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WWW MicroLEIS
Exploring the Agro-ecological Limits of Sustainability

Ero&Con
Agro-ecological Field Vulnerability Evaluation System

User's Manual
&
Technical Description

developed by

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Contents

1. The Approach Overview

Within the new MicroLEIS framework, the Ero&Con package is a database/expert system evaluation approach for assessing limitations to the use of the land, or vulnerability of the land to specified agricultural degradation risks. Soil erosion, salinization and diffuse agrochemical contamination are separately considered by several program models. These empirical knowledge-based models also combine simple process sub-models such as to predict rainfall erosivity by the Thornthwaite-Fournier formula. In this sense, Ero&Con can be considered as a set of hybrid methods.

Special attention is given to the management/ technological aspects at farm level. Therefore, agricultural *management factors* are detailed and combined with land characteristics in order to define the *field-units* to be evaluated within each model. Physical-attainable risks are calculated separately from management-related risks, and the two are combined to produce the actual vulnerability classes (Figure 1.1).

Ero&Con models are automated applications of the developed rural resources databases: SDBm (Soil), CDB (Climate) and MDB (Management) (Figure 1.2). The created expert models are based on decision trees as hierachical multiway keys in which the leaves are results such as *land quality* (LQ) ratings, and the interior nodes of the tree are decision criteria such as *land characteristic* (LC) values. The models were partly constructed in accordance with the criteria of the FAO-framework for Land Evaluation.

The created models were initially formulated and calibrated by using expert knowledge (experience) of specialists and land users, and collected literature (knowledge). Then the models were recalibrated and validated by point-to-point application using data (information) of 62 representative sites of the Andalucia region, Spain, and of 42 sites of the European Union. A spatial application of the models was made for the Province of Sevilla (1,400,000 ha), Spain.

The hypothetical predictions, considering climate and management changes, can be useful as tools in designing adaptation strategies to climate changes and in formulating sustainable landuse scenarios by changing agricultural management practices. These "what-if" scenarios are critical pieces of the puzzle in the understanding of global change.

Figure 1.3 shows an overview with the general structure of the Ero&Con system.
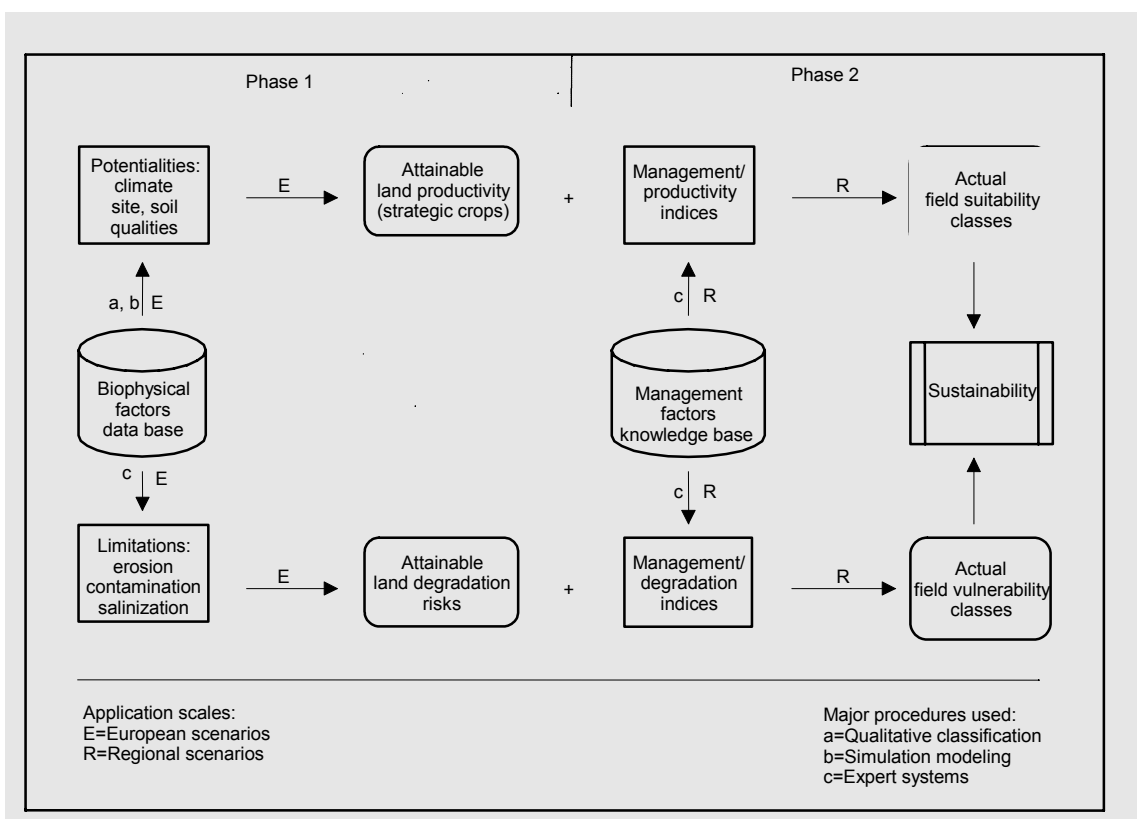
Figure 1.1. General scheme of the new MicroLEIS framework, incorporating
            sustainability in land evaluation.
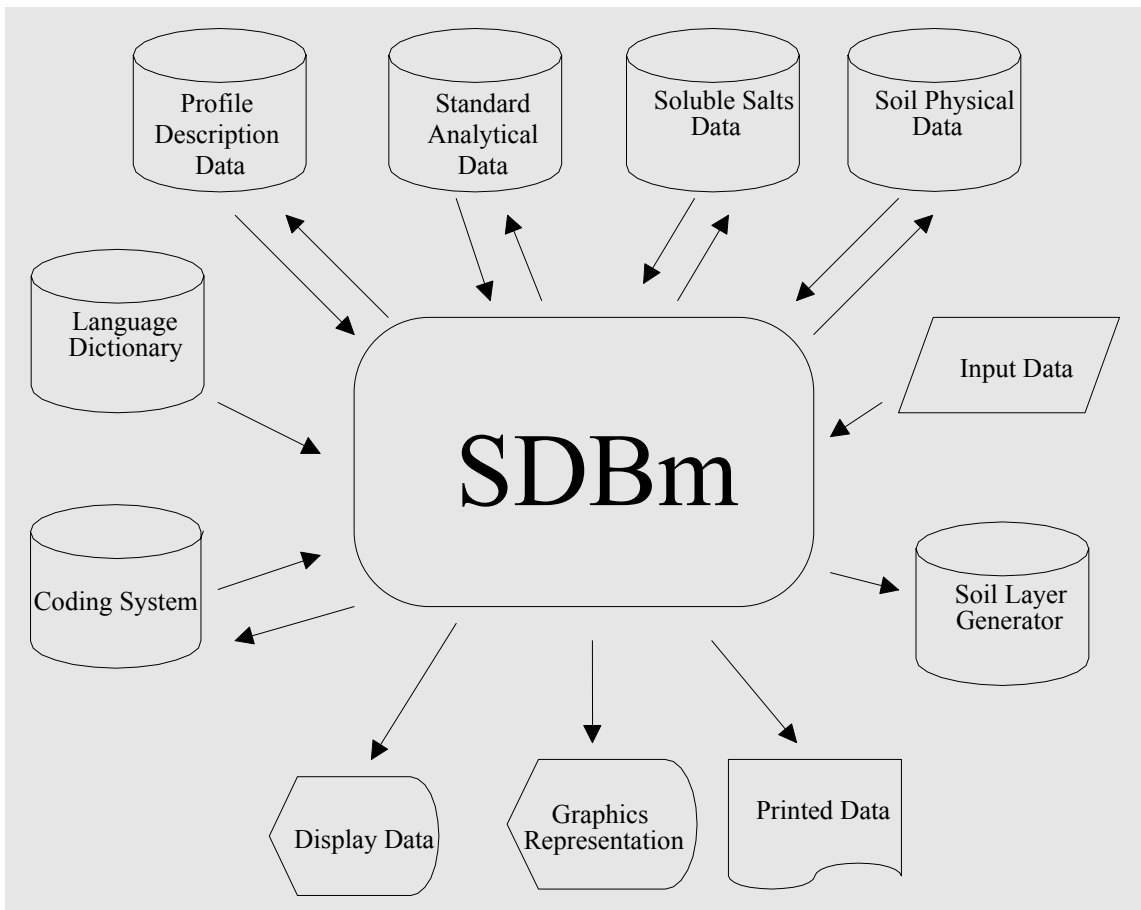
Figure 1.2. General scheme of the SDBm soil database.
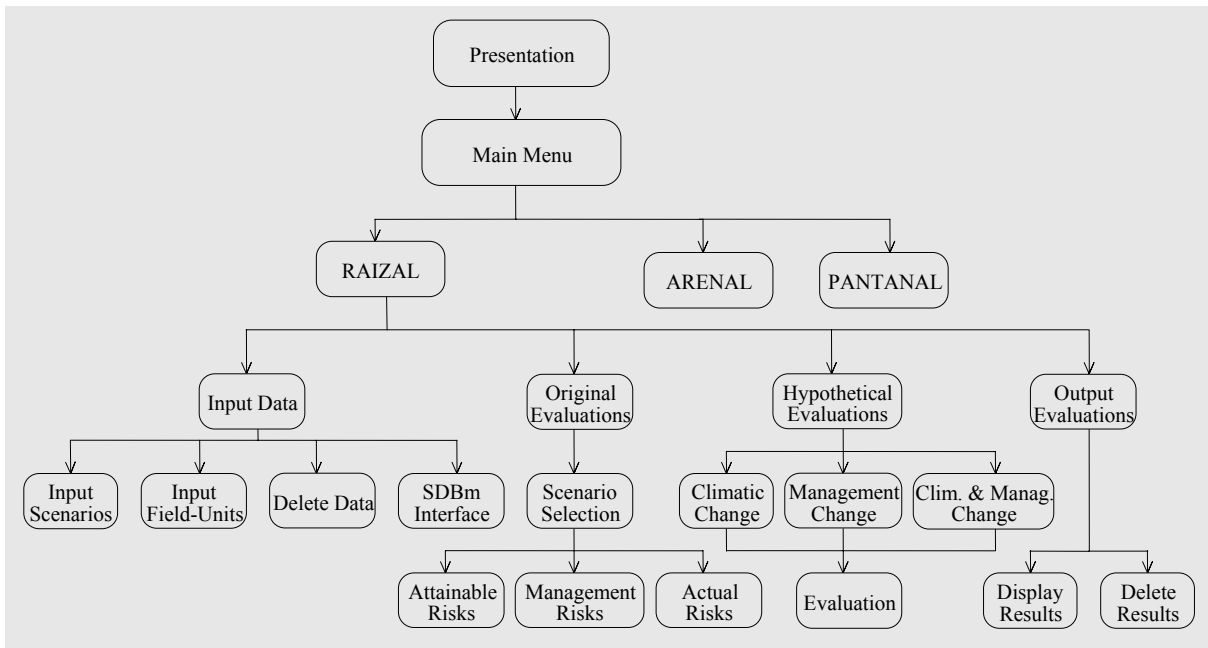
Figure 1.3. The basic structure of Ero&Con front-end.

Table 1.1 . Input variable list of the ***Raizal*** and ***Pantanal*** evaluation models.

Land characteristic, class or unit	Raizal	Pantanal
Site-related characteristics		
LC Landforms, 21 classes	xxx	xxx
LC Slope gradient, %	xxx	xxx
LC Groundwater table depth, m	xxx	xxx
Soil-related characteristics		
LC Drainage, 7 classes	xxx	xxx
LC Particle size distribution, 23 classes	xxx	xxx
LC Superficial stoniness, %	xxx	
LC Organic matter, %	xxx	xxx
LC pH		xxx
LC Cation exchange capacity, meq/100g		xxx
LC Sodium saturation, %	xxx	
Climate-related characteristics		
LC Mean monthly precipitation, mm	xxx	xxx
LC Max monthly precipitation, mm	xxx	
LC Mean monthly temperature, °C	xxx	xxx
LC Latitude, °	xxx	xxx

Table 1.1. (Cont.). Input variable list of the ***Raizal*** and ***Pantanal*** evaluation models

Management characteristic, class or unit	Raizal	Pantanal
Crop-related characteristics		
MC Land use type, 11 classes	xxx	xxx
MC Crop rotation, 4 classes	xxx	xxx
MC Land use on slopes, 2 classes		xxx
MC Growing season length, days	xxx	
MC Leaf duration, 2 classes	xxx	
MC Leaf situation, 2 classes	xxx	
MC Specific leaf area, m2/kg	xxx	
MC Plant height, m	xxx	
MC Maximum rooting depth, m	xxx	
MC Structure of crop, 2 classes	xxx	
Cultivation-related characteristics		
MC Sowing date, 2 classes	xxx	
MC Tillage practices, 5 classes	xxx	xxx
MC Tillage depth, 2 classes	xxx	
MC Tillage method, 2 classes	xxx	xxx
MC Row spacing, m	xxx	
MC Artificial drainage, 2 classes	xxx	xxx
MC Artificial groundwater level, 2 classes		xxx
MC Soil conservation techniques (water), 4 classes	xxx	xxx
MC Soil conservation techniques (wind), 5 classes	xxx	
MC Residues treatment, 3 classes	xxx	xxx
Fertilizer-related characteristics		
MC Use of P-fertilizer, 3 classes		xxx
MC Use of N-fertilizer, 3 classes		xxx
MC Use of animal manure, 2 classes		xxx
MC Use of industrial /urban waste, 2 classes		xxx
MC Time of fertilization, 2 classes		xxx
Pesticides-related characteristics		
MC Use of pesticides, 2 classes		xxx
MC Persistence of pesticides, 3 classes		xxx
MC Toxicity (LD-50) of pesticides, 3 classes		xxx
MC Application methods, 2 classes		xxx

2. Ero&Con Front-end

2.1. General Structure

Following the scheme of the MicroLEIS system, a set of computer programmes was developed to automate the application of Ero&Con models. However, new facilities are included in this package.

The major characteristics of the Ero&Con front-end are:

- Interface with SDBm database (FAO-CSIC 1994, multilingual Soil Database)
- "Pop up" screens showing codes, types and classes
- Batch processing modes
- Hypothetical predictions option
- Link with GIS

These programmes are largely self explanatory. They use menus, as shown in Table 2.1, to inform about alternatives, and prompt you to respond whenever needed. From each menu, the "Explanation" option gives detailed information on the corresponding step.

Many fields in Ero&Con input screens use codes. These codes are included in the Ero&Con software in the form of indices, and can be accessed from the <F1> key while entering/editing data.

Output results for an evaluating scenario in tabular, graphic or CSV format presentation can be displayed or deleted by selecting the corresponding file.

Table 2.1. Main menu of the Ero&Con Agro-vulnerability Field Evaluation system.

```
                ────────────────────────────────────
                        MAIN MENU

                ────────────────────────────────────


            1  RAIZAL model: Soil Erosion
            2  ARENAL model: General Soil Contamination
            3  PANTANAL model: Specific Soil Contamination

            H  Explanation
            Q  Quit

                ────────────────────────────────────
```

2.2. Installation

Ero&Con is simple to install and to run. Installation is by the following steps, during which a few questions are asked:

> - insert the diskette #1 in drive A: (or B: or ...)
> - change to drive A: (or B: or ...)
> - type "MLEROINS" to install the software on a hard disk
> - follow the instructions on the screen

Ero&Con will be installed in directory \MLERO

Finally, to run Ero&Con from the directory \MLERO, type MLERO and press <Enter>. A few examples of *evaluating-scenarios* are included.

2.3. System Requirements
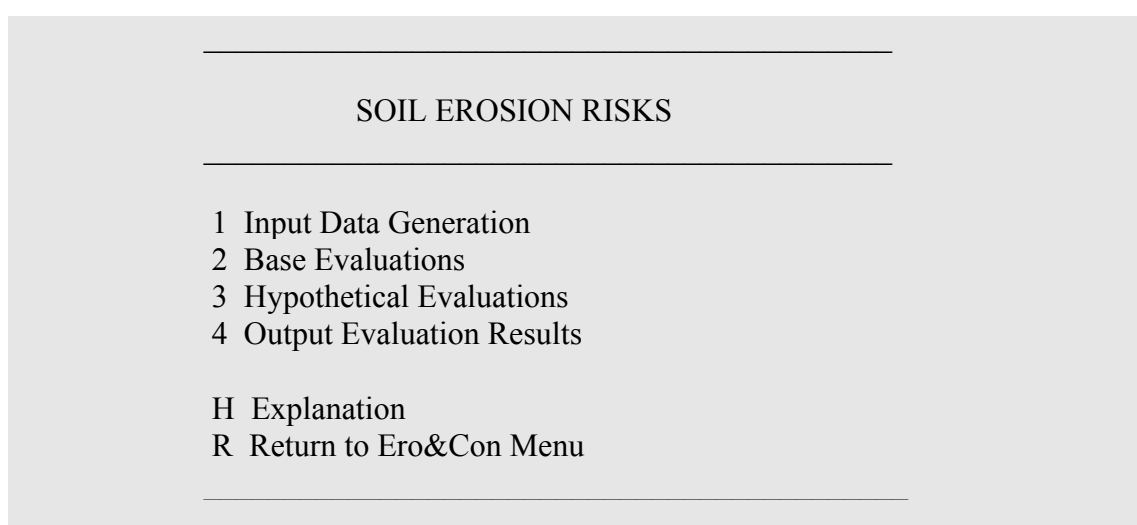
To use Ero&Con you will require a personal computer (PC), MS-DOS version 3.0 or higher, with about 1 Mbytes of free space. It will work with 1 Mbytes of RAM but is likely to be slow if handling large quantities of data.

3. Input Data Generation

3.1. Raizal Model

On the main menu of the Raizal model (Table 3.1), the first option is "Input Data Generation".

Table 3.1. Main menu of the soil erosion risks: Raizal model

SOIL EROSION RISKS

---

1 Input Data Generation
2 Base Evaluations
3 Hypothetical Evaluations
4 Output Evaluation Results

H Explanation
R Return to Ero&Con Menu

3.1.1. New Evaluating Scenarios

As presented in Table 3.2, the first option of input data is the creation of *evaluating-scenarios*. To develop a Raizal application it is necessary to define the *evaluating-scenario* with its internal code locating all the *evaluating-units* to be evaluated. The number of *evaluating-units* within an *evaluating-scenario* is almost unlimited.

It is also possible to select a previously defined *evaluating-scenario* by using the <F1> option.

Table 3.2. Input data generation menu of Raizal model

INPUT DATA GENERATION

1 New Evaluating-scenarios
2 Enter & Edit Data
3 Delete Data
4 SDBm Interface

H Explanation
R Return to Main Menu RAIZAL

For each *evaluating-scenario*, the input data can be generated i) from the keyboard, for soil-, climate- and management-related data; and ii) through the SDBm interface, only for the soil-related data.

3.1.2. Enter, Edit and Delete Data

From the keyboard, it is possible to enter, edit and delete input data. Table 3.3 shows an example of "Enter and Edit Data" screen for soil-related data. The same structure is uded in climate- and management-related variables screens (Table 3.4 and Table 3.5). From all climate data input, the model calculates automatically the Humidity Index and the Derived Fournier/ Humidity Index. These calculated climate variables represent the climate erosivity of a land unit.

Table 3.3. Data input screen for soil-related input variables

MicroLEIS: Ero&Con	RAIZAL Model

```
                        ENTER AND EDIT DATA
_____

                      Evaluating-scenario:   AND

Evaluating-unit: F-AL01                       Representative area, km2: 2000.00

                Code  Name              Longitude    Latitude    Altitude, m
Benchmark Soil: AL01  Greda-roja        W00218       N3717       1260

                        SOIL-RELATED CHARACTERISTICS

Landforms              MO              Particle Size Distribution       SL
Slope Gradient, %          30         Organic Matter,%                 1.3
Groundwater Table Depth, m 20.0       Sodium Saturation,%              5.0
Superficial Stoniness,%    25
Drainage               W
```

Table 3.4. Data input screen for climate-related input variables

MicroLEIS: Ero&Con   **RAIZAL Model**

```
Evaluating-Unit:      F-AL01                              Evaluating-Scenario:
AND

                Code  Name          Longitude    Latitude    Altitude
Climate Station: AAL01  Almanzora-Alto   W00245       N3725       1200


                    CLIMATE-RELATED CHARACTERISTICS

         JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC
Pmax    58.0   62.0  170.0  180.0  122.0   85.0   59.0   82.0   72.0  131.0  158.0  191.0
Pmean   25.0   23.0   40.0   48.0   42.0   28.0    7.0    6.0   15.0   42.0   46.0   56.0
Tmean    4.6    5.6    7.7   10.2   15.0   18.0   23.3   23.0

Pmax:   Maximum Precipitation, mm
Pmean:  Mean Precipitation, mm
Tmean:  Mean Temperature, °C
```

Table 3.5. Data input screen for management-related input variables

MicroLEIS: Ero&Con   **RAIZAL Model**

```
Evaluating-unit: F-AL01                               Evaluating-Scenario: AND


                        Code          Name
Field Utilization Type:  FUT01        Wheat/Intensive


                     MANAGEMENT-RELATED CHARACTERISTICS

Crop Properties                                       Cultivation Practices


Land Use Type                 1        Sowing Date                    1
Growing Season Length, days   180      Tillage Practices                 1
Leaf Duration                 2        Tillage Depth                     1
Leaf Situation                2        Tillage Method                2
Specific Leaf Area, m2/kg     1        Row spacing, m                0.40
Plant Height, m                        0.50   Artificial Drainage
        2
Maximum Rooting Depth, m      1.00     Soil Conservation Techniq.,Water   1
Structure of Crop             2        Soil Conservation Techniq.,Wind    2
                                       Residues Treatment                 3
                                       Crop Rotation                      4
_____
```

The <F1> key can be used for each qualitative variable. It displays on-screen all the possible valid codes and their meaning for this particular characteristic (Table 3.6). Any code can be selected using the cursor and that code is automatically introduced into the variable field.

Table 3.6. "Pop up" window for the qualitative land characteristic "Drainage" which opens when pressing the <F1> key

_____
            LC Surface Drainage
_____

V   Very poor
P   Poor
I   Imperfect
M   Moderately well
W   Well
S   Somewhat excessive
E   Excessive

_____

Appendix A lists the names and classes of all variables (*Land Characteristics,* LCs; and *Management Characteristics,* MCs) used within the Raizal model.

Within the Raizal framework, it is possible to delete an *evaluating-scenario* or *evaluating-unit*. Table 3.7 shows the option to delete an *evaluating-scenario* or *unit*.

Table 3.7. Menu to delete the *evaluating scenario* or *unit*.

DELETE INPUT DATA

1	Delete Evaluating Scenario
2	Delete Evaluating Unit
H	Explanation
R	Return to Input Menu

3.1.3. SDBm Interface

The soil-related data used as diagnostic criteria in Raizal can be automatically captured from the SDBm database (FAO-CSIC, 1994) by using the "Soil Layer Generator" option of SDBm. When useing this option, the input files generated by SDBm must be placed in directory C:\MLERO\INPUT to be imported.

The soil profile variables stored in SDBm which are used in Raizal are the following:

1. Site characteristics:
- Latitude, [LAT]
- Longitude, [LON]
- Altitude, [ELEV]
- Land form, [LAFO]
- Slope gradient, [SLGR]
- Stoniness, [STON]
- Drainage, [DRAI]
- Ground water table depth, [GWAT]
- Location, [LOC]

2. Horizon (layer) characteristics:
- Texture, [TEX1]
- Organic carbon, [OC]
- Cation exchange capacity, [CECS]
- Sodium saturation, [NA]

The structure of SDBm files as created by the "Soil Layer Generator" is shown in Example 3.1.   For this example a layer or control section of 0 to 50 cm from the surface was considered for the soil horizon and analytical characteristics.

Example 3.1. An SDBm input file, for six soil profiles and one control section, including the SDBm soil-related characteristics which are
diagnostic   criteria for the Raizal module.

Reg	PRNO	LAT	LON	ELEV	LAFO	SLGR	STON	DRAI	GWAT	LOC	TEX1	OC	CECS	NA
1	SE0052	N374715	W054015	320	HI	6	C	W	0	Constantina	SIC	1.25	23.6	0.0
2	SE0058	N374300	W060600	490	VA	3	F	W	5	Almaden	SIC	1.21	8.5	0.0
3	SE0059	N374520	W060020	400	VA	4	F	M	5	Castilblanco	SCL	0.84	21.1	0.0
4	SE0060	N374341	W055629	350	VA	3	V	M	5	Castilblanco	LS	0.82	10.6	0.1
5	SE0061	N374044	W060218	200	MO	7	C	S	0	Castilblanco	SL	2.52	20.0	2.0
6	SE0064	N375204	W060524	490	VA	4	F	W	5	Almaden	SL	1.69	12.6	0.3

3.2. Pantanal Model

On the main menu of the Pantanal model (Table 3.8), the first option is "Input Data Generation".

Table 3.8. Main menu of the Pantanal model.

AGROCHEMICAL CONTAMINATION RISKS

1	Input Data Generation
2	Base Evaluations
3	Hypothetical Evaluations
4	Output Evaluation Results
H	Explanation
R	Return to Ero&Con Menu

3.2.1. New Evaluating Scenarios

As presented in Table 3.9., the first option of input data is the creation of new evaluating scenarios. To develop a Pantanal application it is necessary to create an evaluating-scenario with its code within located all the evaluating-units to be evaluated. The number of evaluating-units within an evaluating-scenario is almost unlimited.

It is also possible to select a previously defined evaluating-scenario by using the <F1> option.

Table 3.9. Input data generation menu of Pantanal model

INPUT DATA GENERATION

> 1   New Evaluating Scenarios
> 2   Enter & Edit Data
> 3   Delete Data
> 4   SDBm Interface
>
> H   Explanation
> R   Return to main menu

For each evaluating-unit, the input data can be generated i) from the keyboard; for soil-, climate- and management-related data; and ii) through the SDBm interface, only for the soil-related data.

3.2.2. Enter, Edit and Delete Data

From the keyboard, it is possible to enter, edit and delete input data. Table 3.10 shows an example of "Enter and Edit Data" screen for soil-related data. The same structure is used in climate- and managment-related variables screens (Table 3.11 and Table 3.12). Only those variables which are necessary to evaluate the chosen specific compound vulnerability are highlighted on the screens. From all climate data input, the model calculates automatically the Humidity Index, Annual Temperature and Annual Rainfall. These calculated climate variables represent the climate influence on the contamination vulnerability of a land unit.

Table 3.10. Data input screen for soil-related input variables

MicroLEIS: Ero&Con   **PANTANAL Model**

ENTER AND EDIT DATA

Evaluating-scenario: AND

Evaluating-unit: F-AL01   Representative area, km2: 2000.00

	Code	Name	Long	Latit	Altit
Benchmark Soil:	AL01	Greda-roja	W 00218	N3717	1260

SOIL-RELATED CHARACTERISTICS

Landform	MO	Drainage	W
Slope Gradient, %	30	Particle Size Distribution	SCL
Groundwater Table Depth, m	W	Organic Matter, %	1.7
		pH	7.1
		C.E.C., meq/100 gr.	18.1

Table 3.11. Data input screen for climate-related input variables

MicroLEIS: Ero&Con   **PATANAL Model**

ENTER AND EDIT DATA

Evaluating -unit: F-AL01   Evaluating Scenario: AND

	Code	Name	Long	Latit	Altit
Climate Station	AAL01	Almanzora-Alto (Baca	W00245	N3725	1200

CLIMATE-RELATED CHARACTERISTICS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Pmen	25.0	23.0	40.0	48.0	42.0		28.0	7.0	6.0	15.0	42.0	46.0	56.0
Tmen	4.6	5.6	7.7	10.2	15.0		18.0	23.3	23.0	18.4	13.6	7.7	4.8

Pmen = Mean Precipitation, mm
Tmen = Mean Temperature, °C

Table 3.12. Data input screen for management-related input variables

MicroLEIS: Ero&Con   **PANTANAL model**

ENTER AND EDIT DATA

Evaluating-unit: F-AL01   Evaluating-scenario: AND
                                      Code   Name
Field Utilization Type: FUT01   Wheat/ Intensive

                          MANAGEMENT-RELATED CHARACTERISTICS
Land Use Type   11   Use of Pesticides   1
Crop Rotation   4   Persistence of Pesticides   2
Land Use on Slopes   1   Toxity (LD-50) of Pesticides   400
                                                 Application methods of Pesticides   2

P-Fertilizer   2   Artificial Drainage   2
N-Fertilizer   1   Artificial Groundwater Level   2
Animal Manure   2   Residues Treatment   3
Industrial/Urban Waste   2   Soil Conservation Techniques   4
Time of Fertilization   1   Tillage Practices   4

The <F1> key can be used for each qualitative variable. It displays on-screen all the possible valid codes and their meaning for this particular characteristic (Table 3.13). Any code can be selected using the bar and that code is automatically introduced into the variable field.

Table 3.13. "Pop up" window corresponding to the qualitative land characteristic "Drainage" which opens when pressing the <F1> key.

	LC DRAINAGE
V	Very poor
P	Poor
I	Imperfect
M	Moderately well
W	Well
S	Somewhat excessive
E	Excessive

Appendix A lists the names and classes of all variables (Land Characteristics, LCs; and Management Characteristics, MCs) used within the Pantanal model.

Within the Pantanal framework, it is possible to delete an evaluating scenario or evaluating unit. Table 3.14 shows the option to delete an evaluating scenario or unit.

Table 3.14. Menu to delete the evaluating scenario or unit.

```
        _____

                 INPUT DATA DELETE

        _____


        1        Evaluating Scenario
        2        Evaluating Unit
        3        Benchmark Soil
        4        Climate Station
        5        Field Utilization Type


        R        Return to Input Menu

        _____
```

3.2.3. SDBm Interface

The soil-related data used as diagnostic criteria in Pantanal can be automatically captured from the SDBm database (FAO-CSIC, 1994) by using the "Soil Layer Generator" option of SDBm. When using this option the input files generated by SDBm must be placed in directory C:\MLERO\INPUT to be imported.

The soil profile variables stored in SDBm which are used in Pantanal are the following:

1. Site Characteristics:
        - Latitude, [LAT]
        - Longitude, [LON]
        - Altitude [ELEV]
        - Landform [LAFO]
        - Slope Gradient [SLGR]
        - Stoniness [STON]
        - Drainage [DRAI]
        - Depth of Groundwater Table [GWAT]
        - Location [LOC]

2. Horizon (layer) and Analytical characteristics:
        - Texture [TEX1]
        - pH water [PHW]
        - Organic carbon [OC]
        - Cation Exchange Capacity [CECS]
        - Sodium saturation [NA]

The structure of SDBm files as created by the "Soil Layer Generator" is shown in Example 3.2. For this example a layer or control section from 0 to 50 cm from the surface was considered for the soil horizon and analytical characteristics.

Example 3.2. An SDBm input file for six soil profiles and one control section, including the SDBm soil-related characteristics which are diagnostic criteria for the Pantanal model.

PRNO	LAT	LON	ELEV	LAFO	SLGR	STON	DRAI	GWAT	LOC	TEX1	PHW	OC	CECS
SE052	N374715	W054015	320	HI	6	F	W	0		SIC	5.8	1.3	23.6
SE058	N374300	W060600	490	VA	3	F	W	5		SIC	5.5	1.2	8.5
SE059	N374520	W060020	400	VA	4	V	M	5		SCL	5.9	0.8	21.1
SE060	N374341	W055629	350	VA	3	F	M	5		LS	6.0	0.8	0.6
SE061	N374044	W060218	200	MO	7	C	S	0		SL	6.1	2.5	20.0
SE064	N375204	W060524	490	VA	4	V	W	5		SL	6.0	1.7	2.6

4. Base Evaluations

Ero&Con models evaluate the vulnerability risks of an agricultural field to land degradation, considering separately three types of vulnerability: attainable, management and actual; and for each degradation factor: water and wind erosion; and nitrogen, phosphorus, heavy metals (Cu, Zn, Cd, Hg, Pb) and pesticides (general, hydrophile and hydryphobe) contamination (Table 4.1).

The attainable vulnerability considers the biophysical risk of the capability of the soil being harmed in one or more of its ecological functions.

The management vulnerability considers the risk of a particular *Field Utilization Type* to land degradation.

The actual vulnerability considers simultaneously the biophysical and management risk factors of a particular field unit.

Table 4.1. Combination of vulnerability classes according to attainable, management and actual degradation risks

Land degradation factor	Vulnerability type		
	Attainable risk	Management risk	Actual risk
Raizal model			
Water erosion, W	VAW	VMW	VCW
Wind erosion, D	VAD	VMD	VCD
Pantanal model			
Phosphorus contamination, P	VAP	VMP	VCP
Nitrogen contamination, N VCN	VAN	VMN	
Heavy metals contamination, H	VAH	VMH	VCH
Pesticides contamination, X	VAX	VMX	VCX

Any type of the evaluation is made in batch-running mode for all the *evaluating-units* included within the selected *evaluating-scenario*. So, the option "Scenario Selection" of Table 4.2 is the first step in making an evaluation. Having selected the scenario, the type of vulnerability which you want to evaluate is chosen.

Table 4.2. Menu to compute original evaluations of RAIZALmodel.

ORIGINAL EVALUATIONS

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1 Scenario Selection
2 Attainable Vulnerability
3 Management Vulnerability
4 Actual Vulnerability

T Decision Trees Observation
R Return to Main Erosion Menu

4.1. Raizal Model

4.1.1. Vulnerability Classes

The soil erosion vulnerability classes (10) established by Raizal for the Attainable and Actual Vulnerability risks (VAW, VAD and VCW, VCD) are defined as follows:

Class V1 None. These field units are not vulnerable to water or wind erosion - the risks to these processes could be considered as nil and the land unit will be uneroded.
For these fields, management erosivity is not considered to be a controlling factor and almost any farming system can be implemented.

Class V2 Very Low. These field units present a very low vulnerability to wind or soil erosion. Soil erosion will occur rarely and only during extreme climate conditions.
For these fields the influence of the management systems on the soil degradation is low.

Class V3 Low. These field units present a low vulnerability to water or wind erosion. Soil erosion will occur rarely. The soil could have a few rills or places with thin A horizons that give evidence of accelarated erosion, but not to such an extent as to alter greatly the thickness and character of the A horizon.

The wind will remove only a very small amount of the soil.

For these fields the effect of management change on the vulnerability classes could be important. There are no differences in use capabilities and management requirements from the uneroded soils.

Class V4 Moderately Low. These field units present a moderately low vulnerability to wind or wind erosion. Only a few properties of water erosion (especially inter-rill erosion) will be visible in the field. The soil of the areas in this class can be eroded to the extent that ordinary implements reach through the remaining A horizon.

The wind will remove a small amount of the soil.

For these fields the effect of management change on the vulnerability classes could be important. There are small differences in use capabilities and management requirements from the uneroded soils.

Class V5 Slightly Low. These field units present a slightly low vulnerability to water or wind erosion. The soil will erode to the extent that ordinary tillage implements reach through the remaining A horizon, or well below the depth of the original plowed layer in soils with thin A horizons. Generally, the plow layer will consist of a mixture of the original A horizons and underlying horizons. Mapped land units will have patches in which the plow layer consists wholly of the original A horizon and others in which it consists wholly of underlying horizons. A few shallow gullies will be present in the field. The wind will remove from the soil a sufficient amount of the A horizon that ordinary tillage brings up.

For these fields the effect of management change on the vulnerability classes could be considerable.

Class V6 Slightly High. The field units present a slightly high vulnerability to water or wind erosion. The soil will erode to the extent that a big part of the original surface soil, or A horizon, will be removed. Water erosion processes will be active during each year. Numerous shallow gullies will be present in the field.

The wind will remove from the soil a large amount of the A horizon that ordinary tillage brings up and will partly mix the B horizon or other underlying horizons with surface soil in the plow layer. Rarely will this be condition uniform throughout a mappable land unit.

For these fields the effect of management change on the vulnerability classes could be considerable.

Class V7 Moderately High.   These field units present a moderately high vulnerability to water or wind erosion. The soil will erode to the extent that practically all of the original surface soil, or A horizon, will be removed. The plow layer will consist essentially of materials from the B or other underlying horizons. Patches in which the plow layer is a mixture of the original A horizon and the B horizon or other underlying horizons will be included within the mapped field units. Shallow gullies, or a few deep ones, will be common on some soil types.

The wind will remove all of the A horizon and a small amount of the B or other underlying horizon. The plow layer will consist of original horizons below the A horizon.

For these fields the more management-erosive farming systems have adverse effects on the environment.

Class V8   High.   These field units present a high vulnerability to water or wind erosion.   The soil will erode to the extent that all of the original surface soil, or A horizon, will be removed.   The plow layer will consist essentially of materials from the B or other underlying horizons.   Patches in which the plow layer is a mixture of the original A horizon and the B horizon or other underlying horizons will be included within the mapped field units.   Shallow and moderately deep gullies will be present in the field unit.   Where land is afforested or drained there will be often a "slug" of erosion before channels are stabilized by vegetation, but the rates of erosion will continue to be greater than those prevailing before.

The wind will remove all of the A horizon and a part of the B or other underlying horizon.   The plow layer will consist mainly of the original horizons below the A (or below the original plowed layer in the soils with thin A horizons), although some patches will have much of the original A horizon remains in the field unit. Sometimes an occasional blow-out area of the field unit will be included.

For these fields the more management-erosive farming systems have adverse effects on the environment.

Class V9   Very High.   These field units present a very high vulnerability to water or wind erosion.   The field will erode until it has partly an intricate pattern of moderately deep gullies. Soil profiles will be destroyed except in small areas between gullies. Such fields will not be useful for crops in this condition. Reclamation for crop production or for improved pasture is difficult but will be practical if other characterisics of the soil are favorable and erosion is controlled.

The wind will remove a big part of the soil profile.   The plow layer consists of the original horizons below the A-horizon.   An occasional blow-out part of the field unit will be included.

Class V10 Extreme.   These field units present an extremely high vulnerability to water or wind erosion.   The field will erode until it has an intricate pattern of moderately deep or deep gullies. Soil profiles will be destroyed except in small areas between gullies. Such fields will not be useful for crops in this condition. Reclamation for crop production or for improved pasture is very difficult but will be practical if the other characteristics of the soil are favorable and erosion is controlled by soil conservation techniques, for example by construction of terraces.

The assessment of the soil erosion management vulnerability (VMW and VMD) is classified into four classes:

Class V1   Very Low. The human influence on these field units is very small regarding the vulnerability to water or wind erosion. In general, this class represents good soil conservation methods and the actual vulnerability of a field unit will be dependent only on the attainable risk. This class represents the best field management

methods for a particular field unit to become a possible sustainable land use system (economical issues are not involved).

Class V2   Moderately Low. The influence of field management is small regarding water or wind erosion vulnerability. In the sense of sustainable land use, when the attainable risk is high then the risk of field management has to be Class 1 or Class 2 (land use with higher vulnerability is excluded).
   Class V3 Moderately High. Field units with this risk class are in danger of becoming less suitable in the agricultural sense and their field methods are vulnerable to water or wind erosion. The field use with this management risk is considered not to be sustainable.

Class V4   Very High. Field units with this management class are in real danger of becoming unsuitable, because their management methods greatly accelerate the processes of water or wind erosion. To sustain the field it is necessary to avoid this management class.

Besides vulnerability classes, subclasses are also presented as evaluation outputs. The subclasses show the user the vulnerability limitations of the evaluated field unit and help in understanding the evaluated classification.

4.1.2. Decision Trees

The classes of each *Land Characteristic* (LC) or *Management Characteristic* (MC) are connected with the severity levels of the corresponding *Land Quality* (LQ) or *Management Quality* (MQ) by complex decision trees, based on the approach of expert systems. The connections between the severity levels of the *Land* and *Management Qualities* and the vulnerability classes of the Attainable, Management and Actual types are through decision trees (Table 4.3).
   Appendix A shows the different classes of the *Land* and *Management Characteristics*.
   The following *Land* and *Management Qualities* are involved:

Land Qualities (with their subclass code)
LQ1 Relief, t
LQ2 Soil erodibility to water erosion, k
LQ3 Rainfall erosivity, r
LQ4 Soil erodibility to wind erosion, e

Management Qualities (with their subclass code)
MQ1   Crop properties to water erosion, o
MQ2   Cultivation practices to water erosion, z
MQ2.1 Cultivation practices to water erosion: soil, x
MQ2.2 Cultivation practices to water erosion: plant, y
MQ3   Crop properties to wind erosion, c
MQ4   Cultivation practices to wind erosion, u
MQ4.1 Cultivation practices to wind erosion: soil, s

MQ4.2 Cultivation practices to wind erosion: plant, p

Almost all the Land and Management Qualities separate four severity levels, as follows:

Very low
Moderately low
Moderately high
Very high

The whole Raizal model is based on 19 decision trees (Figure 4.1). All the decision trees can be observed by selecting the option "Decision Trees Observation" from the Original Evaluation Menu, and are presented in Appendix B.
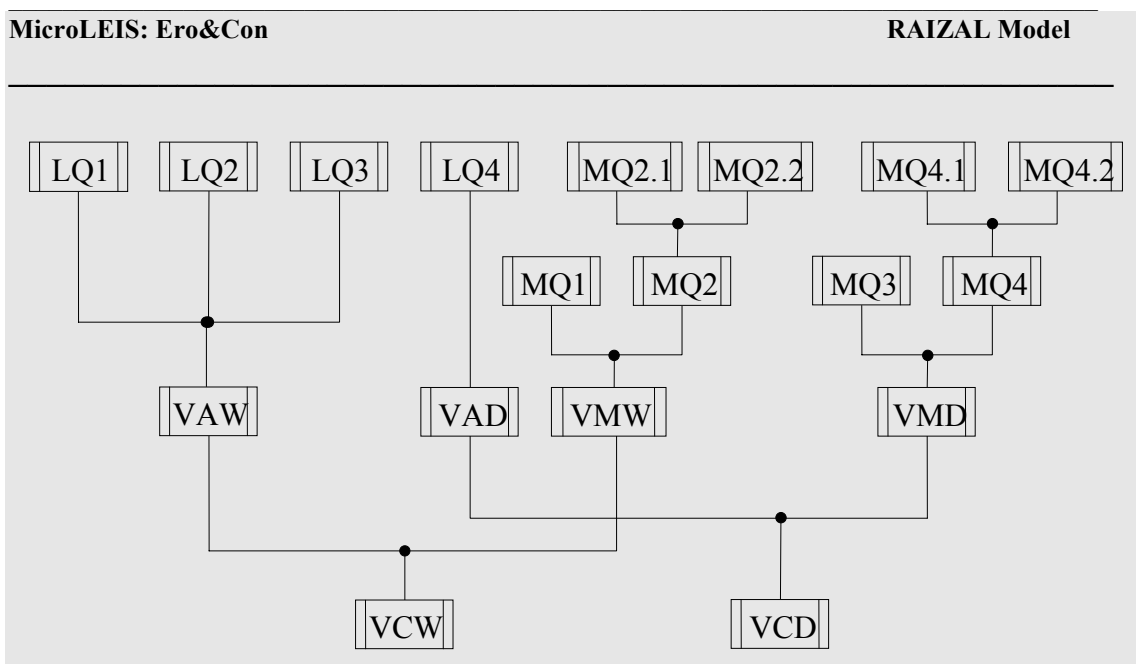

Figure 4.1. Index of the decision trees of the Raizal model

Table 4.3 . Summary of environmental land/management qualities and associated characteristics, for each vulnerability type of Raizal evaluation model.

Land/management quality	Vulnerability type	Land/management characteristic
Attainable erosion risks		
Relief, t	W, D	Landform; Slope gradient.
Water soil erodibility, k	W	Particle size distribution; Superficial stoniness; Organic matter; Drainage; Sodium saturation.
Rainfall erosivity, r	W	Mean monthly precipitation; Max monthly precipitation; Mean monthly temperature; Latitude.
Wind soil erodibility, e	D	Groundwater table depth; Particle size distribution; Organic matter; Mean monthly precipitation; Mean monthly temperature; Latitude.
.*Management erosion risks*		
Crop properties, o	W	Landuse type; Growing season length; Leaf duration; Specific leaf area; Plant height; Maximum rooting depth; Sowing date.
Cultivation practices (soil), x	W	Tillage practices; Tillage depth; Artificial drainage; Soil conservation techniques.
Cultivation practices (plant), y	W	Row spacing; Residues treatment. Crop rotation.
Crop properties, c	D	Landuse type; Growing season length; Leaf situation; Plant height; Structure of crop.
Cultivation practices (soil), s	D	Tillage practices; Tillage depth; Tillage method; Soil conservation techniques.
Cultivation practices (plant), p	D	Residues treatment; Crop rotation.

Vulnerability types: Water erosion (W), Wind erosion (D)

4.2. Pantanal Model

4.2.1. Vulnerability Classes

The agrochemical contamination vulnerability classes (4) established by Pantanal for the attainable and management vulnerability are defined as follows:

Class V1 None. Almost invulnerable to agrochemical contamination by agricultural activities, and the biophysical risks to soil, surface and groundwater diffuse pollution are very low. The corresponding fields have a very big storage capacity for agrochemical compounds and/or the amount of leaching and run-off of the contaminants is very low. The management system of this class does not lower the quality of the soil, surface and groundwater of the field unit.

Class V2 Low. A reasonably low vulnerability to agrochemical compounds which diffusely contaminate the soil, surface and groundwater. The agropollutant storage capacity of the corresponding fields is high, and/or the amount of leaching and run-off are low. The management system of this class could harm the quality of the soil, surface and groundwater of the field unit on a small scale.

Class V3 Moderate. A reasonably high vulnerability to agrochemical compounds which diffusely contaminate the soil, surface and groundwater. The agropollutant storage capacity of the corresponding fields is low and/or the amount of leaching and run-off ranges from moderate to high. The management system of this damages the quality of the soil, surface and groundwater of the field unit on a high scale.

Class V4 High. Very vulnerable to agrochemical contamination by agricultural activities, and the risks to soil, surface and groundwater diffuse pollution are very severe. The fields have a very small storage for agrochemical compounds, and therefore leaching could be very high. Also fields which are strongly vulnerable to run-off could damage the quality of surface water. The field management system of this class harms the soil, surface and groundwater quality of the field unit on an extremely high scale.

The assessment of the actual vulnerability is classified into five actual vulnerability classes:

Class V1 None. Field units of this actual class are almost invulnerable to agrochemical contamination because of their biophysical condition and management system. The actual vulnerability to soil, surface and groundwater diffuse pollution are very low. This management system is not considered to be a controlling factor and almost any other farming system could be implemented.

Class V2 Low. Field units of this actual class are slightly vulnerable to agrochemical contamination because the combination of the management system with

the biophysical conditions of the classified field unit does almost no harm to the soil, surface and groundwater quality.

Class V3 Moderate. Fields units of this actual class are moderately vulnerable to agrochemical contamination; the combination of the management system and biophysical characteristics of the field unit harms the quality of soil, surface and groundwater. The effect on the intensity of the management system to actual vulnerability class can change considerably.

Class V4 High. Field units of this actual class are highly vulnerable to agrochemical contamination, because the simultaneous impact of the management system and the biophysical characteristics damages the quality of the soil, surface and groundwater of the field unit on a high scale. More-intensive farming systems have adverse effects on the environment.

Class V5 Extreme. Field units of this actual class are extremely vulnerable to agrochemical contamination, because the intensity of the agricultural activities on the field unit and the high biophysical vulnerability of the field unit itself harm the soil, surface and groundwater quality on an extremely high scale. The water management and the quantity and toxicity of the pollutants have to be carefully applied to the field unit.

Besides classes, subclasses are also presented as evaluation outputs. The subclasses show the user the vulnerability limitations of the evaluated field unit and help in understanding the evaluated classification.

4.2.2. Decision Trees

The classes of each Land Characteristic (LC) and Management Charactersistics (MC) are connected with the severity levels of the corresponding Land Quality (LQ) and Management Quality (MQ) by complex decision trees. The connections between the severity levels of the Land and Management Qualities and the vulnerability classes of the Attainable and Management vulnerability types are through decision trees (Table 4.4).

Appendix A shows the division of the Land and Management Characteristics. The following Land and Management Qualities are involved:

Land Qualities (with their subclass)
LQ1   Surface Run-off, r
LQ1.1 Surface Run-off, Relief
LQ1.2 Surface Run-off, Soil erodibility
LQ1.3 Surface Run-off, Rainfall erosivity
LQ2   Leaching Degree, l
LQ3   Pesticides Sorption, o
LQ4   Biodegradation, g
LQ5   Denitrification, d

LQ6   Cation Adsorption Capacity, c
LQ7   Phosphate Fixation, f

<u>Management Qualities</u> (with their subclass)
MQ1   Phosphorus/ Arsenic Management, i
MQ2   Nitrogen Management, j
MQ3   Heavy Metals Management, q
MQ4   Pesticides Management, t
MQ5   Soil Erosion Management, r

Almost all the Land and Management Qualities separate four severity levels, as follows:

> None
> Low
> Moderate
> High

The Pantanal model is based on ?? decision trees (Figure 4.2). All the decision trees can be observed by selecting the option "Decision Trees Observation" from the Base Evaluation Menu, and are presented in Appendix B.
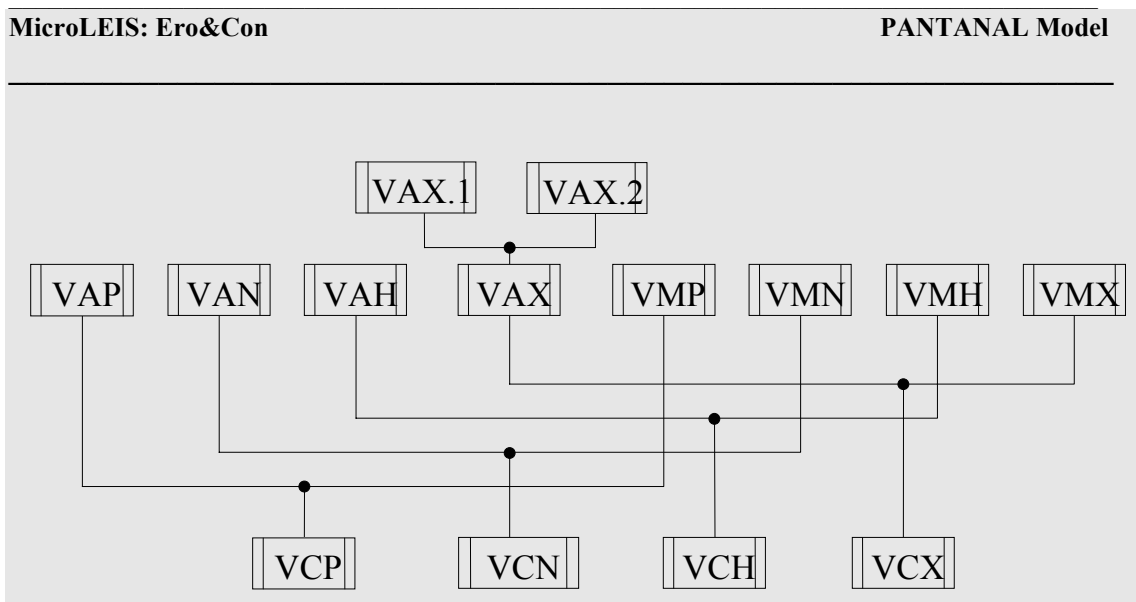

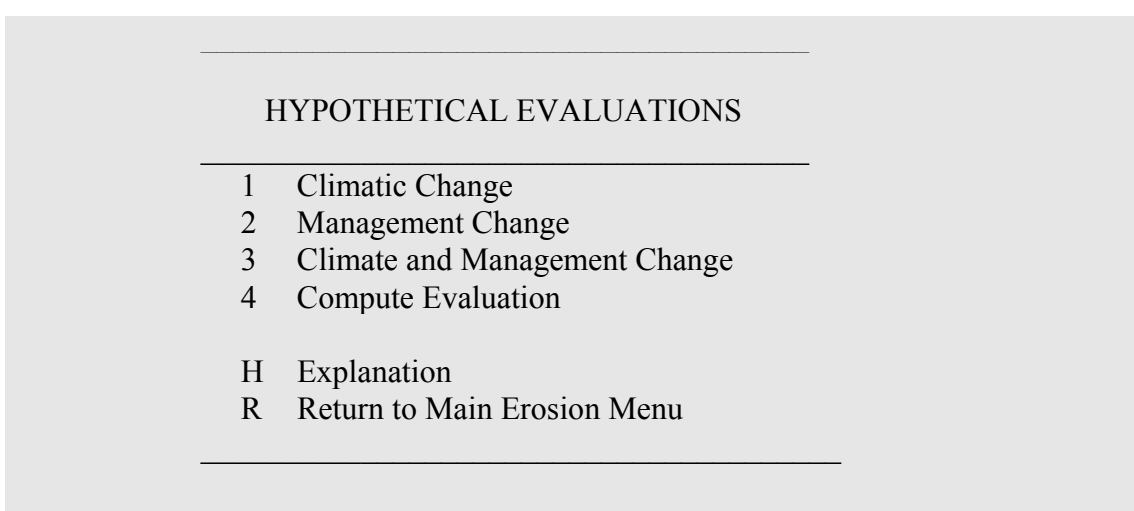Figure 4.2.   Index of the decision trees of the Pantanal model

Table 4.4. Summary of environmental land/management qualities and associated
characteristics for each vulnerability type of Pantanal evaluation model.

Land/management quality	Vulnerability type	Land/management characteristic
Attainable contamination risks		
Surface run-off, r	P, N, H, X	Landform; Soil erodibility; Rainfall erosivity.
Leaching degree, l	P, N, H, X	Monthly precipitation; Monthly temperature; Groundwater table depth; Drainage; Particle size distribution.
Phosphate fixation, f	P	pH; Particle size distribution; Organic matter.
Cation retention, c	N, H	pH; Particle size distribution; CEC; Organic matter.
Denitrification, d	N	Monthly temperature; Groundwater table depth; Organic matter; pH.
Pesticide sorption, o	X	Organic matter; pH; Particle size distribution; CEC.
Pesticide degradation, g	X	Monthly temperature; Monthly precipitation; pH; Organic matter.
Management contamination risks		
Phosphate incidence, i	P	Landuse type; Use of P-fertilizer; Artificial drainage.
Nitrogen incidence, j	N	Landuse type; Use of N-fertilizer; Crop rotation; Tillage practices; Time of fertilization; Residues treatment.
Heavy metals incidence, q	H	Landuse type; Crop rotation; Use of pesticides; Use of fertilizers; Use of waste.
Pesticides incidence, t	X	Landuse type; Persistence in soil; Toxicity of pesticides; Application methods; Artificial groundwater level.

Vulnerability types: Phosphorus (P), Nitrogen (N), Heavy metals (H), and
Pesticides (X).

5. Hypothetical Evaluations

The user has the option to generate hypothetical predictions by changing the climate- or/and management-related variables. So, it will be possible to predict for example the impact of climate changes on the field vulnerability to water erosion, or to predict the impact of the residues treatment of a field unit to pesticides contamination vulnerability. Table 5.1 shows the different options to run the hypothetical prediction.

Table 5.1. Menu to select type of hypothetical evaluation.

HYPOTHETICAL EVALUATIONS

1	Climatic Change
2	Management Change
3	Climate and Management Change
4	Compute Evaluation
H	Explanation
R	Return to Main Erosion Menu

5.1. Climate Change

Selection of the Hypothetical Climate Change option displays the screen shown in Table 5.2. At first, it is necessary to define the climate perturbation(s).

Table 5.2. Data input screen to generate a hypothetical prediction by changing the climate-related factors (ΔP and ΔT)

```
MicroLEIS: Ero&Con                                              RAIZAL Model
_____

                               CLIMATIC CHANGE
_____


_____
        Jan   Feb   Mar   Apr   May   Jun   Jul   Aug   Sep   Oct   Nov   Dec

Δ Pmax  0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
Δ Pmean 0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
Δ Tmean 0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

_____
Δ Pmax: Increment (+ or -) of Maximum Precipitation, %
Δ Pmean: Increment (+ or -) of Mean Precipitation, %
Δ Tmean: Increment (+ or -) of Mean Temperature, °C
_____
```

Three climate perturbation results from GCMs assumptions for the Mediterranean South can be selected using the <F1> key (Table 5.3). To apply these increments (ΔP and ΔT), the months December, January and February are included in the winter, and July, August and September in the summer. No changes are considered in the other months of the year. However, any arbitrary set of climate perturbations can be used.

The option "Compute Evaluation" selects the *evaluating-scenario*. When selected, the model automatically evaluates the hypothetical climate change scenario.

Finally, the model asks for names of files of tabular, graphical and CSV format presentation to display the output evaluation results.

Table 5.3. "Popup" screen showing three climate perturbations.

MicroLEIS: Ero&Con				RAIZAL Model

```
       Predicted climate perturbations  (after Kenny et al. 1993)
     _____
                 ΔT, °C                      ΔP, %
       Year    _____           _____

               Winter     Summer          Winter     Summer

                       Mediterranean South

       2010     0.5        0.25            -1.0        -8.0

       2030     1.25       1.25            -2.0        -8.0

       2050     1.5        2.0             -3.0        -12.0
```

5.2. Management Change

A Management Change evaluation can be made by changing:

- All the *Management Characteristics* (FUT).   Selecting a`particular *Field
  Utilization Type* (FUT),   by using the <F1> key, imposes it on all the
  evaluation-units of an *evaluating-scenario.*

- One or more *Management Characteristics* (MC). Selecting the classes of
  the MCs imposes them on all the *evaluating-units* of an
  evaluating-scenario.

In both cases, the option "Compute Evaluation" selects the *evaluating-scenario.*
When selected, the model automatically evaluates the hypothetical management change
scenario.
Finally, the model asks for names of files of tabular, graphical and CSV format
presentation to display the output evaluation results for this hypothetical scenario.

5.3. Climate and Management Change

Ero&Con models can also make hypothetical evaluations considering climate and management changes simultaneously. This option combines two of the previous changes: climate factors and management characteristics.

The option "Compute Evaluation" selects an *evaluating-scenario*. When selected, the model automatically evaluates the hypothetical climate/management change scenario.

Finally, the model asks for names of files of tabular, graphical and CSV format presentation to display the output evaluation results for this hypothetical scenario.

For this double hypothetical evaluation and for the two previous single hypothetical evaluations, the changes of input variables are not saved in the climate and management input database of Ero&Con models.

6. Output Evaluation Results

Three types of presentation - tabular, graphical and CSV format - are generated by Ero&Con models. These outputs are stored in files whose names were asked for by the program, and placed in the directory C:\MLERO\OUTPUT. The "Evaluation Results" menu (Table 6.1) gives access to all these output files of the models.

Table 6.1. Evaluation results menu of the RAIZAL model

EVALUATION RESULTS

1   Display Results
2   Delete Results

H Explanation
R Return to Main Erosion Menu

6.1. Display Results

The "Display Results" option is used to show the files of evaluation results, both original and hypothetical, referring to all the *evaluating-units* of a particular *evaluating-scenario*.

For the three types of vulnerability class - Attainable, Management and Actual - the evaluation results are shown in the following formats:

1) The tabular presentation of the *evaluating-scenario* with the evaluating unit, location, water and wind vulnerability classes (subclasses), and total index. For the actual vulnerability the following construction is used:

Class (attainable subclass/management subclass) e.g. V9 (kr/oz)

A summary of the vulnerability classes and their representative area, in km2, for this evaluated scenario is also included.

2) The graphical presentation shows the water and wind vulnerability class distribution, in percentage of the area, for the evaluated scenario.

3) The CSV format presentation, as the best manner to link the Ero&Con models with a GIS, is used on a similar way to the tabular presentation: including longitude, latitude and altitude of each evaluating-unit.

The results of hypothetical evaluations are presented in the same formats, although a reference to the climate or/and management change is also included.

The following pages show these output evaluation results for a scenario formed by a set of benchmark fields of Sevilla province. The original evaluation of results is followed by the corresponding results for a hypothetical evaluation of Sevilla province.

Example 6.1. Tabular presentation of the attainable contamination risks classes of the first 15 evaluating-units of *evaluating-scenario* Andalucia.
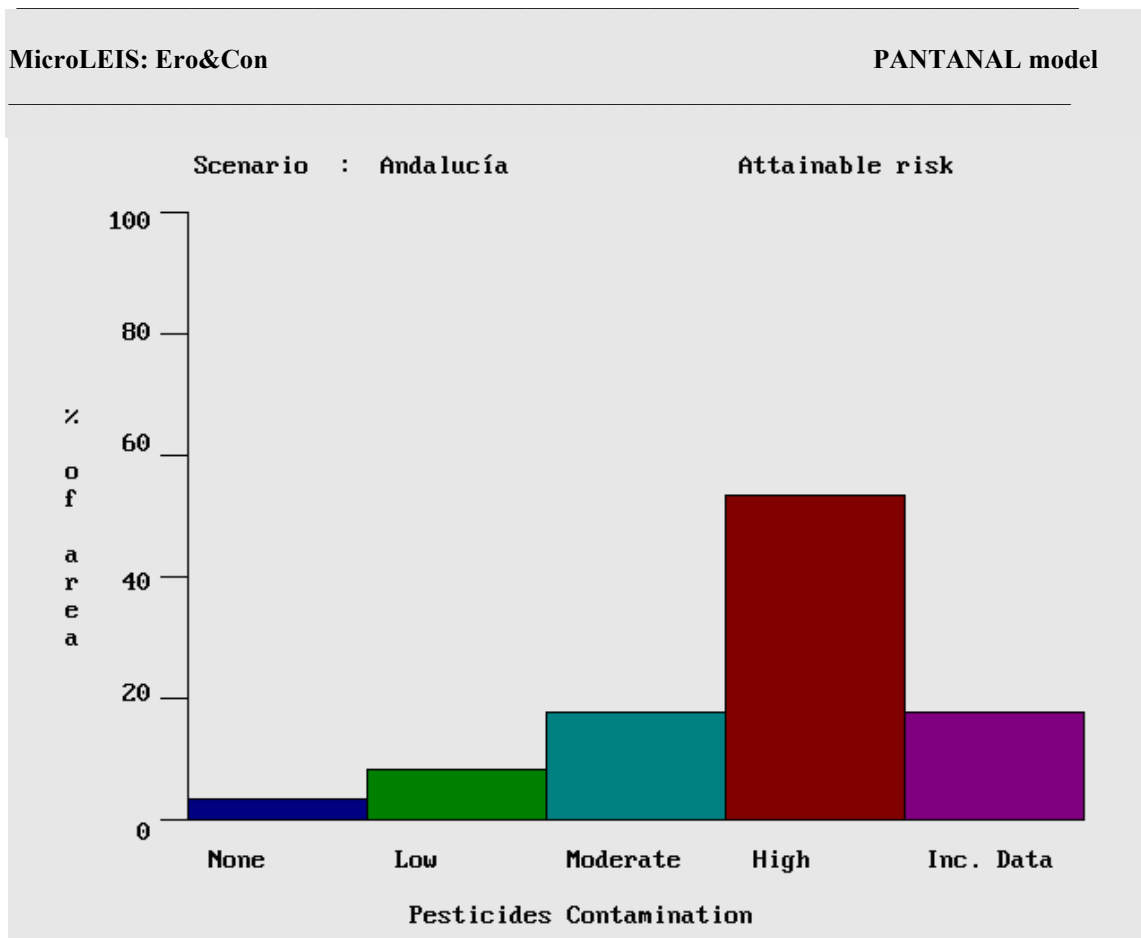
MicroLEIS: **PANTANAL model**

Base Scenario: Andalucia

Attainable contamination vulnerability classes

Evaluating unit	Location	Land Vulnerability types			
		Phosphorus	Nitrogen	Heavy metals	Pesticides
F-AL01	Greda-Roja Almanzaro-alto	V1	V2r	V3r	V4or
F-AL02	Pardo-calizo Almanzaro bajo	V1	V2c	V3c	V3g
F-AL03	Rendsina Andarax-Gabor	V1	V2c	V3c	V3g
F-AL04	Salino Campo-Dalías	V1	V3cd	V3cr	V3g
F-AL05	Volcánico Campo-Níjar	V2	V2c	V3c	V3g
F-AL06	Desértico Campo Tabernas	V3r	V2c	V3c	V3g
F-AL07	Pardo-calizo Los-Vélez	V1	V3c	V4cr	V3g
F-AL08	Aluvial Río-Nacimento	V2	V3cd	V3c	V3g
F-CA01	Tierra-negra Campiña	V3r	V4cdr	V4cr	V2r
F-CA02	Bujeo-blanco Campo-Gibraltar	V1	V3cd	V3cr	V1
F-CA03	Rojo Costa	V2	V3cd	V4cr	V4g
F-CA04	Tierra-parda Janda-Aljibe	V1	V4cr	V4cr	V4r
F-CA05	Albariza Rincón-Jerez	V3	V4l	V4cr	V2
F-CA06	Terra-rossa Sierra	V1	V4r	V4r	V3r
F-CO01	Albariza Campiña-alta	V4r	V4lr	V4cr	V4r

Example 6.2. Graphical presentation of the attainable contamination risks classes of the first 15 *evaluating-units* of *evaluating-scenario* Andalucia.

MicroLEIS: Ero&Con   **PANTANAL model**

Scenario : Andalucía   Attainable risk

Pesticides Contamination

Example 6.3. CSV format of the first 15 *evaluating-units* of *evaluating-scenario* Andalucia.

MicroLEIS: Ero&Con   **PANTANAL model**

Base Scenario : Andalucia

Land Unit	Long.	Lat.	Alt.	P	N	H	X
F-AL01;	W00218;	N3717;	1260;	1;	2;	3;	4;
F-AL02;	W00152;	N3714;	210;	1;	2;	3;	3;
F-AL03;	W00234;	N3654;	900;	1;	2;	3;	3;
F-AL04;	W00237;	N3644;	3;	1;	3;	3;	3;
F-AL05;	W00211;	N3654;	90;	2;	2;	3;	3;
F-AL06;	W00225;	N3702;	300;	3;	2;	3;	3;
F-AL07;	W00218;	N3736;	1080;	1;	3;	4;	3;
F-AL08;	W00247;	N3709;	700;	2;	3;	3;	3;
F-CA01;	W00600;	N3648;	53;	3;	4;	4;	2;
F-CA02;	W00522;	N3612;	70;	1;	3;	3;	1;
F-CA03;	W00609;	N3630;	20;	2;	3;	4;	4;
F-CA04;	W00540;	N3630;	450;	1;	4;	4;	4;
F-CA05;	W00611;	N3644;	60;	3;	4;	4;	2;
F-CA06;	W00534;	N3648;	200;	1;	4;	4;	3;
F-CO01;	W00439;	N3731;	240;	4;	4;	4;	4;

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