P-46

Multisensor Monitoring of Deforestation in the Guinea Highlands of West Africa

Final Report, NASA Grant 1359

Peter T. Gilruth
Charles F. Hutchinson

Arizona Remote Sensing Center
The University of Arizona
Tucson, AZ 85721

April 23, 1990

(NASA-CR-186709) MULTISENSOR MONITORING OF DEFORESTATION IN THE GUINEA HIGHLANDS OF WEST AFRICA Final Report (Arizona Univ.) 46 p CSCL 02F
N90-25396
Unclas
G3/43 0290755

TABLE OF CONTENTS

ABSTRACT

Multiple remote sensing systems were used to assess deforestation in the Guinea Highlands (Fouta Djallon) of West Africa. Sensor systems included: (1) historical (1953) and current (1989) aerial mapping photography; (2) current large-scale, small format (35mm) aerial photography; (3) current aerial video imagery; and (4) historical (1973) and recent (1985) Landsat MSS. Photographic and video data were manually interpreted and incorporated in a vector-based geographic information system (GIS). Landsat data were digitally classified. General results showed an increase in permanent and shifting agriculture over the past 35 years. This finding is consistent with hypothesized strategies to increase agricultural production through a shortening of the fallow period in areas of shifting cultivation. However, our results also show that the total area of both permanent and shifting agriculture had expanded at the expense of natural vegetation and an increase in erosion. Although sequential Landsat MSS cannot be used in this region to accurately map land cover, the location, direction and magnitude of changes can be detected in relative terms. Historical and current aerial photography can be used to map agricultural land use changes with some accuracy. Video imagery is useful as ancillary data for mapping vegetation. The most prudent approach to mapping deforestation would incorporate a multistage approach based on these sensors.

INTRODUCTION

The Fouta Djallon, located in the highlands of Guinea (Figure 1), gives rise to most of the major rivers that deliver water to the Sahelian Zone of West Africa. Because changes in land use or vegetation cover in the Fouta Djallon will have profound effects on the flow regimes of rivers that support agriculture, transportation, and energy needs throughout the Sahel, the management of lands within these headwaters is of regional importance. Downstream countries potentially affected by land degradation in the Fouta Djallon include Guinea-Bissau, The Gambia, Senegal, Mali, Mauritania, and Niger.

As in many of the developing countries throughout the world, there is a paucity of environmental data available for Guinea; this is an important issue, given that these same countries also support many land use practices that can severely impact environmental quality. These practices include mining, shifting cultivation, deforestation, livestock grazing, and disease eradication. Individually or in concert, they can bring about the gradual degradation of the environment through pollution, soil depletion/loss, removal of vegetative cover, encroachment of desert conditions, or groundwater contamination. All these impacts have been observed in Guinea, but little documentation of their progression, extent, or severity exists (Varady, 1983).

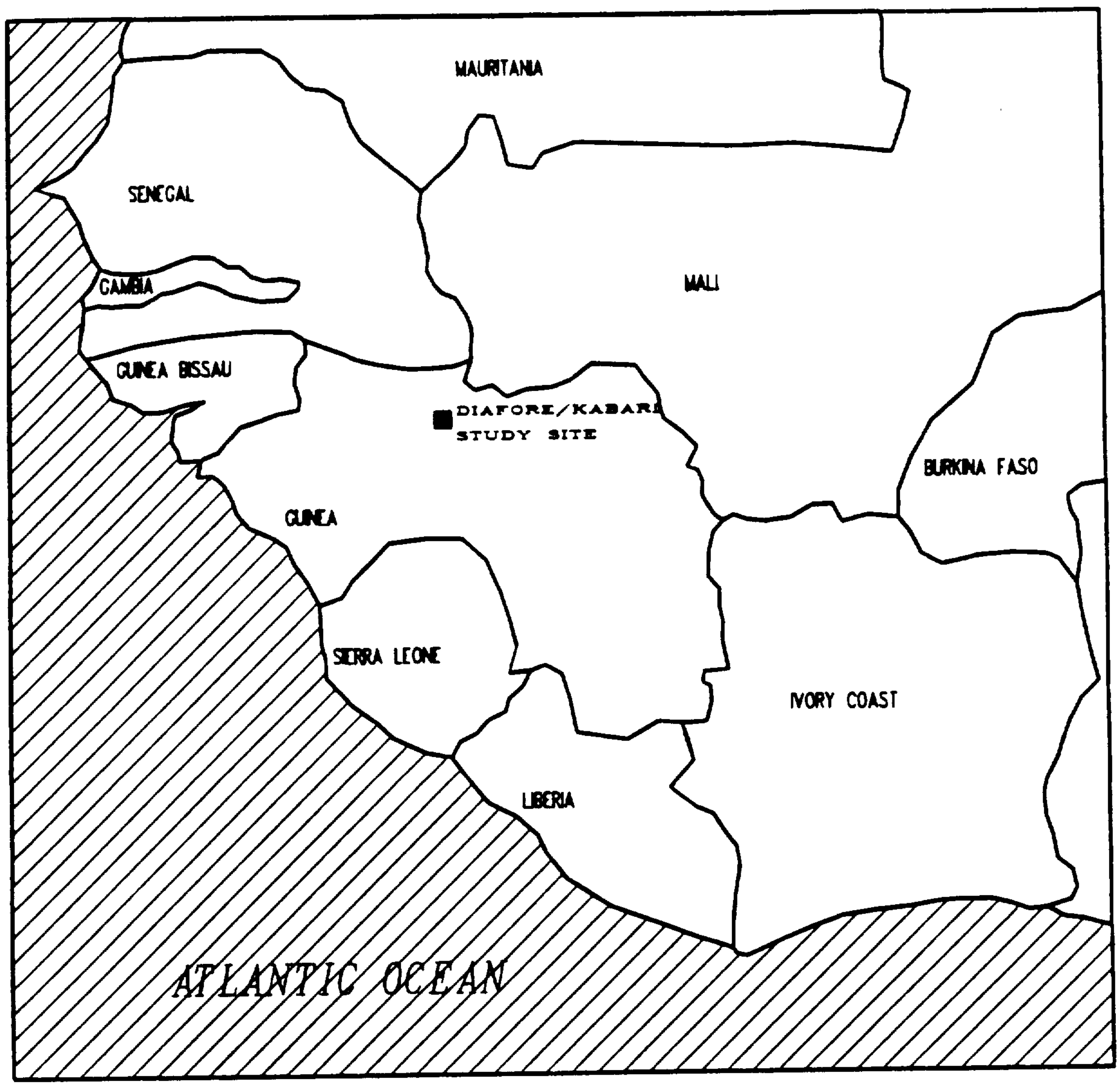

FIGURE 1: LOCATION OF DIAFORE/KABARI STUDY SITE

Of all the natural resources found in Guinea, the soil is perhaps the most fragile and thus has been the target of accumulated effects of population pressure. Where destructive land use practices have occurred, the vegetative cover has been removed, and can no longer protect the soil surface from the effects of rainfall and runoff. In many areas, fertile topsoil has been permanently lost, leaving infertile and largely impervious laterite behind in its place.

The loss of vegetation cover in the Fouta Djallon can be attributed to wood harvest for fuel and fences, shifting agriculture, clearing for residential areas, and mining. As in other tropical regions, shifting cultivation is an increasingly large contributor to deforestation: as the amount of land available for cultivation shrinks in the face of a quickly growing population, traditional fallow periods are shortened to the point where they are insufficient for restoration of soil fertility and forest regeneration (McGahuey, 1985). While there is general agreement that significant environmental changes have taken place in the Fouta Djallon as a result of deforestation, the rates of change and the areas most affected are not precisely known. Moreover, there is no system existing or planned that would monitor these changes.

Here, we report the results of a study of deforestation and land degradation in the Guinea Highlands (NASA Grant No. NAGW - 1359). The impetus for this research is the need to better describe the types and rates of change within the tropical environment and, ultimately, to understand how changes in land use and vegetation cover might affect the regional environment. The specific objectives of this study were: (1) to determine types and rates of changes in permanent and shifting agriculture within the region; (2) to identify the types of land degradation that has accompanied these changes; and, (3) to develop an effective combination of multisensor remote sensing data to achieve these ends.

<u>Training component</u>

The Arizona Remote Sensing Center cooperated with the Guinean National Direction of Forest and Game staff during data acquisition and interpretation, and GIS analysis and map production. Their participation, including a training program at ARSC, was supported by the U.S. Agency for International Development.

<u>Environmental degradation</u>

Different opinions exist as to the current rate of soil loss, deforestation, and laterization (irreversible formation of ironstone hardpan through wetting and drying) in the Fouta Djallon. The region was described as early as 1949 as being overpopulated, and even in 1821 as being deforested and consequently converted to laterite (Richard-Molard, 1949). Thus, it has been asserted for some time that erosion problems in the Fouta Djallon are serious and constitute a regional hazard.

Recently, however, it has been argued that current erosion rates are only one of the geological processes responsible for shaping current topography in the Fouta Djallon (Boulet and Talineau 1986). Hesch (1985), suggests current erosion problems in the Fouta Djallon are significant only on a local level, and do not extend to entire watersheds or even the larger West African region. Unfortunately, because no long-term studies have been undertaken, most hypotheses are based on a very few cases. Most observers do agree that the greatest danger of soil erosion is just prior to planting when prepared soils are most erodible and the heaviest rains occur (Pascual, 1986). Brush fires, set by local farmers to clear fields for shifting cultivation, can also escape and destroy organic material contained in the surface soil horizon.

Several researchers feel that the major problem in the Fouta is not erosion at all, but a loss in soil fertility due to an increase in human population and the consequent shortening of the fallow period in the shifting agricultural rotation (Pascual, 1986). In certain areas, fallow periods have been shortened from 9 - 15 years to 5 - 7 years (Heermans and Williams, 1988). As a consequence, crop yields have declined as traditional methods of insuring soil fertility have lapsed.

STUDY AREA

Physical Environment

The study was conducted in two neighboring watersheds located within the Fouta Djallon (Figure 2). The Tougue District, which encompasses the Diafore and Kabari River Basins, is on the gently sloping eastern face of the Fouta Djallon. The two watersheds are located between 12° 25' and 12° 45' North, and 11° 20' and 11° 45' West. The Diafore watershed has an area of $60km^2$, the Kabari $61km^2$. A small watershed located between the two, the Belakoure ($20km^2$), was also included in the analysis.

Neither the Diafore nor the Kabari basin exhibits exceptional relief, with the tallest plateau not exceeding 900 meters. The region is composed mostly of sandstones, which develop into rich, but easily eroded soils (Heermans and Williams, 1988).

Guinea possesses a tropical climate in which variation is due to the migration of a discontinuous front known as the Inter-Tropical Convergence Zone. The rainy season occurs between May and October, while the remainder of the year is typically dry. Annual rainfall in Tougue averages around 1500mm, although local farmers complain of a downward trend (Heermans and Williams,

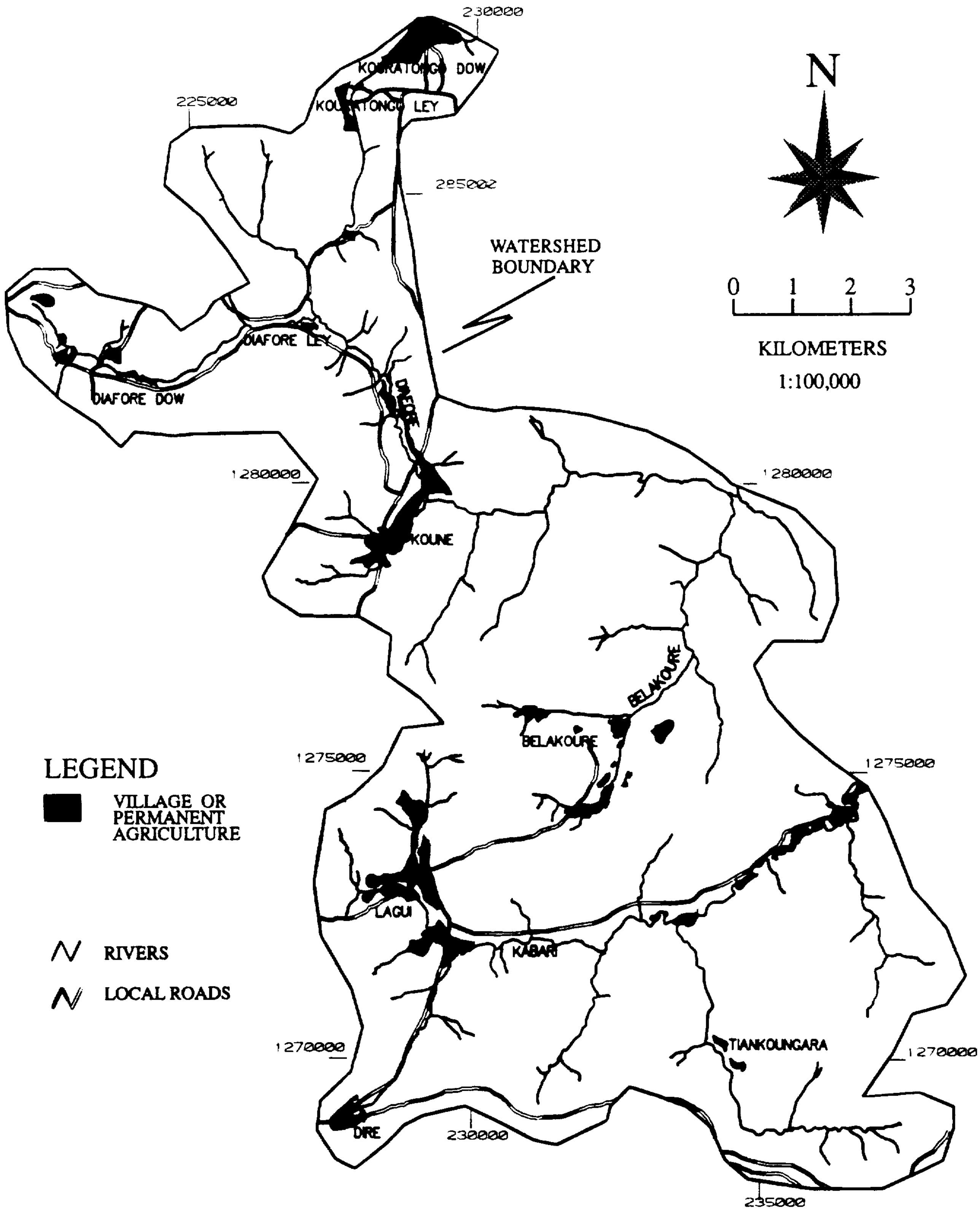

FIGURE 2: DIAFORE - KABARI
VILLAGE LOCATION MAP, 1989

1988). Isbecque (1985) reports an approximate decline of 300mm of annual rainfall in the Fouta Djallon over a 15 year period, beginning in 1970.

The main control on both human population and vegetation distribution is the presence of deeply dissected lateritic plateaus, occurring either as bare surfaces (Photo 1a) or veneered by a thin soil layer supporting a sparse woodland. These surfaces play a major role in the agro-ecological system and in the evolution of the landscape: they determine water flow, percolation, ground water dynamics, soil fauna, and have an effect on the local climate (Pascual, 1986). Local people generally do not settle on bare laterite because there is no possibility of growing crops. These extensive and often barren plateaus are less common in other areas within the Fouta Djallon and make the Diafore/Kabari area one of the poorer agricultural districts in the region.

The Diafore/Kabari landscape is characterized by a dense stream network associated with multi-tiered gallery forests in the bottomlands. A dry woodland is often found on slopes[1], with the density and height of vegetation canopy a function of the most recent agricultural clearing. Laterite plateaus and uplands are covered with grasses and scattered trees. The Diafore/Kabari

[1]The term "slope" is a direct translation of <u>versant</u> which French geographers typically use to describe this landscape unit.

PHOTO 1a: LATERITE PLATEAU

PHOTO 1b: HOME GARDEN IN KOUNE VILLAGE

Basins are somewhat drier than other parts of the Fouta Djallon to the south and west (Heermans and Williams, 1988).

Of the two basins, the Kabari is more heavily vegetated and has fewer exposed lateritic upland surfaces than the Diafore. Local officials report both a higher density of livestock and a higher productivity on slopes used for secondary agriculture in the Kabari.

Land Use Patterns

Traditional agriculture in this region is a complex system which utilizes each landscape element. The permanent agricultural unit is the home garden (Photo 1b), a small field of about 0.5ha surrounding the living quarters. Although not always true in others areas of the Fouta Djallon, home gardens in the Diafore/Kabari basin are most often interspersed with gallery forests in the fertile bottomlands. Brush fences surround each garden to prevent entry of domestic or wild animals. Maize, taro, sweet potatoes, okra, beans, hot peppers, tomatoes, and spinach are planted yearly. Fruit trees such as oranges, bananas, and avocados are also cultivated.

Home gardens are the nucleus of the family unit defined by a household head and wife. Polygamy is common, although the man must provide each wife with her living quarters and garden. Each unit has an average of 3 cows and 4 sheep or goats. Cultivation within the home garden is strictly a woman's duty, whereas the man is responsible for the maintenance of the surrounding fence.

Shifting cultivation is practiced on the wooded slopes and comprises a secondary agricultural unit (Photo 1c). Individual families or entire villages may cultivate a piece of land for two or three years or until yields begin to decline significantly. Generally, slopes are planted with mountain rice in the first year and with fonio (*Digitaria exilis*) in the second year. Until recently, normal fallow periods were typically between ten and fifteen years.

Livestock production forms the other major base of the Fouta Djallon agricultural system. During and after the rainy season, cattle graze the plateaus where forage is locally abundant. In the dry season, when range forage is depleted, the cattle are returned to the vicinity of the home garden where their manure revitalizes the soil.

The population of the Diafore watershed is concentrated in 12 villages, with a total of 1511 inhabitants, yielding a density of 25 inhabitants/km^2 (Heermans & Williams, 1988). Although no statistics were found for the Kabari watershed, it is reasonable to assume a comparable density there.

PHOTO 1c: DEFORESTED SLOPE USED FOR SHIFTING AGRICULTURE

PHOTO 1d: HOME GARDEN ON SLOPES (KOURATONGOU VILLAGE)

Due to physical limits on the amount of arable land, the growth of permanent agricultural land has not kept pace with the expanding population within the region (Richard-Molard, 1949; Boulet and Talineau, 1986). Thus, to increase total production villagers must intensify cultivation on valley slopes in two ways. One way is to shorten the rotation in shifting agriculture. This leads to a loss of soil fertility and consequent decline in yield. The other way is to establish new permanent home gardens on the lower portion of valley slopes just above the crowded bottomlands (Photo 1d). However, these soils are generally shallower, rockier and require more fertilizer inputs than traditional bottomland home gardens.

A visual representation of the Fouta Djallon landscape with the land cover classes identified is depicted in Illustration 1. The effects of agricultural intensification and improper land use are portrayed in Illustration 2.

DATA ACQUISITION

Remote sensing data

Several remote sensing data types acquired on several dates were assembled to assess change in agricultural land use over the past 35 years (Table 1). Data were selected to give a variety of spatial and spectral resolutions. Fortunately, most of the historical data were collected near the end of the dry season when the land cover classes are easiest to distinguish.

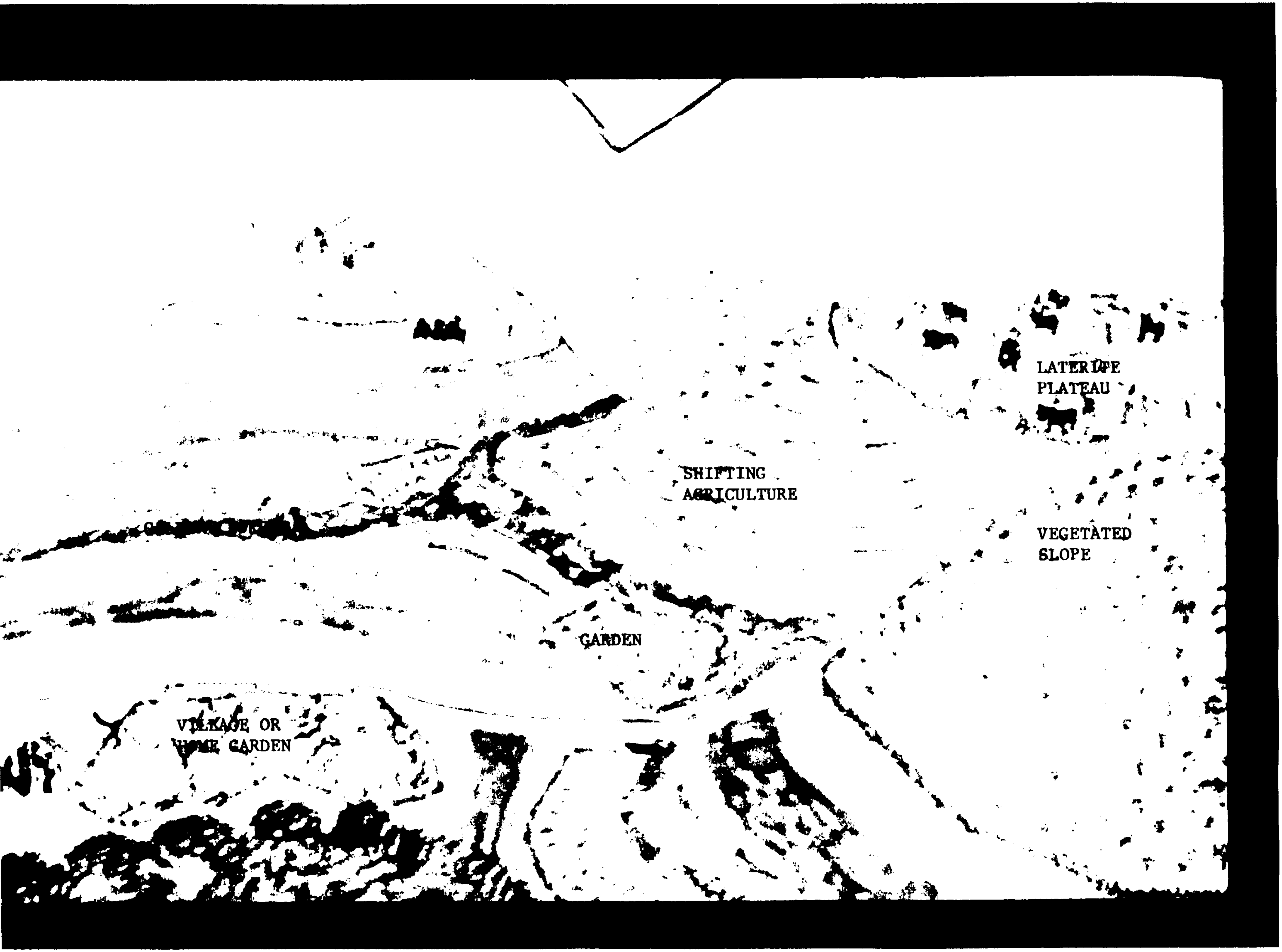

Illustration 1: Fouta Diallon Landscape Schematic

Illustration 2: Land Degradation Schematic

TABLE 1: REMOTE SENSING DATA COLLECTED OVER DIAFORE / KABARI STUDY SITE

DATE	SENSOR	FORMAT	SCALE AT INTERPRETATION (SPATIAL RESOLUTION)	SOURCE
3/53	AERIAL CAMERA	9"X 9" B & W PRINTS	1:50,000	NATIONAL DIRECTION OF FORESTRY AND HUNTING, CONAKRY, GUINEA
3/7/73	LANDSAT MSS	COMPUTER COMPATIBLE TAPE	1:40,000 to 1:125,000 (79m)	EOSAT/ EROS DATA CENTER
4/15/85	LANDSAT MSS	COMPUTER COMPATIBLE TAPE	1:40,000 to 1:125,000 (79m)	EOSAT/EROS DATA CENTER
4/89	AERIAL CAMERA	11" X 11" B & W AND COLOR IR PRINTS	1:30,000	HZ AERIAL SURVEY AND MAPPING, CONAKRY, GUINEA
5/31/89	AERIAL CAMERA	35MM COLOR SLIDES	1:20,000	ARIZONA REMOTE SENSING CENTER, TUCSON AZ
5/31/89	VIDEO CAMERA	780 X 488 PIXEL VHS IMAGE	1:6,000 (4m)	ARIZONA REMOTE SENSING CENTER, TUCSON AZ

1953 mapping photography. Black and white photography flown by the French military in 1953 before independence served as baseline data. Although old and frayed through long use, these photos still allowed identification of agricultural classes.

1989 mapping photography. The 1989 HZ photography, flown under contract with the Government of Guinea, is currently being used to develop large scale topographic maps of the watershed study areas.

Landsat images. The 1973 and 1985 Landsat MSS scenes were selected to (1) encompass the longest time span possible within the Landsat MSS record, and (2) keep within seasonal requirements for data comparison.

35mm photography/aerial video. A team from the Arizona Remote Sensing Center (ARSC) collected the most recent data set immediately prior to the onset of the 1989 rains. A combined 35mm camera and bi-spectral video camera platform was mounted in the belly port of a locally rented aircraft. This system was developed at ARSC for assessing and mapping vegetation in rural environments (Hutchinson et al., 1990). Meisner (1986) and Marsh et al. (1990) described the advantages and disadvantages of using video imagery for mapping vegetation and land-use.

Field Observations

Although limited to a few days of field work, the ARSC team gathered field data to help identify land cover classes. We visited 25 sites based on interpretations of 1953 and 1989 photography. For each site we noted both interpretations, and 1985 Landsat MSS false color image spectral and texture characteristics. Ground observations included land use, vegetation density and structure, estimates of canopy cover, and any signs of land degradation. Finally, color slides were taken in each of the cardinal directions to aid in air photo interpretation. Aerial photos were used to locate sample points in the field.

In conversations with local inhabitants, we found that the greatest change perceived by villagers is a decrease in annual rainfall. In their view, the streams no longer run throughout the year and some wells go dry before the onset of the rainy season. When watercourses dry up, they no longer function as a natural firebreak.

AGRICULTURAL CHANGE ANALYSIS (1953 - 1989)

Definition of land-use classes

Land use classes mapped were: (1) permanent agriculture; (2) shifting agriculture; (3) bare laterite plateau; (4) gallery forest; and, (5) a variously vegetated slope class dominated by a mixed tree savanna or brush (Photos 2a and b, respectively a 35mm color print and video image, were collected simultaneously). From the 1989 ARSC photography, it was also possible to identify two subclasses of vegetated slopes and secondary agriculture showing signs of active erosion (Photo 2c). These classes were derived from analysis of photography, discussions with Government of Guinea's Ministry of Forestry staff, and site visits.

Permanent agricultural units, defined in the project area description, were fairly easy to interpret. Key signs included irregular honey-comb shaped villages interlaced with prominent fences constructed of live or dead brush. Villages in the Diafore/Kabari region are usually found in bottomlands on alluvial soils. Because all photography was acquired in the dry season, only crop residue was left in the fields.

Rectilinear cuttings into the forested slopes were interpreted as shifting agriculture. This class is characterized by large, isolated trees left standing after brush is cleared for planting. Fallow fields of one or two years were also discernible, but were not included in this class; only active fields were mapped.

Exposed laterite plateaus were typically devoid of woody vegetation and were easily interpreted as medium gray tones (on black and white photography) or dull reddish hues (on color photography) with a smooth texture.

PHOTO 2a: AIR PHOTO SHOWING LAND COVER CLASSES:
A: HOME GARDENS B: LATERITE PLATEAU C: SHIFTING AGRICULTURE D: VEGETATED SLOPE E: GALLERY FOREST

PHOTO 2b: BI-SPECTRAL VIDEO IMAGE COLLECTED SIMULTANEOUSLY WITH PHOTO 2a

PHOTO 2c: AIR PHOTO SHOWING ERODED AREAS

Forest cover was differentiated by density and size of tree crown. Due to the small scale of the 1953 data, only large stands of gallery forests were interpreted, however a thin ribbon of very large trees did border both the Diafore and Kabari rivers but is not shown on the 1953 photomap. This class is characterized by dark tones and a very rough texture. On the larger scale 1989 photography, the band of forest along rivers was delineated in addition to the larger stands. Hence, the 1989 estimate for gallery forest area was greater than that of 1953.

The vegetated slope class is actually covered by a dry forest characterized by medium gray tones and a rough texture on the black and white mapping photography. Fallow fields were included in this class.

Eroded subclasses were identified by the accumulation of sediments at the foot of slopes or on the slope itself. The eroded secondary agriculture thus became a third agricultural class. It was not possible to identify eroded areas as a distinct spectral class on either set of satellite imagery.

GIS: Data base creation

The aerial photo data were manually interpreted for land-use/land cover with a mirror stereoscope and plastic overlays. Interpretations were mosaicked onto a single map and digitized into ELAS at NASA Stennis Space Center in Mississippi. The photomap could not be registered to the best available topographic map (1:250,000 U.S. Army Mapping Service) because of scale differences and poor map quality.

Instead, the 1985 Landsat MSS image was registered to the U.S. Army map and served as a reference base. Next, the 1953 photomap was registered to the satellite image. The ELAS map was then converted to ERDAS at the University of Arizona and transformed into vector format in pcARC/INFO[2].

Aerial photography: Interpretation

The objective of this analysis was to compare the extent of agricultural land interpreted from 1953 photography (Figure 3) with interpretations made from data collected in 1989. The two types of data were not comparable in scale or quality. Thus, we concentrated on changes that were easily interpreted and unambiguous. This restricted analysis to changes in agricultural land use (Figure 4) rather than deforestation. In addition to mapping agricultural change, evidence of land degradation was also inventoried by mapping areas of active erosion (Figure 5).

Two sets of 1989 photography and video imagery were combined to produce the map of current land-use. The difficulty of mosaicking a series of video frames precluded the use of video imagery as the

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[2]The use of trademarks is for the benefit of the reader and does not constitute an endorsement by the University of Arizona.

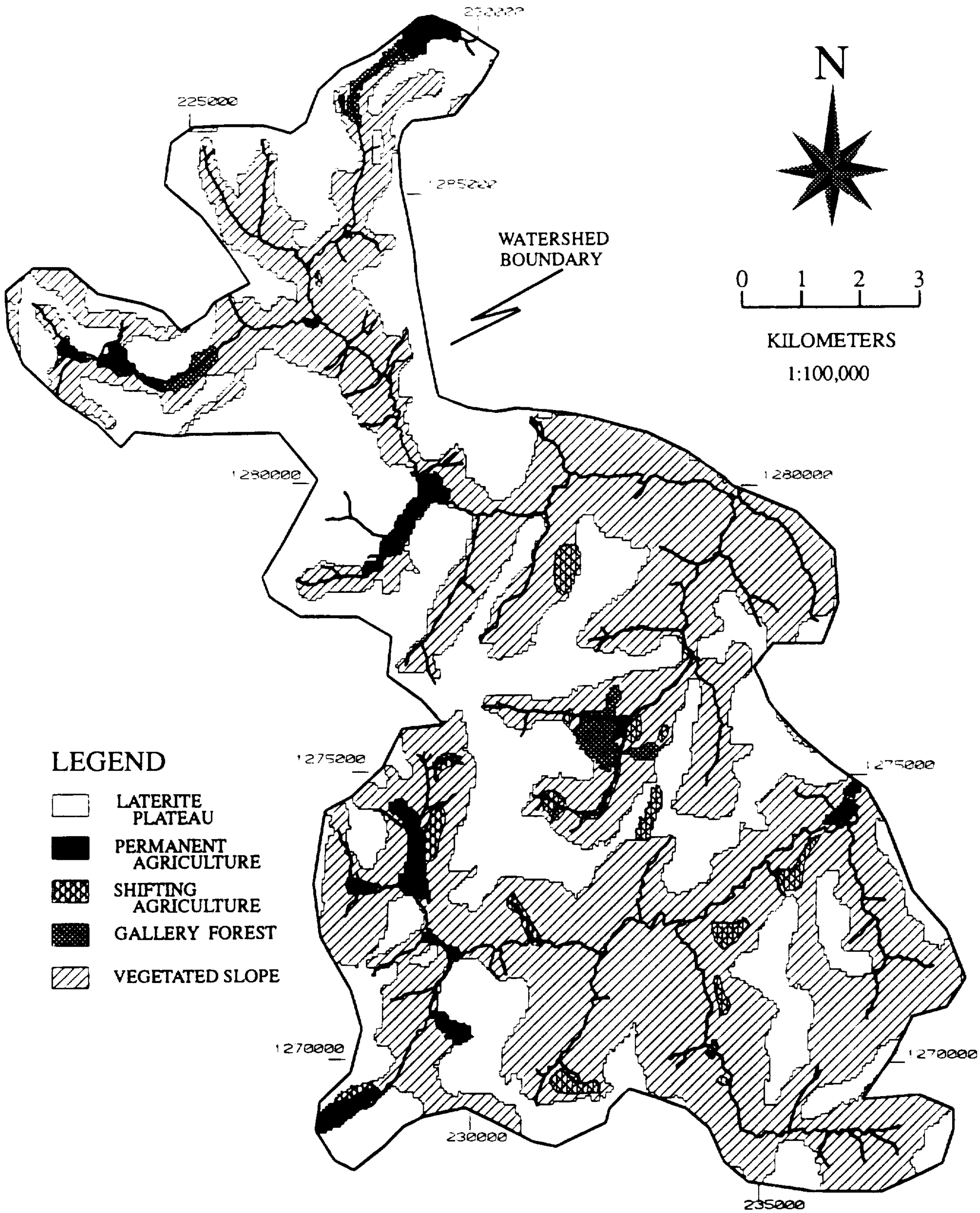

FIGURE 3: DIAFORE-KABARI
1953 LAND COVER MAP

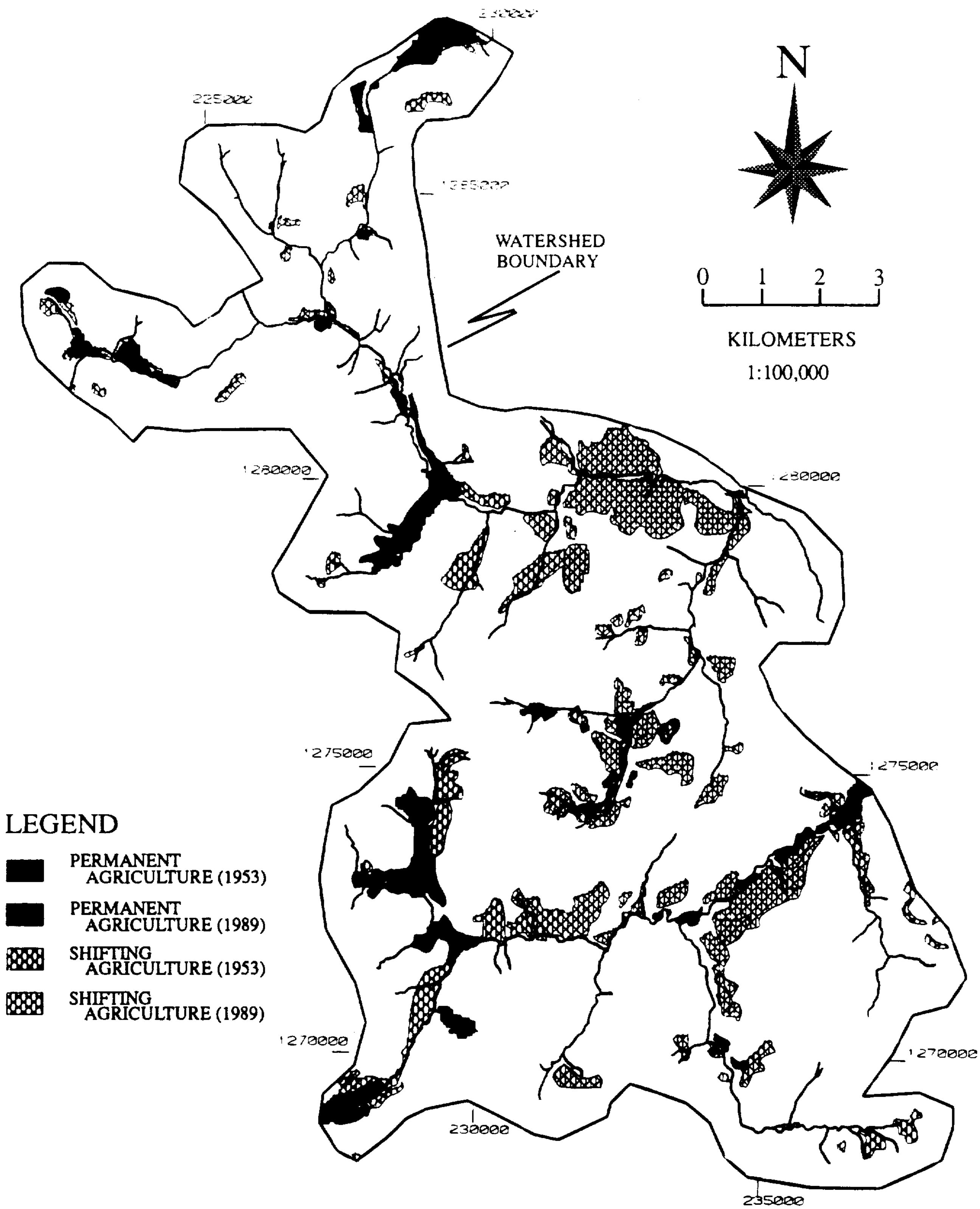

FIGURE 4: LOCATION MAP OF AGRICULTURAL EXPANSION, 1953 - 1989

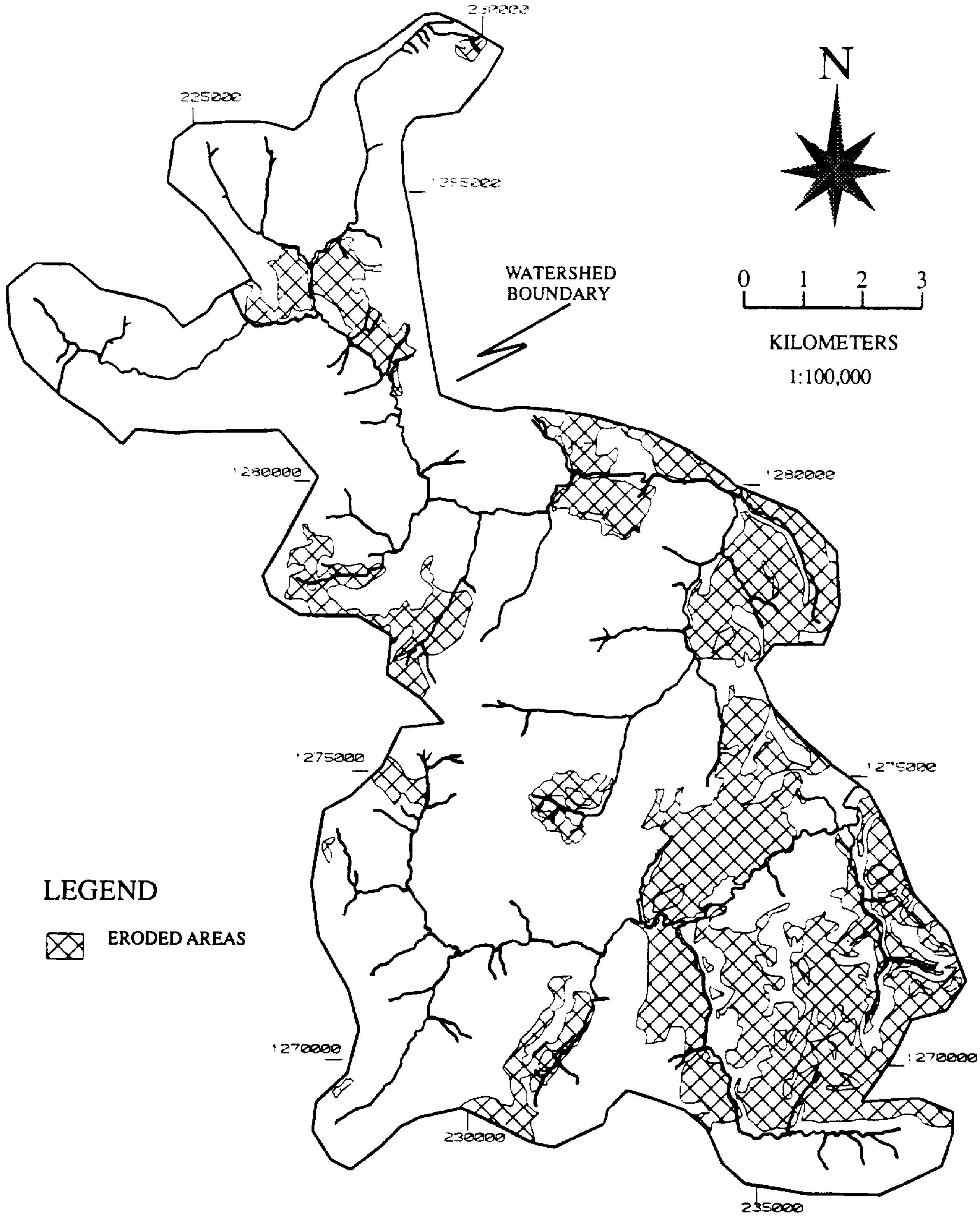

FIGURE 5: 1989 EROSION EXTENT

main data source (Marsh et al., 1990). However, the infrared data the video provided were necessary to distinguish between denser gallery vegetation and dry forest on slopes.

The 1989 map used for change detection was produced through the combined interpretation of the aerial 35mm and video imagery with interpolated interpretations from the HZ data on areas not covered during the ARSC aerial survey. The HZ data were interpreted first and used as a template upon which the ARSC data interpretations were transferred with a reflecting projector. The resultant land use map (Figure 6) was registered to the 1985 Landsat reference and digitized.

Aerial photography: Area comparison using a GIS

Three classes (primary agriculture, shifting agriculture, and eroded shifting agriculture) were extracted from the 1989 interpretation. Maps of the same classes derived from the 1953 photography were logically subtracted from the 1989 coverages to create a new coverage depicting agricultural change. To produce a display map showing the direction of change, the original 1953 agricultural classes were then graphically combined with this coverage to create the change map (Figure 4). Both 1953 and 1989 agricultural classes were summed using database capabilities to obtain tabular estimates of changes in absolute area (Table 2).

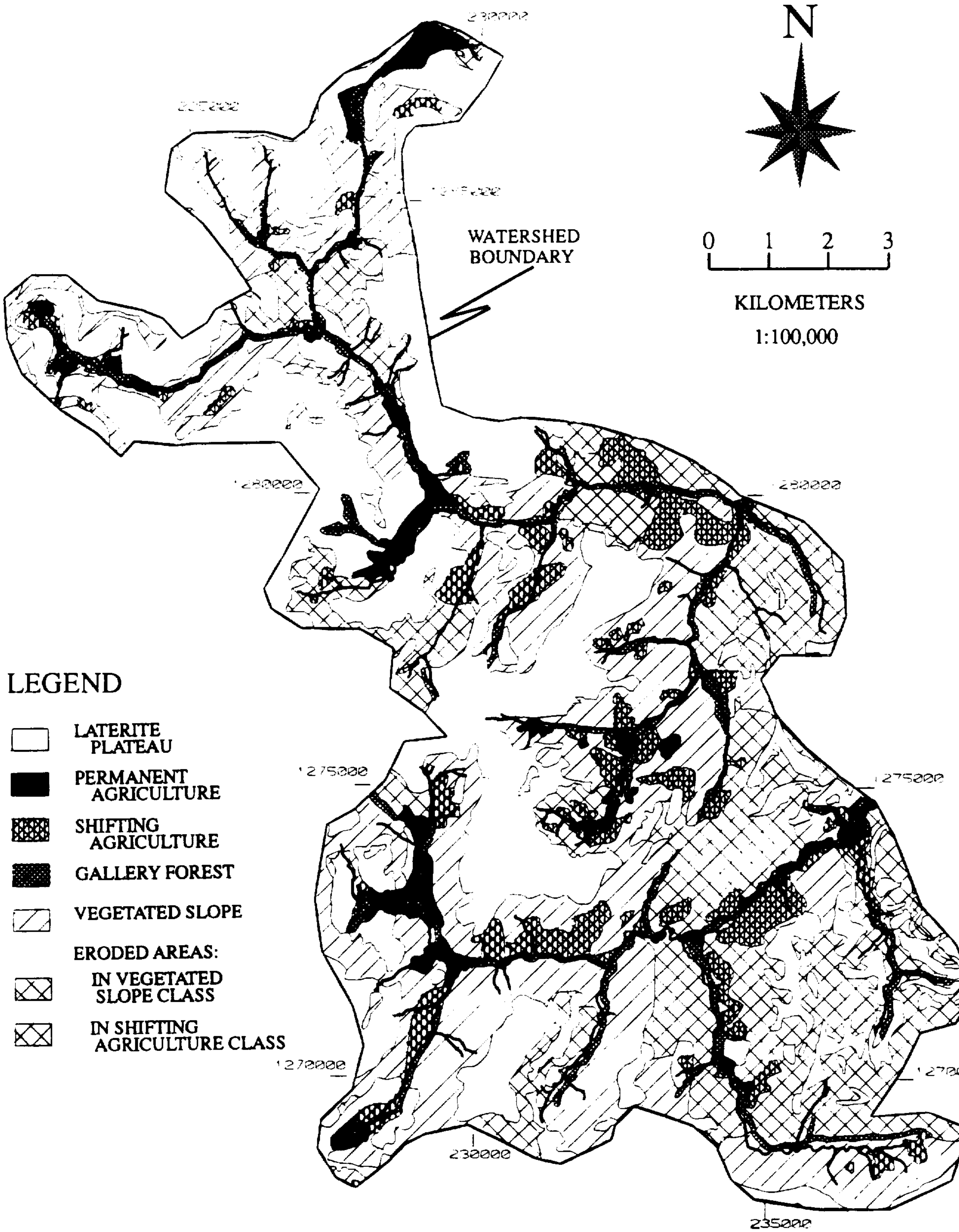

FIGURE 6: 1989 LAND COVER MAP

TABLE 2: SUMMARY OF LAND COVER AREA ESTIMATES FROM AERIAL PHOTO INTERPRETATION (HECTARES)

	1953 PHOTOS	1989 PHOTOS & VIDEO
LATERITE PLATEAU	5734	4661
VEGETATED SLOPE	7902	4089 3204 (ERODED)
PRIMARY AGRICULTURE	292	432
GALLERY FOREST	135	642
SLASH AND BURN AGRICULTURE	243	1125 153 (ERODED)
TOTAL	14306	14306

Landsat Classification

Part of our research involved an evaluation of Landsat MSS data for detecting agricultural land use change. MSS data were registered to the 1:250,000 base map, and a scene subset (339 x 428 pixels) covering the project area was extracted for classification using ERDAS software.

No ancillary data existed for either the 1973 or 1985 data sets, so it was not possible to select training fields within the shifting agriculture class. Instead, a hybrid classification was used in which an unsupervised clustering algorithm derived ten spectral classes for the 1973 scene and eight for the 1985 scene. These spectral clusters were used to seed a maximum likelihood classifier. Resultant spectral classes were merged to four land cover classes (agriculture, vegetated slope, laterite plateau and riverine vegetation), smoothed with a 3 x 3 majority filter and exported to the ARC/INFO database and registered to the common Landsat reference. Area in land-use classes was summed for each date (Table 3).

RESULTS: CHANGE DETECTION ANALYSIS

Aerial photography

Between 1953 and 1989, the area under primary agriculture expanded from 292ha to 431ha, an increase of 48% (Figure 7). As expected,

TABLE 3: SUMMARY OF LAND COVER AREA ESTIMATES FROM LANDSAT MULTI-SPECTRAL CLASSIFICATION (HECTARES)

	1973 MSS	1985 MSS
LATERITE PLATEAU	2794	2766
VEGETATED SLOPE	7658	7890
PRIMARY AGRICULTURE	243	581
GALLERY FOREST	3611	3069
TOTAL	14306	14306

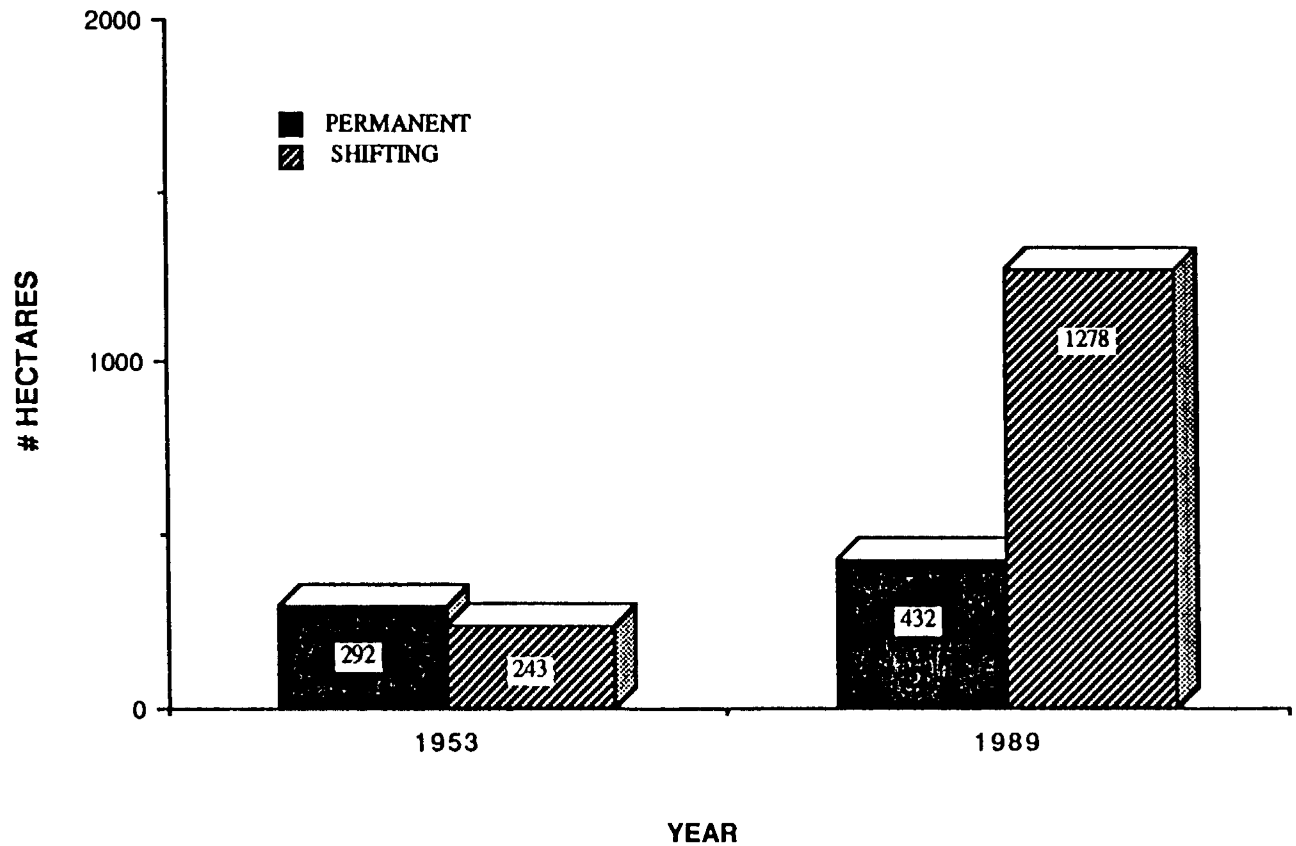

FIGURE 7: AGRICULTURAL EXPANSION, 1953 - 1989
DIAFORE AND KABARI WATERSHEDS

a comparison of Figures 3 and 4 suggests this growth occurred in bottomlands and on vegetated slopes.

The most striking result was a five-fold increase in shifting agriculture from 243ha to 1278ha. This change occurred almost entirely within the vegetated slope class. Although it is possible that secondary agriculture was underestimated to some degree in the poor-quality 1953 photography, this change is still pronounced and impressive. The extent of eroded area in 1989 was estimated at 3357ha. The area in this class is greater than in shifting agriculture, but the difference is consistent with the hypothesized intensification of agriculture on slopes.

Digital Landsat MSS

Our analysis of Landsat MSS data from 1973 and 1985 showed that agricultural land use increased from 228ha to 581ha (Table 3). This spectral class, identified as agricultural land use with the aid of ancillary data, includes only the largest, contiguous home garden groupings and some bare areas, but no isolated dwellings (Figures 8 and 9). Thus the extent of 1973 and 1985 agricultural land use mapped using MSS data was underestimated.

The area of gallery forest on both data sets was overestimated because we could not consistently distinguish between gallery and dense stands of dry forest.

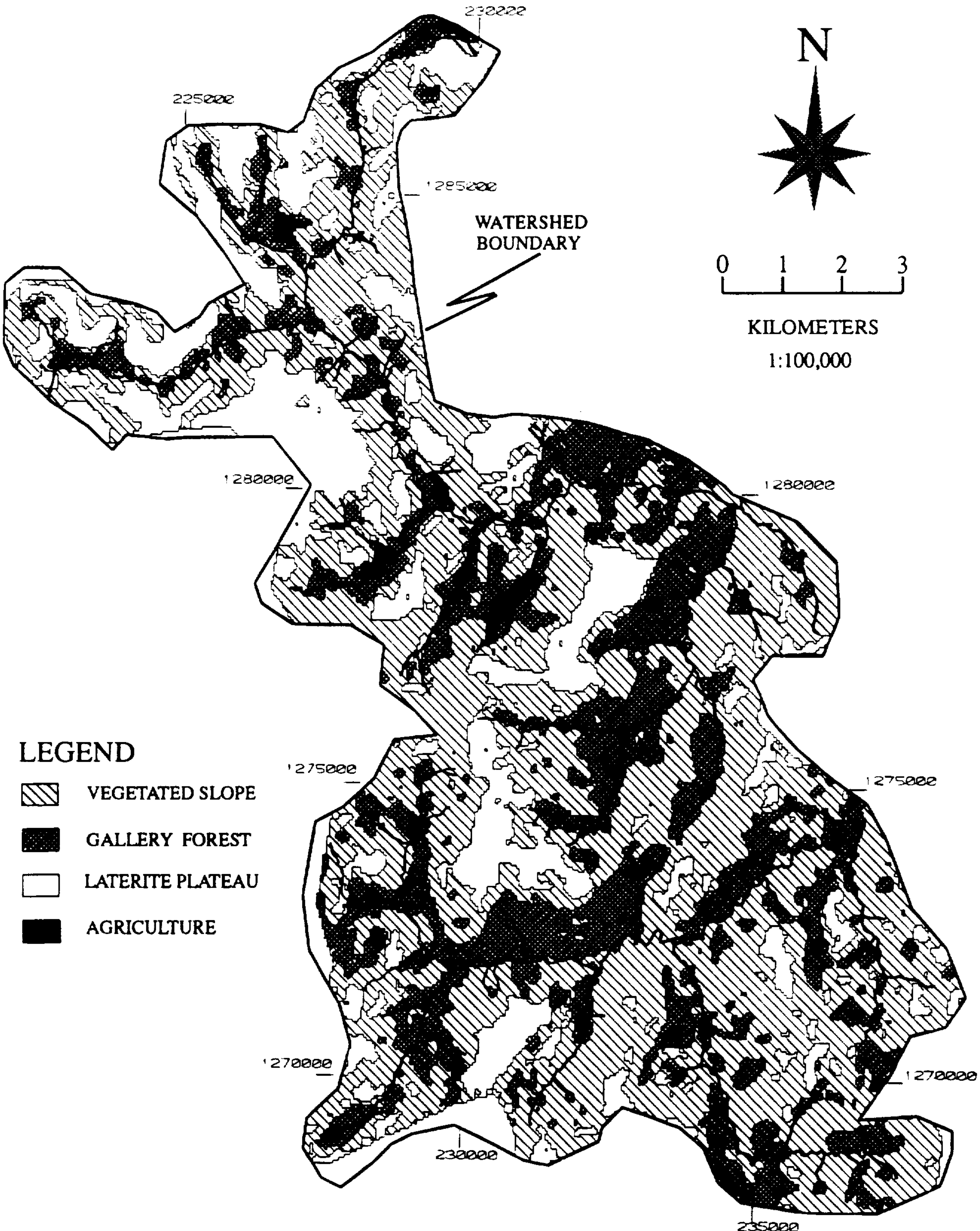

FIGURE 8: 1973 LANDSAT MSS CLASSIFICATION MAP

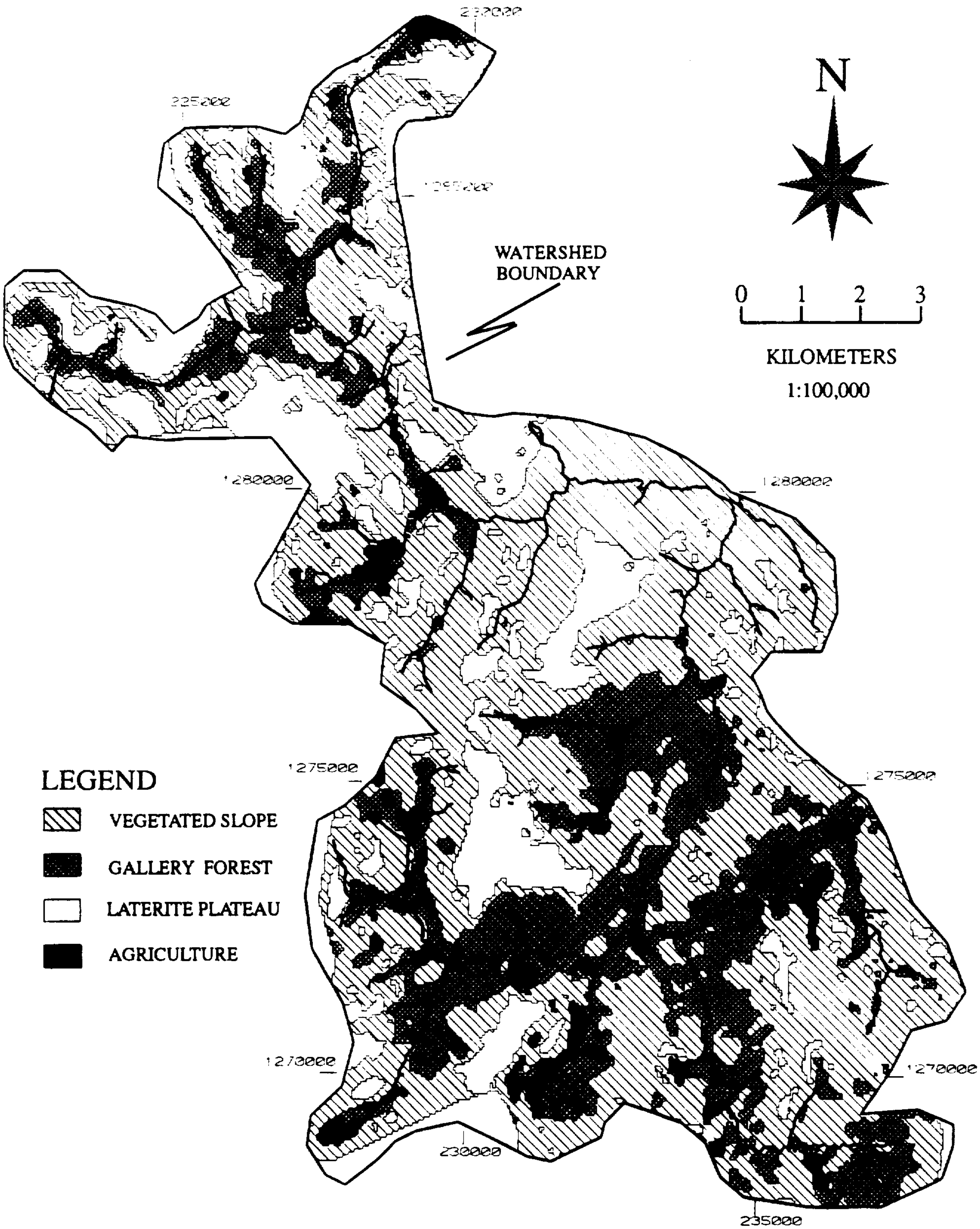

FIGURE 9: 1985 LANDSAT MSS CLASSIFICATION MAP

DISCUSSION

Deforestation Dynamics

Our findings are consistent with earlier statements regarding land use change in the region. As suggested by Richard-Molard (1949), much of the prime agricultural land was occupied prior to 1949. Thus, given that other land units (laterite plateau and most of the vegetated slope class) are less suitable for permanent agriculture, the main means of increasing productivity is by decreasing rotation periods. This simple strategy increases the amount of area under cultivation at any one time, even if the total available area remains constant.

Richard-Molard's hypothesis is static, assuming that no new land is developed. However, we found that permanent agriculture did expand along the river bottoms and, most significantly, up the lower valley slopes from existing villages. Thus, the intensification of cultivation involved both: (1) shortening the fallow period and thus expanding shifting agriculture; but also, (2) increasing the area under permanent agriculture by extending into marginal slope areas. Both of these management practices accelerate erosion.

Based on the above results, it is possible to predict future agricultural growth and environmental consequences. The following assumptions for this projection are made: (1) secondary agriculture occurs only within the vegetated slope class; (2) to maintain fertile slopes, fields are cultivated for two years and left fallow for eight years (Heermans and Williams, 1988); all of the vegetated slope is assumed to be fertile; (3) eroded areas are unproductive and are excluded in the calculations; and (4) current expansion estimated from photointerpretation is constant at a yearly rate of 29ha/yr. From Table 2:

Total vegetative slope	4089 ha
Present secondary agriculture	1125 ha
Total hectares available for secondary agriculture	5214

Given two-year cultivation to eight-year fallow ratio, the available number of ha/yr for cultivation is 5214/5 or 1043 hectares. As 1125ha are currently in use, the rotation must be decreased to maintain production. As more of the vegetated slope class goes into eroded areas and out of production, the rotation is again shortened and the resource base continues its downward spiral.

Sensor Comparison

In the bottomland environment, removal of gallery forest is restricted because of the need to protect river banks from erosion. Nevertheless, local officials claim that the width of these gallery forests has diminished in recent times. It was not possible to substantiate this observation with the available data because the gallery forests on the 1:50,000 scale 1953 photography were too narrow to accurately map.

It was not possible to accurately estimate permanent agriculture with Landsat MSS data. Isolated home gardens with their occasional fruit trees cannot be detected by MSS; only larger groupings are identified. The data do show that expansion in a mixed agricultural/bare surface class did occur, but appear to be underestimated. However, they do suggest that MSS data may be used with some confidence to target areas in the Fouta Djallon that are undergoing change. Once identified, these areas can be subjected to more intensive data collection with a combination of sensors (e.g. 35mm photography; aerial video) and field work.

Shifting agriculture and vegetated slope classes were difficult to separate with MSS data because of their high spectral variability. This variation is due to several factors: (1) mixel (mixed pixel) problems with occasional large trees remaining in fields after clearing; (2) growth of underbrush in fields farmed for a second year after clearing; (3) variations in soil type; (4) seasonal variations in spectral reflectance; and (5) variations in canopy density within the vegetated slope class.

CONCLUSIONS

This study was designed to detect types and amount of deforestation in the Fouta Djallon region of Guinea, West Africa, using a variety of sensors coupled with geographic information systems technology. We found the greatest change in vegetative cover occurs on slopes where: (1) shifting agriculture is expanding; (2) rotation periods are being shortened; and (3) permanent agriculture is being extended at increasing cost and diminishing return. All of these factors reduce vegetation cover and increase erosion hazard.

A classic multistage sampling/interpretation approach to studying deforestation is an appropriate technique to apply in the Guinean environment. Sequential satellite imagery can be used to identify areas showing overall increase in bare surfaces/shifting or permanent agriculture. After general areas (strata) of potential hazard are identified, large-scale photography/video imagery can be used to develop estimates of specific parameters that can be extended over larger satellite-derived strata. In addition, historical aerial photography can provide a temporal dimension to environmental studies that is otherwise unavailable.

ACKNOWLEDGEMENTS

This research was funded by a grant from NASA (Grant No. NAGW - 1359). The authors wish to thank August Hartman and the U.S. Agency for International Development in Conakry, Guinea, for their training support, and Dr. Ourey Bah of the Guinean National Direction of Forest and Game for logistical support. Dr. Armond Joyce and the NASA Science and Technology Laboratory at Stennis Space Center provided technical support during the initial data preparation and training phases. We also wish to acknowledge the invaluable suggestions provided by Stuart Marsh, James Walsh, and John Regan of the University of Arizona.

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