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Introduction

Land degradation is related to climate and soil characteristics, but mainly to deforestation and inappropriate use and management of the natural resources soil and water. It leads both to a non sustainable agricultural production and to increased risks of catastrophic flooding, sedimentation, landslides, etc, and effects on global climatic changes (Pla, 2000).
The problems of soil and water degradation and derived effects are increasing throughout the world, partially due to a lack of appropriate identification and evaluation of the degradation processes and of the relations cause-effects of soil degradation for each specific situation, and the generalized use of empirical approaches to select and apply soil and water conservation practices. In some occasions, the wrong selection or application of soil and water conservation practices and structures may increase land degradation processes and derived environmental impacts.
Landslides in hillslopes, which have been generally viewed as isolated catastrophic events resulting from infrequent rainfall and seismic events, are becoming major erosion and sediment transport processes worldwide, where deforestation (Sidle, 1992) and drastic land use changes occurs, causing irreversible land degradation. Even in cases where landsliding is related only to extreme rainfall events with long return periods, the amount of soil removed and off-site effects generally outweigh the effects of the more studied continuous surface erosion processes. The influence of the effects of land use and management changes, including the injudicious application of soil and water conservation practices and structures, like terracing, in triggering landslides and mass erosion in general, is largely overlooked.

Causes of land degradation

Economic and social problems, connected to population pressure, market changes and prices, and technical needs, may produce drastic and sudden changes in land use and management, which may increase the potential hazard of land degradation and side effects (Pla, 1993).
In some countries or regions of the World, agricultural production patterns and practices have changed over the last century, becoming highly mechanized, capitalized and specialized, emphasizing labor-substituting technologies, which focus on the generation of short-term cash flow. In the absence of sufficient economic incentives for conservation, this type of agriculture incorporates no concern for long-term sustainability of production. In others, population growth and lack of resources have obliged to intensify the use of marginal lands without appropriate conservation practices, which is leading to land degradation and non sustainable agricultural production.
Global climate changes may contribute to accelerate some land degradation processes and their effects in some regions of the World, but in any case, land use changes, including deforestation and other human activities leading to soil degradation processes may affect more the processes and effects of land degradation than the previewed global climatic changes, or may increase the influence of these changes (Pla, 2000). Moreover, appropriate land use and management can substantially reduce the buildup of atmospheric greenhouse gases and the derived global warming, reducing CO_2, N_2O and CH_4 emission and increasing carbon sequestration in vegetation and soil.
Although land degradation risk may be mitigated by specific soil and crop management practices, some degree of production risk will always remain. In advanced agricultural systems land degradation processes are generally compensated by constant external inputs of energy, nutrients and other control measures, to avoid soil and water degradation effects. Any break in these artificial measures may cause a complete loss of productivity, as it frequently happens in developing countries due to economic setbacks. The negative effects of land degradation may be masked by technological inputs like improved crop varieties, heavy use of fertilizers, better pest and disease control, irrigation and improved tillage and planting methods, but there is eventually a point at which those inputs can no longer sustain economic production.

Soil and water conservation for sustainable land use

Sustainable land use must be based on a balance among competing technical, social, economic and environmental considerations. The lack of multiobjective focus on land use and planning has produced an unilateral approach to resource utilization taken not into account the interdependence of environmental, production and social factors. The consequence has been problems of soil and water degradation, resulting from soil erosion, inappropriate land management practices and conflicting land uses. As a result, not only is the inherent productive base of the land resource affected, but the off-site impacts accrues significant social costs, which in most cases have failed to be acknowledged and quantified (Watkins, 1991). Off-site impacts of soil and land degradation frequently generate more concern than the effects on the land or soil itself, due to their visibility.

To achieve sustainable land development, it is required a full cooperation of governments, the community at large, and the land users themselves. A sound understanding of the actual and potential causes and processes of land degradation would prevent implementation of costly and non effective soil and water conservation projects and plans, and would lead to gradual and inexpensive changes leading to more sustainable forms of land use.

Planning and implementing land use properly leads to fewer degradation problems, achieving both short-term and long-term benefits (Sheng and Meiman, 1988). In planning land use, there must be considered the requirements and limitations affecting both the crops, the management and the environment. It is important not only to assess the risk of degradation, but also to have a sound understanding of the causes and processes of degradation, and of the possibilities available for their control (Pla, 1994).

Soil and water conservation is the most important part of land-use planning, and must be inserted into the whole context of land-use planning for land development. Soil and water conservation programs must be seen as the development and application of land use systems that preserve or enhance soil productivity. The factors responsible for detrimental land use must be identified and removed before the adoption of new land-use systems. For justifying soil conservation projects within land use planning programs, it is necessary to make an economic analysis in terms of costs and benefits. There are required data relating soil degradation to productivity loss, but sometimes the losses and gains are mainly off-site than on-site.

In the economic assessment of land conservation projects it is necessary that the policy makers and land users be aware that land degradation is not only leading to crop yield reductions, but that it may cause serious problems offsite (downstream), including silting up of streams, dams and channels, damage to hydroelectric and irrigation schemes, restrictions to navigation in rivers and harbors, and increased frequency and severity of flooding and landslides.

The development of new and improved technologies for increasing production of crops, wood, cattle, etc, to satisfy requirements of food, fuel, shelter and cash must ensure that the natural resource base water and soil, on which land degradation is based, is not depleted. Sustainable land management focuses in technology that minimizes risk, increases or guarantees production, and ensures the integrity of the resource base. It must match agro technology to the particular agro environment, not only to meet the goal of stabilized and increased yields, but also to protect the land resource base, so that it is conserved for future generations (Virmani and Eswaran, 1991).

Natural disasters like flooding, landslides, etc., linked to extraordinary climatic events, need to be considered in preparing guidelines for evaluating soil and water conservation practices (Brammer, 1991). It is necessary to identify appropriate interventions which could, where feasible, eliminate or reduce the impact of specific kinds of disasters.

Hydrological approach for assessing soil and water conservation practices

Land-use planning strategies must be based on adequate integrated management of soil, water and crops, to increase sustained agricultural productivity, taking into account that inappropriate land use often is tied to local social-economic and political issues. The planning framework for the achievement of sustainable land management must consider and be aware of the increased complexity of environmental processes and problems derived of land degradation, from local to regional, to national and to global dimensions. That understanding is essential for developing a realistic approach for the effective application of soil and water conservation practices to prevent land degradation and for the achievement of sustainable land use.

Planning land use and management is a dynamic and iterative process, and plans must be considered only points of departure rather than rigid projects (Sheng and Meiman, 1988). Any plannification should allow for continuous refinements as experience is gained through in site adequate monitoring, and should reconcile what have to be done, based on biophysical factors, and what can be done, based on social-economic conditions, and capability and interest of land users.

The cost-effectiveness of expenditures on soil and water conservation practices may be greatly increased if a goal balance is previously established, and multiobjective planning is used as a basis for decision making. For this we have to be aware that although the general principles of the control of soil degradation are the same everywhere, there are no ready-made solutions to land degradation which can be applied universally, and each situation requires planning strategies adapted to its own complex local conditions and circumstances. The assessment of sustainable land management required for planning land use requires an understanding of potential changes, associated to climate and land use and management, in the soil parameters, which determine productivity and land degradation potentials. Among the different land degradation processes, soil water erosion is the major threat to the conservation of soil and water resources. The processes of soil erosion generally result on, or there are caused by unfavorable changes in the soil moisture regime, and in the possibilities of root development and activity. Besides surface erosion in gentle to moderate slopes, mass movements and landslide erosion are common in more steep slopes. The hydrological processes leading to surface or mass erosion are different, and therefore, soil conservation practices very appropriate for controlling surface erosion processes may increase erosion danger by mass movements under specific combinations of climate, soil and slope. Landslide erosion processes, or mass movements in general, are more common in deep unconsolidated sedimentary or volcanic materials, and although occur less frequently than surface erosion may lead to much higher and more concentrated soil losses, with more dangerous offsite effects.

Landslides in steep terrain, are becoming major erosion processes worldwide, where deforestation and drastic land use changes have occurred. Many major landslides result from infrequent rainfall or seismic events that induce unstable conditions. These extreme events generally only attract attention when lives are lost, but in addition to threaten human life and personal property, landslides can seriously decrease land productivity. Landslides normally occur during or soon after unusually heavy and prolonged rains, and are triggered when the water pressure builds up at the contact between the loose soil mantle and the underlying relatively less permeable boundary. Up to now, landslides have been viewed as isolated, catastrophic events, and the influence of the effects of land management practices on mass erosion is largely overlooked.

Land use changes associated with techniques of land preparation causing massive soil redistribution and slope morphology changes, like land leveling and bench terracing, causing rerouting and concentration of runoff and drainage water, increase risks of catastrophic mass movements. Bench terraces have been considered probably the single most technically-effective measure to combat the erosion and the associated loss in site productivity. Terracing, and specially bench terracing, is an extremely expensive form of land treatment, both in term of initial construction and subsequent upkeep. These terraces, allowing more rainfall to infiltrate, and in some cases concentrating drainage water from upslope, may reach under intense and prolonged rainfall soil moisture conditions triggering landslides and disastrous collapse of the same terraces, specially if they are not well designed, maintained or adapted to the particular conditions of climate, soil and slope. The flow processes associated with landslides may lead to active gully incisions, with continued and increasing erosion by gully erosion and retreating slumping, resulting in large and non controllable gullies and heavy sediment loads, with very dangerous off-site effects.

There are required methods for predicting, avoiding and controlling soil mass movements, based on rainfall intensity-duration relationships, antecedent moisture, field evaluation of topographic, geologic, soil, hydrology and vegetation. Sidle (1992) proposed a model where the probabilities of landslides is related to specific forest management practices, based on soil, site, root strength data and probability of occurrence of a landslide triggering factor. Hydrological approaches, where hydrological processes and soil water regime are evaluated may help to clarify the connection between climate, soil, topography and land use and management changes with mass erosion, to predict and control negative effects (Pla, 1997). Sometimes, due to difficulties in measuring hydrological processes related to very variable climatologic, geomorphologic, soil and land use conditions, they are simulated using empirical or semi- empirical relationships, usually with disastrous consequences.

Hydrological approaches would be essential to assess the effectivity of soil and water conservation practices to control or to cause unfavorable environmental impacts. Integrated with economic and land use data over time, using modeling (Baier and Dumansky, 1991), the generated information may be used in planning strategies for land use, and in the selection of soil and water conservation practices based on probabilities of success, levels of risk and long term sustainability (Pla, 1994; 1997). Simulation modeling require data collection, updating of information and monitoring. Uncritical use of results from any model supplied with poor available data, for taking “decisions urgently required”, which is a common situation, is very dangerous, and may lead to catastrophic consequences.

Models must be based on well established cause-effect relationships for prediction, and flexible enough to be able to include the variety of possible soil-climate-cropping-socioeconomic situations, and to be constantly improved as more is known about the influence of specific land and climate characteristics on degradation processes. It is desirable to develop models which can show results of interactions among land resources, degradation processes, conservation measures and productivity over future years. The combination of geographic information systems (GIS) and that kind of modeling offers the opportunity of assessing environmental impacts of different soil and water conservation practices, and presents a logical framework for integrating subsequent monitoring.

Planning land use for soil conservation, needs of reliable data on the characteristics of soil and water resources. To develop modified and improved or new land use and management systems to avoid adverse effects on water supply, food production and quality , and nature conservation, fundamental knowledge about physical, chemical, hydrological and biological processes in soils have to be available. Good soil data base are also required for modeling the potential for carbon sequestration, under changing conditions of land use and climate. The analysis itself, by models, GIS, etc does not add any new information, and when it is based in empirical approaches developed for different conditions, to substitute non available local data, it may lead to gross inaccuracies and misinterpretations. In general, there is a need for more efficient collection of basic information on land and its use for an appropriate evaluation and modeling of land-use planning.

Methodology for an adequate quantitative characterization and prediction of the affected soil hydrological properties is required to evaluate the actual problems and to assess the potential environmental impacts of different soil and water conservation measures. Besides measurements under precise conditions in the laboratory, useful for understanding the hydrological processes, these have to be approximately quantified at field scale.

The methods and techniques applicable for predicting soil hydrological behavior under field conditions include from simple, straightforward field techniques, usually providing rough estimates of soil hydraulic properties, to rather complicated techniques for more accurate time consuming measurements, requiring sophisticated skills and costly equipment. The simple field techniques must be preferred (Pla, 1990), because of operational considerations, and because they are more able to be adapted to the required sample volume and spatial variation of soil hydraulic properties under field conditions. Although modern indirect techniques like remote sensing, computerized data processing, GIS and simulation models may help in the required evaluations, they will always require of actualized and accurate direct measurements or estimations of soil hydraulic parameters. Specially needed are better and simpler methods to monitor important hydraulic properties of soils and their dynamics on a field scale, for both diagnostic and prediction purposes. In any case it is desirable to keep the information that must be obtained simple, so that basic objectives can be achieved (IBSRAM, 1995).

The use of empirical regression-based models – based on a limited number of land characteristics and qualities hidden in black boxes and interacting in a linear multiplicative or additive way – sometimes with local weighting or calibration factors, to predict land degradation in order to plan efficient land use for sustained production, in regions other than those for which they were developed, is frequently leading to failures and even disastrous consequences. There are required more efforts toward more quantitative hydrological approaches, using process based simulation models, where the main dynamic factors and processes responsible of sustained production and of land degradation are included (Foster and Lane, 1987; Pla, 1997).

Figure 1 shows the flow diagram, which was the basis for the development of the simulation model SOMORE (Pla, 1997). It simulates the evolution of the soil water balance in the soil profile with a time step of one day, using easily obtainable soil and meteorological data as input. It may be used to predict the soil moisture regime, including water logging, rainfall losses by surface runoff, and surface and internal drainage, under different conditions of soils, topography, climate, vegetation, crops and management. The predictions may be used to identify the more probable degradation processes, and for the selection of the best alternatives, with more probabilities of success and for the assessment of environmental impacts of soil and water conservation practices for each combination of soils, climate and topography.

Hydrological approaches allow to combine the characteristics of climate with the characteristics of soils and landforms and land-use types, for interpretation and prediction of land degradation hazards. When applied to a series of scenarios of land use and potential environmental and climate change impacts, the results can be used by decision makers for future land use planning and implementation. This approach makes the extrapolations more soundly based and provides a scientifically solid base which leaves little space for subjective interpretations leading to alternatives for different land use and management for agricultural and non-agricultural purposes. Modeling hydrological processes has proved to be a very reliable tool for evaluation and prediction of land degradation processes for guiding planning strategies for soil and water conservation and management practices, under very different climate, topography, soils, cropping and management conditions (Pla, 1994; 1995; 1997; 1998; 2000).

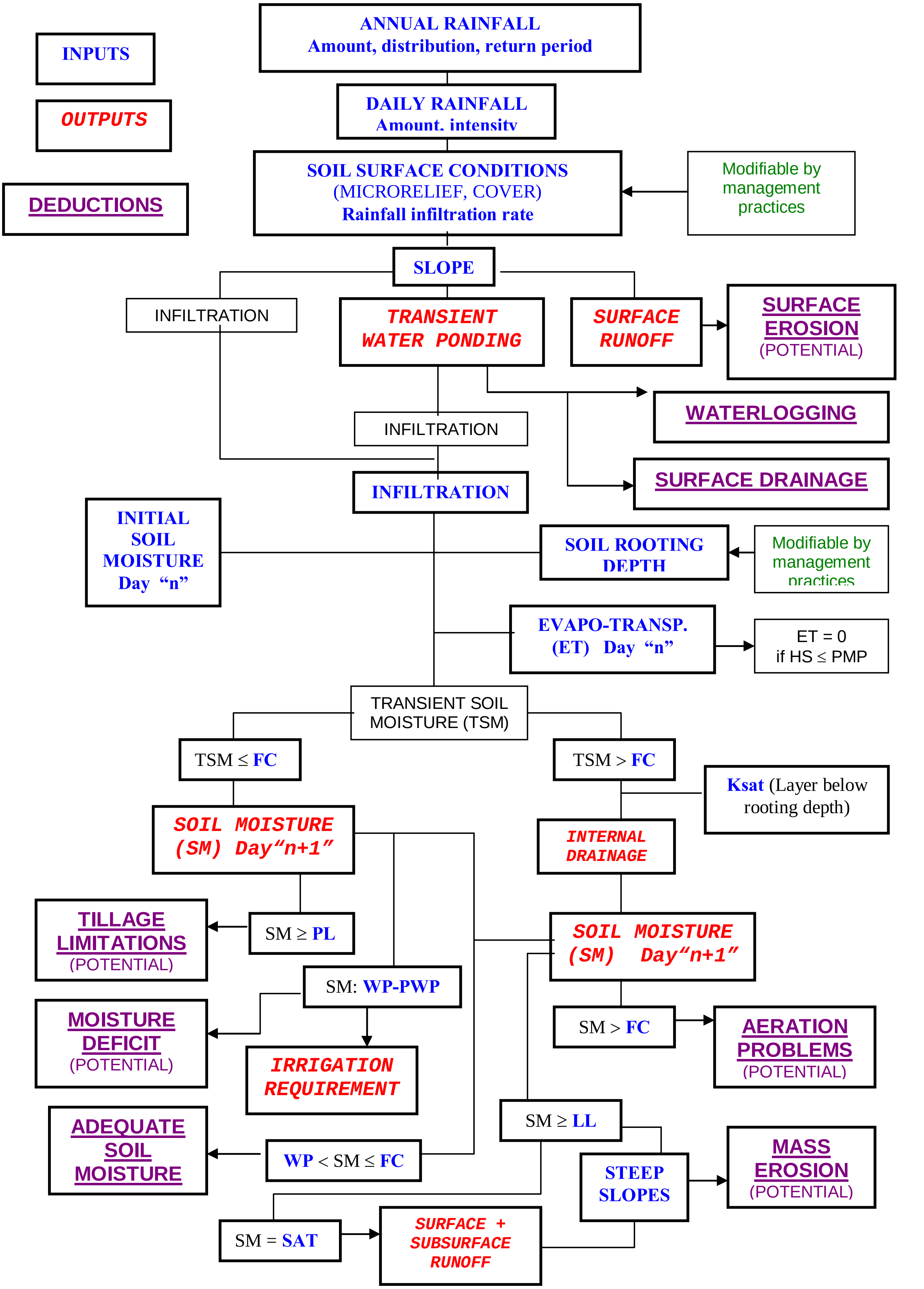
Figure 2 shows in a very simplified way the interactions of the different conditions and processes leading to potential land degradation processes and effects, both on-site and off-site, and the steps to be followed for land evaluation and land-use planning leading to effective soil and water conservation practices for sustainable land use and management, in different biophysical and socioeconomic scenarios.

Conclusion

The evaluation of soil and water degradation processes must allow the design of sustainable and productive land use and management strategies which guarantee protection of the environment, previewing the effects of different combinations of climate, soil, slope and management, including extraordinary events with low return period. That requires to change the present mostly empirical, subjective and qualitative evaluations, for quantitative evaluations based on hydrological processes. The evaluations must take into consideration that soil degradation not only causes problems in site, but it may cause serious problems off-site. An hydrological approach does facilitate a more integral evaluation at both levels.

The processes of soil and water degradation are strongly linked to unfavorable changes in the hydrological processes responsible for the soil water balance and for the soil moisture regime, which at the same time are affected by the climate conditions, and by the use and management of the soil and water resources, including soil and water conservation practices. This requires an interaction of monitoring studies, experiments and modeling, in order to be able to evaluate and predict the effects of climate changes, specially of extraordinary climate events, which are responsible of most of the soil loss by erosion, and of flooding, landslides, sedimentation, and related disastrous impacts, which may threaten human life and damage personal property, infrastructures and lands.

Although modern indirect techniques like remote sensing, computerized data processing, GIS and simulation models may help in the required assessment of the actual and potential environmental impacts derived of the application of different soil and water conservation practices, they will always require of actualized and accurate direct measurements or estimations of soil hydraulic parameters.



(Ksat: Saturated hydraulic conductivity; FC: Field Capacity; WP: Water retention at 0,15 Mpa; PWP: Water retention at 1,5 Mpa; PL: Plastic limit; LL: Liquid limit; SAT: Saturation)

Figure 1. Flow diagram of a conceptual hydrological based simulation model to predict the soil moisture regime and to assess the potential soil degradation processes (Pla, 1997a)

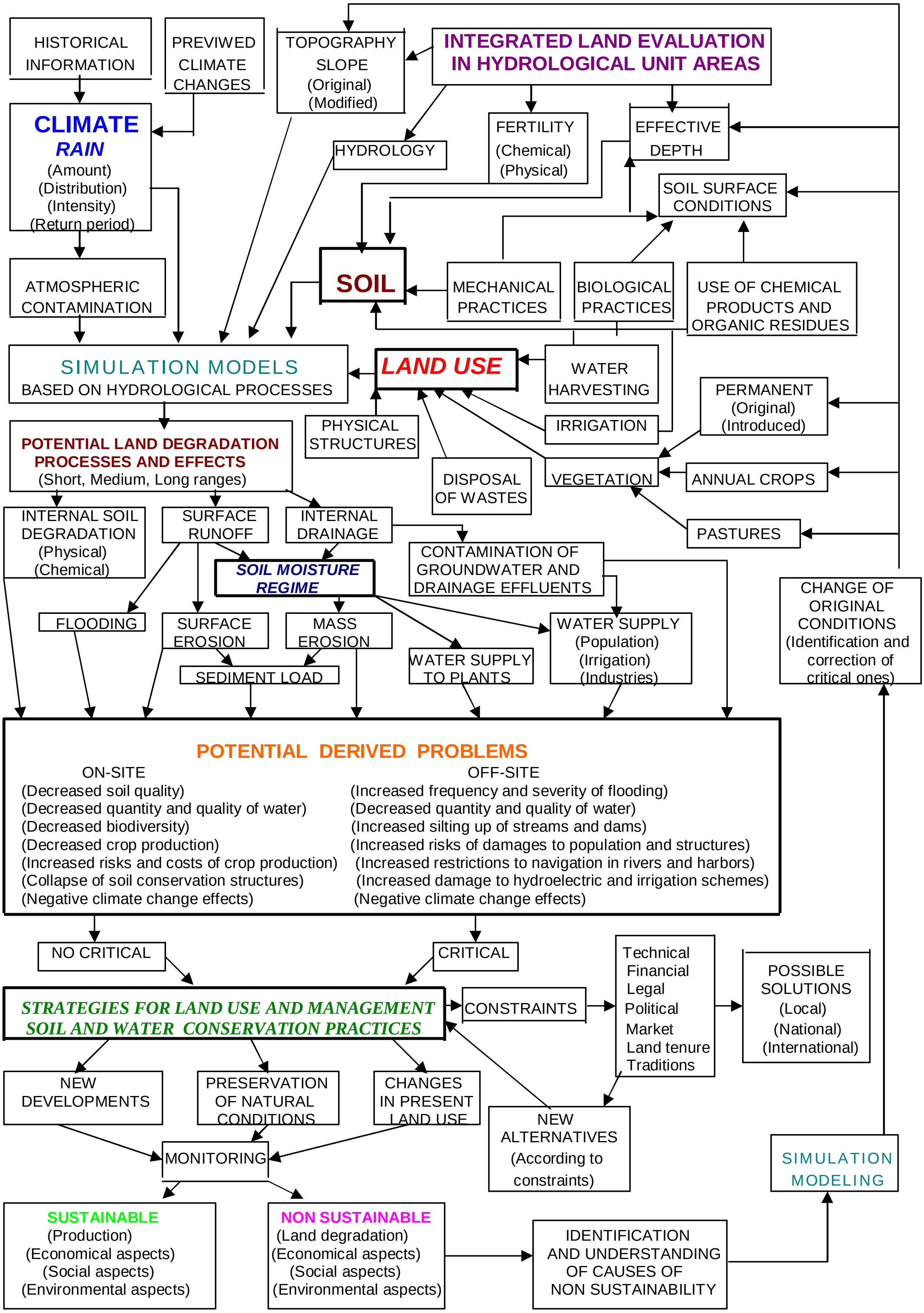


Figure 2. Interactions of land degradation processes, causes and effects, with land use, management and soil and water conservation practices.

Although modern indirect techniques like remote sensing, computerized data processing, GIS and simulation models may help in the required assessment of the actual and potential environmental impacts derived of the application of different soil and water conservation practices, they will always require of actualized and accurate direct measurements or estimations of soil hydraulic parameters.

Therefore, it may be concluded that new approaches, based on the evaluation of the hydrological processes, under different scenarios on changing climate, soil properties, and soil and crop management, with the use of practical and flexible models and computer based programs, would help to select or develop more adequate packages of technologies to reduce soil and water degradation, and to control their growing negative environmental impacts and effects on crop productivity, degradation of ecosystems, and on derived catastrophic events.

Abstract

The problems of soil and water degradation and derived effects are increasing throughout the world, partially due to a lack of appropriate identification and evaluation of the degradation processes and of the relations cause-effects of soil degradation for each specific situation, and the generalized use of empirical approaches to select soil and water conservation practices. A sound understanding of the actual and potential causes and processes of land degradation would prevent implementation of costly and non effective soil and water conservation projects and plans, and would lead to gradual and inexpensive changes leading to more sustainable forms of land use. The processes of soil erosion generally result on, or there are caused by unfavorable changes in the soil moisture regime, and in the possibilities of root development and activity. Besides surface erosion in gentle to moderate slopes, mass movements and landslide erosion are common in more steep slopes. The hydrological processes leading to surface or mass erosion are different, and therefore, soil conservation practices very appropriate for controlling surface erosion processes, like bench terraces, may increase erosion danger by mass movements under specific combinations of climate, soil and slope. Hydrological approaches would be essential to assess the effectivity of soil and water conservation practices to control or to cause unfavorable environmental impacts. Integrated with economic and land use data over time, using modeling, the generated information may be used in planning strategies for land use, and in the selection of soil and water conservation practices based on probabilities of success, levels of risk and long term sustainability.

Keywords: Hydrology, erosion, environment, landslides, degradation, conservation

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