some constants applicable in the entire observatory for this period can be defined either globally or for each strategic group (or even each particular group) in the table of Season parameters. Enumeration parameters must be checked to be in agreement with local conditions such as the name of the seasons, land use names, activity centres type names.

In term of land uses the observatory is linked to its activity centres from where the Agents are exploiting the area around (resource extractions according to some seasonal parameters). Exploitation strategies are described by the typology of Combined Practices which have different operational characteristics eg. degree of artificialisation, land uses and productions depending on local land conditions e.g. soil aptitude or pastoral quality . The agent groups may have different strategies by belonging to different strategic groups having specific combined practices. The spatialisation through a model builds the plan of human activity : the Combined Practice Units (CPU).

In term of resources the observatory is also linked to its landscape (LU) from which vegetation resources are measured according to land uses and season(. The Landscape units layer is built by crossing different layers encompassing the landscape description (*physical factors*: geo-morphology, pedology, global relief classes from DEM, *biological factors*: vegetation, ecological zones…, *human factors* : global land use allocations (cultivated, not cultivated), infra-structures, etc.

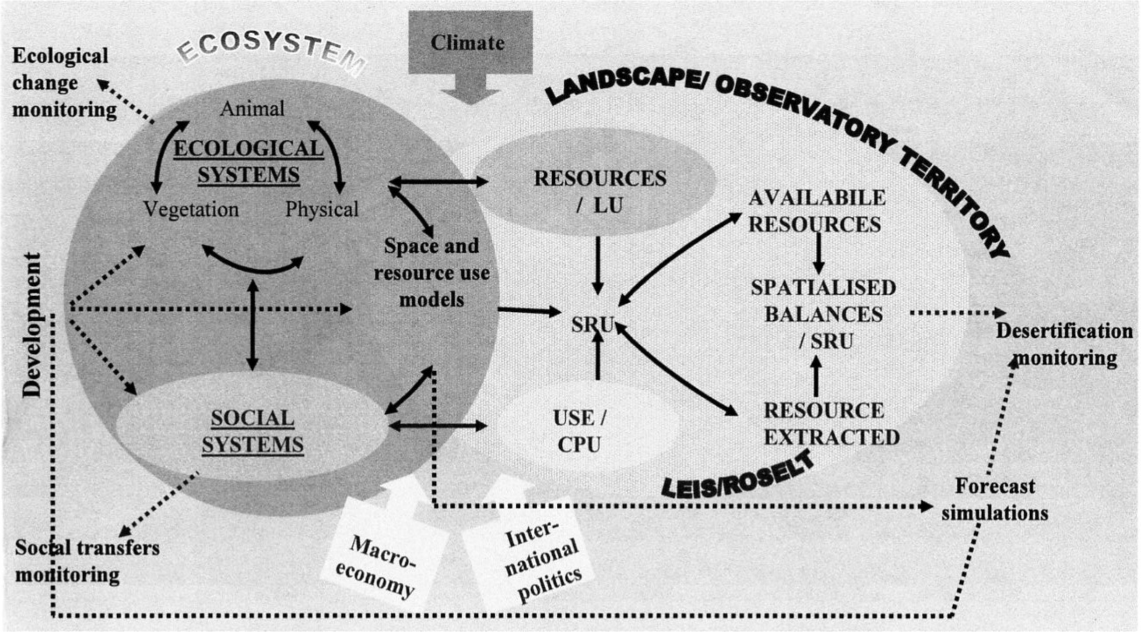

Figure 2. LEIS conceptual diagram

4. OUTPUTS FROM THE LEIS MODEL THAT COULD BE USED BY PATTERN

Both the LEIS model and the PATTERN model work as raster systems, but the first one is static and the latter dynamic, and therefore the spatial and temporal scale at which the data will be exchanged for their integration will be a key issue in the development of the new coupled model. All the data provided by the LEIS model is spatial and in the form of raster maps (90 m resolution is expected), and the optimal temporal resolution for output would be monthly data.

Since the LEIS model is a human-socio-economic model, it provides some information related on land management practices through the Combined Practice Units with an attribute related to it (e.g. tillage, terracing, erosion dams, irrigation…) in order for the PATTERN biophysical model to be able to model the biophysical impacts of the land management (e.g. change in infiltration rate). Therefore the first step would be to know which land management practices, which are currently taking place in the target area of Oum Zessar, are considered/modeled within the LEIS model framework. This is part of the socio-economic survey performed before building the LEIS. PATTERN works on land use maps to be able to model the impact on the soil-hydrological properties of the specific practices PATTERN (e.g. change in soil infiltration due to overgrazing). This is directly coming from the extractions of vegetation on particular land uses (grazing intensity or livestock biomass in tonnes/ha/yr). According to the main principles of the LEIS these information can be obtained once extractions and computed and reported on each SRU (crossing CPU and Landscape Units). Likewise, using the CPU map the LEIS model will also provide some information/data on water demands by the population/agriculture (e.g. irrigation volumes for the irrigated areas). The PATTERN model will have to model the impact of these activities on the ecosystem.

Data	Description	Resolution
Water demands		
dripirrig.map from CPU	Raster map of the area covered by drip irrigation (yes=1, no=0)	90 m resolution, seasonally or annually
immersionirrig.map from CPU	Raster map of the area covered by immersion irrigation (yes=1, no=0)	90 m resolution, seasonally or annually
Land use practices		
Landuse.map from CPU	Categorical raster map of the different land use classes in the target area	90 m resolution, seasonally or annually
Vegetation demands		
VegeTypes.map from Landscape Units	Categorical raster map of the different vegetation classes in the target area	90 m resolution, seasonally or annually
pressureIndex.map from Landscape Units and CPU	Raster map of pressure index	90 m resolution, seasonally or annually

The first two series of maps will be extracted from the same layer of the Combined Practice Units with different attributes. One must also notice that *sensu stricto* the Combined Practice Units are not land use maps but each unit represents a spatio-temporal distribution of land uses over the period of modelling. In raster terms each pixel will not represent a single land use but rather a distribution of land uses.

The final series of maps will be used to parameterise grazing/overgrazing model of PATTERN (see further).

5. OUTPUTS FROM THE PATTERN MODEL WHICH COULD BE USED BY LEIS

PATTERN can be very useful for the scenario aspect of the combined tool but probably also for better estimation (extrapolation of field measures) for certain parameters.

As part of LU (Landscape Units) layer phytomass information has to be collected (ProducUP) according to a field protocol established for the monitoring. It is therefore limited (just covering the different classes) and could be readjusted by the PATTERN model to obtain a map of the phytomass characteristics by polygon instead of by classes of polygons. In the mean time for agricultural structuring activity production for practices could be re-estimated according to the location of the practice, i.e. a first step would be to build the CPU using first estimated global values (survey) and for scenario analysis PATTERN would readjust these values according to local data (rainfall, soil …) and climatic forcing during a initialisation step. When expressing a scenario of evolution of main driving parameters such as rainfall (using climate forecast provided within DeSurvey) PATTERN would be linked to LEIS through natural productions forecasts…and or agricultural productions forecasts.

At the moment the LEIS tools provide balances and/or pressure index only on vegetation but would benefit from PATTTERN -based soil outputs (e.g. erosion) to provide an index on soil degradation on the same functioning units allowing to build a combined vegetation-soil pressure summary. Some research on soil erosion estimation has already been done within ROSELT and research to put them together with PATTERN models will lead to this soil degradation index.

For the improvement of estimation as well as for forecasting purposes the output looked for from PATTERN would need only to be a structure of either mean by classes and for given periods (season or same season over few years or agricultural cycle) or maps of means for each season and landscape units or Combined Practice Units (according to which production is looked for). Rasters are sufficient as a means by which polygons or classes can be easily obtained if needed. *A priori,* LEIS which tries to use little data as possible would need only data by LU classes but the spatial information provided by PATTERN could improve LEIS without more effort for data collection. This would require adaptation of the LEIS modules in order to take advantage of the new data.

Data	**Description**	**Spatial resolution**
Leaf biomass for Landscape Units layer		
Leaf Biomass map from PATTERN	Raster map of leaf biomass (kg/m^2) averaged by current CPU	90 m resolution, seasonally or annually
Land condition properties for agricultural structuring		
Long term soil moisture (integrated rainfall, evapo-transpiration and soil water storage properties including effects of erosion))	Raster map of soil moisture (m^{3}water/m^{3}soil) averaged by current CPU	90 m resolution, seasonally or annually
Long term crop specific yield (integrates all aspects of land condition with a crop specific impact that is also based on the crop specific land management)	Raster map of crop specific yield (kg/m^2/yr) averaged by current CPU for a range of crops	90 m resolution, seasonally or annually

6. PROTOCOL FOR INTEGRATION

One of the main aims of WP 1.4.2. in DeSurvey, is to scientifically integrate the PATTERN biophysical model with the LEIS socio-economic and land use model, for its application in the selected North-African target area of Oum Zessar (Tunisia). The biophysical models are designed to facilitate an understanding of the outcomes of specific policy options in terms of land use and water resource management as filtered through the complex Mediterranean landscape and within the context of continuous external drivers such as climate variability and change.

The strategy for integration of PATTERN-LEIS models will focus on the development of scenarios by LEIS and by PATTERN which are used offline to drive the companion model. PATTERN would take static scenarios from LEIS (e.g. population growth, land use change, water use, firewood harvesting). PATTERN will run with the current meteorological data and with scenario data in order to produce a quantitative bio-physical assessment of land degradation which can in turn be used by LEIS as a driver of the further socio-economic change. One example could be that LEIS provides scenarios of land use change under particular policies and these are used by PATTERN to produce corresponding measures of biophysical land degradation (land condition – vegetation cover, leaf area index, biomass, water availability) which are then used by LEIS to drive land use evolution and through extraction models provide balances and indices of pressure on natural resources. Alternating the socio-economic model from LEIS, the natural productions models from PATTERN and the balances models from LEIS will lead to the consideration of scenarios as successions of steady land use (CPU) states. These will provide land use dynamics associated with dynamic of pressure on vegetation. This integration should account for the different modelling paradigms, temporal and spatial resolutions that characterize these two models.

The PATTERN-LEIS integrated model will be spatial and operate at a fine-landscape scale, providing information at a sufficient level of spatial resolution to reflect the scale of variation in the most important physical, environmental and socio-economic variables. Moreover, it will effectively represent all the important processes with the aim of obtaining results as robust, reliable and accurate as possible. Finally, the overall model should also provide an easy understanding of the scenarios generated, in terms of environmental changes, anthropic impacts and management options, so that the user can be taken through.

The general timestep of the PATTERN model as well as for each of its modules and sub-modules will be hourly. However, the outputs may be computed as monthly or seasonally and on the basis of the landscape units (LU) or vegetation types in order to be of use by the LEIS model. Likewise, the data provided by LEIS should be in the form of raster maps (90-100 m spatial resolution) and at a monthly or seasonal interval to be used by PATTERN.

The developments and improvements of the PATTERN model for application in the DeSurvey context are summarized as follows: the improvements will have to be made in order to take into account processes which (a) are likely to be important in the Oum Zessar catchment but were not developed by the PATTERN model, (b) improve the accuracy or performance of the biophysical modelling, (c) better integrate the biophysical modelling with the socio-economic modelling or end user indicators and (d) simplify or reduce the data requirements for the modelling. In all cases the model will be adapted if only minor repairs or reformulations of the model, its algorithms or code are required to have it perform its tasks more appropriately. The model changes will be made to the model running in the PCRaster dynamic GIS.

A meeting on the field at Jeffara is planned for the last week of September to discuss these matters for this site.

Additionally, new model components will have to be developed to fill the gaps and missing links in the integrated system representation. Here, each individual process has to be understood separately and will have to be integrated within the context of dynamic process based spatial models. The following new components are being considered:

Grazing/Overgrazing (tonnes/ha/yr): a crude grazing model is already available in the PATTERN model, but this will be adapted to use spatial livestock outputs from LEIS, since overgrazing is produced by the LEIS model in terms of a quantitative assessment of the resources through practices of grazing.

Fire (biomass burned in tonnes/ha/yr): this model will be developed from scratch, making use of the canopy wetness, and enhanced litter production module and the existing woody biomass outputs of PATTERN.

Wind erosion/deposition (tonnes/ha/yr): both wash and wind erosion should be part of the coupled model, since both processes occur in the Jeffara catchment. Wash erosion is already computed in the PATTERN model, but a wind erosion component will have to be incorporated in the model for the North-African area where the presence of winds is important in winter with cool and humid eastern-northeastern winds, and in summer with hot and dry southeastern winds (Chili or Guebli). The wind erosion model will have to account for the regional winds corrected for topographic exposure and wind directions warped to landscapes.

Irrigation: The PATTERN model in its original version considers drip and spray irrigation. The arid area of Oum Zessar has two main irrigation techniques: *drip irrigation*, which is designed to reduce as much as possible the loss of water as runoff and to deep percolation, and *traditional irrigation*, which requires the construction of large water distribution systems such as dams and reservoirs in order to make it available to other areas and is possible only where abundant sources of surface water are available. However, no spray irrigation is present in the study area and therefore, the PATTERN-LEIS model will have to be adjusted accordingly.

Water management forms the most critical process in dry areas such as Tunisia, as it impacts livelihood, food security, land conservation and productivity and society in general. In this area, considerable investments are being made in maintaining the old water harvesting techniques (WHT) and introducing new ones to capture the scarce amount of rainwater for agricultural, domestic and environmental purposes. In this context, it is clear the need of developing within the PATTERN-LEIS framework a new model representing the balance of the water resources in this arid region with the possibility for the policy-maker to try out different techniques in order to tackle the problem of water scarcity and find the best water management options for a particular area. This water resources module will probably have to be joint PATTERN/LEIS. The PATTERN model will have to provide the water supply elements from the hydrology module and the LEIS model the water demand elements.

At this initial phase an integration on-line of the two models is out of the scope of the project. However, this option could be considered at a later stage if there is enough time and all the parts agree on the importance that this additional work could represent. In this context, the redevelopment from scratch in hard code of the LEIS and PATTERN models (e.g. applying a similar methodology as the one used for the MedAction PSS model) could be considered an advantage. Nonetheless a compromise integration could be possible within ArcGIS by just packing or wrapping the PATTERN model in one or many “outside servers” (.exe) called within a module built and added as dll in ArcMAP. This module could then be called either for an ArcGIS version of PATTERN or within an additional or modified menu in LEIS.

The models should be based on knowledge developed from previous activities and but should be developed to s more like “policy models” though there should be, a continuum between them. The advantages of this approach are that the end product is more likely to be useful to a policy analyst, it is likely to be more streamlined, simpler, better targeted at the specific policy issue and better rounded in terms of the robustness of the underlying model philosophy and the quality of the process integration (especially across the biophysical/socio-economic divide). For that purpose a full menu section of the coupled LEIS-PATTERN tool will focus on rendering results.

7. FIELD SITES SELECTION

7.1. Guadalentin, sensitivity analysis and validation site

A large number of European funded research projects have worked in the Guadalentin Basin including MEDALUS I, II and II, MedAction and DESERTLINKS. The areas has a substantial database of spatio-temporal data and the PATTERN model has already been applied there alongside the RIKS socio-economic component as the MedAction model.

7.2. Castilla la Mancha, application site (Mediterranean)

The Castilla La Mancha field site with an area of 1225 km² is located in the southeastern part of Spain, in the Albacete province. This semiarid environment characterized with shallow soils, water scarcity, groundwater resources overexploitation and traditional agricultural crops (cereals, vineyards, etc), is a typical Mediterranean site subject to a high risk of desertification.

Several European, national and regional projects related to land degradation and desertification issues have been developed in the area over the last decade being the followings the most important ones:

EFEDA-I, EU : Study about the causes of desertification in a representative area of the Mediterranean basin.
EFEDA-II, EU : Study about the causes of desertification in a representative area of the Mediterranean basin.
MERIT, EU : Modelisation of water management in the HU Eastern Mancha, using Bayesian networks.
NIWASAVE, EU : Efficiency improvement in the use of water and the fertilisation when irrigating.

Therefore, CLM a part from having being selected for being representative of a Mediterranean site, it has the main advantage of having a considerable amount of field and GIS data available about the territory and the production systems from previous work, data which will be essential for the development and application of the coupled PATTERN-LEIS model.

7.3. Oued Oum Zessar watershed application site in North Africa

The Oued Oum Zessar watershed is a typical arid zone threatened by desertification. It was chosen and certified as ROSELT/OSS site. This site is also part of the arid zones observatory implemented by the Institut des Regions Arides (IRA) in the frame of the national monitoring system of desertification coordinated by the national point of the UNCCD.

The adaptability and transferability of the PATTERN-LEIS model will be tested in the 330km^2 Oum Zessar area of Tunisia; the site with best available data and most support for this work within the ROSELT/OSS network. Additional scientific and practical considerations for the selection of the pilot region are:

(a) The Oued Oum Zessar watershed is a site of major development programs in terms of agriculture and industry activities.
(b) It has been the study site of previous research for development projects (e.g. WAHIA (1998-2001), Medrate (2000-2002), Jeffara (2001-2003)).
(c) There is a relatively important biophysical and socio-economic database in addition to images (aerial photos, satellite images, etc.)
(d) A well-established collaboration with other local actors exists in the area (e.g. agriculture, NGOs, administration, etc.)

8. BRIEF DESCRIPTION OF FIELD SITES

8.1. Guadalentin field site description

The Guadalentin basin in the Murcia Region of South East Spain (37.9°N, 1.5°W, 332123 Ha.) is representative of many Mediterranean environments under threat of desertification. Soils are shallow and very stony (50–90 per cent rock fragments by mass) over highly fragmented bedrock (Puigdefabregas et al., 1996). In this area they are classified as Eutric, Mollic and Lithic Leptosols (FAO, 1994). The area is largely rounded landforms from 520 to 960 m, with moderate to steep slopes. The main land use in the study area is almond cultivation, replacing the matorral vegetation (Poesen et al., 1997). Almond groves are ploughed three to five times a year in order to control weeds and to conserve soil water (Poesen et al., 1997). In some parts of the basin unproductive almond groves or vineyards are being abandoned and matorral is thus regenerating. The climate of the Guadalentin basin is mainly semi-arid, with an annual precipitation of 225–483 mm. Most of the rain falls in spring, often as high-intensity storms with no obvious spatial pattern (Cabezas, 1996).

8.2. Castilla La Mancha field site description

The Castilla La Mancha application site covers an area of 1225 km^2 in the Albacete Province, Spain. The geodetic coordinates (UTM) of site central area are: X=587000 Y=4332500 (WGS84 datum). The area, which ranges from 620 to 720 m a.s.l., has a Mediterranean climate with an average precipitation of (spatial range, mm/yr): 300 – 400 mm/yr, and an average temperature of (spatial range ºC/yr): 13 – 14ºC.

The 67.2% of the area is considered flat, a 16.4% and 16.2% a sleep range percentage of 0.5-0.2 and 2.0-10.0 respectively and a 0.2% of the topography is classified as rough (>10% sleep range).

With regards to the geology, the superficial materials, which cover 80% of the area and are made of limestone, marl, gravel and sandstone, belong to the Superior Pliocene. Pleistocene materials, which include run gravel and sand, cover 15% of the total surface and are located in the North and South East of the area. Holocene materials, mainly fine gravel filled with clay, lime and sand, polygenic gravels and sandstonnes, constitute the remaining 5%.

Most of the soils of the area (around 80%), have carbonate horizons, so they are included within the main group “Calcisols”, according to FAO methodology (1988), being “petric calcisols” (the most frequent one) and “haplic calcisols” soil units represented. There are soils with clay illuvial horizons associated to old alluvial systems, on both River Júcar banks. They are included within the main group Luivisols, “calcilc luvisols” and “chromic luvisols” to be precise. There are also “chromic cambisols” and “calcaric fluvisols” soils, although they are less frequent.

Agriculture is the main activity in the target area, where the 75.4% is arable land, 12% heterogeneous agricultural, and 5.4% permanent crops. Forest and semi-natural areas (e.g. shrubs) cover the 3.0% and 1.6% of the landscape respectively, and the rest of the territory is predominantly considered artificial surface.

8.3. Oued Oum Zessar field site description

The Oued Oum Zessar watershed has a total surface of 33600 ha, divided into two sub-zones, an upstream and a downstream area, covering 22000 ha and 11600 ha respectively. The study site is located in the Medenine region, southeastern part of Tunisia (Figure 3). The geodetic coordinates (UTM) of site central area are: X=627550 Y= 3698809 (Carthage datum), and its altitude ranges from 0 to 669 m a.s.l. The site has a Mediterranean arid climate with an average precipitation in the range of 150- 230 mm/yr, and an average temperature between 19 and 22ºC. The watershed is situated on the edge of two major geological landscapes, the Djebel Matmata, with a relief without vegetation where many slopes are totally uncovered, by wind or water erosion; and the Jeffara, located in the coastal plain.

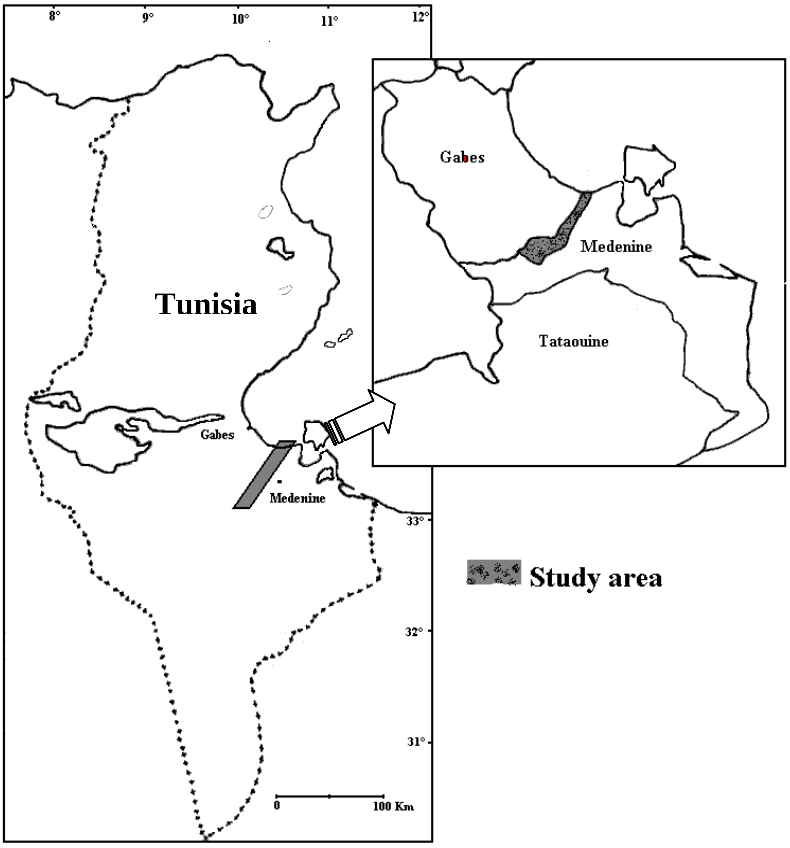

Figure 3. Location map of the watershed of wadi Oum Zessar

With regard to the soils, according to the French classification four types can be distinguished: minéraux bruts and peu évolués, isohumiques, calcimagnésiques, and halomorphes.

The main land use in the watershed area is the rangelands, being the steppes the dominant vegetation. However, the species composition is generally subject to the relief and soil type and therefore, four main ecological systems characterize the study site: *Mountainous zone, Wadi beds and waters courses, Plains,* and *Saline area.*

There are two main production systems in the area: tree farming and pasture farming system.

The tree farming encompasses two sub-systems. On the one hand *the sub-system of "Jessour"*, which is a traditional ancient harvesting technique basically consisting of terraces that collect water and eroded soil so that as little water and nutrients as possible are wasted. This system is widely spread in the region of the mountains of Matmata. It is practiced in the inter mountain and hill water courses to intercept runoff and sediments, and it is developed in the upstream areas of the study site. It is marked by fruit trees, mainly olive and fig. On the other hand, *the sub-system of olive trees*, which is marked by rainfed fruit cultivation is dominated by olive trees. This system is mainly encountered in the plain and in the piedmonts

The pasture farming systems is divided into three sub-systems: (a) *The sub-system multicrops – breeding*, where the agriculture is of the rain-fed type associated to an important livestock husbandry component, (b) *The sub-system of agro-breeders*, which are former breeders who are transforming their system by introducing an agricultural component, which becomes increasingly important at the expense of livestock husbandry; and (c) *The small ruminants sub-system*, which since the nomadic period, the production of small ruminants represent one of the more important socioeconomic activities. The planting of tree crops and cereals on the coast and mountains has generated a deep change of the social and economic status of animal production.

However, the main production remains the meat of lambs. Milk production is secondary though this is largely for subsistence consumption.

9. DATA FOR APPLICATION

9.1. PATTERN model data requirements

The essential data required for application of the PATTERN model is a DEM, land use data, a basic geology map and some land use and geology specific parameterizations which can be taken from the published literature, gained from consultation with local experts and or measured in the field using a stratified sampling scheme (Table 1, 2). All in all, it is not a high level of data input for such a sophisticated model and the model makes the best use of routinely available data.

In the model, the first step to defining the spatial dataset is the definition of the study area, which is determined on the basis of the best available Digital Elevation Model (DEM). For the Oum Zessar site a 30 m DEM is available. This DEM will be reprocessed in order to have the all the DEM raster cells in the same resolution and then they will be aligned with the geology GIS data. The geology map (E:1:100000) is also an important parameter determining soil hydrological properties and processes. The outline of the catchment is defined according to the topography of the 90 m resolution catchment using the PCRaster dynamic GIS.

PATTERN has conventionally used the CORINE land cover categories for determining the land use data. However, this classification is not applicable to the North Africa and there is no similar region-wide dataset. The land use determination will be conducted on the basis of ready available satellite images (year 2004) from the target area. The vegetation functional units determined from the land use classes are mapped in the plusarea.map. The functional units are biophysically based and are used to determine the biophysical properties and parameters of the land cover (Table 2). The fewer the number of classes, the more computationally efficient and the easier to parameterise those classes, so class numbers should be kept to a minimum. The classification adopted should be a functional one whereby the functional attributes of a particular land use are emphasized. Once the land cover types are determined much of the vegetation parameters needed in the PATTERN model can be easily obtained from the literature (Table 2).

Both the physical (PATTERN) and land use/socio-economic (LEIS) models require some key infrastructural data for their parameterization. Thus, for PATTERN, the location of dams and reservoirs is important for understanding water availability and sedimentation and the locations of erosion checkdams is important for understanding sediment transport and deposition (Table 1).

Table 1. Maps required by the PATTERN climate, hydrology and plant growth models

soil	
clay.map	Raster map with sand fraction content of cell x,y, extrapolated from point data
sand.map	Raster map with silt fraction content of cell x,y, extrapolated from point data
Silt.map	Raster map with clay fraction content of cell x,y, extrapolated from point data
topography	
dem.map	Raster map of the altitudes above sea level (m)
infrastructure	
dripirrig.map	Raster map of the drip irrigation area (1=yes, 0=no)
sprayirrig.map	Raster map of the spray irrigation area (1=yes, 0=no)
terraced.map	Raster map of terracing areas (1=yes, 0=no)
dam.map	Raster map of the areas with river dam (1=yes, 0=no)
checkdam.map	Raster map of areas with sediment check dams (1=yes, 0=no)
groundwater	
geology.map	Categorical raster map of the areas covered by different geological classes
gwsal.map	Raster map of groundwater salinity derived from published maps (g/l)
aquifbdy.map	Raster map of aquifer boundaries, derived from published maps
climate and land use	
plusarea.map	Categorical raster map of vegetation functional types, based on land use classification
rcorrf.map	Raster map of rainfall correction factors, from spline interpolations between station data
toffset.map	Raster map of temperature offsets, derived by interpolation between station data (deg C)

Aquifer data are needed for the PATTERN groundwater and salinity models. Since groundwater flow can occur laterally between cells (along gradients of water table elevation), the aquifer boundaries map is needed to ensure that flow could be constrained within the aquifers (Table 1). For the Salinisation module, as well as the aquifers and aquifer types, it is important also to know the approximate salinity of groundwater sources.

In terms of soil data requirements, on the basis of a series of point measurements in the area, the fractional maps of sand, silt and clay are created.

Since the Mediterranean is highly exposed to natural climate variation (of rainfall particularly but also of all other climate parameters) on a seasonal, interannual, decadal and long term scale, it is important that long term climate data are available so that model simulations take into account climate variability as well as climate change. In this same context, the meteorological data are required to understand better the characteristics of the climate in the area as well as to provide a historical dataset for model verification. These data will also be used to parameterise the storm generator which generates storms from monthly rainfall.

Temperature and rainfall data will be spatialise across the catchment (rcorrf and Toffset maps). Additionally, rainfall and temperature hourly determinations and mean daily temperature are also needed as inputs in the model (Table 2). Regarding the irrigation data, for the North African area, maps of the area covered by drip irrigation and immersion irrigation will be needed in PATTERN.

Table 2. Geological, hydrological and vegetation parameters required by the PATTERN model as well as the meteorological data as times series

Geological parameters	
Geological class	Description of each identified geological class
Soil thickness	(m)
Rock permeability	(mm/hr)
BDslope	Bulk density change per unit depth increment (g/cm3/m)
Rock density	(g/cm3)
Maximum groundwater reserves	(mm)
Rock fragment content	(fraction)
Seal hydraulic conductivity	(mm/hr)
Sediment=1; Hard geology=0	
Hydrological parameters	
Vegetation/Land cover class	Description of each identified land cover
Leaf specific water retention	(mm/m2)
BDinterc	Bulk density at the soil surface (g/cm3)
Vegetation parameters	
Vegetation/Land cover class	Description of each identified land cover
Soil thickness	(m)
Whether vegetation is present or not	(1= yes)
Leaf specific density	(g/m2)
Root fraction	(g/g)
Woody fraction	(g/g)
Yield fraction	(g/g)
Annual vegetation	(1= yes; 0= no annual)
Sow day	
Plough day	
Irrigation Threshold moisture ON	(m3 water/m3 soil)
Irrigation Threshold moisture OFF	(m3 water/m3 soil)
Harvest day	
Height per unit stem biomass	(m/g)
Maximum vegetation height	(m)
Manning’s (n)	Based on literature
Initial Leaf biomass	(g/m2)
Initial Root biomass	(g/m2)
Initial Woody biomass	(g/m2)
Maximum plant salinity	(g/m3)
Agriculture=1; Natural=0	
Meteorological Time Series data	
Timestep	Number of hours in 1 year (8760 hours or timesteps)
Rainfall	(mm/hr)
Temperature	(deg C/hr)
Mean daily temperature	(deg C)

Finally, the sampling strategy for any missing data needed as input in the model or in the validation process, will be based on standard methods (spatially). In general, the data then will be interpolated either using stratified interpolations (against topographic characteristics) or using spline interpolations (e.g. in ArcView).

9.2. LEIS model data requirements

The data requirements for application and validation for the Jeffara site are the ones usually required for any ROSELT observatory, (see Loireau et al. 2004). These have not been yet specified for the site and the planned meeting at the end of September on site will give more precise answers. As an example, Figure 4 shows the input data as applied in another ROSELT observatory, the Menzel Habib. For this region, the data used was derived from past and on going multidisciplinary monitoring of the observatory covering the biophysical (soil, water, climate, vegetation) as well as the agro-socio-economic (population, agriculture and pasture practices, land use, etc.) aspects.

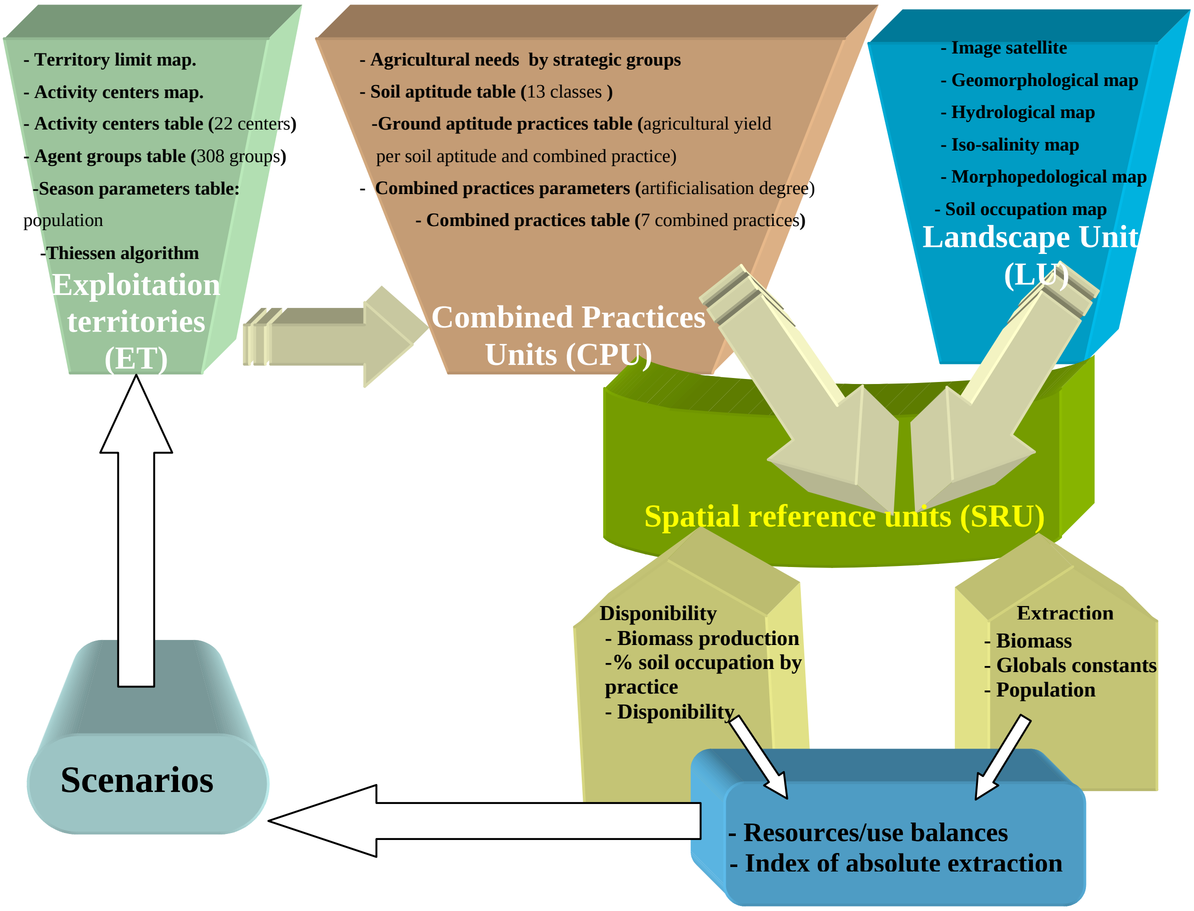

Figure 4. LEIS modelling stages applied to the Menzel Habib observatory.

The LEIS methodology applied is stepwise made of five main stages until reaching the final results. The first step of modelling is the *Exploitation Territories (ET) construction*, which is based on the weighted Thiessen algorithm. The second step is the *Combined Practices Units (CPU) construction*, which consists of building the map of CPU, which requires the determination of the combined practices characterizing the observatory. The third step is the creation of the *Spatial References Units (SRU)*, by crossing two types of geographical information: LU and CPU. The fourth step is the creation of the *resource/usage balances and calculation of indicators,* which is based on the estimation and modelling by LEIS of the needs of the population and the resources available. Finally, thee last step is the creation of *Scenarios*.

10. DATA FOR VALIDATION

10.1. PATTERN model validation data requirements

Individual components of PATTERN have been validated but since changes to the model will be necessary for application at the new site a re-validation will also be necessary. The validation performed will depend upon the components of the model which are of interest for application. However, it is likely that some of the following components will be validated in the ways indicated.

- Soil moisture budget – by comparison with site specific measurements (time series of soil moisture)
- Vegetation above ground biomass – by comparison with remote sensing derived indicates of vegetation cover and density and their change over time
- Runoff – by comparison of modeled water yields with those measured at a reservoir or other moniotoring site
- Soil erosion – by comparison of model results with published sedimentation rates for reservoirs.

10.2. LEIS model validation data requirements

The LEIS model is being tested for the first time and only in the observatory of Menzel Habib (Tunisia) and it is as yet unclear which validation data will be necessary for application in the Jeffara region (Oum Zessar watershed) in the framework of the DeSurvey project. At the moment, the LEIS tool incorporates two validation "tests". The first one covers the initial modelling step, which is the construction of the Territories of Exploitation, towards the Combined Practice Units (CPU) and tests whether these plots are well allocated. The second test covers the final modeling step, which is based on the testing of the allocation of CPU. In this latter test, one plot is surveyed to be part of or used by a type of Combined Practice, so then it can be compared with what has been spatialised by the model at the place where the plot lies (i.e. total or partial inclusion of the plot in a CPU).

11. Conclusions

The specific problems of desertification and mitigation measures are addressed at the Mediterranean and local scale, with the ultimate goal being to aid local decision-making with regard to policy formulation for sustainable land management at the local level. In Tunisia, desertification is a major problem threatening around 52% of the land area suitable for agriculture, forestry and pasture farming (MEAT, 1998). In general, the loss of land productivity has been triggered by incompatible forms of land use that result in soil degradation and salinisation, water and wind erosion. The study area, the Oum Zessar watershed, which is representative of the problems of this region, will be subject to the application of the PATTERN-LEIS model, in order to tackle the bio-physical as well as the socio-economical aspects of land degradation and desertification. Thus, the development of the DeSurvey PATTERN-LEIS coupled model will address a number of policy themes concerning water resources, sustainable agriculture, desertification and land degradation in a typical Mediterranean region of North Africa. The complementarity of the two models should permit to come to an integrated model covering the essential physical, ecological, economic and social processes related to degradation. However, the development of a policy support system (PSS) is more than developing an integrated model, and the system will need to focus on process interaction and connectivity and be able to support policy questions and provide policy relevant information (van Delden et al., 2004).

The two models were available in different stages of development. The PATTERN model was fully finished and had been tested and validated against real world data, while the LEIS model is in the process of being validated for the first time. Therefore, several difficulties and issues need to be solved within the framework of the integration process, such as the temporal and spatial scales of both models, and the adaptability of the models in order to represent the main processes taking place in the study area.

SUMMARY PROTOCOL FOR COUPLING PATTERN AND LEIS

Field sites

- A thorough sensitivity analysis of the PATTERN model is being carried out for the Guadalentin area with a view to making the necessary simnplifications for application in North Africa
- The PATTERN model will be applied alone or in combination with the RIKS socio-economic modules to issues in Castilla La Mancha
- The coupled LEIS-PATTERN model will be developed and applied in the Jeffara catchments of Tunisia and perhaps also in the Menzel Habib observatory for which extensive datasets are already available.

Timesteps and spatial resolution

- The PCRASTER version of PATTERN is an hourly model whereas LEIS operates on annual and seasonal timesteps.
- Thus, where the processes permit, the PATTERN model will be simplified to daily or even monthly operation
- All outputs of PATTERN to LEIS will be written seasonally, the seasons to be used are yet to be defined for the study area.
- PATTERN is a raster based model which uses grain sizes of less than 100m whereas LEIS uses some raster data but its unit of calculation is a changeable polygon – the so-called CPU (combined practice unit).
- Thus PATTERN will receive a raster of the CPU boundaries for each year and will aggregate its output within those boundaries for supply to LEIS, supplying a fractional cover, mean and/or standard deviation within the CPU for each variable, as appropriate
-

Points of connection

- LEIS is essential a model of socio-economic activities and their impacts on land use and land management practices.
- PATTERN is a model of the impact of land use and land management practices on biophysical properties and land degradation in a spatially and temporally variable climate

- The coupled LEIS-PATTERN model will close the feedback loop between human use of the land and its biophysical impact in a spatially and temporally detailed manner

LEIS will supply the following to PATTERN

Data	**Description**	**Spatial resolution**
Water demands		
dripirrig.map from CPU	Raster map of the area covered by drip irrigation (yes=1, no=0)	90 m resolution, seasonally or annually
immersionirrig.map from CPU	Raster map of the area covered by immersion irrigation (yes=1, no=0)	90 m resolution, seasonally or annually
Land use practices		
Landuse.map from CPU	Categorical raster map of the different land use classes in the target area	90 m resolution, seasonally or annually
Vegetation demands		
VegeTypes.map from Landscape Units	Categorical raster map of the different vegetation classes in the target area	90 m resolution, seasonally or annually
pressureIndex.map from SRU	Raster map of pressure index	90 m resolution, seasonally or annually

PATTERN will supply the following to LEIS

Data	**Description**	**Spatial resolution**
Leaf biomass for Landscape Units layer		
Leaf Biomass map from PATTERN	Raster map of above ground biomass (kg/m^2) for herbaceous short woody and tall woody species	90 m resolution, seasonally or annually
Land condition properties for agricultural structuring		
Long term soil moisture (integrated rainfall, evapo-transpiration and soil water storage properties including effects of erosion))	Raster map of soil moisture (m^{3}water/m^{3}soil)	90 m resolution, seasonally or annually
Long term crop specific yield (integrates all aspects of land condition with a crop specific impact that is also based on the crop specific land management)	Raster map of crop specific yield (kg/m^2/yr) for a range of crops	90 m resolution, seasonally or annually

Technical aspects

There are two ways in which the models can be integrated:
A simple scientific integration – LEIS is run to produce a set of annual land use and practice maps and associated variables and these are fed afterwards to PATTERN which produces a series of corresponding changes in biophysical properties which are, in run fed to LEIS which is run again to produce a 'coupled' scenario
A full technical integration - PCRASTER and PATTERN are installed on the machine on which LEIS runs. LEIS calls PCRASTER **one LEIS timestep at a time (which may be many PCRASTER timesteps)** and PCRASTER reads the input data from LEIS in arcview format and outputs data to LEIS in arcview format. This is the preferred option.

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