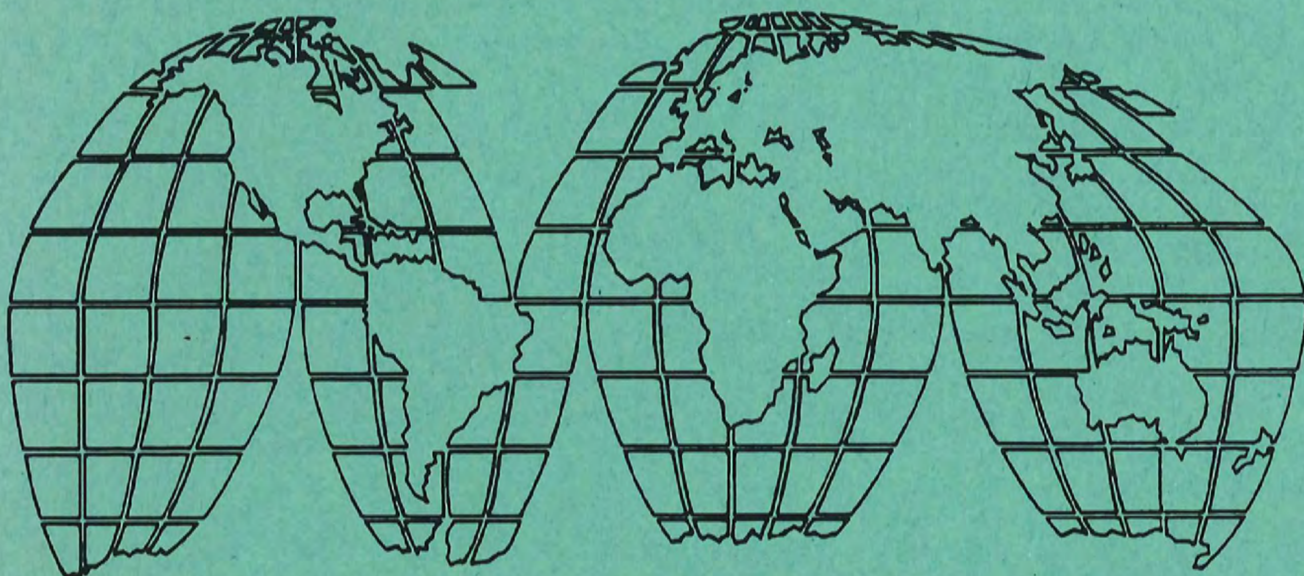
A.I.D. EVALUATION OCCASIONAL PAPER NO. 34

IMPACT INDICATORS FOR MEASURING CHANGE IN THE NATURAL RESOURCE BASE



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IMPACT INDICATORS FOR MEASURING CHANGE IN THE NATURAL RESOURCE BASE

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by

Ralph J. McCracken
(Senior Consultant)

U.S. Agency for International Development

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TABLE OF CONTENTS

FOREWORD

The Agency for International Development (A.I.D.), Bureau for Program and Policy Coordination/Center for Development Information and Evaluation (PPC/CDIE), in cooperation with the Bureau for Science and Technology and three regional bureaus, organized a workshop on indicators for measuring changes in income, food consumption and food availability, and the natural resource base. The purpose of the workshop was to identify and discuss a set of simple, practical indicators that can be used by overseas Missions and A.I.D./Washington for monitoring the impact of agricultural and rural development assistance.

The workshop was held on June 20-22, 1988 in Virginia and was attended by 60 development specialists, including A.I.D. staff, consultants, and outside experts. Four background papers written by experts were presented at the workshop; this paper is one of them. The titles of the others are "Indicators of Household Income for Use in the Evaluation of Agricultural Development Projects," "Food Availability and Consumption Indicators," and "Impact Indicators: General Issues and Concerns."

A report by Krishna Kumar, entitled "Indicators for Measuring Changes in Income, Food Availability and Consumption, and the Natural Resource Base," presents the main findings of the workshop. Of related interest is a paper issued by CDIE, entitled *Methodologies for Assessing the Impact of Agricultural Development Projects*, A.I.D. Program Design and Evaluation Methodology Report No. 11.

I am confident that these publications will be of great help, not only to A.I.D. staff and contractors, but also to host governments and institutions struggling to develop effective and efficient monitoring and evaluation systems for development activities.

Janet C. Ballantyne
Associate Assistant Administrator
Center for Development Information
and Evaluation
Agency for International Development
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1. INTRODUCTION

There is ample evidence that the attempts of people in developing countries to meet their basic needs for food, fiber, fuelwood, and shelter are leading to the degradation and deterioration of the natural resource base on which their future depends. The problem is greater in countries where population growth rates are high, poverty is prevalent, and per capita food production growth rate is stagnant or declining. These pressures often lead to ill-conceived government policies that can increase stress on the natural resource base. The problem is especially acute in countries where natural resources are limited or fragile.

The natural resources most critical to meeting the food, fiber, fuel, and shelter requirements of a population are soil, water, plants, and animals. These resources affect each other as they interact in ecosystems. The objective of development assistance programs concerned with natural resources must involve the concept of sustainability. Sustainability refers to the maintenance and enhancement of the productive capacity of the natural resource base over time, within reasonable and practical limits of what is technically and economically feasible, without causing the deterioration of environmental quality.

This paper identifies and describes several impact indicators that can evaluate changes in the natural resource base over time--changes that may be associated with development assistance efforts. These indicators can measure positive (conservation and enhancement) as well as negative (deterioration) changes in the soil, water, plant, and animal components of the natural resource base. Because development projects seek to alter a variety of factors (e.g., agricultural practices, crop mixes, access to new markets, improved livestock care) in the rural economy, evaluators usually need to select a set of indicators to capture a variety of anticipated impacts in the environment. Another reason for selecting a set of indicators is that various components of each natural resource are highly interrelated; therefore, changes in the status of one often result in changes in others. Finally, it is not feasible to recommend the use of a common set of impact indicators for all interventions. Variations in climate, soil, and vegetation in different locations and over time require different sets of indicators.

The selection of the indicators discussed in this paper was based on their conformance to several of the following criteria:

-- High degree of association with Agency for International Development (A.I.D.) development objectives at the project and program levels

-- Close relationship to parameters of interest

-- High importance to the sustainability of the productive capacity of natural resources

-- High sensitivity to changes in parameters over relatively short time periods

-- Ability to aggregate and compare results at program and regional levels, ease and low cost of information collection, and availability of computer models and simulations to assess the indicator

A useful first step in carrying out an effective evaluation of impacts on natural resources is to perform a thorough inventory of the geographical area of concern, describing the status and capability of various resource components in the area. Such an inventory uses a variety of data collection methods, which can include soil and water samples taken from different sites to analyze soil properties and water quality, surveys that document the health status and presence of plant and animal species, and remote sensing by aerial photography or satellite imagery to evaluate the status of cropland, forests, rangelands, and wetlands. However, such a comprehensive approach to baseline data collection may not be feasible in most situations because of time and financial constraints.

In some cases, assessment of certain indicators does not require the collection of a large variety of baseline data. However, because analysis of change in the natural resource base is of necessity comparative, a means for a comparative study of the status of several components must be found before the intervention occurs. Various kinds of secondary sources of information can be especially useful when a comparative analysis is required. This paper proposes a list of 17 impact indicators separated into four natural resource categories--soil, water, plant, and ecosystems. Air is also typically treated as a major component; however, it is not included in the list because in most situations air plays a minor role in the productive capacity of the natural resource base.

A checklist of baseline data needs is provided below.

-- Soil surveys showing the location of the various kinds of soils in the area of interest and describing their properties and qualities. The survey should be done according to generally accepted standards and procedures, using an internationally accepted system of soil classification.

- -- Constraints to production and plant growth as revealed in a technical soil system such as the Fertility Capability Classification (Sanchez, Couto, and Buol 1982).

- -- Plant nutrient status (especially the major plant nutrients nitrogen, phosphorus, and potassium), as revealed by soil fertility evaluation, including soil testing done according to procedures appropriate for the soils and the crops under consideration.

- -- Average annual rates of fertilizer and lime usage and estimates of the rate of use of animal manures, mulches, and compost, as well as plant response to these materials.

- -- Presence or absence of soil salinity and location if present.

- -- Location and severity of water and wind erosion with respect to tolerable soil loss or the threshold of permanent soil productivity loss; location and sizes of areas of highly erodible soils.

- -- Land use, including cropping patterns and area cropped, area of rangeland if present and grazing patterns, size and types of forested area and timber and fuelwood harvesting patterns, occurrence of shifting cultivation in the area and the length of the cycles, average production with these land uses, and land area built up or urbanized.

- -- Acreage of the various crops grown and their average yields; carrying capacity of any rangeland in the area, as well as forest species present and their rate of growth and quality; fuelwood supply and source.

- -- Species, population size, and condition of wild animals and fish and the general quality of their habitats.

- -- Amounts of runoff and the plant nutrient and pesticide content of such runoff, or estimates thereof, based on normal usage of the land areas concerned; estimates of off-site effects of water runoff, such as undesirable sedimentation and water pollution.

- -- Amounts of pesticides normally used and estimates of the proportions of these pesticides found in surface waters or underground aquifers (water-supply beds).

- -- Normal water supply, water quality and adequacy of surface and groundwater sources, and efficiency of use of irrigation waters.

-- Annual and monthly rainfall, temperatures, and water evaporation rates; also average wind velocities near the ground; long-term climatic information and trends therein will also be useful.

Information about all the indicators is summarized in Table 1 at the end of this report.

2. IMPACT INDICATORS FOR NATURAL RESOURCE CATEGORIES

2.1 Soils

A significant component of sustainable agriculture is maintenance or enhancement of the productivity of the soil over time--that is, the inherent capacity and capability of the soil to produce. The loss of valuable topsoil with its humus and other properties favorable to plant growth causes decline in production, although this may be partially offset or masked by increases in production inputs (such as fertilizer) or improved technology (such as improved crop varieties). However, if soil erosion continues to the point of severe gullying, that is, loss of the entire soil material, permanent loss of productivity can occur in the affected areas. Once the reduced production capacity of the soil becomes permanent, it is generally not economical to restore productivity.

Significant soil erosion is an indicator of soil degradation and poor management of the soil resource with respect to its capabilities and the erosion hazards endangering the soil. Soil erosion may also be indicative of harmful off-site effects, such as sedimentation and choking of streams and reservoirs caused by deposits from the erosion. Changes in the severity of the erosion over time after interventions have been instituted are an indicator of the effectiveness of erosion control practices. Two indicators are proposed for assessing severe soil degradation: one measures soil degradation that has not yet resulted in permanent loss of productivity, and the other measures permanent soil degradation, with irreversible loss of productivity due to major stripping of the soil surface or complete loss of soil.

2.1.1 Soil Resource Indicator 1

Soil Resource Indicator 1 measures water-caused erosion that is greater than the tolerable soil loss--erosion that has resulted in potential decline but not permanent loss of productivity. In such cases of soil erosion, declines in production may be restored or partially masked by additional production inputs that are economical.

Soil Resource Indicator 1 is expressed as soil loss in tons per hectare or per acre per year, or as soil loss per year relative to the tolerable soil loss (T). T is defined as the annual rate of soil loss by erosion above which production cannot be economically sustained over time and is equated with the assumed rate of soil formation. In the United States, the most commonly used T values are 5 tons per acre per year for the average soil in cropland and 2 tons per acre per year for rangeland and forests.

A qualitative method of estimating the severity of soil erosion is to compare the thickness of remaining topsoil with the normative or virgin and natural topsoil thickness for the soil type. Another qualitative source of data is soil survey reports, many of which describe and map the occurrence of the phases of soil erosions. Water-caused soil erosion can be measured directly by weighing the sediment in the runoff, but this is very costly and time consuming. A relationship known as the Universal Soil Loss Equation (Wischmeier and Smith 1978) is commonly used to estimate and predict the amount of soil loss, based on soil properties, degree and length of land slope, rainfall intensity, crops, and the tillage and erosion control practices. However, Hudson (1982) points out that the Universal Soil Loss Equation is not applicable to many tropical and subtropical conditions because of the common higher intensities of rain in those areas and the frequently different distribution patterns of the rainfall throughout the year.

But basic erosion prediction and control principles apply universally. And, with the acquisition of the needed data, it should be possible to adjust the rainfall intensity and soil cover factors of the Universal Soil Loss Equation so that the equation could also be applied to the tropics (Foster et al. 1982). In the United States, the Universal Soil Loss Equation is soon to be replaced by the Water Erosion Prediction Program. It is anticipated that this program will be more applicable to tropical soils than the Universal Soil Loss Equation.

2.1.2 Soil Resource Indicator 2

Soil Resource Indicator 2 assesses the type of soil erosion that is sufficiently severe to have permanently lowered the productivity of the soil--a loss in productivity that cannot be restored economically with present technology. This level of soil erosion is reached when soil surface layers are stripped, exposing the much inferior subsoil for plant production, or when the soil material is completely removed, exposing the underlying rock, which may be hard or soft. Permanent soil degradation may be inferred when yields decline despite heavier use of fertilizer or manure applications. Such conditions can also be identified by comparing the soil in the target area with soils of similar origin that have not yet reached this condition.

Highly erosive soils that are very prone to severe degradation can be identified by applying a Soil Erodibililty Index derived from the Universal Soil Loss Equation (Bills and Heimlich 1986). Models, such as the Productivity Impact (Pierce et al. 1983) and EPIC (Williams et al. 1983), have been developed that can be used to identify highly erosive soils and estimate when soil erosion can be expected to reach permanent degradation if sufficient erosion control is not used. EPIC is being adapted to tropical conditions in developing countries through the IBSNAT program sponsored by the Natural Resources Division of A.I.D.'s Bureau for Science and Technology.

2.1.3 Soil Resource Indicator 3

A different set of factors is responsible for soil erosion caused by wind than for erosion caused by water. With wind-caused soil erosion, the stripping of surface soil and redeposition of particles is more uneven and air quality is affected. This type of soil erosion can also be a symptom of the onset of desertification. Wind erosion is symptomatic of improper tillage practices (e.g., plowing and tilling of land that should have been left in grassy vegetative cover) or overgrazed rangelands, or it may reflect oncoming climatic change or long periods of unusual drought.

Soil Resource Indicator 3 measures wind erosion by estimating the amount of topsoil blown away, the size of areas affected, the extent of damage to crops by windblasting of plants and redeposition of wind-transported material, and the reduction in air quality due to dust introduced into the atmosphere by wind. This indicator can be applied by comparing direct measurements of remaining topsoil thickness in the area with data from comparable sites not undergoing wind erosion. Measurements of the thickness of obvious wind deposits on previously existing soil surfaces can also be used with this indicator. The loss in air quality due to dust can be determined quantitatively by air sampling or qualitatively by visual observation and estimation of the extent and severity of airborne dust.

To predict or measure wind-caused soil erosion, a Wind Erosion Equation has been developed, which requires information on soil erodibility, soil surface roughness values, distances of fields unshielded from winds, data on windspeed and rainfall patterns, and values (numbers) for effectiveness of various types of vegetation in stopping or slowing wind erosion. By using the Wind Erosion Equation, it is also possible to identify and locate soils with high wind erodibility potential. However, it has been shown that this equation may overestimate wind erosion in areas differing in climate from the area in and near Kansas (the Southern Great Plains in the United States), where the equation was developed. Work is proceeding in modifying and adjusting the Wind Erosion Equation to make it more generally applicable to other areas.

2.1.4 Soil Resource Indicator 4

The amount of water-eroded sediments in streams, impoundments, channels, canals, and lakes and of undesirable sediments piled on soil surfaces is an indication of the extent to which off-site deposition from water erosion has taken place. In many countries, the costs of this off-site deposition are higher than the on-site damages, and decreases in productivity are reflected in lower crop yields and poorer range and forest growth due to water-caused soil erosion. Furthermore, the damage to the bodies of water results in a decrease in the capacity of the impoundment behind a dam, a need for dredging choked waterways and harbors, and a decline in the quality of water for drinking and for recreation, as well as poorer quality habitats for fish and other life in the aquatic ecosystems. Also, the sediments from fields often carry pesticides and phosphate absorbed on their surface particles, which are released when the sediments enter the bodies of water, causing further damage to the environmental quality of aquatic ecosystems.

Using special measuring flumes and sediment collectors, the amount of sediments leaving local watersheds and entering bodies of water can be measured. Amounts of sediments suspended in the water and the pesticides and phosphates they carry may be measured by repeated sampling with specialized equipment.

Models and simulations have been developed for estimating and predicting off-site sedimentation. These models require climatic and hydrological data on rainfall, overland flow rates of water, a factor for the detachment of the particles from the soil at the original erosion site, and a deposition factor for how far various sizes and types of sediments are carried in the water before they are deposited.

Estimates of deposition of sediments can be made by measuring sediment thickness at key sites, by the turbidity and color of the water containing the sediments, and by rough calculations using the soil loss data from Soil Resource Indicator 1.

2.1.5 Soil Resource Indicator 5

The difference between actual crop yields and maximum potential yields based on the soil properties and economically optimum production inputs, including irrigation, is an indicator for determining whether additional plant nutrients and, in many instances, lime are needed. (However, the occurrence of serious pest and disease outbreaks, which can seriously reduce yields, must also be taken into account.) Soil fertility maintenance is a must for optimum crop production. The additional plant nutrient and lime requirements can also be determined by soil tests and accompanying soil fertility evaluation procedures. Based on this information the appropriate amounts of fertilizer and the amount of lime needed to supply calcium (and neutralize the exchangeable aluminum in acid soils) can be added. By using this indicator it is possible to determine the soil fertility status of farms and ranches and thereby estimate the fertilizer and lime needs for a region or a country. Through these procedures it is also possible to monitor the trends in a region or a country and evaluate the effectiveness of programs designed to improve soil fertility.

The data required for this indicator can be obtained by analyzing composited soil samples from which plant nutrients are extracted with chemical solutions appropriate for the kind of soil and the climate and crop to be grown. Lime needs are determined by measuring the active acidity in a soil sample which must be neutralized for best plant growth. The results of these laboratory tests are compared with fertilizer nutrient response results from field experimental plots and greenhouse pot tests. Such procedures have been developed for the three major nutrients--nitrogen, phosphorus, and potassium--as well as for the secondary nutrient elements and most of the minor elements or micronutrients. This methodology can also be used to detect toxicities of chemical elements in soils which are affecting plant growth.

Data are available, generally at nominal cost, from soil fertility evaluation programs and soil testing conducted by research labs at universities and other research centers, from extension services, and from private soil laboratories, fertilizer companies, and distributors. Calibration and yield prediction procedures for applications of varying amounts of fertilizer and lime have now been rather well worked out. However, the fertilizer needs indicated by any soil test can be interpreted in several ways, depending on the goal and the philosophy of the person or group doing the interpretations. Some interpret fertilizer needs to mean the economically sound amount to produce the next crop, whereas others seek to build the soil levels of nutrients up to an optimum level and keep them there; some take into account the likely economic conditions at time of harvest, and others factor in the skill and the financial position of the farmer.

2.1.6 Soil Resource Indicator 6

Current land use is compared with the suitability and capability of the soil resources to indicate the degree to which land use patterns in a region or a country are compatible with basic soil properties, the climatic environment, and location (e.g., nearness to or remoteness from villages). Soil Resource Indicator 6 may also show the degree to which prime agricultural lands are being preserved or built on. Periodic applications of this indicator will reveal trends in land use patterns, which can be used to gauge the effectiveness of programs. The indicator will also reveal the status of land uniquely suited for certain types of animal habitat, such as wetlands, and the status of reforestation programs near villages with fuelwood needs.

To use this indicator investigators need assessments of current land use (e.g., data on agriculture, rangelands, forestry, wildlife habitat, agroforestry, or urban building). Such asssessments must be done periodically to indicate trends and problems needing attention and to provide data for land use planning. The assessments are used to compare the fit between actual land use and the optimum land use indicated by soil surveys. A by-product of such assessments is information on rotations, cropping patterns, use of shifting cultivation, and length of cycles.

The optimum data collection method for this indicator is on-site measurements and observations at statistically selected sample sites according to a specified sampling intensity, repeated in a multiyear cycle. However, this method can be costly, as it requires trained on-site observers and rather sophisticated statistical expertise in the area of sampling design. A more generalized approach using remote sensing or sampling frames designed for other purposes is an alternative. This latter set of procedures is described in the summary of this section, as it is common to other natural resource data collection needs.

2.1.7 Summary of Advantages and Disadvantages of Soil Resource Indicators

Advantages: Soil resource indicators show the status, conditions, and trends of a natural resource category that must be maintained in a sustainable condition and use mode for a successful agricultureand fiber program. These indicators can also be used to help maintain environmental quality while the resource is being used for food production.

Disadvantages: Procedures have been developed for the use of models, simulations, and statistical sampling systems in collecting data and making predictions and estimates, and many can be adapted to the tropical and subtropical conditions of developing countries. However, additional research and development are required before some of the models and prediction equations--the Universal Soil Loss Equation, for example--can be used in the tropics or subtropics. Also, use of these models and equations requires computer equipment and very large amounts of data, neither of which may be available in some locations. And many of these more sophisticated methods of collecting information require staffs that are well trained and specialized in computer science, modeling, and statistics.

However, there are techniques that require less funds and fewer personnel. An example is remote sensing. Use of the more advanced and high-resolution imagery from Landsat and SPOT satellites can be very cost-effective, especially with the present rapid advances in technology. Advanced Very High Resolution Radiometry from GOES weather satellites gives a more generalized lower resolution view. Even less costly and demanding is the use of high-altitude air photography. For certain types of soil resource-related remote sensing, the use of low-flying light planes with aerial cameras mounted in the floor of the planes has recently been successful. Some type of image analysis and digitizing equipment is needed for these techniques, a fact that adds to their cost.

Special-purpose statistical sampling is a very effective method of obtaining data for many of the soil resource indicators, but it is expensive and requires trained personnel. An alternative is to use the same sampling frames and personnel used for collecting general agricultural statistics. But even if statistical precision is not possible, evaluators can get some idea of the magnitude of the soil resource indicators with relatively simple measurements--for example, comparison of topsoil thickness in areas of wind and water erosion with normative thickness; or use of interpretive material in soil survey reports about erosion phases, land capability, yield potentials of various soils, and soil suitability for various land uses.

2.2 Water

The importance of water in agricultural development may be emphasized by several facts: in most countries the agricultural sector is the major user of water; in fact, in some locations, groundwater is being mined (i.e., used) at a faster rate than it is being recharged. In many areas, upstream flooding causes major damage. Furthermore, water is highly vulnerable to pollution, with resultant damage to its suitability as an aquatic life habitat and for use by humans. Indicators that can assess this natural resource category include quantity and quality of surface water and groundwater, flood frequency and severity, and degree of efficient delivery and use of irrigation water.

2.2.1 Water Resource Indicator 1

Measuring the extent to which groundwater and surface water supplies meet the needs for irrigation, human use, and maintenance of aquatic life habitats is useful for measuring the impact of water conservation and water development projects and for projecting probable levels of food production on the basis of the water that is likely to be available to produce the crops. Use of this indicator requires consideration of trends in past usage, current status, and projections for the future. Parameters include soil moisture storage for plant growth, water available for recharge of groundwater, groundwater withdrawal rates, human use rates, extent of soil moisture deficits in time of drought and probable irrigation rates, amount of flow in streams, and the level of water in lakes and impoundments required to maintain aquatic life habitats.

Application of this indicator is greatly aided by use of regional and local water budgets or balances, which take into consideration the soil moisture storage capacity and the extent to which it is filled, precipitation, actual and potential evapotranspiration rates (amount of water evaporated directly and that lost through evaporation from plant leaves), any rainfall in excess of soil moisture storage and evapotranspiration rates that trickles down through the soil to recharge the groundwater supply, and the surface runoff and base flow from groundwater that keep streams flowing. These budgets or balances furnish a measure of the irrigation needs, net recharge or loss of groundwater, and stream runoff; thus they are indicators of the water supply situation for the area or region in question.

Water budget, stream flow, and groundwater supply situation information may ususally be obtained from several sources including weather bureaus, irrigation districts, or city water departments. Water budgets may also be relatively easily calculated from information on the parameters described above. Procedures for calculating water budgets or balances are presented in several text and reference books (e.g., see Buol et al. 1980).

If insufficient information is available to calculate budgets or balances, then estimates of water supply can be obtained from experienced extension agents, operators of irrigation districts, meteorologists, and hydrologists. Wildlife specialists can provide information on the rate of flow or water levels required to maintain sufficient water supply for desirable species of aquatic life. The status of groundwater supplies can be estimated by periodic measurements of water levels in sampling wells.

2.2.2 Water Resource Indicator 2

Because upstream flooding damages crops and property and deposits harmful sediments, the frequency with which it occurs and the size of the areas it affects can be major resource concerns in humid areas. The costs of such flooding can exceed the on-site costs of water erosion because of reduced productivity and production. This flooding is an indication of the need for small upstream dams and watershed water control programs, and it can be used as a measure of the effectiveness of water control programs, upstream structures, and flood-area zoning regulations.

Data needed for this indicator are historical records on flood frequency and damage estimates, or airphotos and satellite imagery for remote-sensing techniques.

2.2.3 Water Resource Indicator 3

The efficiency with which irrigation water is conveyed to farms and ranches and is used on farms is an important indicator of the amount of water actually being applied to plants and of water being lost in transit. The efficiency rate is especially critical in water-short areas. Inefficient on-farm handling of irrigation water causes irrecoverable loss of valuable water, excessive use of energy in pumping and distributing the water, lost opportunities for higher crop yields, and possible degradation of water quality and soil properties through buildup of soil salinity from high water tables and resultant evaporation.

Data required to calculate on-farm efficiency include measures of the volume of water stored in the soil and actually used by the crop expressed as a ratio or percentage of the volume of water reaching the farm or ranch site, measures of the volume of water actually delivered to the farm or ranch site, and estimates of the volume of tailwater or return flow (if any) to canals and streams. (A problem in this last estimation is that some of the water applied to the field seeps down through the soil and may recharge an underlying aquifer and thus may not be lost to the system if the aquifer is being used as a source of irrigation water.) The use efficiency can be calculated relatively easily if the appropriate data and estimates are available. The data can be obtained from the records of the irrigation district or of farmers.

Applications of the indicator include evaluating the impact of water conservation programs, calculating the response of crops to applied water by measuring the amount of water actually reaching the crop, obtaining more precise estimates of the volume of water needed for irrigation of specified areas, and determining the need for programs to increase on-farm efficiency.

Off-farm conveyance efficiency is an indication of how much of the water drawn from the stream, aquifer, or impoundment actually is delivered to the farm or ranch. Conveyance losses can be high--Postel (1985) has estimated worldwide conveyance efficiency at 38 percent. Losses come from evaporation, withdrawal by plants lining the delivery canals, and leakage from the canal channels. This portion of the overall irrigation efficiency indicator can identify a need for programs to increase water conveyance efficiency and to measure the impact of water conservation programs.

Data required to calculate conveyance efficiency include the amount of water leaving the impoundment or other sources and the amounts actually delivered to farms and ranches. Such data are available from irrigation district records, water resource departments and agencies, and water use associations. Problem areas can be identified by the presence of plants, which use some of the water in evapotranspiration, lining the main canals (observed from the ground or air or in aerial photographs) and the presence of obvious seep spots along the canals. Actual losses may be very difficult to trace to a specific source if the seepage is underground, however.

In summary, there are both advantages and disadvantages to the indicators proposed for the supply portion of the water natural resource category. Advantages are that most of the data needed for the indicators are relatively easily obtained (provided the water users and organizations involved are willing to release their data) and calculations can readily be made. Large numbers of highly trained scientific and technical personnel are not required to collect most of the data. Some of the information can be obtained by aerial reconnaissance or relatively inexpensive aerial photographs from light planes. Program impacts can be relatively easily determined in most cases.

Disadvantages of the indicators and of data collection for them are that some components must be based on rough estimates; it can be difficult to maintain water flow or impoundment levels so as to preserve aquatic life habitats because of differences in views or lack of information about what constitutes satisfactory aquatic habitats; and there may be some sensitivity about water use data in areas where water is in short supply and there is competition for it. It may be difficult to collect data for upstream flood control and water conservation because of the need to get villages, cities, and landowner groups together on flood control districts and zoning. (For examples of water supply management in a developing country, see Ng and Lethem 1983 and Postel 1985.)

2.2.4 Water Resource Indicator 4

Indicators for measuring surface water pollutants are used for determining the presence of damaging contaminants and assessing the effectiveness of soil conservation and environmental activities. Several types of pollutants introduced in streams, impoundments, and lakes present major concerns for the quality of surface waters. These pollutants include suspended sediments, toxic chemicals, out-of-place nutrients, and fecal matter. Such contaminants not only present problems for human use of water for drinking and for recreational purposes, but also pose serious threats to aquatic life in the affected waters.

Suspended sediment loads in streams, lakes, and reservoirs are a result of soil erosion from cropland, construction sites, and stream banks and of natural events such as volcanic eruptions and mudslides. A particular problem with suspended sediments from cultivated fields is that they may carry into the water pesticides and phosphates that cause further contamination. In most developed countries, about two-thirds of the suspended sediment load comes from nonpoint sources (i.e., from fields and other diffuse sources rather than from readily identifiable discharge pipes or ditches). One component of the indicator can be used to identify farmland areas where high erosion rates, and thus high sedimentation into streams, are prevalent. The presence of damaging amounts of suspended sediments, toxins, and nutrients can be used as a basis for prioritizing surface water pollution abatement programs and projects. Such data can also be used as a general measure of the effectiveness of ongoing soil conservation and environmental protection activities.

Data collection required for use of this component of the indicator includes measuring the concentration of suspended sediments in surface waters over a period of time to determine what the trends are and when peak loads occur. Information also should be obtained on pesticides and phosphates absorbed on soil particles entering bodies of water. These data can usually be obtained from the records of government agencies with water quality programs. If the data are not available, it is necessary to sample the water periodically and analyze the sediments in it, using sites for gauging stream flow if possible. (An excellent example of a program to analyze water samples for sediments and other pollutants and interpret the results is given in a paper by Smith, Alexander, and Wolman 1987).

Prediction models and simulation procedures have been developed for predicting the amounts of surface water pollution due to erosion and sediment transportation (e.g., Resources for the Future Model Simulator for Water Resources in Rural Basins, or SWRRB; Soil Conservation Service Models for Chemicals, Runoff, and Erosion from Agricultural Management Systems, or CREAMS; and Sedimentology by Distributed Model Treatment, or SEDIMOT II). However, models require large amounts of data and skilled operators and interpreters.

The second component of surface water pollution involves the toxic chemical pesticides that are used in farming, horticulture, and urban lawn care and that may be washed into nearby streams. Large amounts of chemical pesticides are used in modern agricultural technology, and it has been estimated that about 5 percent of these chemicals find their way into surface waters through runoff. This kind of pollution is especially likely to occur during heavy rains shortly after pesticide application; stream water concentrations of such pollutants are generally very low during long periods without rain and outside the pesticide application season.

Data on the occurrence of these toxins may be used to prioritize surface water quality improvement efforts and to measure the impact of programs to reduce agricultural chemical use, such as integrated pest management and biological control of pests. As has been indicated, concentrations of the toxic chemicals in surface waters vary, and thus sampling programs must be designed to sample the peak periods of concentration and to indicate trends. It must be noted that for many of these chemicals, detection and measurement require sophisticated equipment and procedures. The same models and simulations used to predict the occurrence and concentrations of suspended sediments in surface waters may in some cases also be used for the toxic chemicals.

Surface waters naturally contain some nutrients, but their nutrient loads increase when the plant food nutrients, nitrogen and phosphorus (often referred to as nitrate and phosphate), wash into water from fields; when sewage that is not fully treated is discharged into surface waters; and when animal wastes wash into streams. Large amounts of these nutrients in waters cause eutrophication, an enrichment of the water that causes aquatic plants to grow profusely and stimulates microbial growth. These developments cause problems in boating and swimming and may also reduce the oxygen level in the water, resulting in fish kills. Salinity (presence of sodium and other alkali salts in solution) may be introduced in surface waters by erosion of geologic deposits rich in salts, by saline return flows from irrigation, and by evaporation; which increases salt concentrations in lakes and impoundments.

Determination of nutrient loads helps to identify the need for enhanced conservation programs, for educational programs on excessive use of nitrate fertilizers, and for improved human and animal waste management. Surface waters can be monitored to help measure the impact of erosion and waste handling programs.

Data collection requires repeated sampling of surface waters according to a well-designed sample collection program and analysis of water samples for nitrate, phosphate, salinity, and fecal coliform (and perhaps streptococcal) bacteria. Such data may be available from Federal, state, and local water resource and environmental quality agencies and health departments. The prediction models and simulations described above may also be used. The data required are relatively simple and may be collected without extremely sophisticated equipment.

The advantages of this water-quality-related indicator are that many of the data are readily available, several of the pollutants are relatively easy to detect and measure (the pesticide chemicals are an exception), and samples are relatively easy to collect. In addition, many of the effects of pollutants are obvious and striking--such as large fish kills due to toxic chemicals or large amounts of untreated sewage or animal waste in the water; and the tremendous growth of water weeds and algae due to eutrophication, which often turn the water green.

Several disadvantages are also associated with the pollutant indicator. Some of the chemicals are detected and measured only with sophisticated analytical equipment and skills; amounts of pollutants may vary widely over time, and thus continual sampling may be required; and many of the pollutants in surface waters come from nonpoint (diffuse, not readily recognizable) sources, so that it is often not possible to determine with certainty what the origin of the pollutants is and who or what is responsible for the pollution.

2.2.5 Water Resource Indicator 5

Another indicator in the water resource category measures the contamination of groundwater with toxic chemicals, excess nitrates, and salinity. Effects on water quality are the same as those on surface water pollutants, and methods of data collection and analysis are similar to those for the surface waters indicator. However, there are important differences between surface water and groundwater contamination and pollution. If pollutants are introduced into groundwater, it is nearly impossible to remove them; furthermore, their presence may not be recognized for a long time because groundwater moves so slowly and cannot, of course, be observed visually. Pollutants may be introduced into groundwater through surface applications of pesticides or nitrogen fertilizers that filter downward into the groundwater zone. Pollutants may also be introduced into groundwaters by leakage from rainfill disposal sites, underground storage tanks, or buried barrels and drums of chemical residue.

Some types of groundwater pollution are even more hazardous than surface water pollution. For example, polluted groundwater is more likely to be drawn from wells for drinking than is polluted surface water. The "blue baby" syndrome is one result of excess nitrates in groundwater that is used for drinking: the nitrate is converted to nitrite in the baby's system and causes problems with the hemoglobin supply. High salinity in groundwater near the surface can result in harmful salt concentrations in soil due to evaporation of the water. (Such salt concentrations can be avoided or reduced by proper water table management and by applying sufficient irrigation water to leach the salts below the reach of plant roots.)

Methods of data collection and analysis for this indicator are similar to those for surface water indicators, except in the case of measuring salinity in soils. To measure salinity, conductivity of soil extracts, water analyses for dissolved salts, and determination of the amount of sodium absorbed by the soil's exchange complex are needed. Aerial photographs taken from a light plane with a camera in its floor or by high-altitude airphotography of appropriate scale can help detect and monitor areas of severely salt-affected soils.

Advantages of this indicator are that a sampling and monitoring program can help avert some very serious problems; the samples needed may be collected relatively easily, and much of the data may be available from other agencies and organizations. Disadvantages are that detecting and measuring some of the chemicals require expensive equipment and skilled operators;

moreover, it is difficult at best to know when some types of groundwater pollution have occurred without a very extensive and expensive monitoring program.

2.3 Plants

Plant resource indicators include measures and observations of area, density, and quality of, stresses on, and species present for four types of plant cover: shifting cultivation, range, forest (including fuelwood), and wetlands. (Intensively cultivated cropland, also a type of plant cover, was discussed in the soil resource section because intensively managed plants interact closely with soils.) These indicators show the extent to which the soil is protected from wind and water erosion; present and future food production potential; availability of animal forage; supply of timber and fuelwood; potential impacts of such stresses on vegetation as diseases, insect pests, and nutrient deficiencies and toxicities; status of animal habitats, including numbers and species of large animals present; and extent of community awareness of and interest in natural resource programs such as reforestation around villages.

2.3.1 Plant Resource Indicator 1

Plant Resource Indicator 1 shows the extent to which shifting cultivation is used and the length of the cultivation cycle, the rate of conversion from shifting cultivation cycles to continuous cultivation, what species of plants are used, and whether commercial fertilizers are used. Shifting cultivation is important because it aids in maintaining some degree of forest cover for erosion protection and animal habitat and in maintaining a sustainable agriculture with low-technology inputs. The length of the cycle reflects the native fertility of the soil (short cycles are associated with low fertility) and the pressure on the soil-plant environment for food production (short cycles may also indicate greater pressure to produce food). The cultivators' knowledge and economic position are reflected in the selection of more productive varieties and species and the use of some fertilizer.

Data collection for this indicator should determine the extent of areas of shifting cultivation, whether there is a trend to replace shifting cultivation with continuous cultivation, what the length of the cycle is in years, which food crop species are used in the cultivation portion of the cycle, and whether any fertilizers or animal wastes and mulches are used. The type of soil and estimates of its native fertility should also be determined.

Advantages of this indicator are that it furnishes information about pressure to produce food in the area and yields information about the extent of preservation of forest and its animal habitats. The type of shifting cultivation used gives a picture of the cultivators' skill and economic situation and of native soil productivity. Data are easily collected, and the published literature contains much information about this method of agriculture. Disadvantages of this indicator are that, in some places, cycle lengths are more heavily influenced by local customs, ethics, and economic situations than by soil quality or food pressures, and that it can be difficult to locate areas of shifting cultivation or determine their area and inventory production practices because of rugged terrain, remote locations, and small size of tracts.

2.3.2 Plant Resource Indicator 2

The second plant resource indicator shows the carrying capacity (forage supply) of rangeland, which is highly related to range condition--the kinds and number of plants present in relation to the climax range vegetation (the plants present on range in its natural, undisturbed condition). Range condition is also highly correlated with the potential for wind and water erosion and onset of desertification of the rather fragile ecosystem occupied by the range grasses. Finally, of course, range condition also is correlated with the effectiveness of the range as wildlife habitat.

Data collection involves determining what plant species are present and what their size is, and comparing this information with the climax species for the range area. (Climax species vary according to the local environment, climate, and soil.) Other useful information is the extent to which rangeland has recently been plowed and cultivated for crops and the extent to which rangeland in the area is undergoing degradation such as desertification. Information about occurrences of plagues of locusts and grasshoppers is needed to estimate how this stress on forage supplies may have decreased the carrying capacity for livestock and wildlife.

Advantages of this indicator are that the data on range condition are easily and cheaply collected, and trends on changes in land use or condition can be monitored by remote sensing or aerial photographs. Disadvantages are that the estimates of range condition and carrying capacity must be done by a trained and experienced range scientist, dependable criteria for animal habitat on rangelands do not seem to be fully defined at present, and the range condition cannot be evaluated by remote sensing or aerial photography--on-site visits are required.

2.3.3 Plant Resource Indicator 3

The third plant resource indicator shows the kind and quality of woody species and their suitability for lumber and fuelwood, the area of forests and the extent to which they are being converted to cropland, and progress in reforesting hilly eroded areas. Forests, which supply lumber, fuel, and animal habitat, must be maintained for the future as sinks for carbon dioxide in order to reduce the amount of carbon dioxide escaping to the stratosphere and contributing to the greenhouse effect.

Application of this indicator requires information on stand densities and age, size, and species of trees and woody shrubs. Information is also needed about areas and locations of forest and agroforestry stands, suitablity of the species for various uses, rates at which forests are being converted to cropland and other uses, area and status of reforestation programs, numbers and species of large animals in the forests and types of habitat available, and fuelwood demand and availability. Information is also needed on reforestation projects--the species used and their size, whether the projects supply fuelwood as well as timber, and whether local people support the project.

Data collection requires exerienced foresters to "cruise" forest stands to determine the type of species and their volume and condition. Remote sensing and airphotographs can be used to determine forest areas, trends in land use, insect and fire damage, and location and size of reforestation areas.

The advantage of this indicator is that, in general, it provides useful information for forestry management and projections. A disadvantage is that detailed studies and measurements are required to obtain the necessary hard data. For example, determining fuelwood supply and demand requires interviews with villagers and other local people. It must be added, however, that a qualitative indication of extreme shortages of fuelwood is the use of animal dung rather than wood for cooking and heating fires.

2.3.4 Plant Resource Indicator 4

The fourth plant resource indicator assesses wetlands--their types, their suitability for various wildlife habitats, and their present uses. Wetlands are defined as areas with hydrophytic (moisture-loving) plants and hydric soils (water-saturated or flooded, or showing evidence of long-term water saturation), and they are excellent habitats for certain types of wildlife. Various types of natural vegetation occupy these sites, according to the environment, soil characteristics, and degree of continuous water saturation.

Wetland areas can be detected by airphotographs or remote sensing imagery, but on-site inspection is required to establish the kind of wetland, its degree of water saturation, and its precise boundaries. Information about species of wildlife inhabiting or using wetland can be obtained from Federal and state wildlife or fish and game departments or agencies.

There are both advantages and limitations to the use of all the indicators for the plant natural resource area. Many of the components of this area can be studied, characterized, and delimited with the use of remote sensing imagery (including Advanced Very High Resolution Radiometry and the Landsat and SPOT satellites) and by airphotographs. But on-the-ground involvement of experts is called for in the more specific, exact determinations. Obtaining data is not as expensive and complicated as in aspects of some of the other natural resource areas described. However, plants are components of dynamic ecosystems, which are difficult to describe and characterize and which cause frequent changes.

2.4 Ecosystems

2.4.1 Ecosystem Indicator 1

Ecosystem Indicator 1 measures general ecological deterioration, sometimes called ecological deterioration syndrome, which reflects a general breakdown in plant soil nutrient cycles, degradation of cropland, increases in soil erosion, disappearance of forests and fuelwood supplies, poor range conditions, and a general overloading of the environment with human and animal populations. Symptoms are declines in cropland and range productivity, the disappearance of forests, widespread use of animal manures for cooking fuel, and large populations of people and animals. Desertification may be the final result. To avoid such a crisis, components of this indicator should be applied early, when symptoms of ecological deterioration first start to appear.

Information required for this indicator includes trends in plant and animal species over time, trends in forest conditions, extent of water and wind erosion and of sand and dust deposition, trends in kinds of crops grown and their yield, appearance of indicator weeds, nature of cooking fuel used and distances traveled to obtain fuelwood, status of any irrigation systems, and status of human and animal populations. On the basis of these data, the excess demands being made on the carrying capacity of the ecosystem can be estimated and the impact of regional development programs, including those for soil, range, and forest and fuelwood conservation, can be assessed.

(An example of the application of this indicator is a study of 20 African countries, by Leonard Bery of Clark University, reported in Brown and Wolf 1986.)

2.4.2 Ecosystem Indicator 2

The Soil-Plant Ecosystem Food Productivity Index measures the relative productivity in calories of food produced per year per unit area per unit of input over a given appropriate time cycle of a soil-plant ecosystem. These calculations could be done for each of two or more ecosystems under comparison. For example, a shifting cultivation soil-plant ecosystem could be compared with an intensively cultivated soil-crop plant ecosystem of equal size. The resulting ratio, if calculated after the full cycle of shifting cultivation has been completed, should reflect the relative productivity of the two systems in terms of calories of food produced on a comparable basis. It should be possible in some cases to demonstrate that the shifting cultivation ecosystem can be made as efficient as the intensively cultivated one, thus allowing preservation of forest in the shifting cultivation ecosystem without sacrificing food production.

Table 1 summarizes information about all of the indicators discussed in this paper.

Table 1. Characteristics of Natural Resource Indicators

	Indicator Short Title	Advantages[a]	Disadvantages[b]	Data Sources	Data Collection Cost[c]
SOILS					
1.	Topsoil loss by water erosion	1, 3, 4	3, 4	Topsoil thickness, soil loss	M
2.	Permanent productivity loss by water erosion	1, 4	1, 4	Erosion-exposed soil poor for root	H
3.	Wind erosion	1, 3, 4, 5	3, 4	Soil loss, dust & sandstorms	L
4.	Off-site erosion sediment	1, 3, 5	1, 2, 4	Sediment loads & deposits	M
5.	Actual v. potential crop yields	3, 4	4	Crop yields, soil samples	M
6.	Actual land use v. soil suitability	1, 2, 3, 4	4		L
WATER					
1.	Supplies	1, 4, 5	4	Water balances, flow, levels	M
2.	Flooding	1, 2, 5	4	Frequency & area	L
3.	Efficiency of irrigation systems	3, 4		Water delivery to & use on farms & ranches	L
4.	Pollution--surface waters	1, 4, 5	1, 2, 4	Analysis of water samples	H
5.	Pollution--groundwater	1	1, 2, 4	Analysis of water samples	H

Table 1. Characteristics of Natural Resource Indicators (cont.)

Indicator Short Title	Advantages[a]	Disadvantages[b]	Data Sources	Data Collection Cost[c]
PLANTS				
1. Shifting cultivation	1, 4, 5	4	Land use cycles, crops, inputs	L
2. Range conditions	1, 2, 3, 4, 5	1, 4	Plant species & quality, growth	L
3. Forests and fuelwood	1, 2, 3, 5	4	Tree growth, quality, area, fuelwood supply	M
4. Wetlands--water-loving plants	1, 2, 3, 5	4	Area, plant types, soils, areas drained and filled	M
ECOSYSTEMS				
1. General Deterioration	1, 2, 3, 4, 5	4	Erosion, yield decline, plant species, populations	M
2. Food productivity index	1	1, 4	Relative food production of ecosystems, calories/unit area	M

[a]Advantages
1 = Early warning of potentially serious situations
2 = Remote sensing and airphotos useful
3 = Most data relatively easy to obtain
4 = Helps maintain sustainable agriculture
5 = Signals potential problems with animal habitat

[b]Disadvantages
1 = Many determinations and measurements require specialist expertise
2 = Specialized, sophisticated equipment required for some measurements
3 = Some equations, prediction models, technology not applicable to tropics and subtropics
4 = Many estimates and measurements must be made or many samples need to be taken

[c]Data collection costs:
H = High
M = Medium
L = Low

APPENDIX A

NATIONAL RESOURCE INVENTORIES IN THE UNITED STATES

National Resource Inventories were conducted in the United States in 1977, 1982, and 1987 by the U.S. Department of Agriculture's Soil Conservation Service with the assistance and cooperation of the National Association of Soil Conservation Districts and local Soil and Water Conservation Districts. The 1982 inventory was more intensive than the 1977 and 1987 inventories. A smaller number of sampling areas and a lower percentage of the total area was included in the 1977 inventory; about 50 percent of the 1987 inventory was accomplished by remote-sensing techniques. The inventories have proven very useful in measuring the extent and location of erosion of the nation's land and the progress in controlling this erosion, land-use patterns, range conditions, forest cover types, wetlands, and several other natural resource conditions related to the land and its use. In all, more than 20 natural resource features and characteristics have been included in the inventories. The basic procedures are described and discussed in detail in a report by the National Research Council of the National Academy of Science (National Research Council Board on Agriculture, 1986). The procedure has been to record information on natural resources within small, randomly selected blocks of land, and to expand this information to represent larger areas. These inventories have served as a basis for program planning, prioritizing conservation efforts, and appropriating funds for resource conservation, and for many other studies, analyses, and summaries. Analysis of the inven- tories has indicated that a 10-year cycle is frequent enough to monitor natural resources on a national scale. The cost of the intensive 1982 inventory was less than 1 cent per acre.

APPENDIX B

REMOTE SENSING OF NATURAL RESOURCES

Remote sensing of natural resources shows great promise, as rapidly improving technology brings about increased capability and decreased costs. A recent example of its use, in Alaska, illustrates its value.

The need for natural resource inventories over the large and remote undeveloped areas of Alaska resulted in efforts to obtain information using Landsat remote-sensing data and aerial photograph interpretations. Four levels of classification were used. Level I was very general (e.g., water, wetlands, forest, shrub tundra, ice or snow, and rocks). Level IV was detailed, using predominant tree species as a basis for recognizing plant communities in the various environments. Levels II and III were intermediate levels of generalization.

Costs as of 1982 for this remote-sensing project, according to data source and level of detail, are shown below.

Source	Level	Costs per acre, cents
Aerial photos, color infrared, 1:30,000	III IV	30 45
Aerial photos, color infrared, 1:20,000	III IV	15 30
Landsat imagery color 1:250,000	II-III	0.1

The cost of additional computer-aided analysis of the Landsat imagery ranged from 5-12 cents per acre.

This project was conducted by the U.S. Department of Interior's Bureau of Land Management and the National Aeronautics and Space Administration.

REFERENCES

Bills, N.L., and R.E. Heimlich. 1986. "An Improved Soil Erosion Classification: Update, Comparison and Extension." In Soil Conservation: Assessing the Natural Resources Inventory. Vol. 2. 1920. National Research Council Board of Agriculture. Washington, D.C.: National Academy Press.

Bornemisa, E., and A.A. Alvarado, eds. 1975a. "Soil Fertility Evaluation in Tropical America." Raleigh, North Carolina: Soil Science Department, North Carolina State University.

Bornemisa, E., and A. Alvarado, eds. 1975b. "Soil Management in Tropical America." Raleigh, North Carolina: Soil Science Department, North Carolina State University.

Brown, L.C., and E.C. Wolf. 1986. "Assessing Ecological Decline." In State of the World 1986, pp. 22-39. Washington, D.C.: Worldwatch Institute.

Buol, S.W., F.D. Hole, and R.J. McCracken. 1980. Soil Genesis and Classification. 2nd ed. Ames, Iowa: Fowes State Press.

Burrough, P.A. 1986. Principles of Geographical Information Systems for Land Resources Assessment. Oxford: Oxford University Press.

Dasmann R., and P. Reining, eds. 1983. Resource Inventory and Baseline Study Methods for Developing Countries. Washington, D.C.: American Association for the Advancement of Science.

Dudal, R. 1980. "Inventory of Major Soils in the World with Special Reference to Mineral Stress Hazards." In Plant Adaptations to Mineral Stress in Problem Soils, edited by M. Wright, pp. 3-14. Ithaca, New York: Cornell University.

Eckholm, E., and L.R. Brown. 1977. "Spreading Deserts--The Hand of Man." Worldwatch Paper 13. Washington, D.C.: Worldwatch Institute.

Estes, J.E., D. Staw, and J. R. Jensen. 1982. "Monitoring Land Use and Land Cover Changes." In Remote Sensing for Resource Management, edited by C.J. Johannsen and J.L. Sanders, pp. 100-110. Ankeny, Louisiana: Soil Conservation Society of America.

Foster, G.R., W.C. Moldenhover, and W.H. Wischmeier. 1982. "Transferability of U.S. Technology for Prediction and Control of Erosion in the Tropics." In Soil Erosion and Conservation in the Tropics, edited by S.A. El-Swaify. Publication 43. Madison, Wisconsin: American Society of Agronomy Specialists.

Gianessi, L.P., H.M. Peskin, and O.K. Young. 1981. "Analysis of Water Pollution Control Policies: Agricultural Sediment Control." Water Resources--Research 17:803-821.

Greenland, D.J. 1974. "Evolution and Development of Different Types of Shifting Cultivation." FAO Soils Bulletin 18:5-24.

Hudson, N.W. 1982. "Soil Conservation Research and Training Requirements in Developing Tropical Countries." In Soil Erosion and Conservation in the Tropics, edited by S.A. El-Swaify, p. 121-133. Publication 43. Madison, Wisconsin: American Society of Agronomy Specialists.

International Geophysical Union (IGU) and International Cartographic Association (ICA). 1987. World Digital Base for Environment Sciences. IGU and ICA.

National Research Council Board on Agriculture, Committee on Conservation Needs and Opportunities. 1986. "Wind Erosion Estimates." In Soil Conservation: Assessing the National Resources Inventory. Vol. 1, pp. 54-59. Washington, D.C.: National Academy Press.

National Research Council Board on Agriculture, Committee on Conservation Needs and Opportunities. 1986. Soil Conservation: Assessing the National Resource Inventory. Vol. 1. Washington, D.C.: National Academy Press.

Pierce, F.J., W.E. Larson, R.H. Dowdy, and W.A.P. Graham. 1983. "Productivity of Soils: Assessing Long-Term Changes due to Erosion." Journal of Soil and Water Conservation 38:39-44.

Postel, S. 1985. "Managing Freshwater Supplies." In State of the World 1985, edited by L.R. Brown, pp. 42-72. Washington, D.C.: Worldwatch Institute.

Rijsberman, and M.G. Wolman. 1985. "Effect of Erosion on Soil Productivity: An International Comparison." Journal of Soil and Water Conservation 40:349-354.

Sanchez, P.A., W. Couto, and S.W. Buol. 1982. "The Fertility Capability Soil Classification System: Interpretation, Applicability and Modification." Geoderma 27:283-309.

Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987. "Water-Quality Trends in the Nation's Rivers." Science 235:1607-1615.

Tucker, C.J., J.R.G. Townsend, and T.E. Goff. 1985. "African Land Cover Classification Using Satellite Data." Science 227:369-374.

Williams, J.R., K.G. Renard, and P.T. Dyke. 1983. "EPIC: A New Method for Assessing Erosion's Effect on Soil Productivity." Journal of Soil and Water Conservation 38:381-383.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agriculture Handbook 537. Washington, D.C.: U.S. Department of Agriculture.