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Indicators for Assessing Changes in Natural Resources in Developing Countries

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I. Background and Rationale

Agricultural development assistance impacts many components of life in developing countries including, among others, income, food availability, consumption and the natural resource base. A given developmental activity may impact many components simultaneously and it is not uncommon for an activity to positively impact one component and adversely impact others. The purpose of this paper is to identify and discuss some indicators which may be used by A.I.D. to monitor the impact of agriculture development assistance efforts on the natural resource base of host countries.

Concepts, Definitions and Issues

A.I.D.'s Agricultural Focus Statement addresses income of the rural poor, availability of food, and maintenance and enhancement of the natural resource base. Accomplishment of these objectives will require projects and programs that will not only raise income through increased and more efficient production, but will also provide these necessities without degrading the natural resource base. Thus, the concept of natural resource sustainability takes on great importance when assessing the impact of agricultural interventions. Therefore, it is necessary to have an accepted definition of natural resources and of what is meant by sustainability.

Natural Resources

The natural resources most critical to meeting the food, fuel, fiber and shelter requirements are plants, soil, air, vegetation (including crop, range and forest plants) energy and minerals. Climate also can be considered a resource since it influences the choices available for the effective use of other resources.

Sustainability

Sustainability of the natural resource base in developing countries depends on many factors. There is - ample evidence that many of the attempts by people in developing countries to meet their basic needs for food, fiber, fuel wood, and other forest products are leading to rapid degredation of the natural resource base on which their future depends. The problem is greater in countries where population is rapidly increasing, poverty is prevalent and per capita food production is continuing to decline. In addition, some countries have a very limited and fragile natural resource base with few opportunities to expand.

Many natural resource problems are not confined to country borders or political entities. There are also off-farm impacts of agricultural production and many interactions between

agriculture, urban growth and associated industrial development.

Government policies in developing countries are not always supportive of natural resources conservation. Pressures to produce for the short-term tend to override the concern for future generations. This often leads to unwise choices of agricultural practices.

In many parts of the developing world, traditional agricultural practices that have been followed for centuries are not able to meet current and future demands. At the same time, modern, high technology agricultural systems cannot be used because of the high cost that energy and agri-chemicals can impose, not only on the economy but on the environment and natural resource base.

Incorporation of the concept of natural resource sustainability into evaluations of agricultural interventions raises several complex questions, some of which are:

- Does incorporation of natural resource sustainability objectives lead to a loss of short-term production of food, fiber and wood products?
- If short-term production is reduced, what are the social, economic and political consequences?
- What are the trade-offs between allowing some natural resource degredation and complete preservation?
- How can dependence on external resources be reduced and meet needs for food, fiber and wood products?
- Can human caused or human accelerated natural resource degredation be separated from natural geologic trends toward desertification, or climatic change?
- What additional data will be required to accurately assess changes in natural resource bases?

Measuring Progress

Development of adequate indicators for monitoring the impact of agricultural and forestry programs on the natural resource base is a very difficult task. Criteria must be developed for measuring changes in many factors including, among others, changes in rate of desertification, salinization, deforestation, land use, soil loss and water supplies. Also required are criteria and techniques for measuring changes in water quality, aquifers, crop yields, sedimentation, land productivity, use of sustainable cropping systems, use of forest and range resources, integration of livestock and crops into sustainable systems, use

of animal manure and use of integrated pest management. Still other criteria that must be evaluated are reductions in external inputs in agriculture, provision of adequately trained people, improvements in the policy environment, the development of the necessary institutional structures to support the country's agricultural enterprises, and changes in the quality of the environment.

In practical terms, it is not feasible to recommend the use of a large number or a common set of indicators for all agricultural interventions because of the varying size and complexity of agricultural development projects. Some agricultural development projects are quite small, of short duration and have very limited and specific objectives. Others are highly complex, of long duration and have multiple objectives. Still others are designed to discover new techniques through research or to transfer new techniques to specific groups of resource users.

The indicators discussed in later sections of this paper should be viewed as illustrative, and not as a recommended set of indicators for all agricultural interventions. Project evaluators must select the minimum set of indicators required to reach their objective.

A useful first step toward the effective evaluation of agriculture development interventions shoul involve a thorough inventory of the natural resource base in the area of concern. 1) However, this approach may not be feasible in many xases due to time and project financial constraints. Furthermore, the assessment of certain indicators may not require the collection of such a large variety of data. Analysis of changes in the natural resource base is of necessity comparative, therefore, it is essential to assess the status of natural resources before the intervention in order to collect baseline data on indicators. 2) This process allows the investigator to evaluate the indicators selected at appropriate intervals in order to assess change.

Baseline information require will vary depending on the indicators selected, however some examples often used include the following:

- Soil profile characteristics including depth, texture, structure and organic matter content of the surface layer to normal depth of plowing.

- The soluble plant nutrient status, especially the major plant nutrients (N,P, K and Na if salinity is a potential problem).

- The susceptibility of the soil to erosion by wind and

water under normal use.

- The rate of soil formation by natural processes, thereby establishing a tolerable rate of soil loss.

- The animal carrying capacity of range land at various times during the year.

- The normal amount of vegetative cover and rate of growth of woody species in forest land.

- Normal land use including cropping patterns on cropped land, grazing patterns on range land and wood harvest patterns on forest land.

- Amount of runoff and plant nutrient, and organic matter content of runoff from normal usage of land areas under concern.

- Amount of pesticides normally used and the amount of pesticides that leaves the land in runoff water or through leaching to underground aquifers.

- The normal quality of water in impoundments, streams and aquifers.

- Long term climatic information, especially including rainfall amounts and distribution, temperature at various times in the year, wind velocity near the ground, and amount of sunlight during various seasons of the year.

- Normal or expected yields of various crops to be included in cropping schemes.

- The availability of water and the extent of irrigation currently practiced.

Without this type of baseline data precise measurements of conditions after interventions can not be made.

Because of the high cost in terms of time and resources required to precisely measure the effects of interventions, the development and use of other less accurate measurements will be helpful. There is a need to develop improvements in the use of rapid, low cost methods for assessing progress.

II. Indicators for Assessing Changes in Natural Resources

Eight significant indicators of trends and current status of natural resources (emphasis on soil, water,crop plants,

agroforestry and fuelwood, and rangeland), impacts of agricultural practices on water quality and fish and wildlife habitat, and of general degradation processes will be useful in assessing changes in natural resources resulting from AID's interventions.

The sources of data required for the use of each of these indicators are listed and briefly described. More details on each of these data sources are presented in Appendix 1.

The indicators included in this paper were selected according to the following rationale:

- Strength of relationship to thrusts or objectives of AID projects and programs, yet relatively simple and few in number.
- Degree the indicator proxies or represents parameters of interest.
- Relationship to and importance for a sustainable natural resource.
- Possibility of determining environmental quality and social impact of the programs.
- Ease and economy of information collection.
- Sensitivity to changes in natural resource parameters over relatively short time periods.
- Capability of being aggregated to program and regional levels.
- Suitability for supplementation by models or simulations.

Uses of models and simulations, geographic information systems, remote sensing, etc. are discussed in the appendices. Estimated costs, where available, are also shown in an appendices 4 & 5.

1. SOIL PRODUCTIVITY MAINTENANCE

A very significant component of sustainable agriculture is maintenance of the productivity of the soil, therefore assessment of changes in productivity are essential. Erosion by water and wind can temporarily reduce productivity due to topsoil loss and exposure of generally less favorable subsoil to crop plant roots. It can be partially or totally restored by infusions of technology. Severe soil erosion can cross the threshold to permanent productivity loss. Maintenance of soil fertility, and

its improvement where needed, is important to ensuring full production capability. Nutrient deficiencies, high soil acidity or high alkalinity and salinity lower productivity below potential levels. Effective use of animal wastes and plant residues as fertilizers and mulches also are important to ensure productivity maintenance. New technology development and its rapid application are important to increasing productivity to keep pace with population growth.

A soil survey with accompanying soil data and interpretations is a necessary component to a useful inventory of the natural resource base. Data required for such an inventory include: soil surveys with soil characterization data; status and trends of soil erosion in terms of topsoil thickness; crop yield declines, after adjustments for technology advance and weather; area and location of highly erodible soils, soil fertility evaluations, soil constraints in responding to fertilizers, as indicated by Soil Fertility Capability classification; estimates of amount of animal waste used and its nutrient content; and estimates of residues used as mulch and compost.

Sources of data include: soil surveys using internationally recognized classifications and procedures; inventories of soil loss or its estimation by soil loss erodibility, calculated by interpretation of soil surveys and use of loss equations or models; Soil fertility Tests according to standard methods; Statistics on soil fertilizer and lime use in comparison with needs revealed by soil fertility evaluations; animal waste and residue use measured by statistically-based surveys or estimates.

The data described above will provide a good basis for establishing productivity baselines and trends. Reasonable projections of future productivity can be made and sustainability of the soil resource can be estimated. Major weaknesses include the lack of key data in most countries, costs of obtaining data, lack of trained personnel for data collection and interpretation,and a general lack of sufficient data on impacts of soil erosion on productivity.

Given the large data requirement and the complexity of measuring and projecting trends in soil productivity, field observations by experienced Agronomists/Soil Scientists over one or more years, and limited surveys of crop yield trends as reported by farmers will likely be the source of information most used by AID personnel to determine if soil is being lost and if yields are declining or increasing.

[Example] The 1987, National Resource Inventory conducted by US Soil Conservation Service and cooperators.

2. EFFICIENT AND EFFECTIVE LAND USE AND MANAGEMENT

A second significant indicator is the extent of land use according to its suitability capacity and highest production potential consistent with sustainability of production. Important considerations are the intensity of inputs required and the current use of available technology and rate of development of new technology for local use.

Data requirements include: soil surveys with interpretations as to use, suitability and capability; soil constraints to higher production as revealed by soil fertility capability classification and identification of soil potentials; cropping patterns, including rotations and shifting cultivation; whether zero, minimum or high intensity of production inputs are being used, and a soil ecosystem productivity index.

Sources of data include: soil surveys with interpretations as to capability and suitability; soil fertility capability classification; soil potentials showing production levels at stipulated economic input levels; use of crop rotations and shifting cultivation cultures; and relative food production using varying types and intensity of shifting, minimum and high intensity inputs in various cultures, under various soil plant ecosystems and calories per unit area per stated time interval.

The usefulness of indicators that measure the effectiveness of land use and management depends on assessment of the relative effectiveness and efficiency of cultivators and their culture systems. Full production capability can be used as a bench mark against which to estimate the degree to which various management systems can produce needed food supplies. Data which shows that individual sites or areas are not producing at their potential may be used to target areas or practices in technical assistance. Limitations include lack of sufficient data in some areas. The wide variety of practices and cultures which are used, make determination of potentials and actual production difficult and costly.

3. STATUS OF VEGETATIVE COVER AND PLANT HEALTH

Preservation of the soil depends largely on appropriate vegetative cover. It is important to document the relative areas, trends and species composition of major plant cover and land use types--forest, range, cropland. This information is essential for measuring changes and for estimating future availability of fuelwood, building materials, animal forage, food crop production and potential and past loss of prime agricultural land. Major regional problems including soil toxicities and deficiencies for plant production, and areas of regular occurrences of major plant pests and diseases must also be documented. Otherwise, one can be misled when assessing

intervention impacts.

With respect to data required, surveys or estimates of land use according to major plant cover types and trends therein are essential. Furthermore location, area and severity of major crop plant problems--including major regional deficiencies or toxicities in nutrient elements; and occurrence, kind, and severity of such conditions as locust plagues and major plant disease outbreaks must be known.

Local historical records, remote sensing records, statistical sample frames from crop reporting services, airphotos made by low flying aircraft, reports completed by extension personnel, and testimonials from local farmers are all useful sources of data for assessing change.

General regional information on changes in distribution of vegetative cover types and land use can be obtained relatively easily and inexpensively be AVHRR remote sensing from weather satellites on a broad regional basis. Cameras mounted in low flying aircraft can gather information on smaller local areas. These techniques can also be used to detect regional toxicities and deficiencies and occurrences of pest outbreak that must by known when attempting to assess the impact of AID interventions. Sensed data or aerial photography are more expensive and difficult to obtain. Statistical sample surveys can be used, but they are expensive unless tied to ongoing statistical crop reports, not usually available in developing countries. Monitoring and assessing shifting cultivation patterns and cycles is impossible without local observations timed throughout the year. If trained scouts are available, pest outbreaks can be monitored relatively easily with local scouting techniques. Local assessment of nutrient deficiencies and toxicities is also relatively easy for trained scouts. But regional assessment is more difficult even though stress in some types of plants can be detected through remote sensing.

[Example] Vegetative cover and land use were inventoried in the 1987, National Resources Inventory conducted by the US Soil Conservation Service. Reports by USDA National Agricultural Statistics Service have included information directly relevant to this issue.

4. AGROFORESTRY AND FUELWOOD SUPPLY STATUS

It is essential to halt the loss of forested lands and other areas covered by woody species to protect and maintain the natural resources base of most developing countries. Assessment of the impacts of AID interventions on reforestation, fuelwood and timber supplies must be made.

This indicator will require basic data on land use including current acreage, types of woody species and plant communities, trends in rates of production and deforestation, and community wood requirements and types of fuelwood collected. Remote sensing, air photo interpretation, statistical sample frames and surveys, reports from extension personnel, foresters and local authorities are the useful sources of information. General air photo measurements of tree cover are relatively easy and econnomical to obtain. But, information on species composition and quality of the wood for different uses (for cooking, home construction and export) is more difficult and costly. Assessments of fuelwood demand and difficulties in acquiring supplies are relatively hard to determine without personal interviews and on-site observations.

5. RANGE LAND CONDITIONS AND TRENDS

Assessment of range conditions and trends are very important in determining forage supplies and animal carrying capacity for livestock. In fact, carrying capacity can be used as an indicator. Deterioration of range conditions and decreases in animal carring capacity can also be a symptom of approaching desertification and ecosystem deterioration.

Plant species and plant communities (grasses, forbs and shrubs) present before and after intervention must be determined. Knowledge of the climax vegetation, and comparisons of present vegetation to climax vegetation for the local rangeland area is essential.

Profound vegetation cover and distribution may be determined using aerial photography, and on site estimates by range specialists. Total amounts of rangeland can be relatively easily determined. However, range condition determinations are more difficult to obtain, as an experienced range specialist must make observations on-site to obtain reliable estimates. Furthermore, determination of the trends and changes in range conditions require periodic, repetitive on-site visits. Once range conditions are determined, then rangeland carrying capacity can be estimated. After trends are identified and understood, a basis for assessing effectiveness of practices can be established, adjustments in stocking rate can be proposed, and other range management practices can be identified.

[Example] The 1987, National Resource Inventory by the US Soil Conservation Service.

6. WATER SUPPLY

The quantity and seasonal availability of water for plants has an effect on soil cover which is essential for maintenance of the resource and also determines crop and woody plant yields. In

semi-arid and arid areas, water supply data is needed to determine water available for crops and livestock, which in turn determines the productive capacity of an area. Water budget calculations permit the determiniation of water likely to be available for plants, soil moisture storage, groundwater recharge, ane maintenance of minimum stream flow requirements. Annual mountain water and regional drainage supply projections are important in determinig water supplies and seasonal availability for use and management.

Information on upstream flood frequency, area covered and volumes is important to plan and provide for flood control and to develop upstream watershed projects. Groundwater supplies, water storage in impoundments, estimates of mountain water supplies estimates of stream flows, water budgets for each area with unique rainfall and evapoTranspiration levels, and weather and climate information provide data for this indicator. Data on stream flow, groundwater supplies and storage facilities can be collected from water resource an irrigation agencies. Information on precipitation and other weather and climate data is often available from weather services. On-farm irrigation efficiency and system delivery ratios can be obtained from irrigation associations and technical assistance specialists.

Data concerning water irrigation use is relatively easy to obtain from local officals who maintain records for water charges. Information on groundwater levels may be more difficult to obtain because of a lack of historical records on well measurements. However, this data is equally important in areas where water from wells and pumping stations contributes significantly to agriculture. Data on on-farm irrigation efficiency is difficult to obtain, except through special studies and measurements. Yet, this is important because this area is where significant improvements in water use efficiency can be made. Flooding information can be obtained from residents, local extension workers, aerial photography and maps.

Since water is the most limiting factor to food production and plant cover in many developing countries , it is essential that the effects of AID's interventions, which alter water supplies and water use, be carefully assessed. Major changes in water supplies, including water storage, ground water levels, stream flow, or floding will indicate positive or negative effects of interventions, especially with respect to large scale projects. Changes in water supply can also alter plant yields and soil cover in small areas. Yield measurements and observations by agronomists are useful but difficult to quantify.

[Example] The National Water Summary-1983, Hydrologic Events and Issues, available from US Government Printing Office; US Water Resources Council 1978. The nation's water resources, 1975-2000; The 1987

National Resources Inventory, US Soil Conservation Service.

7. ENVIRONMENTAL QUALITY

The effects of AID's agricultural interventions on overall environmental quality should be determined. Protection of the quality of water resources, air quality and fish and wildlife habitat is from pollution by various agents including pesticides, excess usage of nutrients, and sediments from water and wind erosion of soils is important in maintaining quality of the environment. Preservation of wetlands and coastal mangrove areas, critical for aquatic amimals, plants, and other wildlife reproduction, is also an important environmental consideration.

Data required to evaluate this indicator include: quantities of sediments, toxic chemicals, nutrients (especially nitrogen and phosphorus), and animal wastes in surface waters; toxic chemicals and excess nitrogen in groundwater, critical fish and wildlife habitat areas; and surveys on locations and sizes of habitats critical for wildlife reproduction. Data sources include analyses of waters in streams and impoundments by water resource and environmental protection agencies, and by cities and towns using these water supplies; groundwater analyses by hydrologic and water resource agencies; habitat indices and evaluations of critical habitat data from fish and wildlife agencies.

Data on stream and groundwater quality are generally available where these sources are for city water supplies. However, types of information collected will differ from those useful to enviornmental biologists. And, baseline data and data over a period of years sufficient to establish trends are often lacking. Wildlife habitat data are often not available, and there are differences in views about standards or indices for wildlife habitat. Critical habitat data are not generally available, and there is disagreement as to which criteria should be used to evaluate critical wildlife habitats.

Impacts of AID's interventions on overall environmental quality are difficult to determine. However, major changes in amounts of sediment moving in streams, changes in organic solids, dissolved chemical plant nutrients, pesticide residues in surface or ground water, or changes in air quality does provide valuable informtion for assessing the effects of interventions. Chemical analyses and visual observations form a basis for conclusions.

[Example] Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987, "Water quality trends in the nation's rivers," Science 235, pp. 1606-1615. Cowardin, L.M. et al., 1971, "Classification of wetlands and deepwater habitats of the United States," US

Fish and Wildlife Service, Washigton, DC.

8. ACCELERATED GENERAL DEGRADATION PROCESSES

Several sets of processes are gradually and perhaps irreversably affecting many areas of the world, reducing their long-term productive capacity and decreasing the quality of the environment. Criteria for project evaluation should document evidence of general enviornmental degredation. Various types of data provide strong signals of such changes. Accelerated desertification of an area is signaled by changes in plant species and reduced density, increasing dust and sand deposition, soil surface crusting and falling water tables.

Soil salinization may be signaled by increasing water clogging and/or use of irrigation waters with high salinity. Ecosystem deterioration may be signaled by a breakdown in plant-soil nutrient cycles, increasing soil erosion, fuelwood demand exceeding supplies leading to widespread use of animal manures for cooking, and decreases in the carrying capacity or rangelands.

Data can be obtained from range condition and soil erosion surveys, deforestation data from forestry or agricultural organizations, trends in crop yields from farmers or crop reporting services, and reports from extension personnel and relief organizations on fuelwood shortages. Several different sets of information are necessary to confirm the onset of ecological deterioration or improvements of ecosystems. Certain items are difficult to collect and some may not be available. But trends indicated by all available information can provide strong confirmation of the direction of change.

[Example] Study of 20 African countries by ONEP, conducted by Leonard Berry of Clark University (see Brown, L.R. et al., 1986. State of the World 1986, Worldwatch Institute, Washington, DC.).

Appendix 1

DATA SOURCES AND CHECKPOINTS FOR INDICATORS

1. SOIL RESOURCES

1.1 Indicator - Soil Resource Inventory

An inventory of the soil resources of an area, region, or country is a necessary first step in assessing changes in natural resources. Information on location and distribution of soils, descriptions of their properties with interpretations of the significance of and potential problems with these properties, and presentation of data on their physical, chemical and mineralogical properties are all important and useful components of the soil resource, especially in technology transfer and advisory work.

Data of interest include soil morphological descriptions, as well as potential and expected crop yields. Data can be collected from soil maps and reports prepared by federal and state departments of agriculture or similar organizations and from international organizations such as FAO, or world soil maps prepared by various countries.

A large number of technical, single-purpose, interpretive maps and tables can be prepared if basic, up-to-date soil survey information is available. But many areas have no soil maps at all and many other areas have only out-of-date, inadequate maps. Soil surveys should be done by trained and experienced soil scientists. Aerial photos as bases for the soil maps are essential for their most effective use even though, however, these may be difficult to obtain.

This indicator is useful to determine soil suitability for various crops and other uses, land capability and fertility capability classifications, farm planning, determination of erodibility and for estimating erosion and controlling it; crop, range and forestry production estimates under defined levels of management; as a basis for fertilizer recommendations when accompanied by soil fertility evaluation, and for interpretations relative to many nonfarm uses of soils.

1.2 Indicator - Soil Erosion Class or Topsoil Thickness, a Parameter of Soil Degradation

This indicator is a symptom of a type of degradation of the soil resource. By measuring the loss of valuable topsoil with its humus and other favorable properties for plant growth, conclusions can be drawn regarding soil productivity. It is also indicative of sedimentation in off-site locations, including choking of streams and canals and filling of reservoirs by

sediment. This surface soil erosion is also a symptom of lack of/or decline in care and management of the land resource. Furthermore, it can indicate the effectiveness of erosion control practices when repetitive measurements are made, or when evaluated by use of the USLE formula, or Water Erosion Prediction Program (WEPP) which will soon be available.

This indicator can be assessed through direct measurement or observation of topsoil thickness for comparison with typical thickness for soils of the area; presence, number per unit of area and depth of rills, gullies, and ephemeral gullies--either by a soil survey or repetitive observations of sites on a statistical sampling basis. Other data required include direct measurements of sediments leaving specific areas, through use of measuring flumes and stations; and calculations and projections of present and future losses from various land-crop management systems using equations derived from research plots and statistical analysis--such as USLE, or its future replacement--the Water Erosion Prediction Program (WEPP). Data sources include soil surveys, repetitive measurements and observations of small areas selected in a statistical sampling program, calculations using the Universal Soil Loss Equation (USLE) which is to be replaced by WEPP, or by use of other appropriate formulae or equations derived from the climatic features and environment of the area (i.e. tropical versus subtropical areas).

This indicator affords a direct measure of soil loss when measured directly and compared with "natural" topsoil thickness for the soil type in question. Reasonable approximations can be made by direct measurement of topsoil thickness (which is then compared with a "norm"), measurement of sediment moving out of a watershed, semi-quantitative inferences based on the percent of area affected by and depth of rills, gullies and ephemeral erosion channels. In the United States, these measurements can be calculated or projected in semi-quantitative terms through the use of equations such as USLE, or its replacement. Other empirical approaches will be needed for tropical and subtropical areas.

Attempts to measure this indicator may be difficult due to certain limitations. Inferences based on direct measurements of topsoil loss in soil surveys are sometimes in error due to incorrect assumptions on normative topsoil condition and thickness. Direct measurement of sediment loss from a watershed requires precise instrumentation, technical knowledge, skill, and high time commitment, suitable only for research or benchmark studies. Sampling on a statistical basis requires a sound statistical sampling design with appropriate skills and training, visits by trained observers to measurement sites. Expansion from the sample sites to the total area also requires high skills in statistics. Calculations and projections using formula are

dependent upon the degree to which the formula was derived in climatic and environmental conditions similar to those of sites under consideration. For example, demonstrations have proven that the USLE is not applicable to tropical-subtropical areas which are subject to high, short-term intensity and frequency of rainfall. The USLE system of measurement is also limited because it does not measure ephemeral erosion or sediment movement.

1.3 Indicator - Annual Soil Loss

This indicator is used to measure the extent of soil loss by sheet, rill, gulley and ephemeral rill or gulley erosion which reduces the short and long-term productive capacity of soil, and the extent and amount of sediments moving into streams and reservoirs when sediment delivery ratio analysis is applied, including phosphates and pesticides which may be carried into water adhering to soil particles. It is also useful in determining off-site sediment damages, the conservation effectiveness of various tillage and crop management practices. And, it may also be indicative of the general quality of farm and ranch management.

This indicator is important in determining the physical status of the soil resource and extent of its degradation, and in evaluating the effectiveness of conservation practices. Furthermore, it aids in estimating sedimentation rates, and can be used for both individual farm analysis as well as regional analyses in determining if goals of soil loss are being met. This indicator also provides useful data on the extent of off-site sedimentation.

Actual measurements of soil loss based on water carried sediments leaving watersheds can be calculated by using formula or soil loss equations (USLE) (or its replacement, the WEPP) which requires data as to soil type, land slope, erosion control practices in use, vegetative cover, and rainfall intensity factor.

The advantage of this indicator is that quantitative data on rate of soil loss can be calculated using USLE, thus providing an indication of the magnitude of sediment problems in local areas. The limitation of this approach is three-fold; specialized instrumentation and trained technicians are required for the collection of watershed loss data, the USLE system is not applicable in some parts of the world (especially humid tropical and subtropical areas), finally local on-site data collection is required.

This indicator is useful in measuring soil erosion losses to determine extent and seriousness of soil erosion by water, and in evaluating the effectiveness of erosion control practices. This indicator allows an evaluation of the extent and seriousness of

soil erosion losses, and can be used to set appropriate goals and targets for soil conservation. It is also a useful aid in predicting rates of silting in reservoirs. Finally, on a regional basis, it can be used to calculate aggregate tons of soil loss annually for a region or country, in order to measure conservation program impacts.

[Example] The 1982 and 1987 National Resources Inventories, USDA Soil Conservation Service.

1.4 Indicator - Difference between Tolerable Soil Loss (T) in T/ha or T/Acre and Actual Soil Loss

This indicator defines the extent to which land area exceeds the maximum soil loss rate at which productivity can be economically maintained over time. T provides a target level against which conservation program effectiveness and probability of soil productivity decline can be compared.

Information on annual soil loss rate in T/ha or T/Acre is required to assess this indicator. This can be accomplished either by direct measurement or more often by calculation and projection of soil loss rates by USLE or other equations. An accurate assessment requires knowledge of soil type and its erodibility factor (K), land scope, rainfall intensity, cropping pattern and erosion control practices. Data may be assembled using soil survey maps, plus a knowledge of local rainfall intensity, land cover, any conservation practices used and a T value set by conservationists or estimated using assumed rates of soil formation.

This indicator once calculated provides an important signal for changes in soil conditions. The weakness of this approach rests on the fact that T values cannot be precisely determined, but must be estimated based on knowledge of the soil, local experience and personal judgment. For example, considerable disagreement exists over the validity of T values used in USA. For typical agricultural soil, in the United States, T is ordinarily set at 5 T/Acre/year. Still, it remains an important guide and progress indicator for conservation experts, and is used as a planning tool for land users.

[Example] The 1982 and 1987 Natural Resources Inventories conducted by USDA Soil Conservation Service and its Soil and Water Conservation District Cooperators.

1.5 Indicator - Potential Soil Erodibility Classes for Comparison with Actual Erosion and for Prediction Purposes

This indicator is used to evaluate the relative

susceptibility of soils to water erosion. It is useful for evaluating a number of situations. Lands highly susceptible to severe water erosion can be identified for priority attention and land use adjustment. Or, the effectiveness and impact of conservation programs can be determined by examining the extent of erosion and the status of erosion control measures on highly erodible lands. Finally, soils with low erodibility can be given full attention for increased conservation and productivity.

This indicator can be calculated using RKLS factors of Universal Soil Loss Equation A = RKLSCP;

where A = soil loss, tons/year
R = rainfall intensity factor
K = soil irritability (varies with soil type)
L = slope length
T = tolerable soil loss
S = % slope
C = cover (vegetation), and
P = tillage and conservation practices

The soil erodibility index is RKLS/T. Soils with an erodibility index of 8 or more (for water erosion) are considered highly erodible.

Information on the variables identified in the above equation is available from the following sources: climatic records, K from soil survey reports and USDA-ARS tables; L and S from soil survey and topographic maps or site visits; C and P from site visits, remote sensing, or farm records.

The advantage of this indicator is that it can be estimated using a simple formula from data readily available in many locations, and it allows the investigator to conveniently stratify different areas according to different potential intensities of erosion. Unfortunately, this approach may be limited because there are indications that the USLE is not applicable to some tropical and subtropical areas. Furthermore, K factors are not available for some soils.

This indicator can be used to prioritize and target different areas for soil conservation programs and crop use planning. It can identify the erosion potential of areas which are tilled too intensively, and decisions can be made whether or not to target the areas for conservation projects.

[Example] Conservation Reserve Section of US 1985 Farm Bill uses this classification to identify highly erodible land for program purposes.

1.6 Indicator - Soil Productivity Reduction Due to Soil Erosion by Water

This indicator measures changes in the productivity of soil resources, irrespective of changes in technology. Models and simulations can be run to test the probable impacts of a conservation practices or technical innovations before large-scale introduction. This evaluation allows the investigator to sort out and recognize the impact of erosion which would otherwise be masked or remain unrecognized due to yield increases from improved or new technologies, thus allowing a more accurate assessment of the effects of new technology introduced by considering the reduction of crop yields by water erosion. In other words, this indicator can be used to separate the negative yield reducing effects of soil erosion from the positive yield increases resulting from new technology. Furthermore, it may be used to assess the effects of certain selected soil properties on crop yields, and detect the onset of soil degradation.

The data required to calculate this indicator includes information on yields under stipulated sets of fertilization, liming, and tillage with selected soil physical properties used as variables. Sources of data include crop yield information from farming systems research centers, or output from computer models such as EPIC (Erosion Productivity Impact Calculator) and PI (Productivity Impact). (See Bibliography.)

The advantage of such an assessment is that it provides quantitative data on the impact on crop yields of soil erosion over time, and allows assessment of water erosion effects on soil productivity irregardless of increasing crop yields resulting from new technologies and programs. The EPIC model can be used for large areas, whereas PI can be used for smaller areas or in cases when only limited data is available. The limitation of this assessment is that it requires a large set of data for analysis.

Large data bases on various types of information including climate, plant growth, fertilization, liming, etc. are necessary in order to run the EPIC model. Even in the United States, the data required to complete the analysis is typically unavailable.

[Example] Analysis of the effects of long-term erosion on crop yields in the upper midwest of the USA. (See Pierce, F.J. et al. 1984)

1.7 Indicator - Comparisons of Land Use Patterns with Soil Capability and Suitability

This indicator measures the degree to which current land use patterns are suitable for and do not over stress the capability of soils. This indicator is useful because it identifies areas

with potential or actual erosion problems due to more intensive use and less vegetative cover than the land can sustain. It may also be used to indicate the effectiveness of demonstration and education programs in promoting and obtaining the sustainable use of various soils.

The data required for such analysis includes soil type and its land use capability class, land use (including vegetative cover and any rotations) and any conservation practices being used--including minimum tillage. Data can be collected from soil survey map interpretation or use of look-up tables, as well as site visits, aerial photography or remote sensing. Such assessments are useful as a program planning, targeting, and educational tool if data are readily available from survey maps and photo libraries. If soil maps and up-to-date air photos are not available, then on-site visits will be required.

[Example] Appraisal 1980, and the Second RCA Appraisal, 1987, Soil and Water Resources Conservation Act, U.S. Department of Agriculture, Soil Conservation Service.

1.8 Indicator - Sediment Detachment, Transportation and Delivery

This indicator assesses the detachment of soil particles and the extent to which they are transported away from the erosion site and deposited off-site in streams, reservoirs, and channels to the detriment of the environment and water quality.

It has been shown that off-site damages and costs of water erosion are higher than the on-site (on-farm) costs (due to decline in productivity). Estimation of "sediment delivery" can be used as an indicator for determining if programs have resulted in reduced sedimentation. Sediment delivery ratios, calculated by models or measured, can be used to signal erosion problems that need attention, or they can be used to estimate, in advance, potential impacts of programs which may reduce or increase sediment delivery rates off-site. It is also useful to determine the effects of sediments on aquatic ecosystems.

Data required to calculate this indicator include measurements of sediment in water leaving watersheds through flumes and measurements of sediment load in streams, reservoirs, or lakes. Alternatively, the investigator may use models or simulations which draw on hydrologic or weather data on rainfall, overland flow rates and volumes of water, and a factor for detachability of soil particles. Data may be collected from watershed monitoring and research installations, water quality records from stream sampling networks, and output from models such as CREAMS, SWRBB, SPUR, ANSWERS (see USDA, 1987, in Bibliography).

[Example] USDA Soil Conservation Service, 1980 Appraisal, 1980 Soil and Water Resources Conservation Act, Chapter 3B and The Second RCA Appraisal, 1987, USDA Soil Conservation Service, Washington, D.C.
2. SOIL

2. SOIL EROSION BY WIND

2.1 Indicator - Annual Soil Losses and Susceptibility to Wind Erosion

This indicator assesses the rate of soil loss and downwind deposition of soil particles, and may be useful in signaling the onset of desertification.

Wind erosion is damaging because it can lead to a decline in soil productivity due to soil particle loss, and damage to plants from particle blasting. It is further possible that off-site damage may occur due to sedimentation and deterioration in air quality from windblown particles. Wind erosion is symptomatic of improper land tillage practices or poor rangelands conditions. This indicator is useful in assessing the effects of alternative wind control measures, identifying areas of improper land tillage management practices, detecting potential onset and spread of desertification, and measuring effectiveness of programs on air quality.

Data required to calculate this indicator are measurement of the thickness of topsoil loss due to wind erosion, estimates of off-site deposition, and measurements of air quality. It may also be estimated using output from models for measuring and predicting wind erosion, such as the Modified Wind Erosion Equation (WEE). In order to apply the WEE model the investigator needs a soil erodibility value, data on wind speed and rainfall patterns, a soil ridge roughness value, and unsheltered distance across field and vegetative cover values. In order to calculate potential wind erodibility for highly erodible land, climatic characterization values for wind speed and surface soil moisture (c) and susceptibility of soil-to-wind erosion (I) and T values are needed. If CI/T is 8 or higher, land may be classified as highly erodible. Data required is available from conservation research stations and agencies studying and measuring wind erosion (such as Wind Erosion Unit, USDA, Manhattan, Kansas), air quality measurements conducted by environmental agencies, national resource inventories (such as USDA 1982 and 1987 NRI), or output from wind erosion models.

This indicator is useful because it can provide an early assessment of the deterioration and degradation of dry land farming and rangelands areas, and can detect the early stages of desertification, or the impact of wind erosion control programs.

Its limitations include the fact that the wind erosion equation is only applicable to certain conditions for which it was derived, and that erosion by water is typically a greater problem than erosion by wind.

[Example] USDA 1982 and 1987 National Resources Inventories

2.2 Indicator - Soil Degradation and Off-site Deposition Due to Wind Erosion

This indicator assesses soil productivity reduction due to wind erosion and damages from off-site deposition and dust, and soil productivity increases and air quality improvement due to wind erosion control.

Specification of damage to the soil resource base on-site through wind erosion and to off-site areas (land, water, air, wind transpiration and) by deposition of windblown soil is needed. Such analysis is useful in detecting the effects of programs to control wind erosion and retard or stop desertification and improve air quality, targeting areas in need of wind erosion control; estimating the costs and damages incurred from allowing wind erosion to proceed unchecked, and aiding in installing wind erosion control measures in conservation programs.

Data required for such assessments include direct observation, and before and after measurements of amounts of topsoil lost due to wind erosion, measurement of accumulations and accretion of wind-deposited material, samples of dust content in the air resulting from wind erosion. For the United States data can be collected from USDA Soil Conservation Service 1982 and 1987 National Resources Inventories, annual reports on wind erosion prepared by USDA Soil Conservation Service, measurements of particulate matter in the air completed by US Environmental Protection Agency, and wind erosion estimates calculated with a modified Wind Erosion Equation (as prepared by Gillette, 1986).

Before-and-after wind erosion measurements of topsoil thickness and accumulations of deposited wind-blown material provide gross, semi-quantitative measures of large-scale massive wind erosion. A modified Wind Erosion Equation (WEE) can provide estimates and protection that are generally applicable in a variety of conditions. One problem with the WEE data results is that it appears to have overestimated wind erosion in areas differing climatologically from areas and conditions under which the original equation was derived. Furthermore, measurements of atmosphere particulate dust originating from great distances are useful for evaluating environmental quality deterioration, however this approach does not pinpoint sources of the dust. Finally, use of the WEE or similar measures to detect spread of desertification may be too late once conditions for

desertification have already developed, and procedures for obtaining estimates of wind-blasting damage to crops by air-transported particles are not readily observable.

[Example] USDA Soil Conservation Service 1987 National Resources Inventory.

3. SOIL FERTILITY MAINTENANCE AND EVALUATION

3.1 Indicator - Status and Trends in Available Plant Nutrients and Soil Acidity as Revealed by Soil Tests.

This indicator measures the additional plant nutrient and lime requirements of soils for optimum economic production. Soil tests and accompanying soil fertility evaluations can determine the current status of deficiencies in and needs for major plant nutrients. Nutrients can be introduced in the form of fertilizers or lime to supply needed calcium and neutralize exchangeable aluminum in acid soils.

This indicator is useful in determining the soil fertility status of farms and ranches It can be used to evaluate regions and countries through aggregations of data. It can also help determine trends and patterns in fertilizer and lime usage and needs, and measure the impact of programs designed to improve soil fertility.

Data required comes from analysis of composited soil samples from which plant nutrients are extracted with chemical solutions and procedures appropriate for the kind of soil, the climatic environment and the crop to be grown. The results of such tests are compared with fertilizer nutrient response results evaluated in greenhouse pot trials and field experimental plots. Such methodologies have been developed for the three major nutrients (nitrogen, phosphorous and potash) and some of the secondary and trace element nutrients. Lime needs data are determined by appropriate measures of soil acidity, including exchangeable aluminum extractable from acid and mineral soils which must be neutralized by lime additions. Regional trends in total tonnage of fertilizer use can be used to determine trends and responses to programs on a qualitative basis. Data is available from soil fertility evaluation programs conducted by extension services or other public agencies, private laboratories, and fertilizer companies.

The advantage of using this approach is that extraction and calibration methodologies are well defined for most soil and climatic conditions and crops. The weakness of this method is that special trace element deficiencies and toxicities are not easily identifiable. Furthermore, a given soil test can be interpreted differently to indicate several ranges of fertilizer required, depending upon the goal of the investigator (whether

seeking to determine only the amount of fertilizer needed for the next crop or to build soil fertility), varying economic conditions, or the desire to sell more fertilizers.

[Example] Dudal, R. Inventory of major soils of the world with special reference to mineral stress hazards.

3.2 Indicator - Fertility-Related Soil Property Constraints to Plant Growth

This indicator evaluates whether or not soil properties exist that will constrain full plant response to fertilizers and lime. Such constraints must be overcome to achieve optimum agricultural production.

Certain intrinsic soil properties, reflected in soil classification systems, will constrain full crop response to fertilizers and lime unless modified, corrected or otherwise overcome. Use of the Fertility Capability Soil Classification System or FCC allows investigators access to soil classification and soil survey information with a soil fertility evaluation. Progress in overcoming inherent soil constraints is an important indicator of the degree of success of soil improvement and land development projects. Prior determination of the extent and types of agronomic constraints is useful when designing and prioritizing agricultural and rural development programs and projects. This evaluation can be used as a guide to assessing land use suitability, and as an aid to predicting and projecting success of programs and projects. Progress in overcoming constraints can be measured once a project is in operation.

The evaluation requires data on topsoil texture or type, subsoil texture or substrata type, and fifteen soil modifiers. These modifiers are: soil wetness, dry soil moisture regimes, low cation exchange capacity of surface soil, aluminum toxicity, acidity, high phosphate fixation by iron, amorphous clay, very sticky plastic high shrink-swell clay, low potash reserve, highly basic reaction, salinity, high sodium saturation of exchange complex, high sulfates (cat clays), gravel, and degree of slope. Data are available from soil characterizations associated with soil surveys, from soil analyses associated with soil fertility-soil chemistry studies. Or, soil samples can be collected directly and subsequently analyzed in the lab.

The advantage of this assessment is that the data which must be analyzed does not require sophisticated, high technology laboratory procedures (determination of x-ray amorphous clay minerals is an exception), and progress (degree of overcoming the constraints) is readily measured. The disadvantages of this assessment are that interpretation guidelines must be prepared for these indicators based on lab analyses, experience and judgment, and that soil characterization, soil classification and

possibly several lab analyses must be completed before indicators can be applied.

[Example] FONAIAP (National Agricultural Research Foundation of Venezuela) maps and interpretations in several states of Venezuela; Regional Program of Ecuador, CIAT Land Resource Evaluation Study.

3.3 Indicator - Animal Waste and Plant Residue Utilization

This indicator measures the contributions of animal wastes and plant residues to sustainable agriculture. Animal wastes and plant residues can be important sources of plant nutrients and contributors to soil tilth for productive agriculture. More than 800 million tons of these organic residues (dry weight basis) are used in the USA each year. They can act as partial substitutes for expensive commercial fertilizers. This indicator can gauge the effectiveness of programs designed to build systems of sustainable agriculture, and estimate the extent to which these residues replace commercial fertilizers as contributors to soil conservation by providing cover to retard soil erosion.

Data required for analysis include amounts of animal waste applied per year and their approximate nutrient value to judge the degree of replacement for commercial fertilizers, estimates on the total amounts of animal waste available, residues which are returned to the soil, and measurements of soil tilth and other physical properties before and after several years of application in order to measure improvement. Data can be collected from surveys or statistical sampling to determine actual usage of animal wastes and plant residues in comparison with total amounts available, and crop residue usage can be determined by repetitive remote sensing.

[Example] Soil management programs of International Institute for Tropical Agriculture in Western Nigeria (Lal, et al., 1975).

4. LAND USE AND SOIL MANAGEMENT

4.1 Indicator - Land Use and Soil Suitability

This indicator classifies land use patterns and trends, and assesses current land use with respect to soil suitability for use to which it is being put.

It is important to have information on present land use patterns and recent trends in order to set objectives and goals in planning programs, and to gauge the effectiveness of current and past programs which contain components that effect land use and soil use suitability. Such assessments also assist planners

by classifying the status of prime agricultural lands.

Data required for assessment include current land use for agriculture (including cropping patterns and rotations), rangelands, forestry and urban - industrial uses, changes in these land uses over time, and information on soil properties in sufficient detail to determine their use suitability. This information can be collected by periodic statistical sampling or periodic reporting by selected observers, remote sensing (Landsat, SPOT and AVHRR satellite sensing air photos (high altitude, infrared) with digital processing and low altitude oblique), estimates from extension advisory personnel, and computer data layering (included in geographic information systems).

The advantage of this assessment method is that on-site measurements and observations at statistically selected sample sites (2% - 5% sampling intensity) will provide reliable estimates of land use with reasonable accuracy. However, this work does require trained on-site observers and good statistical expertise. One disadvantage of such an assessment is that it is difficult to attain a high degree of accuracy (<85%) for general purpose standard land use cover when using satellite remote sensing. Furthermore, the use of periodic remote sensing with high resolution equipment involves high costs.

[Example] USGS national land use and cover mapping program and data base; Bahr El Jebel area in South Sudan; Pennington County, South Dakota.

5. PLANT MATERIALS, INCLUDING RANGELAND AND FOREST

5.1 Indicator - Vegetative Cover, Density, Stress and Composition

This indicator evaluates the vigor and effectiveness of plants in controlling wind and water erosion, eliminating or slowing desertification, reducing water runoff, maintaining stocks of nutrients in nutrient cycles, preventing soil crusting and providing supplies of firewood.

Monitoring the coverage and health of vegetation will provide an opportunity for planners to target areas which need improvement in plant cover, determine the effectiveness of vegetation-plant cover improvement programs, and target problem areas which require attention.

Data required for such assessments may be collected using periodic remote sensing with image enhancement, and digital processing and interpretation using Landsat, SPOT, or AVHRR satellites in conjunction with collection of ground truth data on soil type, and soil moisture. Information may also be collected

using high altitude aerial photography with interpretation and ground truth. Data could be verified using periodic observations at statistically selected sample sites.

The advantage of new technologies in remote sensing, digital processing and computerized geographic information systems is that they allow large areas to be surveyed saving time and manpower costs, however securing the imagery and processing can be costly. The trend toward private sector ownership and operation of remote sensing satellites may result in greater costs to public agencies, because user charges will be exacted. Furthermore, the technology is currently undergoing rapid improvement and further technical changes, knowledge and routinization is needed for effective interpretations of aerial photography. It must be emphasized that periodic ground observations of statistically selected sites must accompany remotely sensed data in order to yield high quality information of known precision. This aspect does require considerable numbers of trained personnel.

[Example] St. Regis forest management program, Southern United States; African land cover classification using satellite data (see Tucker, C.J., J.R.G. Townshend and T.E. Goff. 1985) about 50% of the 1987 National Resource Inventory by USDA Soil Conservation Service was done by remote sensing.

5.2 Indicator - Crop Stress from Disease, Insects and Nutrient Deficiencies or Toxicities.

This indicator assesses the potential threat of disease, pest and nutrient problems and recommends effective control measures for various cropping patterns and inventories. In order to monitor these threats and recommend effective measures of control, it is useful to have knowledge of a region's cropping patterns including trends or changes therein.

The information base is useful in determining program and project objectives, targets, impacts, and mid-term adjustments. Furthermore, this information is useful when the need arises to increase yields while reducing environmental impact through early detection and integrated pest management techniques.

Data required for this assessment can be collected using various remote sensing technologies. Landsat or Spot satellites can be used for regional studies; AVHRR from weather satellites is useful in cases where continental or global-scale monitoring and assessing is required. Low flying planes with aerial photography are most appropriate for local surveys. All remote sensing work must be accompanied by periodic on-site surveys or observations at statistically selected sites. Pest outbreak and impact of control measures can be handled by local scouts fielded

by government agencies, producer groups or commercial firms. Crop information from field stations sent in the form of regular periodic reports to government bureaus can also provide necessary data on cropping patterns and trends.

Remote sensing and aerial photography provide the opportunity to survey large areas quickly, however these methods are costly and require high technology to operate. Taking measurements from statistically selected sites is a method that generates reliable data of known precision and accuracy, but this approach requires large numbers of trained observers and statisticians. Relying on individual farmers to send in their own reports may not prove adequate, because they may have insufficient knowledge or motivation to provide complete information. Scouting services tied in with integrated pest management programs are useful in detecting early outbreaks of disease and pests.

[Example] Cotton boll weevil control program in the Southern US.

5.3 Indicator - Mulch Management.

This indicator measures the degree to which organic (plant materials) mulch cover is maintained on cultivated soils of subhuumid and humid subtropical and tropical regions. This is an important factor in maintaining healthy soil because it has been demonstrated that a surface cover of mulch consisting of plant remains will control erosion, increase crop yields, improve soil structure and assist in maintaining or increasing soil moisture and organic matter content in subhumid and humid areas of the subtropics and tropics--especially those areas with significant dry seasons or uneven rainfall distribution.

Investigators using this indicator can measure the impact of programs for restoring soil productivity, and controlling soil erosion, especially in degraded "run-down" areas. Furthermore, they can determine the extent to which new mulching practices should be introduced.

Data can be collected directly through field measurements or estimates of mulch thickness for soils at different stages in the crop growing cycle and in different seasons. Indirect estimates of mulch cover may be collected from cropping practices observable or measurable by remote sensing and aerial photography interpretation at selected time periods for various cropping sequences and patterns. Data of importance include the extent of inclusion of a mulch-producing crop in a cropping sequence, periodic plantings of cover crops, use of alley cropping in agroforestry farming, and the extent to which conservation tillage or no-till (the practice of direct seeding in mulch residues without plowing or tilling) practices are used.

Statistical estimates can be obtained by collecting information from small statistically-selected sample sites and expanding these data to the total area.

The advantage of such assessments is that the data collection process does not require laboratory analyses or collection of soil samples, and mulch maintenance programs can be handled by small-scale cultivators without large expensive equipment (with exception of no-till direct seeding in mulch) or extensive training. However, the data will be difficult to obtain and interpret in areas where large numbers of widely spread small farms are dominant, and in cases where there are many types of mulch building and maintenance practices used.

[Example] Experiences is South America (especially Peru) as reported by Sanchez et al., 1982 (Science 236: 821); experiences in Zaire as reported by Lal, 1970 (IITA Proc. Ser. 2).

5.4 Indicator - Range Condition

This indicator evaluates the relative degree to which the different kinds and proportions of plants in the existing plant community resemble those of the natural or climax community of the site. Range land is the largest single land type in the world. It is often useful to evaluate range conditions based on the quantity and quality of forage available, which in turn is highly correlated with the carrying capacity of the range. Range condition is closely related to overall health of the range and forage production. Range conditions determine the types and extent of grazing patterns which can be used. Properly maintained, they provide important watershed protection against wind and water erosion, and can maintain the quality of wildlife habitats.

Use of this indicator helps investigators inventory and assess rangeland conditions and carrying capacity for various uses (grazing, erosion protection, wildlife habitat). It can also determine the impact of development programs which include drainage land improvement, and evaluate trends of retreat toward desertification or invasion by undesirable brush.

Assessments require information on the relative occurrence and productivity of specific rangeland communities, the degree to which the betanical composition of current plant communities resembles that of the natural climax plant community.

Data can be collected through observation and measurements of species composition at sites statistically selected for sampling by range specialists, or by means of measurements from large-scale color and infrared aerial photography and remote sensing imagery. It is important to collect observation and

measurements of range conditions over time to detect and evaluate trends.

This indicator is useful because experienced range scientists can classify rangeland into categories with high homogeneity and specified productivity levels. This information can be extended and then generalized from sample sites using aerial photography or remote sensing and surveys. One drawback is that several classifications of rangeland exist and interpretations may vary. However once these are better correlated and consensus is achieved, remote sensing can be widely used by different individuals to arrive at the same conclusions. Medium-scale aerial photography is the method preferred for most rangeland mapping efforts.

5.5 Indicator - Shifting Cultivation-Length of Cycle and Shifts Continuous Cultivation

This indicator assesses the length of duration of the cultivation and fallow periods in shifting cultivation cycles, and the rate of conversion from shifting to continuous cultivation agriculture.

The relative lengths between the cultivation forest fallow periods are generally indicative of the degree of native soil fertility and its natural productivity. The shorter the cultivation period,the lower the productivity of the soil and the higher the need for soil amendments (fertilizers, etc.) to maintain yields. On the same note, the length of the forest fallow period is generally related to the capability of local vegetation to capture and retain nutrients. Thus, the practice of shorter fallow periods tends to reflect higher native fertility and productivity. The rate of shift to continuous cultivation is one way of measuring the cultivation pressure on the soil resource base.

This indicator is useful in targeting areas with long cultivation-fallow cycles for additional fertilizer use and technical assistance to increase soil productivity. Conversions to continuous cultivation may signal increasing population pressure on the soil resource base,which in turn can identify potential food shortage areas. Changes in cycle length could also be used as a measure of impact of conservation and agricultural development programs.

Data required in this indicator include the length of land cultivation periods (in years), and the rate at which areas previously under shifting cultivation are converted to continuous cultivation (measured in hectares per year). Furthermore, data on soil characteristics are useful to support and complement the data on cycle lengths.

Data can be collected using remote sensing or aerial photography of specific areas over a period of years, land use reports or summaries by various government and non-governmental agencies.

The advantage of using this indicator is that this data is readily available in many areas and has been given a great deal of study. Interpretation of previously completed aerial photos over successive years is a relatively economical approach. The disadvantage to this type of evaluation is that cycle lengths for various times and places are often influenced by social customs, economic situations, and land tenure laws, and therefore may not be dependent on soil quality.

6. WATER SUPPLY

6.1 Indicator - Area Water Budgets Calculated on the Basis of Rainfall, Actual and Potential Evaporation, and Soil Moisture Storage

This indicator measures the status of water budgets, both locally and on a regional basis, by taking into consideration water available for soil moisture storage for plant growth, water available for recharge of groundwater supplies, and the extent of soil moisture deficit (degree of drought). Long-term averages can be used as a guide to weather expectations in an area, and these water budgets can be calculated and updated in the current plant growth season.

Both historical water budgets and current budgets are of great importance, especially in water-short areas, for estimation of irrigation needs, amount of groundwater supply recharge, and amount available for stream runoff.

Water budget calculations help clarify the history of water supplies in an area to determine the need for water projects, provide a basis for irrigation scheduling, and can be used to determine crop suitability for an area.

Information needed may be collected from the current season's weather records and from climatological data of previous years, as maintained by federal weather services or their equivalent. Water budgets are easily calculated with the use of computers if the appropriate data is available.

[Example] U.S. Department of Agriculture Soil Conservation Service. 1982 and 1987 Appraisals, Soil and Water Resources Conservation Act, Wash. DC.

6.2 Indicator - Withdrawals from Groundwater Aquifers.

This indicator measures the rate of usage of groundwater

resources for irrigation and water supply.

Excessive withdrawal rates of groundwater reserves (groundwater mining) can exhaust aquifers (natural underground storage areas) thereby forcing a change in the agricultural productivity of a region. The effectiveness of programs in water conservation and water use efficiency can be judged by measuring rates of groundwater withdrawals. The size (water level) and status (water level changes) for an aquifer can be used to plan for future adjustments in agriculture of an area. Excessive withdrawals of groundwater may cause saltwater intrusion or land subsidence.

Measuring groundwater usage rates helps determine the effectiveness of water conservation and irrigation efficiency programs, detect multi-year trends for planning and projection purposes, and allows time for development of programs to develop alternative sources once groundwater supplies become exhausted or are no longer economical.

Data required for analysis can be collected from national or state geological surveys and natural resource departments and agencies, irrigation organizations, city, farm and ranch records detailing local experience on rates of lowering of water tables, and direct measurements from sampling wells

The advantage of using the indicator is that data records are generally available from several sources on a regional basis which can be analyzed for trends. However, less developed more remote areas may lack such records. In such cases, additional measurements will be necessary. Periodic, repetitive measurements throughout the year will be needed to determine draw-down and recharge rates. Records must be analyzed over several years to detect trends, providing drawn down data on periods of drought and information on recharge rates during periods of greater precipitation.

[Example] Area of Ogallala Aquifer in High Plains of USA (U.S. Geological Survey. 1984. National Water Summary 1983-Hydrologic Events. and Issues, U.S. Govt. Printing Office, Wash. DC).

6.3 Indicator - Upstream Flood Frequency and Area Affected

This indicator measures the extent to which flooding on upstream reaches of streams and their tributaries is a problem. Severe flooding is a major resource concern in humid areas because of the property damage, crops destroyed and excess sedimentation that results.

Upstream flooding damages are worsened when soil conservation practices and programs, especially small watershed

programs and flood plain zoning regulations, are absent or ineffective in slowing the rate of water movement from the land into streams. Upstream flood damages are a major resource concern in many parts of the USA and result in damages of more than $1 billion per year.

This indicator is useful because it helps measures the effectiveness of existing upstream water conservation and watershed programs, and determine whether or not additional small projects for watershed and channel control (levees, bank protection) of smaller streams are necessary.

Evaluation requires data on upstream flood frequency records and damage estimates, the extent to which conservation practices are applied to land which will slow runoff, numbers of upstream reservoirs and lakes for water control, and the extent of levee and stream bank protection programs. Information is also required on the suitability of upstream areas for initiation of small watershed programs to delay runoff and reduce flooding. Data is available from records of state and local natural resource agencies or similar organizations and of departments of water resources, and records of city and town governments. Aerial photos taken during periods of upstream flooding and other types of periodic remote sensing are also useful and should be complimented by interviews with residents on upstream flood frequency and damages. Generalized records on areas of upstream flooding should be widely available. However, incompleteness of records and lack of damage estimates in many less-developed areas may present problems.

[Example] Small Watershed Program in the United States (generally referred to as PL 566 program) administered by USDA Soil Conservation Service in cooperation with state and local governments and local small watershed districts.

6.4 Indicator - Irrigation - On-farm and Ranch Efficiency

This indicator measures the volume of water stored in the soil and used by the crop expressed as a percentage or ratio of the volume of water diverted from a stream or irrigation canal to estimate on-farm water use efficiency. New technologies of drip and trickle irrigation have demonstrated positive effects on water use efficiency, but such techniques are not widely used.

Inefficient on-farm management of irrigation water causes irrecoverable loss of water, local overuse of stream or canal flow, excessive energy use, lost opportunities for higher crop yields, and possible degradation of water quality. In the United States, average on-farm water efficiency is a little more than 50 percent.This analysis helps determine the effects of water use conservation and education programs, as well as the direct

physical application of on-farm conservation measures. It is also useful in determining relative responses of crops to applied water (if crop yield data are available), and estimating total volumes of water needed for irrigating areas.

Calculation requires data on volume of water withdrawn for irrigation, volume of water actually delivered to the crop, volume of water returned to streams, canals or aquifers, and amount of irrigation water applied by drip and trickle methods. Data sources include federal, state and local water resources agencies, irrigation districts, soil and water conservation districts, and water science researchers. Also, field data may be collected through direct measurement or estimation.

Water use efficiency can be easily calculated if data is available, however the collection of data may be difficult and requires measurement overtime. One major problem in the estimation process is that not all withdrawn water that does not reach the plant roots is lost. Some water is lost through deep seepage and recharges aquifers. This process is very difficult and is sometimes impossible to measure accurately.

[Example] Colorado River Basin, USA.

6.5 Indicator - Irrigation - Off-farm Conveyance Efficiency

This indicator assesses the extent to which water delivery system efficiency can be improved. There is a need to increase the efficiency of irrigation water delivery to farms which is now estimated to be 37% worldwide (Postel, 1985) and 78% in the US.

Off-farm convenience efficiency is a direct measure of the water being lost enroute from source to farm. This indicator can be used to identify needs for water delivery improvement, and measure of effectiveness of irrigation water conservation programs.

Data required to calculate this indicator include the percent efficiency of water delivery to farms, as well as information on causes of losses enroute and how much each factor contributes to total loss. Data for analysis is available from irrigation districts, federal, state and local water resource departments and agencies, and through direct estimation, observation, and measurement. Data on water losses can be readily used to compute percentages or ratio, however, some components of loss are difficult to measure, such as losses from water absorbed by plants lining canals and deep seepage from canals.

7. WATER QUALITY

7.1 Indicator - Sediment Loads and Sources

This indicator measures the degree of suspended sediment loads in drinking, recreational and fish-wildlife habitat waters which can create major environmental problems which are costly to remove.

Suspended sediment loads in upstream reaches and reservoirs appear to be highly correlated with soil erosion caused predominantly by cropland and stream banks, lack of upstream watershed programs, major construction sites, or by major natural events such as dust from volcanic eruptions. These sediments can carry pesticides and phosphate absorbed on the particles which are released over time and contribute to water pollution. In the United States, about two-thirds of the suspended sediment load comes from nonprint sources. This indicator can be used to identify farmlands where high rates of erosion are prevalent, estimate off-site damages and costs of soil erosion, measure the general effectiveness of soil conservation programs, and can provide a for quantifying water quality for a variety of uses.

This assessment requires data on suspended sediments in streams, reservoirs and lakes determined by samples taken over a period of years to determine trends, as well as during the current year to determine peak periods of loading-expressed in milligrams per liter or similar units. Data can be collected using records from federal, state, and local departments of environmental quality and water resources, analyses of samples from stream monitoring stations maintained by federal and state agencies, and records from special water sampling programs where problems are most serious. Information can be processed and predictions and projections made using models such as Resources for the Future Model, SWRRB (Simulator for Water Resources in Rural Basins), CREAMS (Soil Conservation Service Models for Chemicals, Runoff and Erosion from Agricultural Management Systems), ANSWERS (SCS - Area Non point Source Watershed Response Simulation), SEDIMOT II (Sedimentology by Distributed Model Treatment), and HSPF (Hydrological Simulation Program in Fortran) developed by Donigian et al.

Information on sediment loads may be collected in many countries, however available data often covers limited time periods making if difficult to establish trends. Information is generally lacking on the extent of absorption of pesticides and phosphates by sediment particles coming from soils, and the degree of correlation of severe soil erosion with sediment load is not fully quantified yet. Very little is known about the composition of runoff from farm fields.

[Example] Study of water quality trends in US rivers by Smith, Alexander and Wolman (Science 235: 1607-1615).

7.2 Indicator - Nutrient Loads and Their Sources

This indicator measures nutrient content levels of groundwater and surface waters derived from nonpoint and point source pollution, a factor which contributes to decreased drinking water quality and a cause of eutrophication of bodies of water (excessive growth of aquatic weeds and algae).

Plant nutrient (especially nitrate and phosphate) concentrations over and above natural background levels can be toxic to cattle, cause "blue baby" syndrome in infants (if in well water) and result in excessive aquatic weeds and algae growth which absorbs excess oxygen thereby causing fish kills, and interferes with boats and swimmers. This excess nutrient load of ground and surface water is due to high water runoff accompanied by soil erosion, excess nitrogen use by farmers, animal waste, and human sewage effluent from poorly functioning septic tanks or privies and low level sewage treatment plants (using primary treatment only). This situation arises because of ineffective programs in soil conservation, and animal and human waste disposal, and ineffective public education programs on appropriate amounts of nitrogen to use as fertilizers.

This indicator is useful in evaluating the need for improved erosion control on farm lands, and education programs for farmers and urban residents on the proper use of fertilizers. Furthermore, it can signal a need to improve animal waste handling and effective septic tank performance. Data can be used to help determine the impact of programs presently underway to improve environmental quality.

Data required for analysis includes measurements of nitrate, phosphate, fecal coliform, and streptococcal bacteria (indicators of presence of animal and human waste in water) in groundwater and surface waters used for drinking, recreation and fishing. These determinations should be based on samples which may need to be taken several times within a season and over a period of years to detect peak load periods and trends. Such data may be available from federal, state and local departments or agencies of water resources and environmental quality, however absence of such records periodic sampling and analyses by experts will be needed. Use may be made of models and simulations when collected dated are not available to make projections and estimates.

This indicator is easy to calculate because the sampling process is easy to complete and does not require high technology to perform, however large numbers of samples over long time periods are required. One drawback is that pollution sources are often difficult to trace because many are nonpoint sources and the motion of groundwater is quite slow, making pinpointing of sources more difficult. Care must be taken to sort out the

natural background concentration of the elements in question or natural, unpolluted water.

[Example] R.A. Smith, R.B. Alexander and M.G. Wolman,. 1987. Water quality trends in the nation's rivers. Science 235: 1607-1615.

7.3 Indicator - Pesticides and Other Toxic Chemical Loads in Surface Water Runoff.

This indicator measures the extent to which toxic chemicals used in farming are washed into nearby streams. Large amounts of pesticides are used in modern agricultural technology, of which approximately five percent finds its way into surface water through runoff. Pesticide concentrations in water are generally very low except after heavy rains.

Because of fish kills and long-term persistence of some chemicals in water which enter into various food chains, the introduction of toxic pesticides into surface water via rainwater runoff can be of major concern locally.

This indicator may be used to monitor the effects of integrated pest management which often require less frequent but more timely applications of pesticides (thereby reducing the total amount used as well as to indicate or not there exists a need for additional training and assistance in farm pesticide use.

Information on the concentrations of selected toxic and persistent pesticide chemicals found in surface waters, especially following heavy rains, during the summer crop production season is required to assess this indicator. This data can be collected from water monitoring stations operated by federal, state, and local water resource or environmental quality agencies, or through field-level sampling during the pesticide application season. Field-level sampling costs and time requirements are minimal because concentrations are low except during peak periods of pesticide use, thus intensive sampling and analysis need be done only during peak application periods, or when fish kills indicate need for analyses. However, some of these chemicals are very difficult and troublesome to identify.

[Example] US Appraisals, 1982 and 1987 USDA Soil Conservation Service Soil and Water Resources Conservation Act Appraisals.

7.4 Indicator - Salinity of Surface Waters

This indicator lists for high concentrations of dissolved minerals in water which can adversely effect crop production. This situation can frequently occur in sufficiently high

concentrations in the irrigation water of semi-arid and arid regions to reduce or prevent crop growth, including saturation of the soil with salts. Salinity in water has harmful effects on livestock and drinking water. In addition to natural sources of salts in rocks in an area, salinity is increased by evaporation, transpiration and by the return flow of water from irrigation field (by dissolving and remaining salts from the soils).

Inefficient irrigation practices, seepage from irrigation canals and high water tables that can be corrected. Buildup of salinity in water and soils of an irrigated region is a serious problem and corrective actions must be taken. If salinity levels can be reduced, or it provides the investigator with a useful in return flow from irrigation indicator of the effectiveness of programs for water conservation. The same is true if high water tables can be lowered on the efficiency of irrigation water usages can be increased. Salinization and water logging tend to reduce the benefits from new irrigation projects in some less developed countries. This indicator directly measures the impact of water conservation, irrigation use efficiency, and erosion control programs, and detects problems and causes of crop yield decline due to salinity.

Data required to analyze this situation include salt loadings of water sources being used for irrigation, salinity of return flow from irrigated fields, salt in rivers flowing through and out of irrigated areas, salt penetration level in water table, conductivity of soil extracts (measure of soil salinity), percentage of saturation of the soil's exchange complex with sodium, and analyses of streams and groundwater not yet used but proposed for irrigation to get a measure of natural background levels of salinity. Data may be acquired from federal, state and local water resource and reclamation agencies, irrigation district records, state experiment stations and extension services, or periodic field sampling for data not available otherwise. Areas of severely salt-affected soils can be detected and monitored by aerial photography.

This analysis is easy to undertake because salt loadings in water and salinity and sodium saturation of soils can be measured by relatively simple methods. One problem which is different to sort out is that soil erosion (of saline soils) and geologic formations containing high percentages of salt contribute to the salinity burden of streams. Frequent sampling of the carious components is necessary to characterize the problems fully.

[Example] salinity studies in the Colorado River Basin and other salt-affected areas (U.S. Dept. Interior Bureau of Reclamation 1975).

8. FISH AND WILDLIFE HABITAT

8.1 Indicator - Habitat Deterioration

This indicator assesses the status of vegetation for cover and food on noncultivated land, residue management on cropland for wildlife benefit, wetland areas, increased streamflow, and reduction of sediments in streams. This information allows the investigator to monitor impacts of fish and wildlife programs, and determine the extent to which agricultural practices have negetative impacts on fish and wildlife habitats.

Data required include acreage of wetlands, area of land with vegetation improved for better wildlife habitat, area of land with residue management designed to improve habitat, stream flow changes, and sediment loads of streams. This information can be collected from federal, state and local fish and game departments, wildlife organizations, and water resource agencies. The advantage of conducting such an assessment is that data collected for other purposes are also useful for this evaluation. However, a drawback is that there appears to be no generally available and agreed-upon indices specifically designed for characterization of wildlife habitats.

[Example] Wetlands measurement and monitoring program of US Fish and Wildlife Service.

9. GENERAL DEGRADATION PROCESSES

9.1 Indicator - Desertification

This indicator evaluates a combination of degradative processes which invade productive land, ultimately turning it into barren ecological deserts (distinct from climatic deserts).

It is important to detect the early stages of desertification, monitor its speed, and measure the effect of programs to eliminate or reduce its effects. Such an assessment can gauge the effectiveness of programs to halt the advance of desertification and to alleviate its effects, as well as recognize early stages of desertification and set programs in motion to control it.

Data may be collected using remote sensing by satellite (Landsat, Spot, AVHRR), aerial photography from planes, and farm productivity and rangeland (grazing land) data from federal, state and local agricultural departments and agencies, agricultural extension services, environmental agencies, and weather services. Several sources of data are available for mapping and monitoring land which has undergone desertification, however it may be difficult to obtain data on incipient

desertification and its onset.

[Example] H.E. Dregne's study of desertification in the Americas.

9.2 Indicator - Ecological Deterioration Syndrome

This indicator evaluates a possible decline of the agricultural-agroforestry ecosystem, as indicated by breakdown in plant-soil nutrient cycles, increase in soil erosion, fuelwood demand exceeding supplies and widespread use of animal manures for cooking fuel, and poor range conditions caused by grazing animals exceeding the carrying capacity.

When a tropical or subtropical environment is overloaded with people and animals and carrying capacity is exceeded, a general decline in productivity of forests (or even their disappearance), rangeland and cropland results. Desertification may be the final result. In order to avoid such a crisis, assessments should allow early detection of a decline in the status, food supply and economic condition of a region. It should also measure the impact of regional development programs which include soil, range and forest, and fuelwood conservation.

Information required for such an assessment include trends in plant and animal species over time, trends in forested area--especially disappearance of woodlands, trends in soil erosion, trends in crop yields and kind of crops grown, trends in wind erosion, including sand and dust deposition, and the nature of fuelwood used for cooking, and status of irrigation systems including conveyance efficiency.

This indicator is convenient to calculate because interpretations as to the status of agricultural-agroforestry ecosystems can be made from sets of data developed to detect incipient desertification. Estimates of the extent of excess demands on carrying capacity of the regional environment can be made, and the food and fuel status of an area community can be assessed. The limitation of such an assessment includes the need for collecting sets of different types of data, including trends over time making evaluations in the immediate future impossible! Few sets of data of the type indicated have been collected, so this procedure has not been well tested.

[Example] Study of 20 African countries in UNEP, done by Leonard Berry of Clark University (See Brown, L.R. et al., 1986. State of the World 1986, Worldwatch Institute, Wash., DC).

9.3 Indicator - Soil-Plant Ecosystem Productivity Index

This indicator measures the relative productivity in

calories of food produced per year per unit area for a shifting cultivation, soil-plant ecosystem in comparison with a similar measurement taken from an intensely cultivated soil-crop plant ecosystem. The resulting ratio provides a measurement (in terms of units important in a development program) of the relative productivity of a low-input, shifting cultivation, soil-plant ecosystem as compared with intense, relatively high input, soil-crop plant systems. This ratio can be calculated as an index number. The assessment calculates the amount of land of a specified quality needed to produce a certain level of food. Furthermore, for a fixed amount (area) of land it allows adjustment of the cropping system to meet the food production level needed. Changes in the ratio or index can be used to estimate the progress or impact of development program in a specific region, or compare relative food production of different types of agricultural systems.

Data required for this assessment includes crop yield records from sample plot areas for the various types of cultivation under study, and calculation of the calorie yield per unit area. It may be possible to acquire this information from research and demonstration plots established for another purpose in the area under investigation.

The advantage of this indicator is that it allows a comparison of the effectiveness of soil-plant systems in terms of food produces. Yield records may not be readily available in some areas, in which case several years of records would be needed to complete data on the total cycle.

Appendix 2

REMOTE SENSING PROCEDURES, DATA ITEMS AND COSTS FOR VARIOUS NATURAL RESOURCE INVENTORIES IN THE USA

The National Resources Inventory 1982 and 1987 conducted by the U.S. Department of Agriculture Soil conservation Service

PROCEDURE

Tracts of land 160 acres to 40 acres in size were randomly selected by a statistical design for inclusion in the survey, such that the sample acres made up four to two percent (depending on intensity of land use) of the total area. (Sampling designs and statistical analysis were prepared by the statistical laboratory of Iowa State University.) Three sample sites were randomly located within each of the areas statistically selected (called sampling units). Approximately 300,000 areas were selected, giving a total of approximately 900,000 sampling sites measured in the USA for the 1982 Inventory. The inventory included all non-federally owned land of the United States. The primary sampling units were located by maps and coordinates, which were supplied by the Iowa State University Statistical Laboratory to Soil Conservation Service personnel who visited each site to collect data. Once field information was collected, acreages and other items were expanded to provide estimates for the total area and for states (and counties within some states). Remote sensing techniques, especially air photos from low flying planes, were used for collecting approximately 50% of the following items; land ownership (private or public), land capability class and subclass, soil loss tolerance factor (T value), farmland quality (if prime or not), degree of soil erosion, arable or nonarable land, farmland acidity (if saline alkali), whether or not farmland was irrigated, water source if irrigated, whether or not farmland was flood prone, land cover (general), land use, cropping history, conservation practices if any, Universal Soil Equation (USLE) factors (K, R, C, P) slope length nad percent, USLE calculation of average annual soil loss in tons/acre/years, wind erosion tons/acre/year, dominant nad secondary soil and water problems, wetland type and vegetation, winter cover kind, pasture condition, range condition and trend, grazing level if rangeland, and forest type--including canopy cover, basal area, and tree diameter.

Costs

The 1982 Inventory covered nearly 1,500,000,000 acres of non-federal land. The total cost for the 1982 Inventory, including statistical design and sampling site visits, soil surveys of sample areas if not previously mapped, checking, and

quality assurance, and distribution of result to all SCS offices and other agencies was $15 million, or one cent per acre.

This National Resource Inventory was first conducted (but on smaller scale) in 1977. The NRI was repeated in 1987, at lower level of intensity and with significant use of remcte sensing about 50% the data were collected by this method. The data was used by the soil Conservation Service for program planning operations, for basic indicators of status and trend of soil and water resources, and for priority setting--and by many other agencies and organizations and by the Executive Branch and the U.S. Congress in considering legislation and making appropriations.

Analysis of trends revealed in the 1977 and 1982 NRI'S indicated that a 10-year interval is sufficient for inventories of this type. This means the per acre year cost of an inventory like the NRI was $0.1 (based on 1982 dollars).

ALASKA MUTIRESOURCE INVENTORY THROUGH APPLICATION OF REMOTE SENSING

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

Costs (as of 1982) of this remote sensing project according to data source and level of detail were found to be:

Source	Level	Cost per acre Cents (1982 costs
Aerial photographs, color infrared, 1: 30,000	Level III	30
	Level IV	45
Aerial photographs, color infrared, 1: 20,000	Level III	15
	Level IV	30
Landsat imagery color composite, 1: 250,000	Level II-III	0.1

Use of additional computer-aided analysis of the Landsat imagery range from five to 12 per acre. These procedures were judged to be efficient and cost effective. This project was conducted by the U.S. Department of Interior's Bureau of Land Management, the National Aeronautics and Space Administration

(NASA) and the EROS Center of the U.S. Geological Survey.

It was estimated (1982) that use of remote sensing technology, (consisting of Landsat data, small-scale aerial photography (1: 60,000), digital terrain data and ground data collection) for integrated resource inventories of the public lands of Alaska was accomplished for 34 cents per acre (including data automation). Attributes included were vegetation and other land cover, slope aspect, and elevation.

Reference: Krebs, P.V. 1982. Multiresource inventory and mapping of Alasks's Wildlands: A cost-effective application of remote sensing, in Remote Sensing for Resource Management, C.J. Johannsen and J.L. Sanders (eds), pp. 81-90. Soil and Water Conservation Society of America, Ankeny, IA.

RANGELAND REMOTE SENSING

A recent study of the parameters of rangeland management and the extent to which these parameters could potentially be monitored by remote sensing technologies produced the following analysis:

Rangeland management Parameter or requirement	Potential remote sensing procedures*
Carrying capacity and site production	9, 3, 1, 8, 5, 6
Condition and trend	9, 3, 1, 8, 5, 6
Grazing system	7, 1, 5, 3, 2, 4
Improvement potential	9, 7, 1, 8, 5, 3
Inventory/classification of vegetation	1, 2, 3, 4, 5
Utilization and range-readiness	9, 7, 1, 5, 6
Watershed protection	7, 7, 1, 5, 3, 8
Wildlife and wildlife habitat values	9, 1, 7, 3, 5

*Key to remote sensing procedures:

1 = Landsat computer-aided
2 = Visible (photo or imagery) small scale, 1: 60,000 to 150,000
3 = Synthetic aperture radar (microwave)
4 = Landsat scenes
5 = Infrared photography
6 = Narrow filter bands, including middle infrared
7 = Visible medium scale, 1: 10,000 to 60,000
8 = Thermal infrared
9 = Visible large scale, 1: 100 to 5,000

Reference: Tueller, T. 1982. Remote sensing for range management, in Remote Sensing for Resource Management, C.J. Johannsen and J.L. Sanders, (eds), pp. 125-140. Soil and Water

Conservation Society of America, IA.

REMOTE SENSING IN NATURAL RESOURCE MANAGEMENT BY STATE GOVERNMENT IN THE USA

Several state agencies are beginning to use remote sensing technologies for inventorying natural resources. In South Dakota, a watershed region of approximately 28,000 acres was inventoried and classified using Landsat data with a very high percentage of accuracy. The data was composited with soil map information to produce sediment yield data useful in modeling nonpoint pollution.

In Texas, a 41,000 acre forested area was classified as to land use and forest type with computer-assisted analysis of Landsat data. Costs were compared with those of the more traditional aerial photography interpretation methodology. Using Landsat costs were about $10,000 or $.25 per acre, in comparison with costs of $294,000 or more than $7/acre for the traditional airphoto interpretation method.

Data collected through remote sensing technology must be compared against and composited with soil survey and geological maps to improve its usefulness and cost effectiveness.

Reference: Tessar, P.A., E.C. Palmer and B.J. Ripple. 1982. Remote sensing as a tool for resource management by state governments, in Remote Sensing for Resources Management, C.J. Johannsen and J.L. Sanders, eds. pp. 519-531. Soil and Water Conservation Society, Ankeny, IA.

REMOTE SENSING APPLICATIONS TO WATER RESOURCE MANAGEMENT AND INVENTORYING

Several papers in a fairly recent book on remote sensing of natural resources (Remote Sensing for Resource Management, C.J. Johannesen and J.L. Sanders, eds.) describe uses of Landsat data and aerial photography. However, they give no cost data and most describe remote sensing used for pilot projects and relatively small areas. The lag time between satellite passes and high altitude airplane flights on the on hand and their availability for interpretation on the other presents problems in inventorying and monitoring water resources. One author (Mallard, 1982) describes extensive use of aerial photography in water projects, but also indicates the need to work with existion soil, geologic and vegetation maps--plus the need for field work to obtain ground truth. A description of remote sensing of wetlands (Carter, 1982) cites aerial photography as the primary tool for wetland mapping and inventorying, and expects the trend will continue because of the versatility and economy of their use--but expects use of satellite data to increase as resolution improves.

The authors describing remote sensing in water quality inventorying and planning reports (Ripple and Miller, 1982) state that, "very few investigators claim to have an operational water quality measurement technique, and that satellite-based data on water quality are few because they tax the technology to its limits."

References:

Mollard, J.D. 1982. Using remote sensing in water resources studies in Western Canada selected case studies, in Remote Sensing for Resource management, C.J. Johannsen and J.L. Sanders, eds. pp. 264-283.

Carter V. 1982. Applications of remote sensing to wetlands, in Remote Sensing for Resource Mangement, C.J. Johannsen and J.L. Sanders, eds. pp. 284-300.

Ripple, B.J. and S.B. Miller. 1982. Remoter Sensing and computer Modeling for Water Quality planning in South Dakota, in remote Sensing for Resource Management, C.J. Johannsen and J.L. Sanders, eds., pp 317-328.

Appendix 3

GEOGRAPHIC INFORMATION SYSTEMS WITH DIGITIZED MAP INFORMATION

A potentially useful and important technology for storing and analyzing natural resource indicator information is a geographic information system with digitized natural resource maps including information on soils, roads, geology political boundaries, etc. A geographic information system is a computer-based technology that uses microcomputers (or larger computer), software programs and graphic display capabilities that encode, digitize, analyze and display multiple sets of data of various types and sources. The analyses of natural resource data can be expressed in tabular, graphic and geographically coordinated map formats. These maps are digitized (converted to numerical bases) for computer storage and printout as maps. The various types of data stored in the computer via the geographic information system software are called "data layers." With this type of capability to store data and map information, it is possible to have the computer print out various types of indicative maps on natural resource information. It is also possible to perform overlaying of maps for comparison--such as maps of a strip or other area of land over a range of years-to detect whether desertification seems to be spreading. During the past few years, great advances have been made in the use of these automated techniques to store, evaluate and display natural resource information maps on a national level. Resource information, once entered into a geographic information system, can quickly and easily be analyzed and redrafted if necessary.

The estimated cost of setting up a complete geographic information system and for digitizing the most important maps is between $100,000 and $300,000 for an area the size of an "average" US county.

A recent survey of geographic information systems using microcomputers for natural resource decision making in U.S. counties (American Farmland Trust, 1986, Wash., DC) showed that as of 1985, 49 counties were already using these systems and another 84 had definite plans to start using them in the near future. Furthermore, 178 other countries indicated they had plans to use such systems in the future.

Several types of resource indicator maps can be stored for display for distribution to program managers, planners, land owners, and land users. Maps from successive time periods can be overlaid and displayed to show trends.

Based on some estimates by the U.S. Soil Conservation Service for pilot tests they have run, costs of establishing a geographic information unit for use in a County or District Soil Conservation Service Office are:

Microcomputer and accessories	$5,000
Digitizer, plotter, etc.	5,000
Personnel to set up station	8,800
Travel and training	1,200
	$20,000 per site

There may be additional software costs unless free software owned by public agencies is used. These costs do not include any map digitization. This estimate only covers hardware and training.

Once installed on-site, a natural resource scientist can operate the computer as needed, with the assistance of a technician on a part-time basis to digitize maps which need to be entered.

Examples can be found in the following reports:

1. Walsh, S. 1985. Geographic information systems for natural resource management. J. Soil and Water Cons., Mar.-Apr. 1985.

2. Pelletier, R. 1985. Evaluating nonpoint pollution using remotely sensed data in soil erosion models. Jour. Soil and Water Conservation, July-Aug. 1985.

Estimated costs of geographic information system hardware with digitized (computerized) map information capability used for "small country" cases have been calculated as follows: $100,000 - $500,000 range for African or Latin American and Central American countries (includes digitization of maps).
Estimates of costs of low technology image processing and map digitizing sensing systems for use in less developed countries:

Small but relatively complete systems for computer processing of remotely sensed data and with geographic information systems (GIS) capability now are priced in the range of $25,000 to $30,000 per unit in the USA.

Appendix 4

COSTS OF SOIL SURVEYS, DIGITIZED MAPS AND GEOGRAPHIC INFORMATION SYSTEMS

Estimated costs of soil surveys:

Map scale	Cost, $ per A.
highly detailed, 1: 5000	$1.80 to $2.20
standard county surveys, 1: 15,280 to 1: 24,000 (farm planning use)	$1.30 to $1.50
Generalized maps-for states and large areas, 1: 250,000	$0.00017
Generalized maps-for countries 1: 5,000,000	$0.00018

Note: The cost estimates presented are based on US conditions and costs as of 1987

Appendix 5

ESTIMATED COSTS FOR REMOTE SENSING OF NATURAL RESOURCES

1. Remote sensing with light planes and 35mm cameras

Costs for remote sensing for the 1987 National Resource Inventory by the USDA Soil Conservation Service using light, low-flying planes and 35mm cameras mounted in the lower body of planes ranged from $40 to $75 per primary sampling unit. The primary sampling units ranged from 40 to 640 acres, averaging 160 acres each. This cost includes photography only and does not include image analysis, processing and interpretation of photos.

2. Remote sensing with Satellites

A full scene or frame (185 square kilometers) of Landsat TM digital data currently (1988) costs about $3,300. A quarter scene (1/4 size of the full frame) of Landsat TM digital data cost about $1,650. No cost data could be obtained for SPOT (the French satellite) remote sensing, which has high ten meter resolution capability, and is now becoming operational.

3. Image analysis and digitizing remotely-sensed data

Small project work on remotely-sensed data can be accomplished by hardware units in the range of $10,000 to $30,000 each. The larger, more expensive units have geographic information system handling capabilities. The lower priced units involve the use of a small microcomputer with accessories. Larger units for image analysis and processing for an entire country probably would range from $500,000 to $1,000,000. An alternative involves contracting for the processing and digitizing for individual small projects. Estimated costs for the average small project probably would range from $10,000 to $20,000 each.

(Personal communications, C.J. Johannsen, Director, Laboratory for Applied Remote Sensing, Purdue University and B. Birdwell, Assistant Director, Soil Survey Division, USDA Soil Conservation Service).

Appendix 6

USDA WATER EROSION PREDICTION PROJECT BEING DEVELOPED TO REPLACE THE UNIVERSAL SOIL LOSS EQUATION (USLE)

The Universal Soil Loss Equation (USLE) has been widely used in the United states (and in other countries in which its use has been found appropriate) for estimation, computation, prediction and evaluation of soil erosion by water. Its use is fundamental to work performed by the soil conservation program in the United States. However, it will be replaced (about 1990) by the Water Erosion Prediction Program (WEPP). The WEPP is being developed by USDA Agricultural Research Service scientists in cooperation with the USDA Soil Conservation Service, the Forest Service, and the USDI Bureau of Land Management. Although the USLE has served its purpose well, new environmental concerns, new erosion modeling capabilities, enhanced computer capabilities and other new technologies not used by the USLE need to be drawn upon. Also, there is a need for estimates of sediment delivery and deposition, and erosion by concentrated flow that is not within the capabilities of the USLE.

Furthermore, there is a need for a prediction equation which can be used in the tropics (the USLE has been shown to be inappropriate in this case) chiefly because of differences in rainfall intensity. The WEPP will be able to compute erosion by a storm. Furthermore, a grid version will allow computations of erosion of an entire area not now possible with USLE.

When WEPP becomes available for use, it is anticipated that it will provide or facilitate the computation of a powerful new set of indicators on soil erosion by water.

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