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LAIKIPIA RESEARCH PROGRAMME
University of Nairobi - Kenya
University of Bern - Switzerland
P.O. Box 144
NANYUKI, Kenya

Tel 0176 - 22'515
Fax 0176 - 22'201

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- to carry out applied research on socio-economic dynamics and on the management of water and soil resources in Laikipia District and on the northwestern slopes of Mt. Kenya
- to support postgraduate training mainly for Kenyan and East African students with focus on practical experiences in arid and semi-arid lands.
- to assist planning through documentation of the development process and to generate options and planning tools for improved development.
- to provide the infrastructure and a methodological approach which attracts other research and implementation institutions.

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PREFACE

The following paper was presented at the 3rd International Conference of the African Mountain Association, 3-14 March 1993, Nairobi, Kenya . The proceedings will be published in the journal **Mountain Research and Development.**

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SIMULATION MODELS AS MANAGEMENT TOOLS FOR SUSTAINABLE USE OF NATURAL RESOURCES FROM THE TOP OF MOUNT KENYA TO THE SEMI-ARID LOWLANDS

Hanspeter Liniger[1] and Francis N. Gichuki[2]

1 Laikipia Research Programme, Nanyuki, Kenya
Group for Development and Environment, University of Bern, Switzerland

2 University of Nairobi, Department of Agricultural Engineering, Nairobi

Key words: planning tool, modeling, applied research, highland-lowland, sustainable production, water and soil resources, extrapolation in time and space.

Abstract

The paper emphasizes on the natural resources - water, soil and vegetation/primary production - in the Mount Kenya region as a typical African mountain system. The ongoing project enhances the ongoing efforts to develop simulation models of natural resources in the Mount Kenya region in order to: (a) assess the effects of land use change on the water and soil resources and on primary productivity, (b) identify the potential for conservation and management techniques and (c) assist in planning for sustainable use of water, soil and vegetation resources. The scientific aim is to develop and combine model modules which refer to three different scales - single plot, small catchment and a river basin - to produce aggregated models at each scale-level. In the first phase, the project will concentrate on the Mt. Kenya - Laikipia area, where ongoing collaborative and interdisciplinary research programs between the Universities of Bern and Nairobi, and other research and development institutions will be further supported and coordinated in order to optimize the use of existing unique data-sets and the modeling experience. The project thrust is to strengthen the partner institution and researchers in the developing country and to provide appropriate tools for sustainable and productive use of water, soil and vegetation resources in African mountain systems. In a second phase (after 1995), the experience gained in Kenya will be applied to other African mountain systems.

INTRODUCTION AND OBJECTIVES

Tropical African mountains are important ecological islands. They provide natural resources which are crucial to the people living on the mountains but also in their vast surrounding lowlands. For example, the Mt. Kenya region provides water for a population of more than 5 million people. These crucial natural resources come under pressure from two sides:

(1) On the mountains and their slopes, land use intensification proceeds rapidly, due to population pressure and economic and technological changes. This development often leads to the degradation of soils and vegetation, and to the over-utilization of water resources (see Figure 1).

(2) In the surrounding lowlands, the demand for natural resources provided by the mountains increases rapidly, due to migration to marginal lands and the respective inappropriate land use practices of the immigrants.

This dynamic and conflicting situation makes management and planning for sustainable use of natural resources in African mountain systems extremely difficult. High standards not only have to be met in management and participatory planning approaches but also in assessment of the dynamics of the natural resources: Many development efforts have failed due to:

(1) inadequate assessments of the effects of land use changes on water, soil and primary productivity,

(2) the inability to cope with inter-regional effects of resource changes and

(3) the difficulties in assessing and demonstrating the potential of conservation and management techniques.

One of the reasons for these failures is that no tool is currently available to efficiently assess and demonstrate the integrated effects of land use changes, improved land use practices and the overall resource limitations of the highland-lowland interactive system.

Experiences in developed countries demonstrate that computer simulation models - in combination with GIS (Geographical Information System) - provide such tools with those current and future risk areas of environmental degradation can be assessed, and the effects of development and conservation strategies can be demonstrated. The basis of these advantages is that the models integrate the findings of different disciplines and guide and minimize the need for experimental and baseline data. Several models to simulate the effects of land use and conservation management on the natural resources have been developed and tested in the developed world: ANSWERS; EPIC; PRMS; SWRRB; CREAMS; SWIM; PERFECT; WEPP, etc. (Thomas 1993). Of special interest is the current development of a "systems model" APSIM in Australia. (Muchow and Bellamy 1991).

Although the use of computers is spreading rapidly in developing countries, few models have been developed for African Mountain Systems and hardly any modeling approach exists which can assist in the integrated planning of water, soil and vegetation resources, and in the identification of productive and attractive conservation and management practices. This is mainly due to:

(1) lack of adequate training and involvement of African scientists in model development,

(2) the lack of adaptation of the models to the conditions in developing countries,

(3) lack of long-term data records to calibrate, verify and validate the model components and

(4) inadequate long-term support for model development and model application in developing countries.

A few attempts were undertaken to assess land management in East Africa: Keating et al. (1992) and Ikonya et al. (1993) explored improved crop production in semi-arid areas of Kenya area with an improved version of the CERES-computer simulation (Jones and Kiniry 1986). A combination of crop production and erosion control measures was studied by Okwach et al. (1992), using the SWIM-model. There has been minimal research undertaken to establish appropriate catchment or river basin simulation models. Earlier research efforts, such as the EAAFRO (East Africa Agriculture and Forestry Research Organization) studies, focused on paired catchment studies to explore the hydrological impacts of land use changes. To date, catchment simulation has been undertaken using the SCRAMENTO model to estimate inflows into Lake Victoria, and by Thomas (1993) who used hydro-meteorological data of the Laikipia Research Programme (LRP) to explore the development of an appropriate catchment model.

In developing countries, computer modeling will gain importance and will be needed in natural resource management because it can be of great help in the following ways:

- To improve the understanding of the processes and as an instrument to generate and test hypotheses,
- To integrate different disciplines (climatology, hydrology, soil science, agronomy, crop / vegetation physiology, economy and sociology) and to bring researchers working in different areas together.
- To identify information gaps and to minimize the need for experimental and baseline data.
- To extrapolate experimental data, obtained in a few places over short periods of time, over a highland - lowland region and over a long time period, including possible effects of climatic variability.
- To asses current and future risk areas of environmental degradation and to set up development strategies.
- To identify optimum resource management and allocation options to maximize primary production and minimize environmental degradation.
- To investigate, in a prospective way, the consequences of land use change and potentials of resource conservation and management techniques.

In this paper, a modeling project is presented, which has the **goal** to enhance the development of computer simulation models of African highland - lowland systems in order:

1. to assess the effects of land use changes on primary productivity and on the water and soil resources;
2. to identify the potential for improved conservation and management practices;
3. to assist in planning for sustainable and balanced use of the water, soil and vegetation resources within an entire project region.

The **specific objectives** are:

1. to strengthen applied field research and modeling capacities and to improve the collaboration among different institutions (South - South and North - South).
2. To develop single modules on water balance, soil erosion, primary production and water demand and allocation.
3. to develop a modeling approach for amalgamating single modules into aggregated computer models for the M. Kenya region.
4. to use modeling to investigate effects of different land use and climatic scenarios.
5. to test their capabilities as a tool for management, education and research guidance.
6. to train postgraduate students and potential users.
7. to improve the applicability of the models and to apply them to other mountain areas.

The presented project is funded and supported from different organizations. The Swiss Development Cooperation (SDC) has been funding the Laikipia Research Programme (LRP) since 1984. In the cooperative effort between the Group for Development and Environment (GDE) at the University of Bern and the University of Nairobi (UoN), application oriented research in ecology and socio-economy has been carried out in order to assist in postgraduate training of East African researchers and to support planning and implementation for sustainable resource use. The approach and some of the results of LRP are presented in Liniger (1992a, b). Together with the support of the Rockefeller Foundation, which started in 1992, a well established field platform has been provided for the project. Additional funding has been made available from the Swiss Science Foundation and the Swiss Development Cooperation, within a programme called 'Priority Programme Environment' in order to complement and improve the modeling approach from 1994 onwards. Within the module 'Development and Environment', the presented project aims at contributing towards 'managing the fragile ecosystems: sustainable mountain development', which was formulated in chapter 13 of agenda 21 during the Rio de Janeiro environmental conference in June 1992.

METHODOLOGICAL ASPECTS

In order to set-up models, which can simulate water and soil resources and primary productivity as a function of changing land and water use and which can investigate the benefits of various conservation practices, proper field data has to be available and experiments have to be conducted. The **study area of the Mt. Kenya region** provides an unique opportunity to develop the model because:

(1) The variety of ecological zones, land use types and dynamics within a short distance and the respective problems of sustainable use of natural resources in this area are exemplary of many African highland - lowland systems.
(2) The Laikipia Research Programme (LRP) - a long-standing collaboration between the Universities of Bern and Nairobi - has developed an extensive data base (including a GIS) and currently maintains a field station network relevant to the proposed modeling project (see Figure 1).
(3) The project has already established collaboration with national and international institutions and is embedded into the local and regional planning and development activities.
(4) The proposed project fits into the core of the Mt. Kenya Ecological Programme (MKEP) which is supported by a wider range of national and international organizations and which will start by 1994.

The **main scientific and methodological questions** which are approached through the project refer:

- to the adaptation of water balance, water demand and allocation, erosion and crop growth modules to the conditions in the Mt. Kenya region,
- to the combination of these modules to produce aggregated models - a framework that allows the interaction between single modules - for the three scale levels (site scale, catchment scale, basin scale),
- to the link and communication between the different scale levels in combination with a GIS.
- to the minimization of data needs and to the concentration on key parameters.

For the **development of the modeling approach** existing knowledge and experience, has to be tapped by a strong **institutional collaboration** between different groups within and outside of Africa. The methods and the approach for this project still have to be developed in collaboration with the different research partners and the potential users at the regional and national level. Therefore, regular **workshops** are planned in the Mount Kenya region, where the collaborators (students, supervisors, modelers) and potential users (researchers, planners, decision makers and implementers) will meet in order:

- to identify users needs, demands and constraints.
- to improve and formalize the collaboration between different organizations and donors.
- to streamline the appropriate approach and methodology: using existing and developing own modules / models and combining single modules into aggregated models
- to identify training and knowledge gaps.
- to present the progress and improve methodology.
- to identify interested partners / projects in other tropical mountain systems in other mountain systems of the tropics for intensified collaboration in the second phase of the project.
- to assess / demonstrate the usefulness of the modeling approach for the users.
- to provide training for users.

This participatory approach to develop and regularly adapt the method and the focus on the users needs has to be considered as a key element of this project.

Modeling will be applied to the following **three scales**, providing for links among them. Figures 2 and 3 illustrate the current set-up on the:

1. **Site scale (farm or paddock scale):** This scale level covers small areas (plots) with uniform land use and natural characteristics in the size of hectares or smaller. The APSIM model (Agricultural Production Systems Simulation Model) which is currently being developed by an Australian group The basic idea is to calibrate and develop individual simulation modules and to link them to a central data base / data exchange. The individual modules such as water balance (including runoff, deep percolation, crop water use, soil- and groundwater changes), erosion, and crop growth / yields have to be able to simulate different management practices. The data for the modeling is provided by experiments on test plots, where runoff, soil loss, soil moisture and primary productivity is monitored. Additional site investigations are climatic measurements, infiltration experiments, soil, vegetation / land-use analysis (see Figure 4). Simulations are performed in time steps of one day or less.

2. **Small catchment scale:** Runoff and sediment transport is modeled on an event base while the water balance will be computed on a daily base. The model on this level needs to be developed, whereby established modules will be adapted and combined by using the same principal approach as the APSIM model, which includes routines for data management and exchange (see Figure 5). The link between the models on the site and the small catchment level will be of special interest. The GIS component is important in order to link the different scales. Model calibration is based on data from 8 small catchments ranging in the size from 1 to 5 km^2 in forested, agricultural and range areas in the highland and low land regions. Simulation models for small catchments would be very useful to assess the potential of water harvesting and the rates of siltation for the planning and designing of small dams,

3. **River basin scale**: Modeling of runoff and sediment transport is done on sub-basins of the size of hundred to several thousand km^2 based on data collected from 15 sub-basins using 30 runoff stations as a reference within the Upper Ewaso Ng'iro basin. The modeling will be based on the principles developed on the small catchment scale and the simplification / generalization process from the small catchment scale. Again, the GIS information and its accuracy will be an important component to link the different levels. The most important layers are on climate, land-use / vegetation, soils / relief. On this level, the experimental set-up and the modeling approach will allow subdivision of the whole basin into different zones from the highlands to the lowlands, and thus to assess the hydrological effects on the resource poor lowlands. Of major concern is the minimum low flow that is needed in the lowlands to provide adequate water supply for the nomads and their animals and for wildlife (see Figure 7). As on the other scales, existing models and modules will be tested and adapted to the conditions of the Mount Kenya area.

In order to achieve the modeling objectives, this project needs to **support and maintain the existing hydro-meteorological monitoring network and the experimental set-up.** This includes the monitoring of the (see Figure 1 and 2):

- perennial and ephemeral (episodic) river flow in the Upper Ewaso Ng'iro Basin,
- climatic parameters,
- river water use,
- different agronomic experiments:: the effects of water and soil conservation on the natural resources and the primary productivity (see Liniger 1992a, b).

Basically **two level of researchers** will be involved in this project:

- Postgraduate students: mainly for East Africa. As part of the postgraduate training, these researchers are involved in clearly identified parts of the whole modeling approach.
- Experienced coordinators, supervisors, modelers and resource management experts: Their role is to supervise students, to complement and synthesize the ongoing research activities, to transfer the knowledge and to improve the collaboration between the different research institutions. During a second phase the coordinators will have to emphasize on the practical applicability and transfer activities.

Single modules and aggregated models will be used to **assess different scenarios** such as the impact of:

- land use changes from forest reserve or bush land to small scale farming using conventional or minimum tillage (see Figure 4).
- changes in land management practices from well managed ranches to communal overgrazed land (see Figure 6).
- catchment land use changes on water and sediment yield and on primary production.
- climatic change on water and sediment yield and on primary production.

CONCLUSIONS AND RELEVANCE TO DEVELOPMENT AND PLANNING

Like most East African mountain systems, Mount Kenya is an outstanding resource oasis not only for the mountain slopes but for the surrounding lowlands with poorer resources. Planning of the resource utilization and conservation is complex and challenging due to extreme changes of the resources from the mountain peaks to the lowlands, due to dependence and interactions between the different mountain belts and due to increasing demands for and conflicts about natural resources. As a result of the complexity to plan natural resources in such a divers human and physical environment, there is need to develop an appropriate planning tool. This tool should help, to assess the effects of different land and resource uses on the short and long-term productivity and it should also assist in solving conflicts about resource utilization and allocation.

Apart from presenting the current approach, the paper aims at stimulating the discussion about the necessity of improved planning and allocation of fragile and increasingly needed African mountain resources. In the Mount Kenya region - as in many other African mountain systems - the demand for water is rapidly increasing whereas the resource is scarce. In the highlands, the soil productivity has to be maintained and the water use and its efficiency must be optimized in order to continue providing water to the resource disadvantaged lowlands (Figure 7).

As pointed out in the methodological approach of the project, there are still many steps needed to identify whether and how computer models should be developed, that they become relevant tools for natural resource management and planning in African highland - lowland systems. The project which uses a wealth of existing field information should be able to contribute to the discussions about the use of computer simulation models. It is strongly hoped that the proposed aggregated models will be relevant to development as they provide for a tool to assess land use-induced dynamics and problems of key natural resources in a prospective way. The anticipated benefits are at least threefold because the models act as a:

1. **Management tool:** The risk of natural resource degradation and the potential for improved land use practices can be assessed and demonstrated. Resource use and allocation can be optimized in terms of yields and sustainability. The assessment of land use scenarios without expensive new field research is crucial to planners and implementers. Further, selected results can be applied in participatory development approaches with the local communities of land users. The close link to the LRP gives the project a strong role in the District and National planning.
2. **Learning and communication tool:** The development and application of the model will catalyze the communication and collaboration among the different scientists involved and enhance the integrated understanding of processes in highland - lowland systems among scientists, administrators and implementers.
3. **Research tool:** The model will allow the use of information obtained at a few places and over a short time period to assess changes of natural resources over larger areas, longer periods of time and in relation to various scenarios. Problem-oriented information gaps can thus be identified and research can be directed accordingly and efficiently. The project will play an important role in promoting integrated research in the South and between South and the North.. It therefore enhances the capacities of the partners involved to carry out application- and problem-oriented research. This intermediate term applicability of the project is further supported by the strong involvement of postgraduate training.

The established links of the project with international organizations like UNEP, AMA (African Mountains Association) and UNESCO (through the Mt. Kenya Ecological Program) will further the models' perceptions of being unique for African mountain systems. They will therefore enhance the possibility to be extended to other mountain systems in future phases of the program.

Appendix: Model names:

ANSWERS Area Non-point Source Watershed Environment Response Simulation
APSIM Agricultural Production Systems Simulation Model
CERES maize simulation model
CREAMS A field scale model for Chemicals, Runoff and Erosion from Agricultural Management Systems
EPIC Erosion Productivity Impact Calculator
PERFECT Productivity, Erosion, Runoff Functions to Evaluate Conservation Techniques
PRMS Precipitation and Runoff Model System
SWIM Soil water infiltration and movement
SWRRB Simulator for Water Resources in Rural Basins
WEPP Water Erosion Prediction Project

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Figure 1: Aerial view of the northern slopes of Mt. Kenya, where the forest has been replaced by intensive crop production up to 3000 m a.s.l. Large scale wheat and barley production system uses minimum tillage, mulching, contour bunds and stabilized waterways as water and soil conservation measures (on the left). Recent subdivision into small-scale farms has not taken, soil and water conservation into consideration e.g. roads going up and down the slope (center bottom). Natural forests are still covering most of the medium and upper slopes of Mt. Kenya. The different vegetation and land-use systems next to each other are used for the experiments and field measurements to calibrate the models. Within this area the water and sediment discharge of 7 small catchments with different land-use is monitored. Additionally, the set-up consists of primary productivity measurements, 14 runoff / soil loss plots, 28 soil moisture tubes, 3 agrometeorological stations and over 10 daily rain gauges.

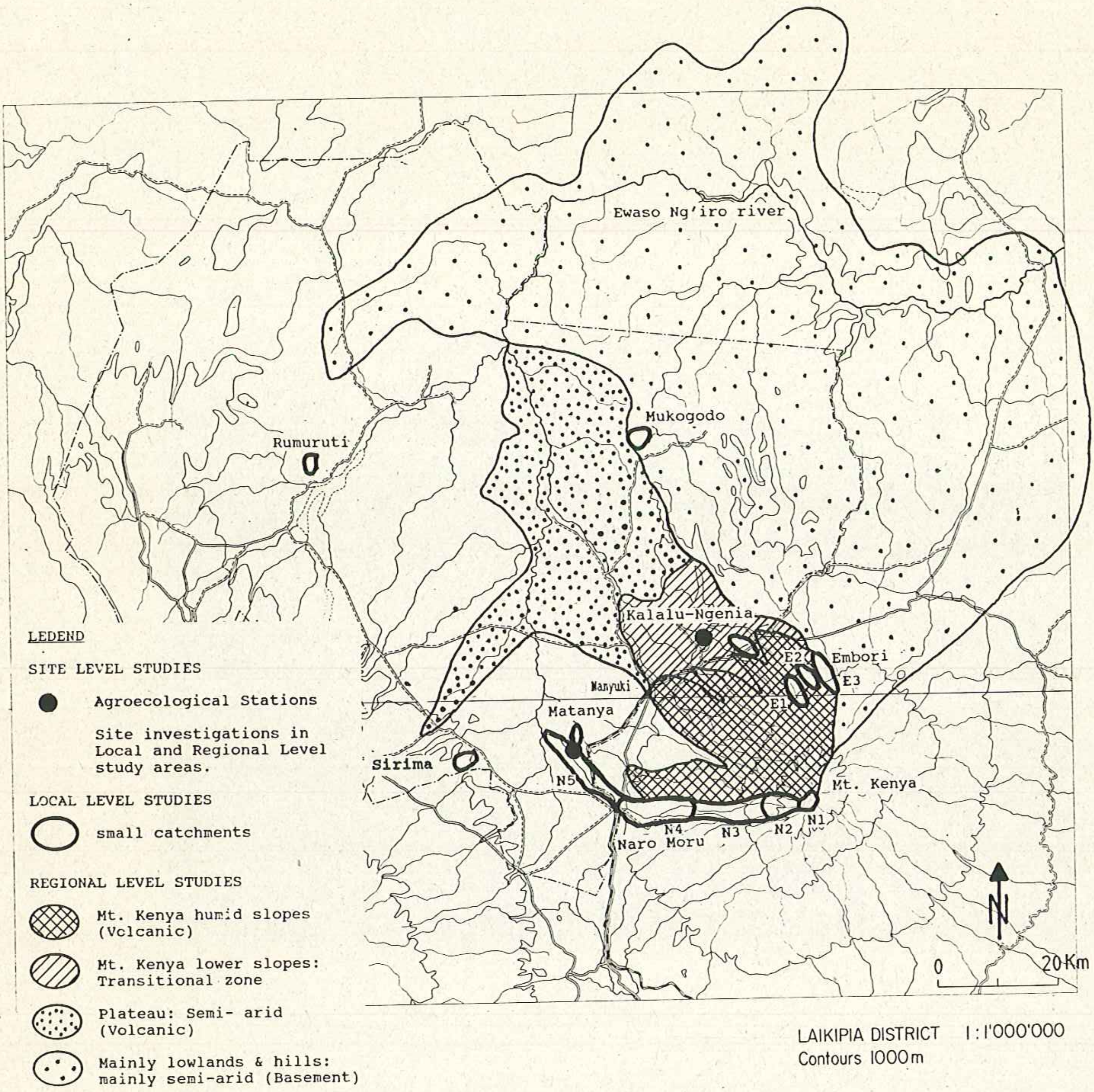

Figure 2: Field set-up and the three scale levels (site, local, regional) for the modeling project in the Mt. Kenya - Ewaso Ng'iro area. A total of 30 river gauging recorders, 15 rainfall recorders, over 50 daily rain gauges (over half are private), 12 agrometeorological station, 53 runoff / soil loss test plots, over 100 soil moisture monitoring tubes and over 50 primary production monitoring belong to the basic field set-up.

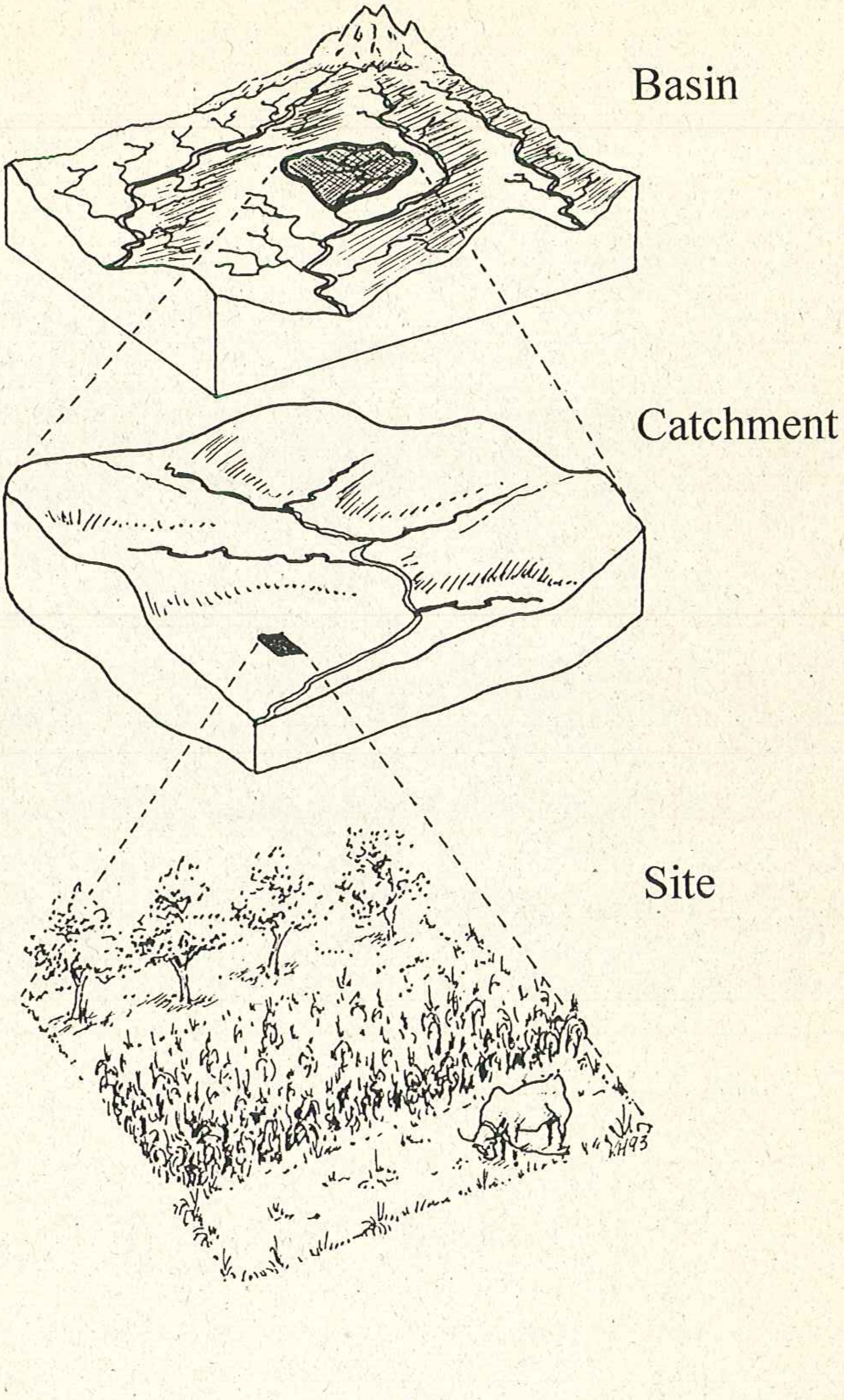

Figure 3: The three scale levels (Drawing: K. Herweg)

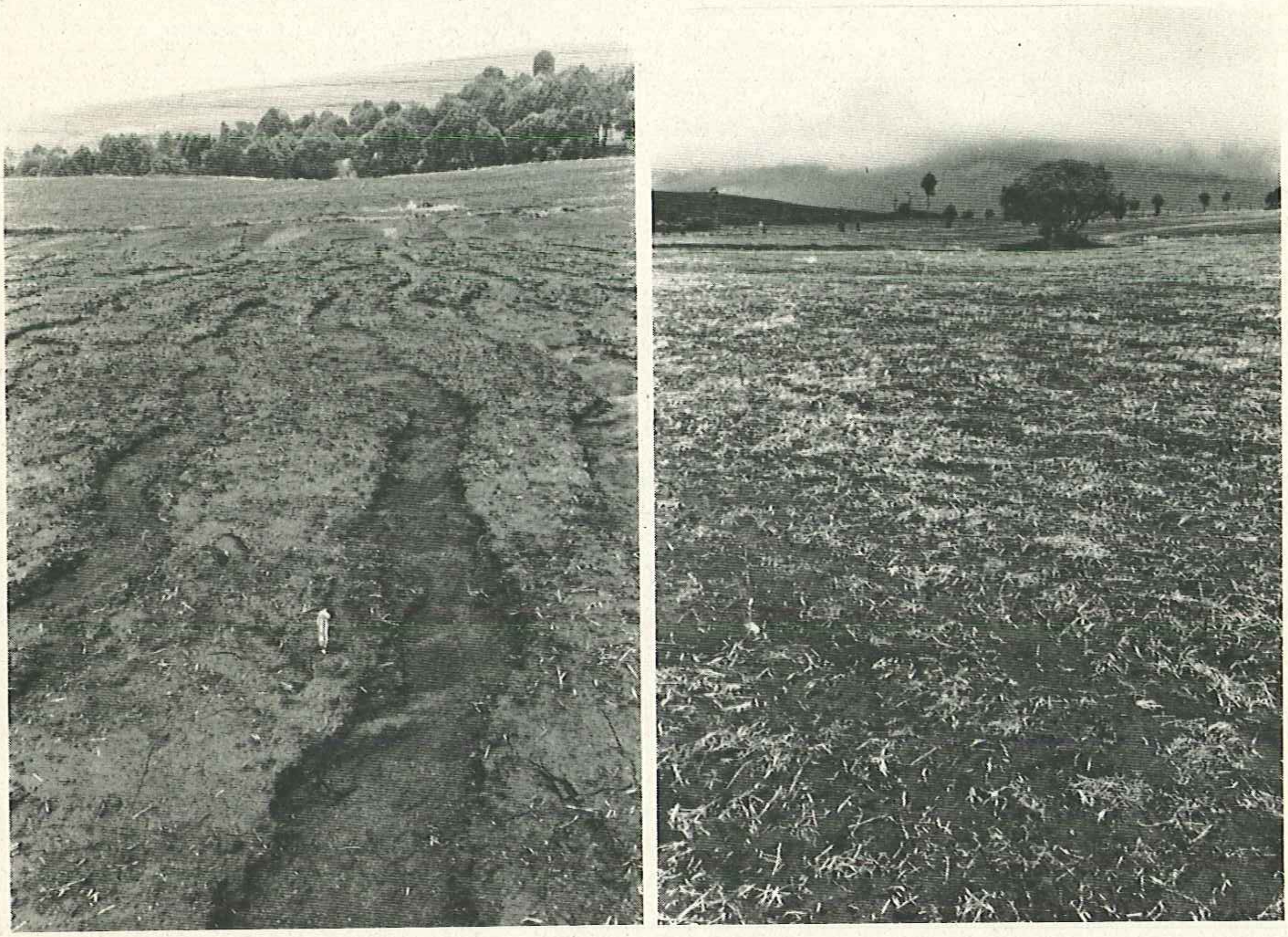

Figure 4: The importance of soil cover and topsoil management for runoff and soil loss in the upper forest zone of Mt. Kenya.

Left: Conventional deep tillage with harrowing breaking down the soil structure and digging the residues under, lead to severe erosion during a heavy storm of over 50 mm. Over 100 t/ha of soil can be removed during such single events, due to severe rill erosion, whereas the natural soil formation could cope with rates of around 10 t/ha. Runoff with such cover conditions are in the order of 30-60% of the storms.

Right: Minimum tillage and mulching (providing a cover of 30 to 40 %), reduced runoff and soil loss to a fraction compared to the adjacent field with conventional tillage. Runoff and soil loss can be reduced to less than one tenth.

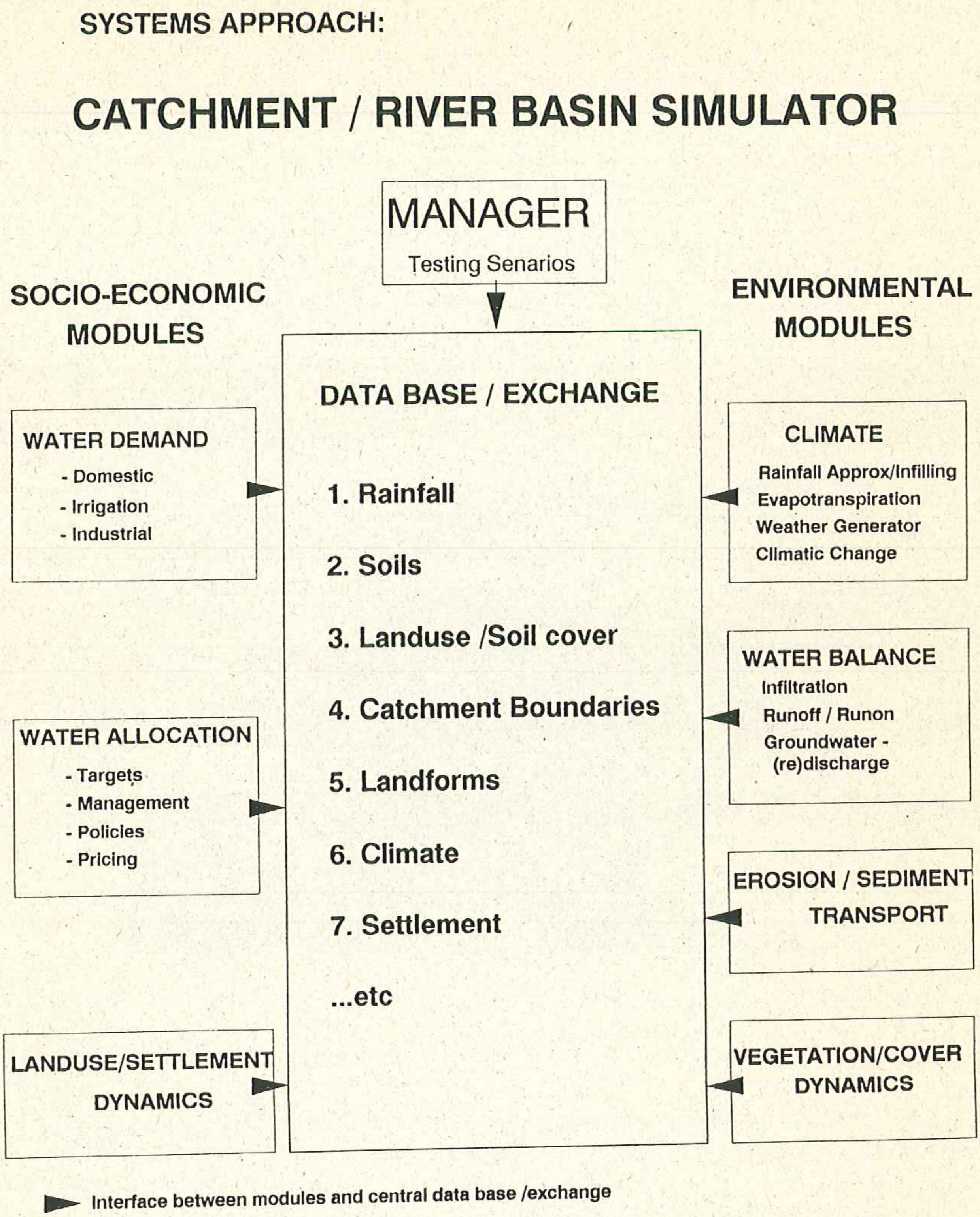

Figure 5: Systems approach (aggregated model) for the catchment and river basin simulator (Adapted from APSIM)

Figure 6: Gully erosion in the semi-arid pastoral area of Mukogodo. High grazing pressure has lead to a vicious cycle: removal of the grass vegetation cover and the compaction of the topsoil by the trampling of the animals has reduced the infiltration rates to about one tenth of the rate a good grass cover combined with a bush layer. The proper understanding and modeling of the effects of vegetation on the infiltration and the runoff soil loss is crucial to assist in the land-use planning and identifying maximum sustainable productivity.

Figure 7: Comparison between normal flow (above) and recent occurrence of no flows in the National Parks along the Ewaso Ng'iro river (below). Many of the Elephants have moved upstream in the search of water and fodder. One lonely elephant is digging for water in the dry river bed. Outside of the National Parks nomads and their animals also need a minimum flow of water. In order to plan that a minimum amount of water will flow to the lowlands proper knowledge of land- and water use in the highland is needed.