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# Land degradation assessment: tools and techniques for measuring sediment load

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# LAND DEGRADATION ASSESSMENT: tools and techniques for measuring sediment load

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The assessment of land degradation through the use of tools and techniques is discussed for the measurement of sediment load in regions of great agricultural potential, such as the Paraná river basin. Land degradation for these prominent agricultural regions is defined as being the actions in land that decreases potential crop production over time. Assessment of land degradation by erosion (soil loss by water, e.g. topsoil removal, rilling and gullying), chemical (carbon and nutrient depletion) and physical degradation (soil compaction and disaggregation, emergence of subsoil with poor physical properties) and the causes of degradation (deforestation, overexploitation, overgrazing and agricultural activities) in these regions are addressed. The effects of land degradation through water erosion and its subsequent impact on rivers and reservoirs downstream are presented through the use of modeling tools and techniques. A methodology for the utilization of models such as the Revised Universal Soil Loss Equation (RUSLE) or the Water Erosion Prediction Project Model (WEPP) to assess the risk of land degradation in large scale agricultural lands is presented as well as the techniques used for continuous monitoring. Issues and problems with the adaptation of a small scale erosion models to function as a large scale risk assessment tools are also addressed. The integration of these models with tools such as geographic information systems (GIS) and the use of various thematic maps derived from satellite imagery and land surveys to feed the models is an essential part of this methodology. The identification of high degradation risk areas will allow for better soil conservation planning where programs can be implemented to maintain a sustainable non-degrading agricultural system and thus, reduce the sediment load into rivers and lakes in the region of interest.

## 1 Definition of land degradation

Land degradation can be defined in several ways depending upon the subject that needs to be emphasized. A general definition of land degradation is presented by Wasson (1987) as: "*Land degradation is a change to land that makes it less useful for human beings*". A more specific definition states that "*land degradation is a decrease in the optimum functioning of soil in ecosystems*" (Kimpe & Warkentin, 1998). On the other hand, according to Kuipers (1980), land degradation is the result of mechanical forces and water movement acting on soils such as precipitation, evaporation, freezing, thawing and plant roots, and as a consequence, soil degradation may be different at different times. Land degradation can also be defined in terms of actions taken which increase the soil loss from agricultural lands affecting crop productivity and increasing sediment loads to rivers and reservoirs. Land degradation may also be considered a combination of the mechanical forces of machinery for plant growth and water breaking down soil aggregates and transporting down the slope eventually reaching rivers and reservoirs.

Since we are mainly concerned here with soils for agricultural purposes, we define land degradation as being the actions in land that decreases sustainable crop production over time. The decrease in production observed is a result from damage in the physical, chemical or biological properties of the soil (Chartres, 1987).

This definition is applicable to any area in which basic soil conservation principles were not obeyed when establishing agricultural lands after deforestation or other land-use change. As an example, the state of Parana, in Brazil, was colonized this way approximately 40 years ago. At that time, there was a predominance of forests, which covered 90% of the state. After colonization and deforestation, land degradation rapidly accelerated erosion by water causing severe soil losses as well as organic matter and nutrient depletion despite engineering approaches to conserve soil. This resulted in decreased productivity over time which was only overcome by adding lime and fertilizers and through the use of modern agriculture techniques such as no-tillage systems.

The causes, types and effects of land degradation are addressed in the next paragraphs. It is shown that if sediment load is to be reduced then efficient tools must be used to identify and treat the areas where sediment production is greatest. Tools and techniques for measuring sediment delivery for large scale areas affecting rivers and reservoirs are also described.

An important study of global land degradations was the GLASOD study (ISRIC/UNEP, 1991) which covered most of the earth's land surface. This study found that 15% of the land area has already been severely degraded by man's activities. The most common form of degradation was the loss of topsoil (70%), terrain deformation (13%), loss of nutrients 6.9% and salinization (3.9%). Lesser amounts of degradation were attributed to compaction, pollution, wind erosion, waterlogging, acidification and subsidence. The loss of topsoil globally is the greatest challenge for sustainable agriculture since once it is lost it takes a long time to reform naturally. Soil erosion by water is the greatest cause of topsoil loss followed by wind erosion. There are many factors related to "soil quality" that change as a result of loss of topsoil. Yields decline for most soils because favorable soil material, high in nutrients is lost at the expense of infertile subsoils with poor chemical, physical and biological properties. This equates to lower yields which can only be overcome by expensive inputs of nutrients (FAO, 1983). When the cost of inputs are no longer sustainable economically land is converted to lower input uses such as the conversion of cropland to pastures, etc.

Typically the economical cost of erosion is based only on the value of the nutrients lost. The value of topsoil is much greater because it is not only the nutrients that are lost but the soil with favorable conditions for delivery of nutrients to the roots which includes good air/water exchange for healthy plant production. If we did not include the cost of nutrient losses, but did include the offsite effects, such as sedimentation of waterways and impoundments, and the cost to dredge the sometimes polluted sediments and dispose of them, the cost global is astronomical. When the long-term loss of the productive capacity and the cost of the required inputs in fuel and amendments to make the soil productive are taken into account, no amount of soil erosion is economical or tolerable.

Unfortunately, in the real world, erosion is a natural process that occurs on a geological time scale. Man's activities tend to decrease the time scale to the point that one can see the effects of land degradation on a seasonal, annual or longer time scale and the resultant problems associated with it. Of course, when adverse climatic conditions such as drought or heavy rainfall/flooding occur, the results are dramatic and attract attention. Although the same processes occur at a lesser magnitude, they are largely ignored until a catastrophic event occurs and by that time the damage has already been done. As good land has been degraded, populations are forced to attempt to produce in more and more marginal lands which further exasperates the problems of degradation.

## 2 Causes of soil degradation (human actions) – history of land degradation in the state of Parana

Human beings enhance land degradation occurring in agricultural areas. The process is a sequence of actions that destroy the physical chemical and biological properties of the soil, therefore, making it more susceptible to natural degradational forces. The main reasons for soil degradation are: deforestation, overexploitation of the soil through over grazing and agricultural activities, and industrialization (Figure 1).

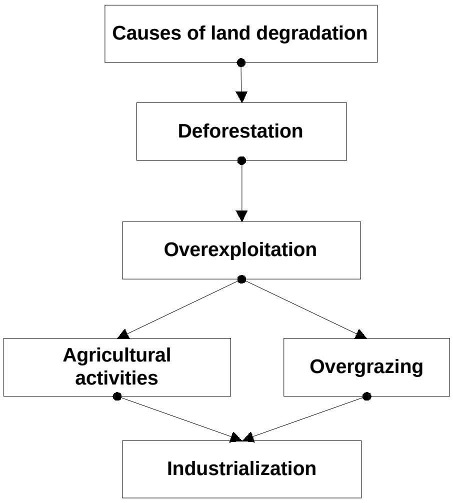



**Figure 1.** History of land degradation processes in Parana.

The history of soil degradation in Southern Brazil is related to the history of agriculture (Castro Filho et al. 1993) and the land degradation processes occurred in the sequence shown in the diagram in Figure 1. The production of sediments starts after deforestation, when the soil is exposed and the land is subject to direct raindrop impact. The raindrop impact starts the process of breaking down soil aggregates, which in turn promotes soil surface sealing, thus decreasing water infiltration. The water accumulated then carries sediments down slope together with valuable nutrients and organic matter.

After deforestation, the process is worsened when overexploitation of the soil by agricultural activities in these lands takes place. Immediately after deforestation, the soil is rich in organic matter and nutrients and the farmers can obtain high yields without the use of fertilizers. An example is the coffee plantations in the state of Paraná, which prospered significantly in the beginning. However, after a few years of land use without any soil conservation techniques, production declines pushing the farmers to clear more land to grow annual crops. The less productive land was left behind and used for pasture. Without any input in this land, the livestock support was very low and leading to overgrazing. Associated with very poor soil cover from the grass, the cattle going in search of water produced bare paths in the soil that look like furrows down the slope. Through these furrows soil erosion begins and many times this is the starting point for gully formation in fields.

The speed with which Oxisols and Ultisols were degraded was high in the first occupied regions by coffee and the initial stage was directly related to the speed of decomposition of the easily oxidized organic matter, which represented 80 % of the total organic matter (Miller et al., 1982; Dabin, 1984). As a consequence, soil physical characteristics, such as permeability, decreased gradually, as well as the soil protection from plant residues and the natural vegetation, this playing an important role on soil degradation. This is the way the State of Parana was developed many years ago.

## 3 Water erosion

### 3.1 The effect of raindrop impact

**Figure 2** shows the processes involved in raindrop impact interaction with soil. That's when the production of sediment by splash begins. However, soil transported from one place to another down the slope is soil which will change names when the soil transported reaches streams and rivers largely occurring when precipitation exceeds infiltration where it is called sediment. To avoid production of sediment it is necessary to take actions that effectively inhibits the soil to detach, splash, and be transported. The small letters in **Figure 2** (a, b, c, d) show where actions can be done in order to minimize the process of the raindrop impact.

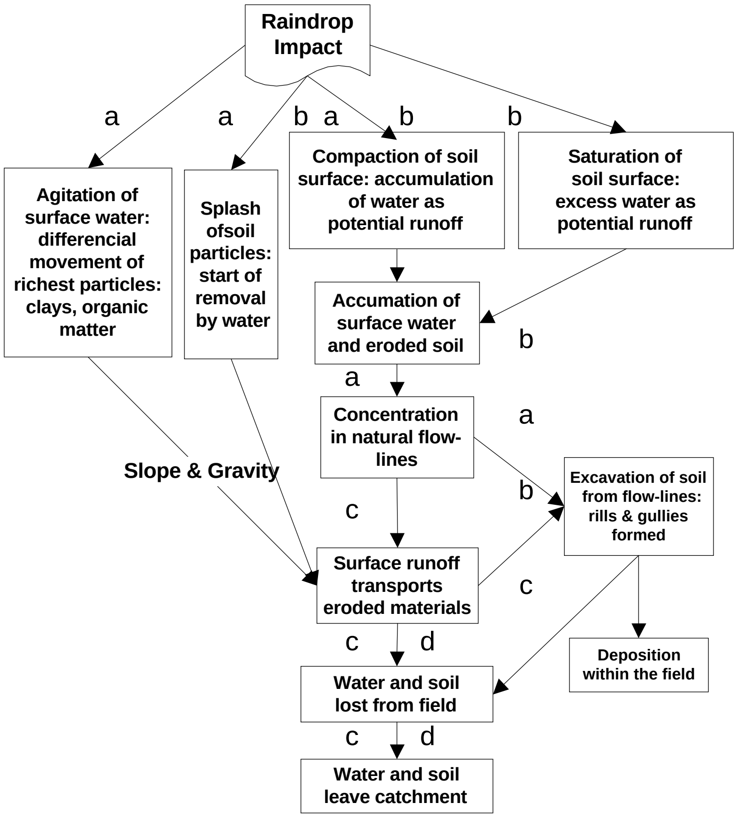
To avoid the disaggregation process actions to increase soil residue cover should be done (a). This will avoid direct raindrop impact over the soil, allowing more time for water to infiltrate. However, if raindrop impact cannot be avoided, which is true in many cases, then, actions should be taken to increase soil structure to resist against aggregate break down (b). One of the most important actions in this sense is the maintenance of soil organic matter. After saturation of the soil surface the water starts moving down the slope profile. That's when actions to prevent or slow surface runoff, such as construction of terraces and other mechanical tools are done (c). At the same time, actions should also be taken to prevent pollution of the soil transported that eventually reaches the rivers. This transported soil may enrich the water with nutrients, organic matter, and some pesticides, thus changing the natural conditions of the fish and other aquatic habitat. All these techniques and actions are summarized for the State of Paraná in Parana Rural (1990).

## 3.2 Flowing water

On the time scale of the beating of raindrops, rainwater interacts with the soil surface through physical/chemical processes. The physical process of raindrops impacting bare soil can be controlled by the use of crop residues or cover, but on a degraded soil this is difficult without expensive inputs. The chemical processes that dominate at the soil surface involve the fact that rainwater is a naturally distilled water low in electrolytes that interacts with the soil on impact (with or without residue). The soil tends to give electrolytes quite rapidly to the rainwater, which results in clay dispersion. This clay that is carried in the infiltrating water quickly plugs up the smaller pores leading to low water intake rates and runoff occurs at even low rates of precipitation.

Once precipitation exceeds infiltration the runoff collects in depressions on the land surface creating small ponds, which protects the surface from rain splash processes. However, when the surface depression storage is exceeded the ponds interconnect and a runoff network quickly develops and water and sediment move even on very low gradient slopes. As the runoff begins to concentrate in small rills, the flow depth is sufficient for the shear of the flowing water to erode through the sealed surface and sediment concentration increases to the carrying capacity of the water and soil is moved down slope. If the stream power is sufficient, the soil will move into waterways and may travel large distances based on the flow dynamics. The finer materials that carry nutrients and chemicals travel the greatest distances and have the greater potential for the environment off-site.

Flowing water can be controlled by mechanical means such as rough tillage that contains a large amount of non-interconnected depressional storage such as chisel plowing or the use of contour tillage. Runoff can be controlled by the use of materials that promote infiltration, stabilize aggregates and reduce clay dispersion. Examples of these materials include organic polymers such as polyacrylamide and electrolyte sources such as gypsum. Surface and subsurface residues are also important in order to slow the velocity of flow once it does occur and prevent soil detachment.




a-actions to increase soil cover and infiltration rates; b-actions to improve soil structure;

c-actions to control surface runoff; d-actions to prevent pollution of the environment.

**Figure 2.** Effects of raindrop impacts on soil erosion (adapted from Shaxon, 1993)

## 3.3 Sediment transport

Sediment transport is a function of many parameters related to the flowing water and the characteristics of the sediment. This is probably one of the least understood, but important areas for land degradation research. Properties of the sediment such as size and density of both primary particles and aggregates are well understood in non-turbulent conditions, but once they are introduced to flow conditions that vary widely and are often supercritical in nature and not well understood.

On a landscape from the summit to the toeslope where rills empty into channels many changes occur in the sediment transport regime. Initially, runoff is shallow and slow. Shallow flows are affected by raindrop impact although moving slowly and can move considerable amounts of soil material. Once the flow depth reaches about three drop diameters, the raindrop impact effect is negated. As the flow concentrates and moves down slope the flow velocity dictates the amount of sediment transported. In all flow conditions this can be estimated for a wide range of soils with a simple equation for stream power (Nearing et al., 1999).

## 3.4 Sediment deposition

Once sediment transport capacity is exceeded or is at equilibrium and flow conditions change, such as flow velocity declines as a result of decreasing slope or spreading out of the flow, deposition occurs (Figure 3). Over the landscape this leads to a change in the geometric configuration of the landscape depending on the balance of the erosion/deposition processes. When gullying and mass wasting processes occur on landscapes, flows typically are at their maximum and deposition commonly occurs. Deposition in streams and impoundments is not necessarily a land degradation process, but it is an extremely important consequence of land degradation and destruction of land upstream.


**Figure 3.** Deposition from changing flow conditions from an actively eroding hillslope. (Photo courtesy of Dr. Mark Nearing).

## 4 Types of land degradation and their effects on soil

According to Figure 4 land degradation can be summarized in four types: degradation promoted by erosion, by wind and also physical and chemical degradation of the soil. All of these processes contribute to sediment production, however, water erosion is the process that eventually carries sediment to rivers and impoundments. In order to prevent water erosion occurring, the soil must have good physical and chemical properties and conditions for plant growth. If good soil conservation is done, plants have better growth and establishment, and, therefore, a good crop canopy is achieved, preventing raindrop impact, reducing surface sealing, and surface water logging which leads to erosion and loss of topsoil, nutrients, and organic matter. It also reduces acidification and terrain deformation through formation of large furrows and gullies. When soil losses reach streams and rivers, in addition to increasing sediment load, it also increases pollution.

### 4.1 Loss of top soil

As previously mentioned the loss of top soil worldwide is the number on land degradation problem. Not only is it the loss of the productive rhizosphere for plant production, but the valuable nutrients leave to cause pollution problems elsewhere. Often the loss of topsoil is associated with soil acidification because it results in the exposure of acid subsoils in many soil orders including alfisols, ultisol, oxisols and others. Aluminum toxicity of these acid subsoils is a major constraint to plant growth and it further enhances the degradation processes by limiting the plant cover and residue. These exposed subsoils are also more often susceptible to soil compaction, have lower infiltration capacity and increase erosion.

## 4.2 Organic matter depletion

Organic matter depletion has been by far one of the most serious problem leading to land degradation. This situation must be reversed and accumulate carbon in the soil which will help preventing land degradation. Several actions must be taken in order to avoid carbon decrease in agricultural areas. In the state of Parana one or more cover crops are used in the agricultural production systems together with the cash crop, especially in the no-tillage system. Several possibilities for cover crops have been suggested by Calegari et al. (1992). However in many situations of soil and climates it is not possible to achieve high yields as it is done in good soils. And in this case the soil use capacity must be taken into consideration to achieve better yields through correct management as it is explained by Castro Filho (1999) after Ramalho Filho and Beek (1995).

One simple way to measure carbon depletion as a function of use was done in the late 70's by Mondardo et al. (1979). They studied carbon from regular soil analysis from three regions picked up in a random way: two regions in the basalt area with a difference in colonization of 10 years period, and the other region was over a sandy soil. The younger region in agriculture from the basalt presented much more organic matter than the other and the region of sandy soil only had traces of carbon being totally depleted. About 11 years after this survey was done, a new study was carried out by Vieira et al. (1990), who showed that that level of organic matter was better compared to the previous survey. They explained the improvement through the use good soil management techniques (no-tillage for example) and the use of cover crops.

## 4.3 Terrain deformation

The result of the combined types of land degradation as described previously often leads to a terrain that makes agriculture difficult of totally unviable especially with mechanization. The development of rill and gully networks makes the use of tractors and harvesters impossible and cause a reversion back to animal or human powered agriculture on degraded lands. The cost of reclamation of such degraded lands so that mechanized agriculture may be practiced is not cost effective giving the low cash value of most crops with the present economy. Typically terrain deformation only leads to an increase in the problem of further land degradation or off-site effects.

## 4.4 Other effects

In irrigated agriculture, salinization is a major problem especially in areas where the irrigation is performed with poor quality water and rainfall is limited. This typically occurs in semi-arid areas and leads to low vegetative cover and an enhanced susceptibility for both wind and water erosion. The loss of low electrolyte rainwater to runoff enhances soil erosion and also further reduces the amount of plant cover due to water stress. The loss of rainwater is additionally important in that it is unavailable to leach the salts from the soil profile that limits plant production. Subsidence is relatively minor for soil degradation, but over historical times has been quite important and caused large population shifts in coastal areas.

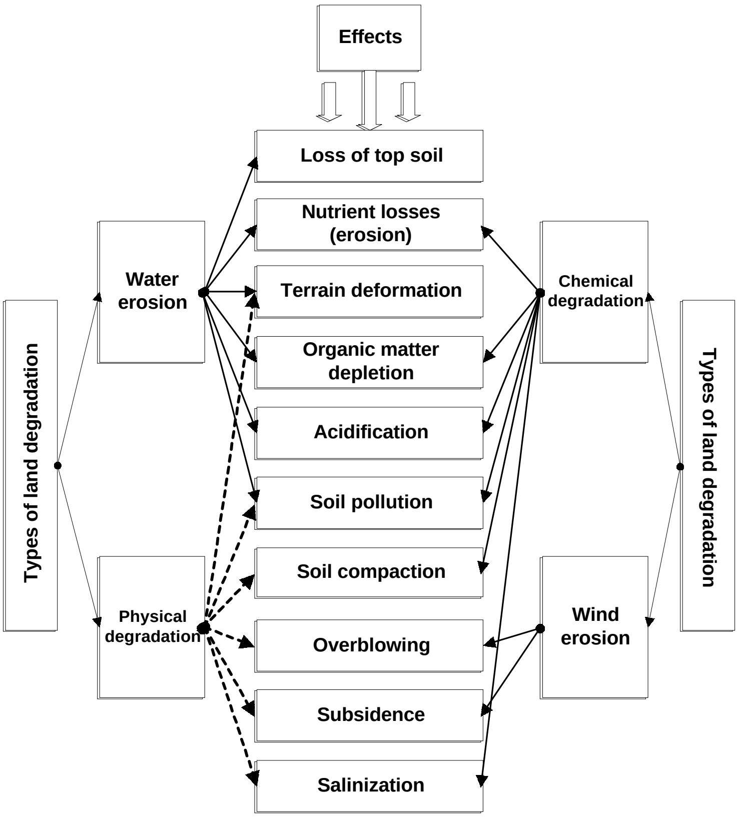



**Figure 4.** Types of land degradation and their effects on soil.

## 5 Assessment of different types of land degradation

Assessment of land degradation in the early 70's has always been done when the problem was already affecting crop production. Assessment can vary depending on the type of degradation process, the scale of assessment, and the method (Figure 5). Early warning indicators (Figure 6) are the first tools used by the decision makers or the farmer. These indicators are very useful for detecting the problem in its early stages and then establish priorities in order to prevent the crop production decrease.

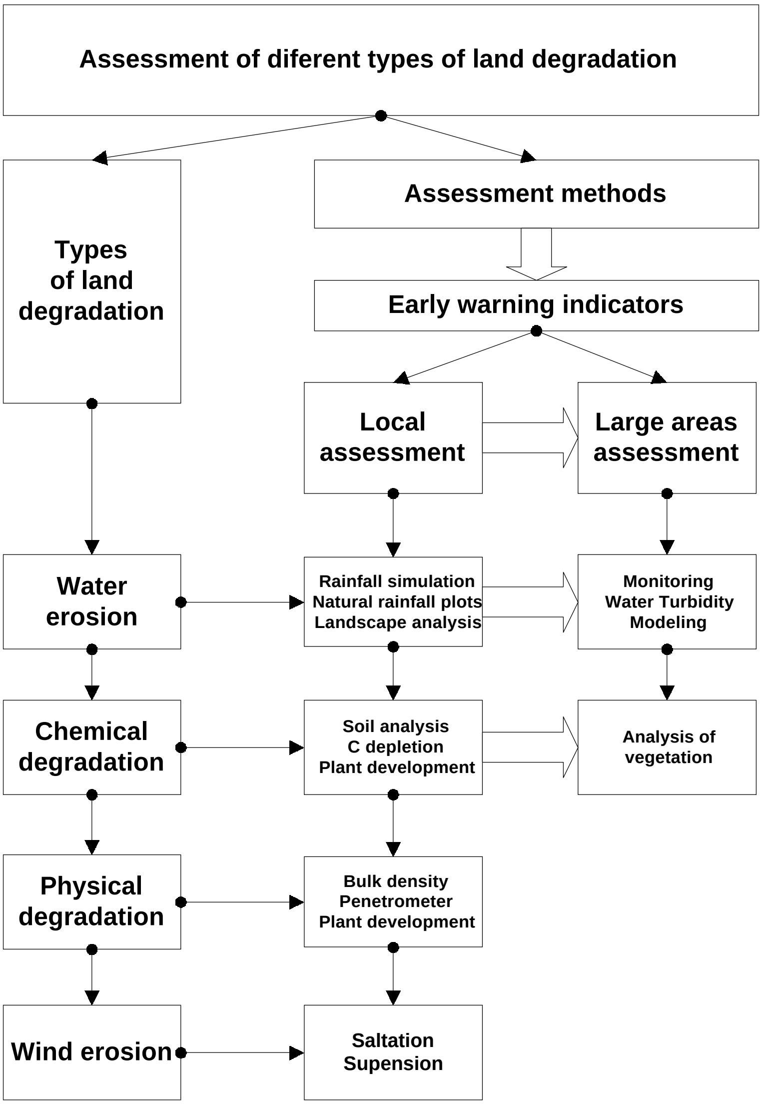



**Figure 5.** Assessment of different types of land degradation.

## 5.1 Local assessment

In Parana, the first soil conservation research results came in the early 70's from the Research Institute of Agronomy (IAC) from the work done by Bertoni & Lombardi (1985).

The state research institute of Parana (IAPAR) accelerated the knowledge of soil protection by plants and the hazard of the different types of soil tillage by using a rotating boom rainfall simulator (Table 1). These generated data were used to convince farmers why they should change from soil tillage with high soil disturbance to less disturbance such as no-tillage, a system wide spread in the state of Parana and rapidly growing all over Brazil and many parts of the world.

Henklain and Casão (1989) showed that carbon losses were proportional to soil losses and represents 25% of the organic carbon reserves in the plow layer (10-20 cm depth). According to Muzilli (1989) no-tillage tended to increase soil organic matter in the soil surface and also showed higher levels of phosphorus and potash.

There are some alternative techniques to estimate soil transported by the erosion process. One of them used by the deJong et al. (1983) elsewhere and by Guimarães and Andrello (2001) in Paraná has been the use of the $^{137}Cs$ methodology.

**Table 1.** Relative soil losses and water in two soils from Parana, with different tillage systems, through the use of a rainfall simulator.

| Tillage type | Dark Red Latosol (clayey) (1) | | Red Latosol (2) | |
|---|---|---|---|---|
| | Soil | Water | Soil | Water |
| 1 plowing + 4 disk harrowing * | 100 | 100 | - | - |
| 1 heavy disk harrowing + 2 disk harrowing * | 75 | 162 | 100 | 100 |
| 1 chisel plow + 2 disk harrowing * | 52 | 143 | - | - |
| 4 disk harrowing * | 37 | 48 | - | - |
| 2 disk harrowing * | 27 | 57 | - | - |
| 1 plowing + 2 disk harrowing * | 23 | 90 | 26 | 30 |
| 1 plowing * | 13 | 38 | - | - |
| No-tillage ** | 5 | 95 | 1 | 98 |

(1) Biscaia, 1977; (2) Farias, 1978; * Soil tillage without incorporating the residues. ** Wheat residues on the soil surface.

According to Vieira (1985) high aggregate stability in no-tillage can be attributed to less pulverization of soil and protection against raindrop impact. Higher aggregation is also achieved by increasing the organic matter level and to some extent lime application (Castro Filho, 1988, Castro Filho et al, 1998; Castro Filho and Logan, 1991, 1998).

As far as crop productivity Sorenson and Montoya (1984) observed that no-tillage and chisel plowing increased the productivity of soybean, wheat and beans. This is also another reason why in the long term the no-tillage system is being adopted all over Parana and Brazil.

For those farmers with 100% no-tillage, incorporation of lime is no longer a problem, as long as they have a good crop rotation system including for example a high production of biomass. Miyazawa et al. (2000) has shown that liming applied over high quantity of biomass of black oats produces organic acids that reacts with the carbonate from liming material and then are leached down the profile where pH needs to be corrected. This technique can not only prevent land degradation, but also saves money since there is no need to plow the soil to incorporate lime. Many types of cover crops have been developed here in Paraná or in southern Brazil to work in a crop rotation system in no-tillage (Calegari et al., 1992).

Sustainable agriculture in Southern Brazil can be achieved with proper soil management techniques, especially the maintenance of organic matter and the use of tillage systems with the least soil disturbance (i.e. no-tillage, Castro Filho et al., 1991).

## 5.2 Early warning indicators

Early warning indicators are very important because they help society be better land stuarts. Figure 6 shows just some examples of these indicators that are easy to see when traveling along a road in Southern Brazil. The type of plants planted may not be one of the best indicators of the soil's health. For example, in terms of natural plants the occurrence of ferns is typical of very acid soil that needs to be corrected. Occurrence of termites is very common is overgrazed pastures and certainly the microbial population is affected.

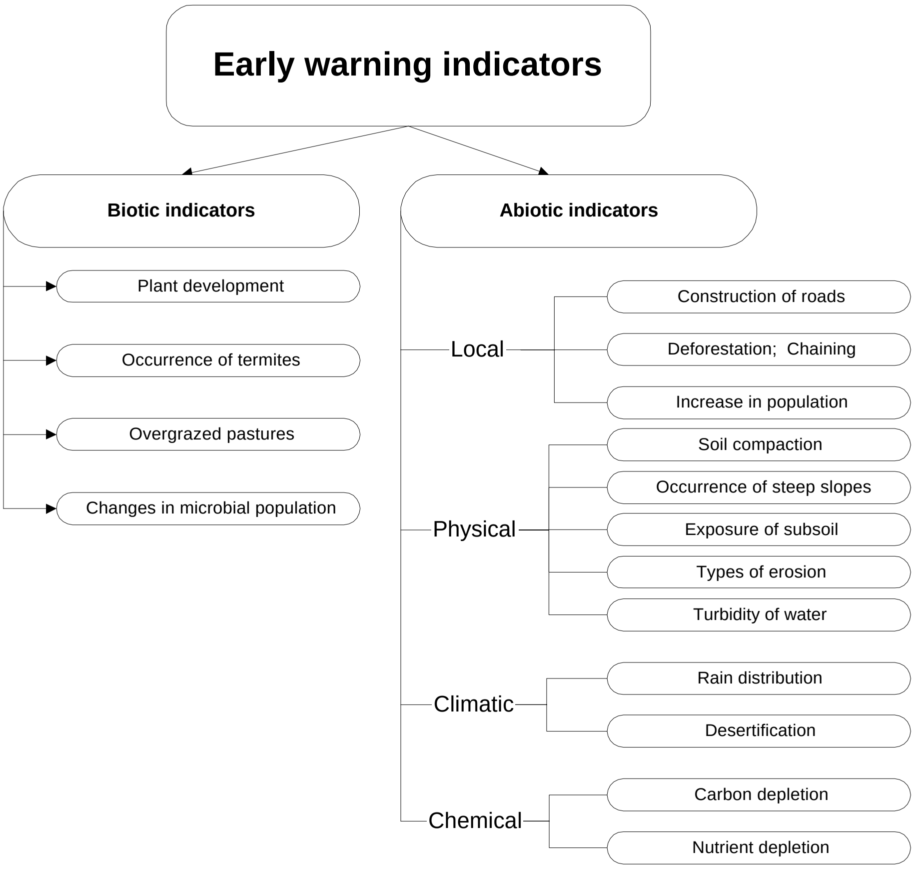



**Figure 6.** Early warning indicators of land degradation.

The abiotic indicators are also easy to see: Construction of roads and population increases causes severe erosion, with consequences for the soil that increases degradation through compaction, loss of top soil, etc. When natural forestland is changed, there are changes in the local climate consequentially affecting rainfall distribution with more intense precipitation and shorter in duration. Another main change that can be seen all over the planet is the excess of carbon in the atmosphere causing green house effects. In this case, carbon sequestration to mitigate this effect is being studied in a very intensive way where no-tillage systems contribute to solving the problem. Izaurralde et al. (2001) pointed out that four main technologies will have an impact on soil C sequestration, therefore, decreasing carbon depletion: genetically modified crops, conservation tillage, organic agriculture and precision farming. In that case the no-tillage system will give a large contribution to reduce carbon depletion from the soil.

## 5.3 Analyzing large areas

In Brazil, there was a large effort to decrease land degradation through the National Agricultural Watersheds Programs (Ministerio da Agricultura, 1987) created in 1987. The objective of the program was to have rational land use at the level of watersheds through the adoption of conservation practices to preserve the renewable natural resources. The State of Parana, through the Parana's Rural Development Program, Soil Management and Conservation Subprogram established as a goal to target 2100 agricultural watersheds for conservation practices. Bragagnollo (2001) pointed out some of the main results of the Parana Rural Program. One of them is the natural reduction of the water turbidity (49.3%) generating a large reduction in the costs of treating the water for human consumption in 16 water treatment plants.

At the State level, the official agricultural research institutes have been trying to investigate and assess land degradation through traditional methods. In the 70's, with the boom of agriculture, something had to be done to prevent erosion and state programs tried to give incentives to construct broad base terraces. However, the main problem with soils at that time was soil compaction promoted by heavy disk harrow (Table 1). Therefore, the size of the terraces increased to giant terraces called "murunduns". The murunduns did stop the water from running down the slope but did not solve the soil compaction problem. Only when farmers tried to eliminate soil compaction the erosion process decreased, allowing for better production and thus better profits.

Currently, it is possible to estimate to sediment load from large watersheds through modeling. There are several models that can predict soil losses and sediment load for small areas but they can be used for large areas. The advantage of this methodology is to speed up the process of land degradation assessment and find out the areas where the erosion process is greatest.

### 5.3.1 Modeling at large scales

The assessment of land degradation in large agricultural areas has been tied to the prediction of soil loss using erosion models originally created for small scale simulations. Small scale erosion prediction technology such as the Universal Soil Loss Equation –USLE (Wischmeier & Smith, 1978), the revised USLE – RUSLE (Renard et al., 1997), and the Water Erosion Prediction Project – WEPP (Flanagan & Nearing, 1995) are used to quantify the soil loss and erosion occurring in small fields and watersheds, but have been applied in larger regional areas. However, as these models are adapted to larger scales, accuracy may be sacrificed and the overall predictions become more qualitative in nature. The reasons for the possible loss in accuracy and the move towards a qualitative or comparative prediction can be attributed to limitations in the models ability to predict large scale erosion processes such as gullying, land sliding, transport through permanent streams and rivers, and spatially distributed deposition of sediment.

It is therefore, of uttermost importance to understand the limitations of the model being used and to be aware that these will pose restrictions on predictions at larger scales. Furthermore, it is important to choose the appropriate model to use for the area and scale being simulated using an appropriate process of selection and verification. An example of the main concepts in such a process is shown in Table 2. Additionally, data availability and processing is also a concern when modeling in larger regional scales. Adaptations of the models for large scale simulations may involve substantial simplification or estimation of inputs and formulation of reasonable assumptions when detailed data is not present. Many of these decisions are dependent on the expected results and the selection of the models to be used. For example, it is important to note that predictions at regional scales can be more forgiving since overall average values may be sufficient to give comparative results if the purpose for modeling is decision making.

**Table 2.** Model selection and verification process.

| | |
|---|---|
| 1. Determine purpose of modeling | expected results (quantitative or qualitative?), decision making, physical modeling, or experimentation? |
| 2. Model selection | based on purpose for modeling, available data sets, and verification of previous applications of models in the area of interest |
| 3. Determine applicability | a) check limitations of selected model for scale being used and range of applicability |
| | b) use data for selected region to ensure model works as expected... may need calibration and adaptation |
| 4. Sensitivity analysis | sensitive to the elements of land degradation which are expected to change |
| 5. Application of models | |

### 5.3.2 Data requirements

In order to assess land degradation in large areas it is important to have sufficient data in the areas of interest. The major categories of data required for modeling sediment loss from agricultural areas are climate, soils, vegetation cover, and topography. The degree of detail and the number of factors required in each of these categories depends on the model used and the proposed simplification for large scale modeling. Digital databases such as the SOil and TERrain digital database of the world, SOTER (van Engelen, et al., 1995), can be useful to obtain raw data to start the assessment in regional scales (Cochrane & Cochrane, 2001.). If available, such databases can offer a variety of soils, landscape, and vegetation information and parameters for the region being studied. Other sources of data that can be used for modeling large areas are agricultural census data. For example, in Brazil, the data obtained from the Instituto Brasileiro de Geografia e Estadistica (IBGE) on agricultural production, properties, demographics and other information, has proven useful to determine types of crops grown, quantity of production and other information which can help determine cover factors and similar inputs for models. Census data can also be used to establish relationships with demographics and its possible effects on land degradation.

Topographic data for the world in the format of digital elevation models (DEMs) is commonly available from the United States Geological Survey (USGS) at large scales and the National Atmospheric and Space Administration (NASA) data soon to be available at smaller scales. These commonly available data sets can be supplemented by local sources of data including soil surveys, topographic surveys, and field studies. Field observations are also an important part of data gathering and should be used to ensure the accuracy of the other data. Additionally, an important source of data are remotely sensed images available from a variety of different platforms. These include aerial photographic surveys and satellite imagery with different instruments such as Landsat, Spot, ICONOS, radar surveys, and other multi-frequency remote sensors. Through remotely sensed imagery, it is possible to supplement information to the databases being used by identifying vegetation cover, drainage patterns, and other information about land use.

### 5.3.3 The use of GIS

Working with large areas requires significant data processing that can be done using commonly available Geographic Information Systems (GIS). A GIS ability to store and display data in a spatial manner helps in the organization of data, the analysis of data and can be used as an interface for the land degradation assessment as shown in Figure 7. The use of GIS together with modeling for assessment of land degradation also enables the simulation of different case scenarios for future land management and decision making. The scenario with the least potential for land degradation can be identified through simulations, and a recommendation can be formulated to implement it.

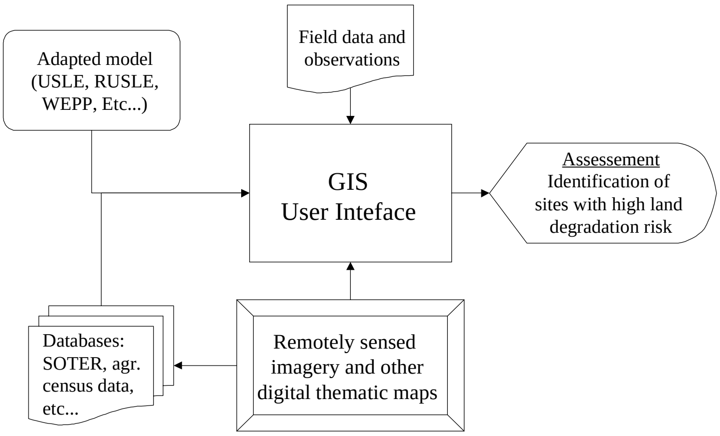



**Figure 7.** Large scale land degradation assessment using GIS, databases, and erosion models.

### 5.3.4 Application of tools: the assessment of the sediment load in large watersheds

The Paraná river basin is used as an example to illustrate tools and techniques that can be used to assess sediment load in large watersheds. This watershed has an area of approximately 850,000 km$^2$ and extends into the states of Goias, Mina Gerais, Mato Grosso do Sul, São Paulo, Parana, and a small part of Paraguay, as shown in Figure 8.

The initial concern within the Paraná river basin was the degradation of land, which had the potential to decrease agricultural productivity over time. Vast conservation programs have since been implemented in some regions, such as the state of Parana, to ameliorate this threat. However, the subsequent effects of land degradation are still a threat. The most significant one is the threat to the production of hydroelectric energy by sedimentation of the numerous reservoirs that exist in the Parana river basin (Figure 8.). This concern has increased recently in Brazil due to recent supposed shortages of energy. The accumulation of sediment in a reservoir can have a detrimental effect on the ability to produce electricity over the long-term. Additionally, sedimentation of these reservoirs can cause eutrophication and thus have a severe effect on aquatic life. It is, therefore, important to monitor the production of sediment from the watershed that flows into reservoirs and to identify the location of areas of high land degradation which produce this sediment. The monitoring of sediment and the identification of high risk areas will lead to better policies for the implementation of conservation practices which in turn will benefit the hydro-electric plants by increasing their useful life.

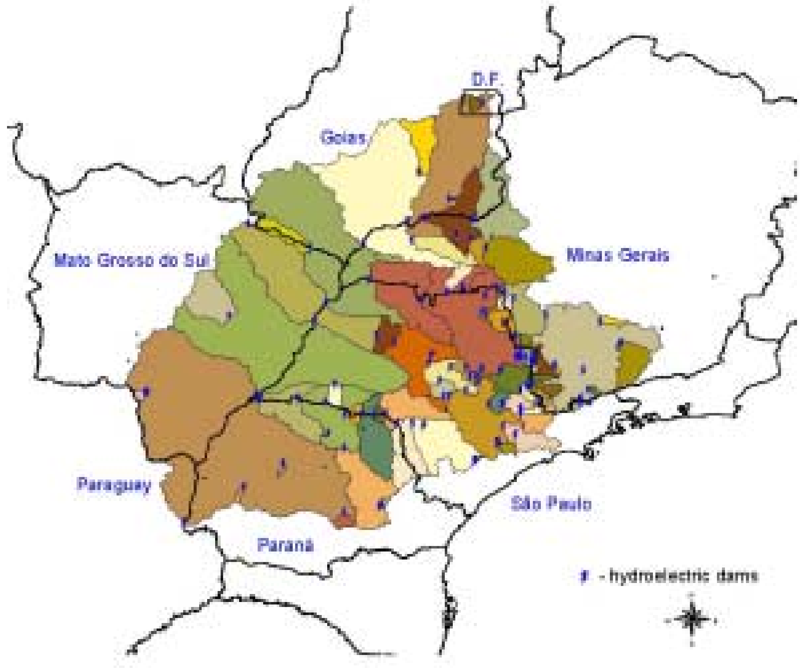



**Figure 8.** Hydroelectric dams with their respective watersheds in the Parana river basin.

A methodology for the continuous monitoring of sediment entering such reservoirs has been developed as well as a modeling approach to identify the high risk land degradation areas within the watershed using an adaptation of the USLE/RUSLE models (Norton, et al., 2001). A description of the methodology follows:

<u>Monitoring tools for sediment load in rivers</u>

Monitoring is done through a network of low cost electronic sensors, which are permanently installed in selected rivers contributing significantly to a reservoir of interest. One sensor is a water level meter that measures the change in pressure head of the water form a fixed point inside the river and thus measures the water level of the river. This sensor is used together with a calibrated flow velocity curve at that section of the river to calculate the flow rate on an hourly basis. The other sensor installed at each of these monitoring sites is a turbidity meter. The turbidity meter is used to estimate the sediment concentration at each specific site every hour of the day. Manual sediment sampling is done on a regular basis to verify and continuously calibrate the turbidity sensors. The measurements obtained by the network of these sensors permit a fairly accurate estimation of the quantity of sediment flowing into the monitored reservoir.

<u>Modeling tools and techniques for large watersheds</u>

Modeling with the USLE factors is illustrated for the Paraná river basin as an example of the techniques that can be used to determine sediment loss in a large watershed. Each factor of the USLE model (R,K,C,P,LS) is calculated for the local conditions using available data. The erosivity factor R is calculated from a network of climatic stations within the watershed (Rufino et al. 1993). Using the mapping and data analysis capabilities of a GIS, a thematic map can be created showing the susceptibility of the region to erosivity by rainfall as seen in Figure 10. The erodibility of the soils (K) is calculated from existing soils maps of the Parana River basin and with data available for the region from the SOTERLAC data base. The cover and practices factors (C and P) are determined using satellite imagery and agricultural census data. The LS factor is calculated from available DEM's from the USGS (Figure 9) and from observed field data available in other local surveys. Assumptions for regional scales have to be made for slope lengths and gradients to calculate the LS factors. A statistical distribution of different possible slope lengths and gradients can be a starting point to determine reasonable factors for certain regions. Other procedures such as the one developed by Desmet &

Govers (1996) use GIS to automatically calculate the USLE-LS factor on topographically complex landscape units.

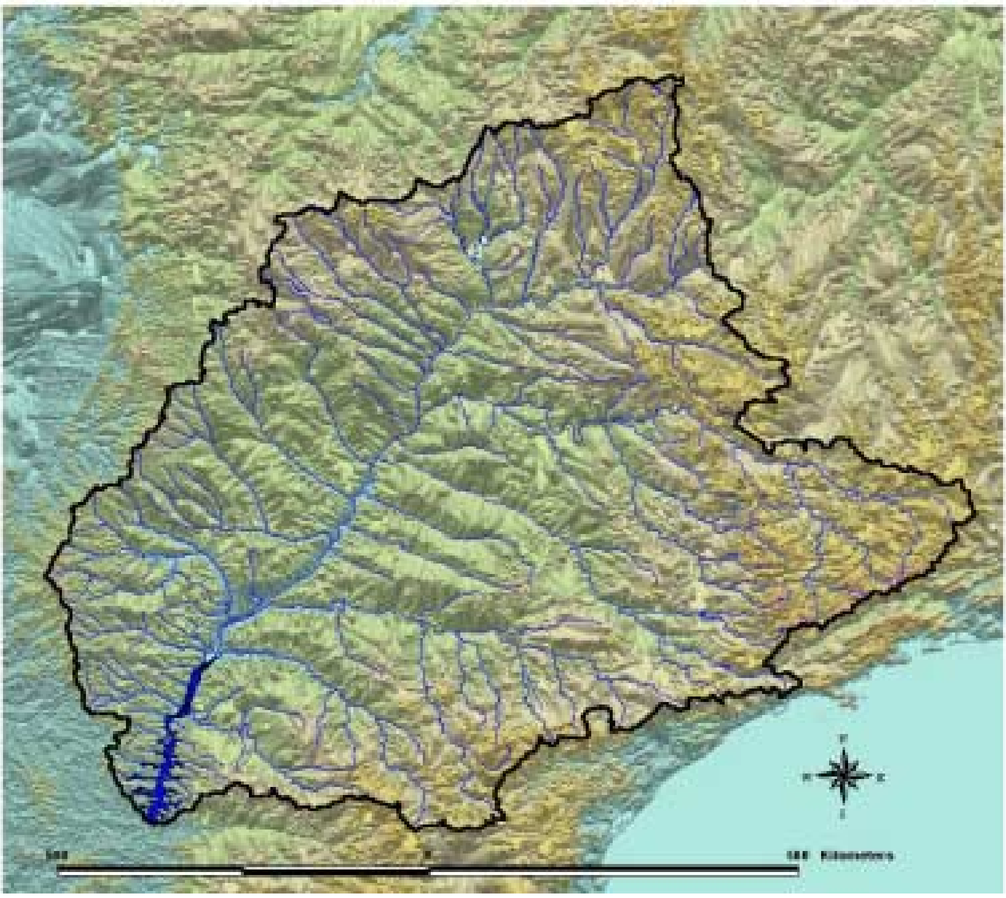


**Figure 9.** DEM data from the USGS for the Paraná river basin.

Preliminary determination of these factors for the model do not ensure the validity of these. It is, therefore, a good policy to verify the results in the field by visiting the areas of interest. On site interviews with local scientists and technicians and visits at different times of the year help to validate simulated or calculated results. This process also helps in determining which parameters need further determination or which ones can be simplified. Selected small scale experiments and simulations with the same model also help determine accurate values for local parameters such as soil erodibility and rainfall erosivity. Calculation of statistical probabilities or modeling errors can also help determine the validation of simulations and whether the parameters are sensitive to changes being proposed.

Once the factors are calculated and verified for the regional scale, the factors themselves can be used independently to help identify risks for land degradation and to find possible solutions to reduce soil loss. For example the R factor by itself identifies the regions with the greatest probability of being vulnerable to rainfall erosivity. It, therefore, indicates what regions may need better cover protection against rainfall impact. For example, Figure 10 shows that the most vulnerable regions of the Parana river basin are located at the north of the watershed.

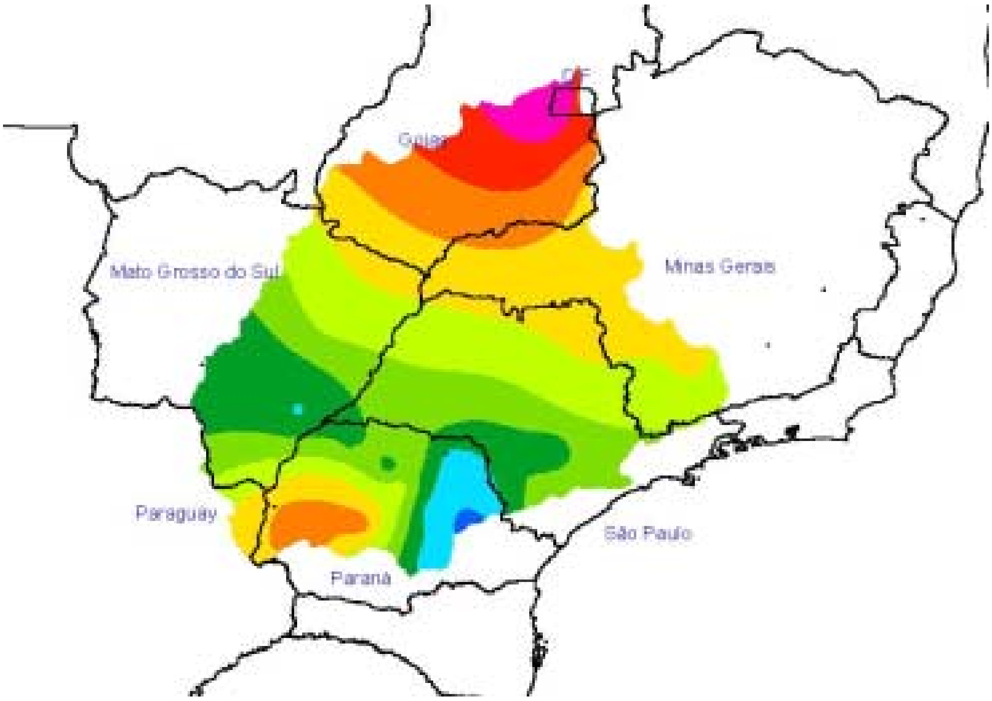



**Figure 10.** Rainfall erosivity factors for the Paraná river basin (increasing in intensity from blue to green to red).

Similarly topography by itself can indicate need for further cover protection. However, since interactions with other factors are not taken into account, the analysis by using the factors independently is only preliminary and a final recommendation should only be made taking into account all factors together.

The interaction of all factors as determined through modeling by USLE or RUSLE indicates the areas that are at a greater risk of land degradation at the present moment. When using GIS for the modeling, different case scenarios can be simulated by altering cropping practices or adding management practices to determine the best course of action to diminish sediment load. Once the best alternatives are selected to reduce sediment loss and these are implemented, changes can be detected by the monitoring network on the long-term. The modeling and the monitoring are complementary to each other.

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