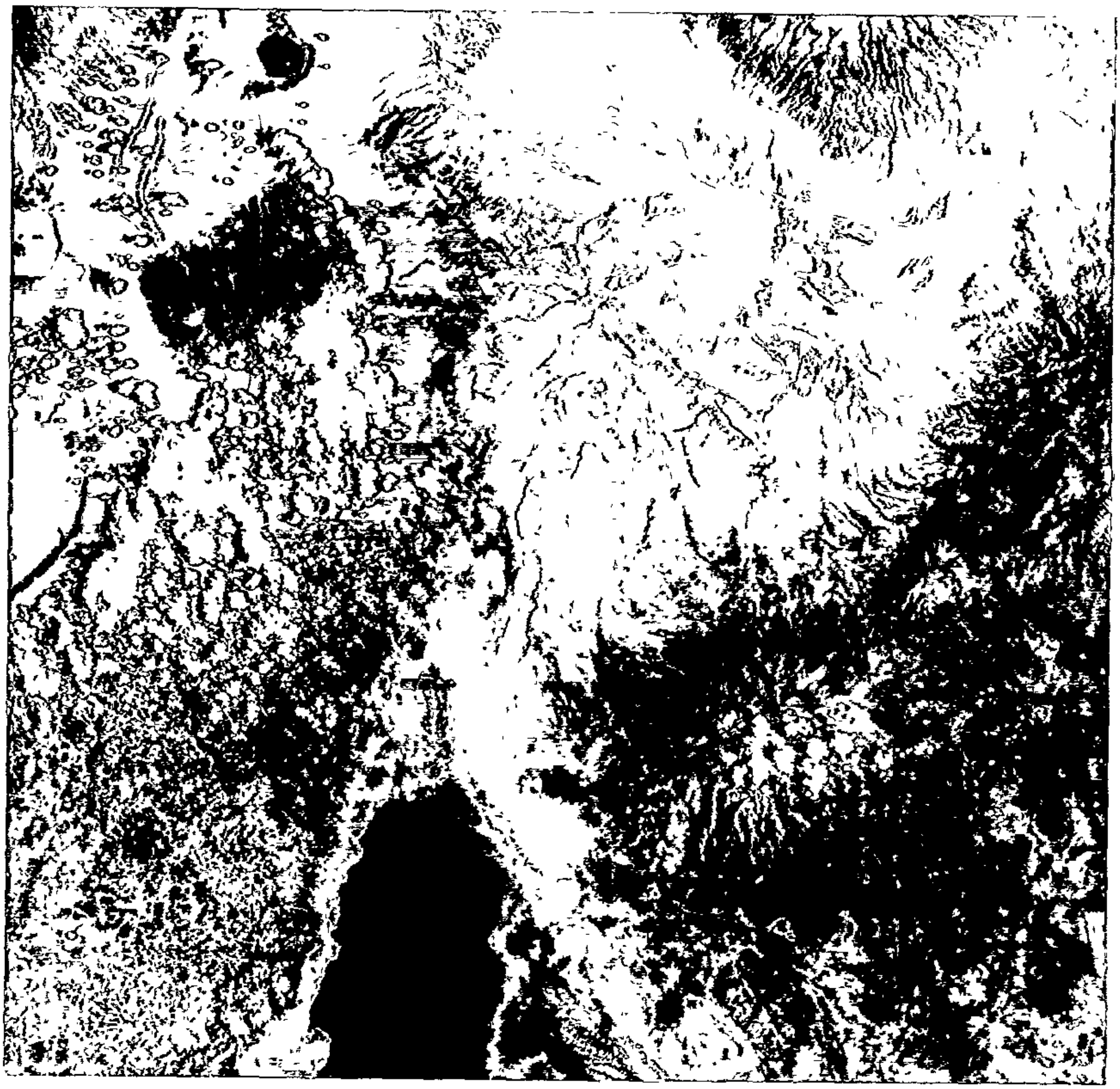
PN-AAJ-917

POTENTIAL GROUNDWATER AND LAND RESOURCE ANALYSIS FOR PLANNING AND DEVELOPMENT, ARUSHA REGION, UNITED REPUBLIC OF TANZANIA



prepared for

U. S. AGENCY FOR INTERNATIONAL DEVELOPMENT

Under Contract AID/afr-C-1119

September 1975
E/S No. 1028 Tanzania

EARTH SATELLITE CORPORATION *(EarthSat)*

Washington, D. C., 20015 and Berkeley, California, 94704

Cover photograph:

MULTIBAND COLOR COMPOSITE OF THE NORTHERN LAKE MANYARA AREA.

COLOR NEGATIVE WAS PREPARED FROM COMPUTER REPROCESSED BAND 4, 5, AND 7 BLACK-AND-WHITE PRINTS SPECIALLY PREPARED FROM LANDSAT-1 MAGNETIC TAPES.

POTENTIAL GROUNDWATER AND LAND RESOURCE ANALYSIS FOR PLANNING AND DEVELOPMENT, ARUSHA REGION, UNITED REPUBLIC OF TANZANIA

Prepared for

United States Agency for International Development

and the

Government of the United Republic of Tanzania

Under Contract AID/afr-C-1119

By

Earth Satellite Corporation

September 1975

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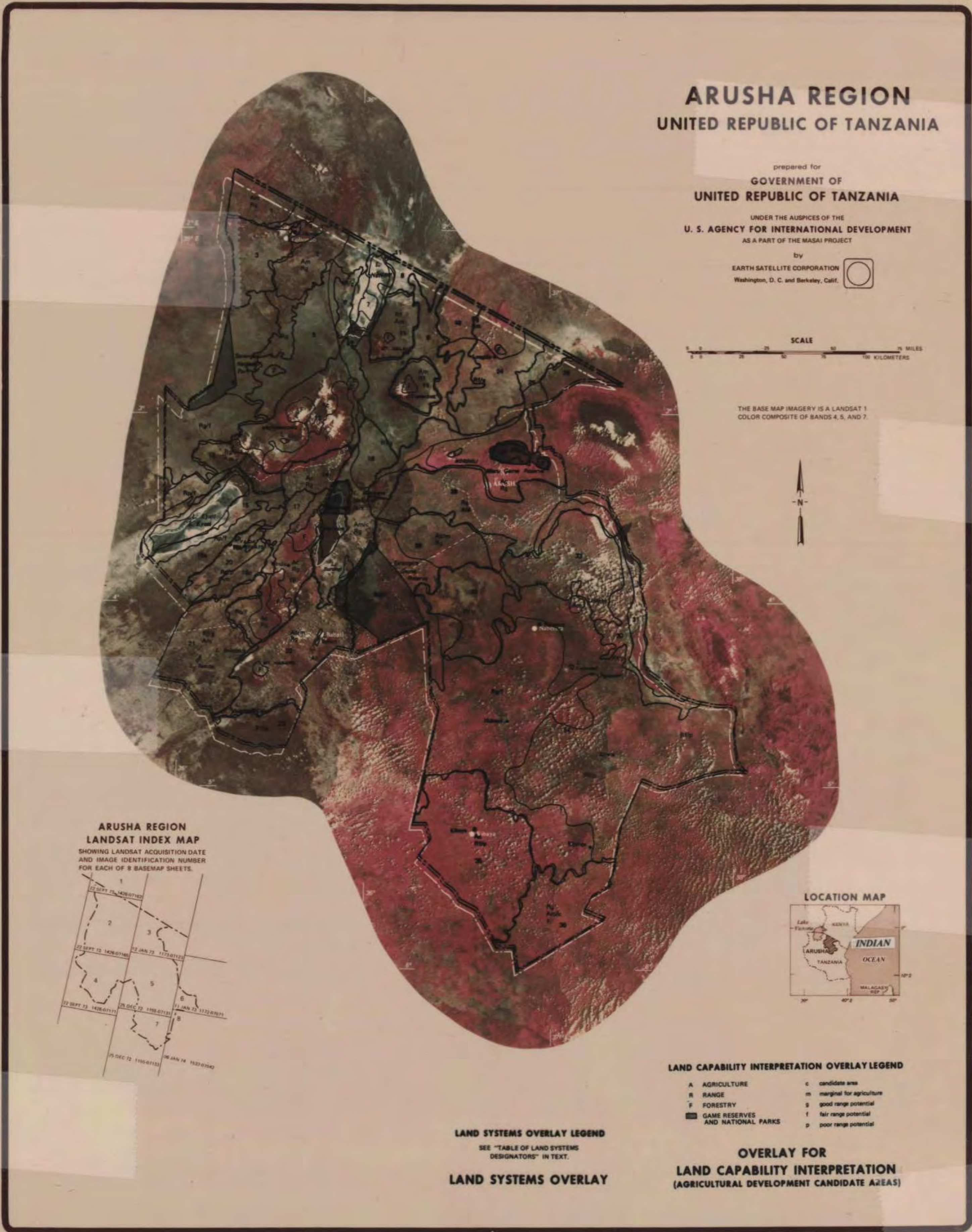
SUMMARY IN BRIEF

- High-probability target areas for exploratory groundwater development surveys are identified and listed in priority order for the Arusha Region. These priority targets are shown on a series of Groundwater Exploration Guide Map Overlays.
- Potential groundwater and land resource analysis underlying this work has been accomplished through interpretation of specially processed LANDSAT (earth resources satellite) imagery. Integrated into the interpretation and analysis is also a substantial array of existing background information and selected field data collected during this project.
- LANDSAT Ground Water Exploration Guide Maps provide immediately useful groundwater resource exploration information for locating potentially productive aquifers capable of supplying water for domestic consumption, livestock use and possibly for agricultural crop irrigation. Specific locations of particularly promising groundwater development potential are identified within Land Systems 12 (Ngorongoro), 27 (Meru-Losiminguri), 5 (Angata Salei), 11 (Gelai-Kitumbiene Shompole Volcanico), 14 (Mbulumbulu) and 28 (Meru-Monduli Toe Slopes). Areas also within which little promise of groundwater potential exists have been defined. Land System 10 (Kisirien-Loldarobo Hills), as an example, is identified as an area where fundamental negative results may impose serious limitations for development of agricultural or village schemes.

- Integrated landforms/vegetation/soils interpretation using comprehensive satellite image coverage have resulted in definition of 36 Land Systems and recognition of some 550 Land Unit (Vegetation/Landform Complexes) of potentially differing agricultural land and rangeland use capability and management potential.
- Candidate macro-areas demonstrating superior agricultural and/or rangeland development potential are located in a regional perspective on the composite LANDSAT mosaic map base illustrated on the page following. Agricultural sub-regional candidate development areas of particular promise are found within Land System 1 (Mundorossi), 22 (Hanang-Babati), 2 (Oldonyo), 14 (Mbulumbulu-Oldeani), 19 (Marang-Nou), 35 (Kibaya), 27 (Meru-Losiminguri), 29 (Masia Steppe Transition) and 12 (Ngorongoro).
- Macro-level land use capability interpretations provide a regional perspective of high and low risk land use development alternatives and a first iteration map that can be converted into a reconnaissance level soil association map by additional groundwork. This would take place in part in a semi-detailed, second phase effort within highest priority candidate areas but principally through the efforts of Tanzanian professional and technical personnel adopting this LANDSAT based scheme as the framework for continued refinement.
- During the course of our field work we have found that the Arusha Regional agriculture range and water resource professionals, with whom we have interfaced, can rapidly integrate information acquired from space and from ground survey experience.


ARUSHA REGION
UNITED REPUBLIC OF TANZANIA
prepared for
GOVERNMENT OF
UNITED REPUBLIC OF TANZANIA
UNDER THE AUSPICES OF THE
U. S. AGENCY FOR INTERNATIONAL DEVELOPMENT
AS A PART OF THE MASAI PROJECT
by
EARTH SATELLITE CORPORATION
Washington, D. C. and Berkeley, Calif.
SCALE
MILES
KILOMETERS
THE BASE MAP IMAGERY IS A LANDSAT 1
COLOR COMPOSITE OF BANDS 4, 5, AND 7.
N
ARUSHA REGION
LANDSAT INDEX MAP
SHOWING LANDSAT ACQUISITION DATE
AND IMAGE IDENTIFICATION NUMBER
FOR EACH OF 8 BASEMAP SHEETS.
LOCATION MAP
KENYA
INDIAN
OCEAN
ARUSHA
TANZANIA
LAND CAPABILITY INTERPRETATION OVERLAY LEGEND
A AGRICULTURE
R RANGE
F FORESTRY
GAME RESERVES AND NATIONAL PARKS
c candidate area
m marginal for agriculture
g good range potential
f fair range potential
p poor range potential
LAND SYSTEMS OVERLAY LEGEND
SEE "TABLE OF LAND SYSTEMS DESIGNATORS" IN TEXT.
LAND SYSTEMS OVERLAY
OVERLAY FOR
LAND CAPABILITY INTERPRETATION
(AGRICULTURAL DEVELOPMENT CANDIDATE AREAS)

1.0 INTRODUCTION

This volume summarizes a study designed to help guide water resource and land development activity in the Arusha Region. The study also provides a methodologic framework for continued and more detailed work on land capability classification and land use in the Region. The study applies new technology and new forms of imagery available from the LANDSAT, (earth resources satellite) to help accomplish these tasks.

The study, which is the first phase in a two phase program, was conducted by Earth Satellite Corporation under contract to the Agency for International Development as a part of the Masai Rangeland Project and is intended to provide information of value to development officials within the Arusha Region.

The key development objective underlying the Masai Project is to assist in the transformation of a portion of society into a more modern agricultural sector and a portion of society into a more efficient, market oriented livestock producing sector. The transformation process is necessary not only because of its intrinsic social values but also because increased food production is required to meet the needs of expanding population and to upgrade the nutritional content of the urban and rural poor.

It has generally been found that in the early stages of programs to increase aggregate agricultural production, increases are mainly achieved by placing more land under cultivation. Therefore, the search for and reasonable selection of the most usable new lands is a critical initial step in the program in Arusha. Another key objective of the regional development activity in Arusha is to integrate programs for improved agricultural output and better rangeland management with the delivery of better educational, medical, and social opportunities for the rural poor. The delivery of such services requires the development of new villages which cluster population in a more rational way and permits the economic delivery of services. A critical path in this process is the discovery and development of new sources of water supply to meet the needs of the new communities.

This volume reports the results of six months of intense analysis of the water and land resource base of the Arusha Region. We have in this brief period of time, mapped and prioritized much of the probable available water resource areas for the 32,000 square miles of the Arusha Region. The next steps are verification, site location and drilling. In addition, we have defined the Region into 36 Land Systems comprising some 550 land units which have relatively homogeneous ecological parameters, containing similar features, and thus may be considered as highly likely to produce similar conditions for agricultural and range development. The next steps here involve prioritization, larger scale interpretation, site location activity and programming.

This project, then, in a brief span of months has been able to take a cut at two of the essential ingredients comprising the Arusha development program. It has provided information for hydrologists and planners upon which to base water and village programs in the short term. It has provided a basis for regional planners and range managers to help better understand where the land's macro potential within the region lies in the short term and site specific programs may be in the longer term, as more detailed work is done.

The study is by no means a prescription for individual project development. It is intended to serve as a basis for continued work by BRALUP at the national level and range and district institutions at the Arusha level. They may, using the base data provided, prioritize their activity and increase understanding of their resource base for program design and implementation purposes.

In the case of geohydrology, the Exploration Guide Map may be put to work in the most pragmatic fashion immediately. Because of its complexity and scale and the vast quantity of information integrated into our LANDSAT land use interpretations, it has not been possible to deal with land capacity prioritization on a Land Unit basis during this first phase in the same fashion as water exploration potential was prioritized. It is the hope of the project group that with the substantial input of Tanzanian professionals this work can be moved forward to the next stage of definition and detail to the point where a base of more detailed information can be provided in both map form for the resource officers and in statistical form for the planning economists to use.

In addition to this report and the base maps and interpretation contained herein at 1:1,000,000 the USAID has received all LANDSAT maps and interpretation overlays at the scale of 1:250,000 for field use and further analysis.

2.0 GOALS AND OBJECTIVES

2.1 General Program Goals

The Tanzanian government is engaged in a program of rural development designed to improve the life and economic condition of all segments of the rural poor. Principal development activities involve rural resettlement and range management. The resettlement program involves relocation of people to villages where food production capability of the land is adequate, where water is available, and where education, health, cooperative marketing, and other social services may be developed on a rational basis. The resource development program associated with village improvement is focused primarily on the agricultural crop production that must be a part of the relocation process.

Range improvement and management programs in the context of recent drought conditions are designed to restore range productivity, increase useable animal products, and enhance the life of the pastoralists.

Both agricultural and range programs require improvement or development of water resources in new areas. The range program requires: (a) the development of reasonable range stocking limitations based upon a knowledge of the ecology and physiology of the more valuable range forage browse species, and (b) bringing of a compatible range resource management technology to bear on the solution of pastoral problems. The relocation and agricultural development program requires, in addition to water at the development sites, information about the land and land use alternatives so that all of the options are available to officials who make decisions in the location of and development of sites.

Recognizing the importance of improved resource information and the possibility that LANDSAT data might provide a rapid and efficient way of providing some needed data, Earth Satellite Corporation (EarthSat) has contracted (1) to perform some of the initial regionwide resource analyses that will be productive in water exploration and; (2) to acquire, map, and organize information about the land so it can more easily be addressed to the needs of the land use planning, development, and management processes. From this base it is expected that Tanzanian professional groups in the Ministries, Regions, and the Bureau of Resource Analysis and Land Use Planning (BRALUP) at the University of Dar es Salaam can update and refine the information base as the need arises or as conditions change. It is our expectation that this report and its related map products will become a part of a growing body of knowledge that will contribute to steadily improving land use decisions, development programs, and resource management activities in the Arusha Region.

2.2 Specific Objectives

The specific objectives of the Phase I effort undertaken by Earth Satellite Corporation are:

1. By appropriate geohydrological investigations utilizing especially processed LANDSAT-1 imagery in conjunction with the other available data, identify and prioritize high-probability ground water areas with the objective

of: (a) reducing the total cost of ground water exploration and drilling programs, and (b) providing planners with a sense of the areal extent of probable water resource areas.

2. By interpretation of LANDSAT imagery and use of available corollary data, identify the land systems and land units on a regional basis that delineate the vegetation-landform systems that comprise the landscape units of the Arusha Region, and develop a comprehensive organizational framework for regional and district level resource data relevant to land use planning.

3. Provide a first approximation interpretation of broad land use capability areas in the Arusha Region defining candidate agricultural areas for more detailed analysis at 1:50,000 or larger scale, and those areas that probably should remain in pastoral use as rangeland.

4. Prepare examples of the components of an in-depth resource analysis and land use capability study to (a) guide follow-on analysis from the LANDSAT data and larger scale aerial photography; (b) identify and where possible eliminate areas of deficiency and need in the existing background and supporting data base; (c) demonstrate ways in which Tanzanian scientists and technicians can use results and maps from the study to refine their understanding of plant ecology, soils, and land-use potential in the Arusha Region.

5. Provide limited training of Tanzanian technicians in use of remote sensing technology for geohydrologic activity, land use planning, and the implementation of development programs.

3.0 METHODOLOGY

This section describes the general technical rationale for the project, and the methods that were pursued to complete the geohydrologic and land resource analysis studies. We also briefly describe the nature of our principal source of information, the earth resource satellite imaging system called LANDSAT.

This work was initiated following planning and programming conferences with the USAID Mission, Tanzania Government officials at national, regional, and district levels; the BRALUP institute at the University of Dar es Salaam, and the Masai Livestock Project Team in Arusha, Tanzania. An intensive search was made for prior resource studies. All relevant maps, natural resource data, and publications that were made available to EarthSat by the various groups were thoroughly reviewed and used as appropriate. Additional baseline information was researched by the EarthSat staff from a variety of sources, and contributed to the interpretations made as a part of this project (see Bibliographic Section).

Field work involved two separate trips to the Arusha Region by three EarthSat staff members, one prior to and one subsequent to initial image interpretation. Ground travel for support observations and data gathering involved over 3,000 miles of surface travel and low-flying aircraft overflights. Ground transportation was provided by USAID and the Livestock Project Team.

The basic tasks of interpretation of land capability was accomplished by an interdisciplinary team that included an agronomist, a rangeland ecologist, a forester, and a geohydrologist. Their judgments, where possible, were tested again in the editorial review process by an additional group of scientists.

The key to our general methodology was to use a senior professional group to do the LANDSAT interpretation, integrate into this interpretation all of the relevant available data, and then to refine the findings and judgments using a multidisciplinary review procedure to get at land capability assessments.

3.1 The Use of Earth Resource Satellites - LANDSAT

One of the values of remote sensing is that it captures and preserves all of the resource detail (to the resolution limits of the system) exactly as it was at an instant in time. These instantaneous records can be preserved for re-examination or analysis in greater depth as future developments require. This procedure has been followed since the serious use of aerial photography in agriculture and the natural resources began in the late 1930's to early 1940's. LANDSAT has added four new dimensions to the traditional values of aerial photography: (1) a large synoptic view; (2) the capability, at very low cost, to look at the same area repeatedly at the same sun-time; (3) the resolution and scale inherent in the system compressess data, and the results are more appropriate to a generalized regional planner's view of resource base; (4) LANDSAT imagery is available at nominal cost after it has been acquired by the satellite.

The goal of this project is serving national, regional, and district planning requirements, and LANDSAT imagery offers distinct advantages. Regional resource surveys may be accomplished much more economically from specially processed LANDSAT imagery.

Although 1:50,000 black-and-white aerial photography is available for portions of Tanzania at this time, it is old with respect to land use mapping and does not represent a better option for regional mapping than LANDSAT imagery. At 1:50,000, approximately 5,250 aerial photos are required to cover the Arusha Region. Interpretation of these data on a regional scale would be very time consuming. Moreover, on any one stereo model, it is impossible to see enough landscape to characterize the macrorelief and landforms at primary to tertiary levels needed for regional scale mapping, and it is not possible to perform geohydrologic analysis work nearly as effectively and rapidly as one is able to do from LANDSAT imagery.

3.2 Summary of LANDSAT System

The Earth Resources Technology Satellite (called LANDSAT-I) launched in July of 1972, operating at an altitude of approximately 500 nautical miles (nm), acquires the imagery of the earth's surface in 4 spectral bands. (see Appendix E)

The satellite's orbit is configured to pass over each point on the earth's surface every 18 days, and given cloud-free days, is capable of supplying or acquiring repetitive coverage of a given point about 3 times every 2 months. Each frame of LANDSAT imagery is 100nm wide and 97nm long with a resolution of 60-100 meters (m), depending upon the contrast between an object and its surroundings. The geometric/geodetic accuracy of the multispectral scanner imagery is found to be approximately 200m uncorrected and 80m corrected.

LANDSAT-I, whose imagery was used on this project, was to have a four-channel multispectral scanner (MSS) and a three-band return beam vidicon (RBV). The RBV malfunctioned on 6 August 1972. The MSS, however, is functioning better than expected. The RBV imagery has poorer spectral resolution, but better spatial resolution and geometric fidelity than the MSS. However, geometric differences are relatively small; thus, the loss of the RBV is not detrimental to most applications. In January 1975, a second satellite virtually identical to the satellite described here was launched. LANDSAT II is acquiring imagery in both the RBV and MSS bands. The two satellites provide coverage of the earth every nine days. A detailed technical description of the LANDSAT system appears in Appendix A.

3.3 Analytical Procedures

3.3.1 Land resource analysis

3.3.1.1 Establishing a data base

Our first step in this project, following the establishment of a general methodology and work plan, was to assemble the material and digest what is already known about the project area.

A resource scientist acting as image interpreter can define what he sees in an image very largely in proportion to what he understands about a specific landscape. The confidence levels that can be associated with a resource interpretation are a direct function of the quantity and quality of corollary information available. The first task in the project, after the programming and design conferences, was to conduct a ground reconnaissance and assemble all of the relevant and available information about the Arusha Region. This fixed the point of departure for the project.

3.3.1.2 Acquisition of corollary information

Publications and numerous reports, such as topographic maps at scales of 1:250,000 and 1:50,000; aeronautical flight charts at a scale of 1:1,000,000; geologic maps at 1:125,000; a set of 12 water resource maps from the Masailand Comprehensive Report; and substantial quantities of geographic atlas information, were all part of the material gathered together from sources in Tanzania, Great Britain, and the United States. The complete index of BRALUP publications and reports was consulted and copies of relevant items obtained wherever possible. Additional information continued to come to our attention throughout the project. All these support documents were consulted and used as appropriate to generate our final products and this report.

The principal publications and reports used in the project are listed in the Bibliography Section at the end of the report. As can be seen, the ancillary information available and used covered a full range of environmental, agricultural, and socio-economic topics. The project placed special emphasis on subjects pertaining to the resource analysis--climate, vegetation, agriculture, range, land use, topography, hydrogeology, and regional infra-structure.

Comprehensive publications on soils of the Arusha Region are not available. However, we did realize some benefit from the available, highly generalized soils map of Tanzania which became very meaningful when used and evaluated with the larger scale geological maps. Copies of two semi-detailed soils studies recently completed by a Canadian Soils Team in the Basotu and Monduli areas were also used. These maps displayed a broad array of soils and environmental conditions including volcanic and non-volcanic soil-forming materials. Using these maps, we were able to increase the usefulness of highly generalized soils information by some effective cross comparisons with these recent and more detailed inventories.

The 1:50,000 topographic sheets were freely integrated into all of the initial interpretations, and were particularly helpful in the evaluation of macrorelief and landform characteristics and in the identification of physiognomic classes in each of the land units mapped. The topographic maps also proved helpful in examining the infrastructure as the land systems were being described and characterized.

Several black-and-white aerial photographs at a scale of 1:40,000 were used for portions of the Arusha-Meru and the Kibaya-Dosidosi areas. They provided larger scale insight into the vegetation and topographic conditions represented by the color, density, and pattern signatures on the LANDSAT imagery.

Our original work plan called for the documentation of current land use on a sample basis by 35mm oblique photography to be acquired by aerial reconnaissance photography. These data were to be used to study relationships between land use practices and specified kinds of land units. Clearance for this 35mm photography was not available. Visual observations supported by recorder tape were made. These, of course, lacked the information content necessary to achieve the levels of detail and confidence levels available from photography.

3.3.1.3 Preparation of a working image base

Parts of eight LANDSAT frames are required to cover the Arusha Region. To identify frame locations each frame was arbitrarily numbered as shown in Figure 3-1. These eight frames were printed as bands 5 and 7

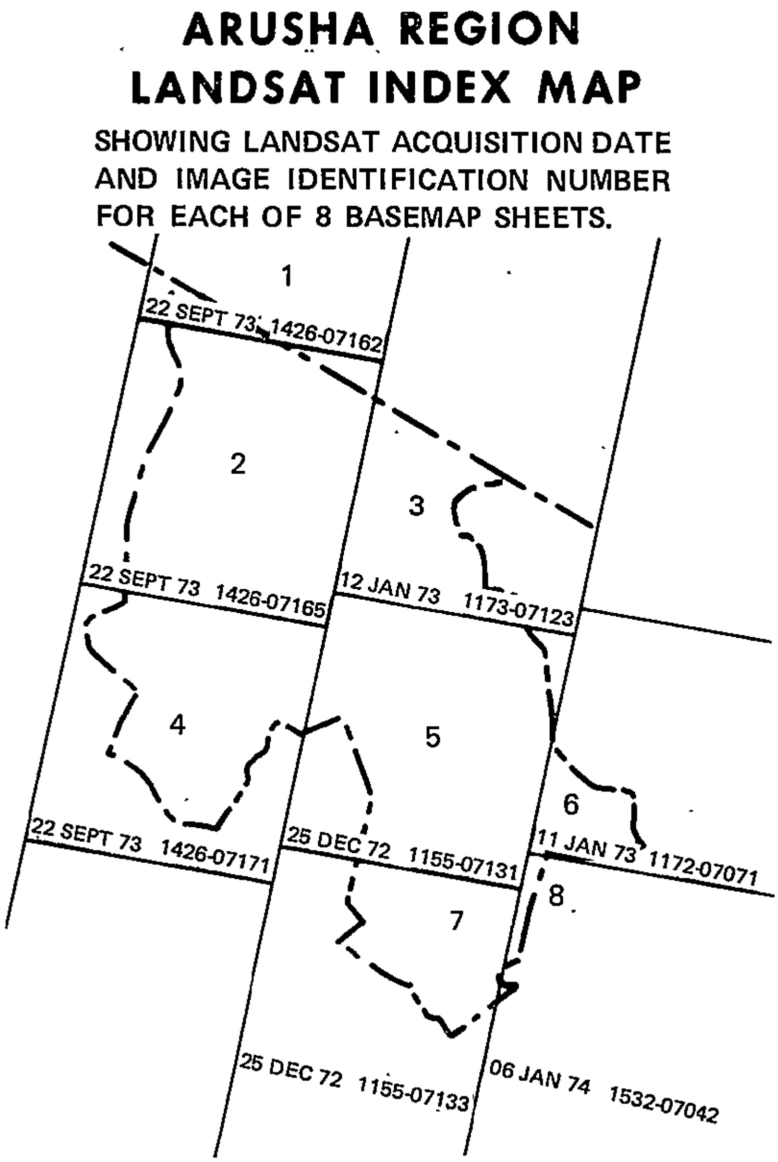


FIGURE 3-1. Arusha Region LANDSAT Image and Basemap Index Map

false color composites at a scale of 1:1,000,000 and laid into a mosaic. The same eight frames were reprocessed after considerable experimentation with optimum color balance and some optical filtering into three-band (4, 5, and 7) false color infrared composites. The color composites were produced at the 1:250,000 scale and served as the final mapping and interpretation base. The frame covering the Arusha-Monduli area, for which only bands 5 and 7 were available from the U.S. Department of Interior, Sioux Falls Data Center, was the only exception.

For frames identified as locations 2, 3, 4, 5, and 7, band 7 was digitally reprocessed in a computer from the magnetic tapes of the LANDSAT imagery. The band 7 data were density equalized, desquared (partial geometric rectification), and edge enhanced. These products, initially prepared at a scale of 1:400,000, were enlarged to 1:250,000 and used for interpretation in all phases of the investigation and were of special utility for structural analysis and determining patterns of land use.

3.3.1.4 Preinterpretation ground observations

In March 1975, two EarthSat professionals traveled completely around the Arusha Region (Korogwe-Kibaya-Kondoa-Babati-Arusha-Moshi-Mkomazi-Korogwe) in an initial field visit. In addition, they circled the productive and varied area around Mt. Meru, undertook a safari onto the plains north of Monduli, and a safari through Ngorongoro and across the Serengeti for discussions with personnel at the Serengeti Research Institute. A safari north and south through the center of southern Masailand was impossible at that time because of weather and road conditions. On this and subsequent ground safaris, scores of ground photographs were taken to illustrate vegetation, soil surface, and landform conditions. Each photograph was located along the route of travel by mileage notations, and a running log of resource and land use conditions observed was tape recorded and related to specific ground locations so that all notes and photographs could be studied in relation to LANDSAT specific image characteristics.

Upon return to the photo interpretation laboratory, these ground note locations were mapped at 1:1,000,000 scale and organized so that they could be referenced in interpretation and subsequent operational work throughout the project.

3.3.1.5 Preparation for interpretation

The resource scientists assigned to the project studied and integrated corollary publications, topographic and geologic maps, sample aerial photography, photographic and recorded notes referred to above, which were transcribed and abstracted onto cards for handy reference. The data integration process resulted in our being able to relate known ground observations to specific image types; thus this process became an important asset in imagery interpretation.

An Information Index was prepared to facilitate access to individual topographic sheets and, when necessary, the aerial photographs from which they were made. A 1:1,000,000 color mosaic of LANDSAT imagery of the Region was prepared with a mylar, stable base overlay which showed the boundaries, name, and number of each 1:50,000 topographic map sheet in its true position with respect to the LANDSAT image. The 1:50,000 topo sheets show the principal points (centers) of the aerial photographs that were the origin of these maps. Thus, using the Information Index, one can quickly go from a point or area on the LANDSAT image to its topographic map representation and from the topographic map sheet to the correct aerial photograph, the numbers of which fall within a designated area on the mylar reference overlay. This Information Index will be very useful to professionals working with the EarthSat prepared maps and overlays who wish to relate the regional perspective to the highly detailed views of aerial photography or ground work.

3.3.1.6 Mapping guidelines

A series of guidelines are established for the legend systems that serve as the framework for a consistent inventory analysis. Specified for the legend system are the maximum or the highest detail of mapping intensity, and guidelines for mapping specified legend class complexes within a single delineation. The guidelines cover the following variables: (a) refinement of mapping, (b) allowable size of inclusions, and (c) manner of delineating complex landscapes.

The following guidelines are established as appropriate for this phase of the project:

1. Contrasting and important classes, such as cropland, are mapped to minimum physical area of 1 square centimeter.
2. Narrow delineations are in the main not separated unless they represent contrasting features and are wide enough to accommodate the legend descriptor within the delineation.
3. Differentiation of non-contrasting classes cannot be justified below about 4 to 9 square centimeters, but generally uniformity of landform controls the delineation when vegetation images are non-contrasting.
4. Where landscapes are intricate in relation to the map scale being delineated, we included

more than one class within the same boundary. These are referred to as complex mapping units. When this is necessary, the landscape is mapped so that normally only two, or not more than three, classes are included within the same delineation. When this occurs, each component is designated by its appropriate legend symbol. The multiple symbols are written in the order of the areal importance of the features each represented.

5. Contrasting and non-contrasting classes that make up 10 percent or less of a delineated area are treated as inclusions and not symbolized in the descriptor.

6. Boundaries are traced as accurately as possible, based on changes in hues, densities, and landform features of the images. For wavy and angular boundaries, the delineation is placed on the actual boundary. An indistinct boundary is treated as a complex area. Intricately incised or dendritic boundaries are averaged by smoothing a delineation boundary through the median extent of the interwoven boundary region.

The application of these guidelines resulted in a realistic and practical definition of the kinds of vegetation-landform systems at the working scale of 1:250,000.

3.3.1.7 The interpretation process

Each delineation represents an interpretation of a landscape unit that is homogeneous in terms of vegetation, soils (to some degree), and its landform characteristics or features. The false color LANDSAT images (at 1:250,000) are interpreted by reading the hues, tones, image patterns, and textures in terms of vegetational types and densities. Landform characteristics and patterns are also considered in establishing delineation boundaries.

In the interpretation process done at 1:250,000 scale on LANDSAT enlargements, all of the corollary data (ground notes, photographs, topographic maps, etc.) are consulted in reaching identification decisions in the delineated areas.

Mapping was done on clear mylar overlays so that the image characteristics are not altered by the overlay material.

In both the geohydrological (see below) and resource analyses, the computer-enhanced band 7 images are used for details not evident on the color composite prints. These details are mapped directly from the band 7 enlargements and transferred to the master overlay which was made from the false color base. Many fracture patterns and agricultural areas that could not be seen on the color images were evident on these special products.

A large sample of delineations and identifications was field checked on the second trip to Tanzania (see figure of ground and air check routes). The mapping and delineation identifications were all subsequently checked on the basis of ground samples and air examination, and changes were made where necessary. Very few corrections were needed in delineation boundaries. We repeatedly find that boundary decisions made from the scale and perspective of 570 miles cannot be improved upon from ground examination unless one's decision is to map more or less finely. Occasionally, one will have separated types on the basis of a subtle tone or hue that ground examination places in the same legend type. Thus it is more common to eliminate types than to add new ones. Identification of resource characteristics in terms of the legend (see below) proved encouragingly good from the first interpretation. We did not prepare an error table, but prior experience shows that our accuracies of identification range between 70 to over 90 percent in similar work. The ground and air checks indicated we were at the upper range of accuracy limits.

3.3.1.8 The mapping legend

The mapping legend consists of a set of classes and descriptors that are used to define each delineation. EarthSat has developed and widely used a legend system that allows characterization of land areas and water bodies in a hierarchical fashion, capable of handling the varying levels of information required for national, regional, and district planning, and expansible to meet the needs of project planning and resource management. The design rests on the concept that vegetation mirrors the unique environments occupied by each vegetational system.

The legend accommodates the definition of anthropogenic changes brought about within the "natural" scene where man has cultivated, built roads, cities, and industrial complexes, and permits characterization of the physical surface in terms of its macrorelief, landforms, and eventually its soils in the context of a progressively refinable hierarchical system. The system provided for many of the kinds of vegetation classes traditionally mapped in East Africa on the basis of physiognomic and structural characteristics. After our first trip to Tanzania, the legend system was adapted as closely as the satellite image characteristics and features permitted to these established classes (Pratt, Greenway and Gwynne, 1966; Van Voorthuizen, 1970).

Legend refinement was carried to secondary and tertiary levels, including a density related level in the shrubland class. After our second series of field safaris, we added a ground cover or biomass-related quaternary level for use with the grassland and shrubland classes. This latter refinement was not uniformly applied. It was used only in those areas where image characteristics and/or available ground truth records enabled us to add a high, medium, or low biomass indicator to the mapping symbol. Obviously there will be more error inherent in these quaternary level determinations, but the image characteristics related to the high and low classes (as with the high, medium, and low bush density categories) are sufficiently distinct to be meaningful. In some cases, grass maturity, localized drought, and grazing pressure prior to imaging will have affected these quaternary level scores. As multiple season imagery becomes available for Arusha, these problems are minimized.

The Land Resources Legend consists of two parts: (1) a numeric symbolic legend which is computer compatible, and (2) a descriptive legend which characterizes or names and describes the symbolic legend classes.

The legend system uses a base 10 numeral system by holding each level in the symbolic legend to a set of 9 components. In each case beyond the primary classes, digit 9 is retained to signify an undifferentiated complex of classes at each subordinant level; e.g., 09 or 009. To indicate any or all classes within a set (hierarchical level) without being specific, only the appropriate digit between 1 and 8 is used. To denote a specific but undifferentiated subset of classes within the level, the digit 9 is used.

The hierarchical scheme for characterizing vegetation and land use in the Arusha Region Inventory is shown in Figure 3-2. Each of these categories is explained or described in Appendix A. Cartographically, these descriptors are used as shown in Figures 3-3 and 3-4.

3.3.2 Geohydrologic Interpretation and Ground Water Exploration Guide Map Preparation

The general process of data acquisition, field work, data processing image enhancement, etc., which is described in the Analytical Procedures section for Land Resource Analysis above applies to the geohydrologic activity. This section therefore presents only the basic procedure, and definitions used to structure the geohydrologic position of the program.

The results of a detailed interpretation of LANDSAT black-and-white band 5 & 7 prints, LANDSAT color composite prints, enhanced color composites, and digitally enhanced band

LAND UNITS OVERLAY LEGEN

SURFACE FEATURES

PRIMARY

- BARREN LAND
- WATER RESOURCES
- NATURAL (NATIVE) VEGETATION
- CULTURAL VEGETATION
- AGRICULTURAL PRODUCTION
- URBAN, INDUSTRIAL, TRANSPORTATION
- EXTRACTIVE INDUSTRY, NON-RENEWABLE
- NATURAL DISASTER AREAS, RECENT
- OBSCURED LAND

SECONDARY

110 PLAYAS (SALT AND ALKALAI FLATS)
120 AEOLIAN BARRENS
130 ROCKLANDS
140 SHDRELINES
150 BADLANDS AND EROSIONAL BARRENS
160 SLICKS
170 MASS MOVEMENT
180 MAN-MADE BARRENS
190 UNDIFFERENTIATED COMPLEXES

210 PONDS, LAKES AND RESERVOIRS
220 WATER COURSES, PERMANENT
230 SPRINGS, SEEPS AND WELLS
240 BAYS, CDVES AND ESTUARIES
250 LAGOONS AND BAYOUS
260 OCEANS, SEAS AND GULFS
270 *UNASSIGNED*
280 SNOW AND ICE
290 UNDIFFERENTIATED COMPLEXES

310 HERBACEOUS TYPES 1/
320 SHRUB/SCRUB TYPES
330 SAVANNA-LIKE TYPES
340 FOREST AND WOODLAND TYPES
390 UNDIFFERENTIATED COMPLEXES

400 CULTURAL VEGETATION (PERMANENT INDUCED) Secondary classes same as for 300'ds., i. e., 440, Planted Forests

510 COVER CRDPS
520 PASTURE AND HAY CROPS
530 VEGETABLE AND ROOT CROPS
540 FRUIT ANO NUT CROPS
550 HORTICULTURAL SPECIALTIES
560 MIXED CROP/SHIFTING AGRICULTURAL
570 NON-PRODUCING, FALLOW AND TRANSITIONAL
580 ANIMAL FACILITIES AND FARMSTEADS
590 UNDIFFERENTIATED CROPLAND

610 CITIES AND LARGE TOWNS
620 VILLAGES AND CLUSTERED SETTLEMENT
630 ISOLATED HABITATION

710 NDN-RENEWABLE RESOURCE EXTRACTION, MINING AND QUARRY

810 BURNED AREAS
820 FLOODED AREAS

910 CLOUDS AND CLOUD SHADOWS

TERTIARY

314 Perennial Grasslands (Moist/Dry Lands)
316 Marsh and Swamp Grasslands (Wetlands)
319 Undifferentiated Grasslands

321 Non-thorny Desert Scrub (microphyllous)
322 Thorn Scrub (Bushland), Dense ("Thickets")
323 Thorn Scrub (Bushland), Moderately Dense
324 Thorn Scrub (Bushland), Low Density
325 Halophytic Shrub
326 Non-thorny, Mesic Shrub (macrophyllous)
328 Mountain "Heath"
329 Undifferentiated Shrub Types

331 Arborescent (Tree-Layer)
332 Shrubby
333 Palm Savanna

341 Gymnosperm Forests (Needleleaf)
342 Angiosperm Forests (Broadleaf)
343 Mixed Forests (341/342)
344 Woodlands
349 Undifferentiated Forests

441 Planted Gymnosperm Forests
442 Planted Angiosperm Forests

1/ A quaternary level designator is added whenever interpretable to indicate the biomass of the grasslands (314) or of the grass understory in the Shrub/Scrub (320) and the savanna-like (330) vegetation types. It is described in the text under the appropriate categories.

FIGURE 3-2. Hierarchial Land Unit legend scheme for identification of land cover and land use features in the Arusha Region

.AND UNITS OVERLAY LEGEND

TERTIARY

314	Perennial Grasslands (Moist/Dry Lands)
316	Marsh and Swamp Grasslands (Wetlands)
319	Undifferentiated Grasslands
321	Non-thorny Desert Scrub (microphyllous)
322	Thorn Scrub (Bushland), Dense ("Thickets")
323	Thorn Scrub (Bushland), Moderately Dense
324	Thorn Scrub (Bushland), Low Density
325	Halophytic Shrub
326	Non-thorny, Mesic Shrub (macrophyllous)
328	Mountain "Heath"
329	Undifferentiated Shrub Types
331	Arborescent (Tree-Layer)
332	Shrubby
333	Palm Savanna
341	Gymnosperm Forests (Needleleaf)
342	Angiosperm Forests (Broadleaf)
343	Mixed Forests (341/342)
344	Woodlands
349	Undifferentiated Forests
441	Planted Gymnosperm Forests
442	Planted Angiosperm Forests

1/ A quaternary level designator is added whenever interpretable to indicate the biomass of the grasslands (314) or of the grass understory in the Shrub/Scrub (320) and the savanna-like (330) vegetation types. It is described in the text under the appropriate categories.

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er

MACRORELIEF/LANDFORM CLASSES

PRIMARY	
1	FLAT LANDS
2	ROLLING AND MODERATELY DISSECTED LANDS
3	HILLY LANDS
4	MOUNTAINOUS LANDS

SECONDARY/TERTIARY/QUATERNARY	
.1	DEPRESSIONAL, NON-RIPARIAN BASINS
.11	SEASONAL LAKE BASINS
.12	MBUGAS
.2	DEPRESSIONAL CALDERAS
.3	BOTTOMLANDS, RIPARIAN
.32	BOTTOMLANDS, RIPARIAN, STRINGER OR NARROW
.33	BOTTOMLANDS, RIPARIAN, WIDE VALLEY BOTTOM
.34	DEPRESSIONAL, CONCAVE (MAY CHARACTERIZE SAME MBUGAS DF EXTERNAL DRAINAGE)
.35	DESERT WASH
.4	PLANAR SURFACES, LOWLAND,
.402	PLANAR SURFACES, LOWLAND, DISSECTED
.41	PLANAR SURFACES, LOWLAND, VALLEY FILL
.412	PLANAR SURFACES, LOWLAND, VALLEY FILL, DISSECTED
.42	PLANAR SURFACES, PEDIMENT OR TOE SLOPE
.422	PLANAR SURFACES, PEDIMENT OR TOE SLOPE, DISSECTED
5	PLANAR SURFACES, UPLAND PLATEAU (BENCHES, MESAS, BROAD RIDGETOPS)
.51	FLAT TO STRONGLY UNDULATING DIP SLOPES
502	PLANAR SURFACES, UPLAND PLATEAU, DISSECTED
.6	STRONGLY UNDULATING TO ROLLING LANDS
.602	STRONGLY UNDULATING TO ROLLING LANDS, DISSECTED
.7	SLOPE SYSTEMS
.71	ESCARPMENTS
.72	VALLEY, CANYON OR GORGE SLOPE SYSTEMS
.73	BUTTE OR ISOLATED HILLS AND KOPJES
.74	HILL AND MOUNTAIN, SMOOTH SLOPE SYSTEMS
.75	HILL AND MOUNTAIN, ANGULAR SLOPE SYSTEMS
.8	GRAVITY AND MASS MOVEMENT LANDSCAPES

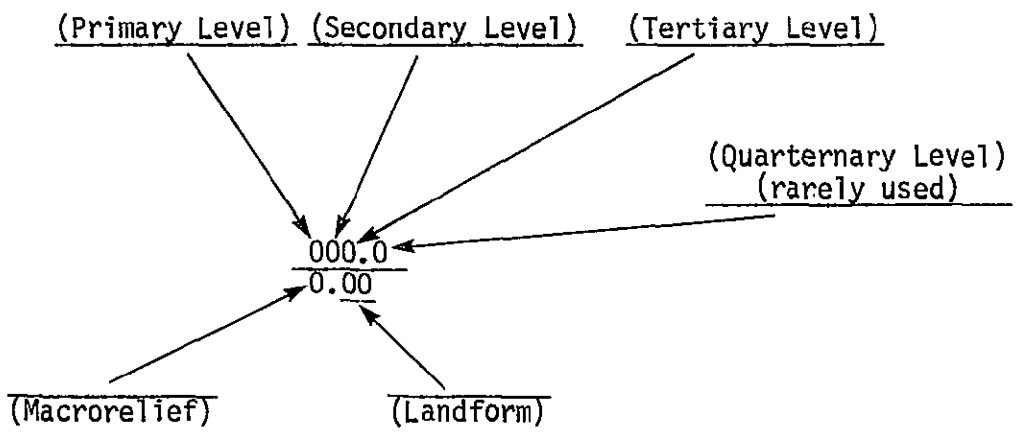
DISSECTED CLASSES FOR USE WITH MACRORELIEF CLASSES 1 AND 2

.XX1 NONDISSECTED
.XX2 MODERATELY DISSECTED
.XX3 STRONGLY DISSECTED

FIGURE 3-3: The generalized format of the symbolic legend used to annotate Land Unit delineations in the Arusha Region.

(General) Land Cover and Use Features / Land Surface Characteristics (Specific)

FIGURE 3-4: The symbolic legend format as it appears on the Land Unit delineations for the Arusha Region.



7 LANDSAT imagery for the various indicators of ground water potential are presented on transparent overlays accompanying this report for each of the eight (8) Arusha LANDSAT images, enlarged to a scale of 1:250,000. LANDSAT image bases and overlays have also been incorporated into this report at reduced scale in Section 4.0.

The first step in interpreting the LANDSAT imagery of the Arusha Region was to delineate drainage basin morphology including both drainage divides and drainage channels (texture and density). Used in this process was LANDSAT imagery and the existing topographic maps for the area, both at 1:250,000 scale. Vegetation within drainage basins provides useful hydrological information by indicating the presence of both surface water (riparian vegetation) and subsurface water (phreatophytes). Vegetation also provides an index to the relative amounts of rainfall and soil moisture available within various segments of the drainage basin. The interpretation and delineation of drainage basin morphology and vegetation described provides a static view of surface and subsurface water containment, transitory corridors, and potential problem areas such as probably saline waters resulting from interior drainage in an alkalic volcanic terrain.

Landforms influencing the movement and concentration of surface and subsurface water, such as alluvial fans, mbugas, depressions, and alluvial deposits in ephemeral water courses, were also delineated at the 1:250,000 scale. Areas of particular groundwater potential which were identified during the geohydrologic analysis generally fall into one of the following categories:

1. large mbugas associated with major fault zones;
2. permeable slopes transected by faults;
3. other permeable landforms; and
4. those areas of disappearing surface drainage which may be diagnostic of a recharge of a permeable zone and thus of an aquifer.

Because a large portion of the substrate in the Arusha Region of Tanzania is composed of impervious crystalline rocks, a general groundwater table rarely exists. Thus, there are large areas which at best contain only small scattered zones in which groundwater of acceptable quality can be found. Much of the groundwater in such areas is concentrated in joints and fault zones where fracturing and attendant weathering have created porosity and permeability allowing for the movement and storage of water in shallow indigenous and alluvial soils. Examples of these areas are:

Land System Number	Land System Name
1	Mundorossi
2	Oldonyo Ogol
3	Angata Kheri
8	Kibangiani Rift
10	Kisirien-Loldarobo Hills
13	Kekessio-Endulen
16a	Yaida Highlands-Kidero
16b	Yaida Highlands-Shipunga
17	Tlawi-Seremal Valley
19	Marang-Nou
23	Mangati Plains
25	Ngasurai
29	Masai Steppe Transition
30	Lelatema Mountains

31	Ruvu River
32	Simanjiro Plains
33	Lolbene
34	Makami-Naberera-Kitwai
35	Kibaya
36	Sunya

Major structural features and fracture patterns are clearly visible in the synoptic view provided by LANDSAT imagery. These have been delineated on the Arusha Region overlays. The specialized photographic and digitally treated imagery were instrumental in the work because they helped to enhance and emphasize subtle zones reflecting porosity, permeability, and higher soil moisture.

The overlay of drainage basin morphology were made and combined with the overlay of fractures and geomorphic features to provide the data needed to rank areas based in their probable potential to provide good quality groundwater.

Available data on boreholes, springs, waterholes, and reconnaissance field surveys, which were received after the LANDSAT imagery was interpreted, provided some additional information for the ranking procedure. While there was very little difference between our "blind" interpretation of probable water location and location of actual successful boreholes, more correlative work of this nature needs to be done in Tanzania to test and refine our general technique.

Ranking areas on the basis of their potential to provide groundwater has been predicated on the interaction of four primary considerations: 1) the relative amount of water supplied and available for recharge. This can be inferred from LANDSAT imagery by considering elevation, density and location of certain kinds of vegetation, drainage patterns, and by available data on precipitation, runoff, and evapotranspiration; 2) identification of likely areas in which water may collect or concentrate, as judged from the density of fracturing, rock types, soil types, or by landforms such as mbugas, alluvial fans, interior drainage basins, and proximity to areas of rainfall accumulation; 3) water quality as revealed on the imagery as saline or sodic lakes and playa depressions, or in the published data on the salinity and fluorine content of wells and springs, and by considering the mineralogy of rock types present; and 4) consideration of available data on the yields from springs and waterholes, and the yield and depth to water in boreholes. These data were regarded only from a qualitative standpoint because they lacked uniformity of quality, age, and completeness.

The following groundwater potential ranking system is formulated based on the procedures and considerations described above. The order of ranking shown is from Relatively High Ground Water Exploration Potential #(1) to Low Potential For Locating Ground Water #(7).

1. Highly fractured limestone in mbugas where available data indicated low salinity and fluorine content in nearby wells and springs. Mbugas close to mountains with higher precipitation rates and mbugas which have large drainage areas will have higher potential for

providing a reliable source of groundwater than those situated farther from high precipitation sources and perennial streams, and which drain relatively smaller drainage areas. In many instances these factors may be reflected in the areal size of the mbuga (dotted areas).

2. Fracture zones that parallel or apparently control streams and drainage ways.

3. Highly fractured zones and fracture traces that intersect perennial and ephemeral streams (semi-circle dotted areas).

4. Interior basins which drain relatively large areas, particularly those which receive drainage from mountainous areas where relatively high amounts of precipitation occur. Although most of these basins contain highly saline or sodic lake waters, there may be potable water below the clay lake beds. Or, boreholes could be located to intercept groundwater before it reaches the central or saline portions of the basin, for example, at the the base of alluvial fans at the edges of these depressions.

5. Less fractured zones than postulated in numbers and 1 and 2 above which zones may or may not intercept streams.

6. Alluvial deposits along non-perennial streams. Sandy river beds act as conduits which may contain relatively large quantities of water during the dry season, depending

on the supply of water and thickness of the alluvium.

7. Weathered zones surrounding isolated bedrock outcrops (tors).

Using the above criteria for ranking groundwater prospects in each land use system results in the identification of several promising areas for further exploration. The well-watered, forested, volcanic uplands are obvious areas with outstanding potential for further exploration and development. Many of these are already developed and offer further opportunity for development. Examples of these are land systems 12 (Ngorongoro) and 27 (Meru-Losiminguri).

Examples of other particularly promising areas for further exploration for groundwater are land systems 5 (Angata Salei), 11 (Gelai-Kitumbiene-Shompole Volcanics), 14 (Mbulumbulu-Oldeani), 22 (Hanang-Babati), and 28 (Meru-Monduli Toe Slopes). The most attractive of these is the Hanang-Babati area. The diversity of landforms and rock types accounts for this in large part. The area is one which is underlain primarily by granitoid gneisses and quartzites, which form the hills and ridges of the area. Superposed on this are two volcanic centers, Kwaraha in the northern part, and Hanang in the southern part. The area is densely fractured, and the lowlands and depressions are provided extraordinary recharge from drainage across the Manyara Escarpment to the west, and from the slopes of Kwaraha and Hanang. A cautionary note must be added that the runoff from the volcanic centers is likely to be of poorer quality than that from the gneissic highlands across the Manyara Escarpment, and the quality of the surface water in Lakes Balangida, Balangida Lelu, and Babati and in the Manghot and other swamps, is likely to be poor, but in general this area has outstanding potential for further exploration and development of groundwater.

4.0 POTENTIAL GROUND WATER AND LAND RESOURCE ANALYSIS RESULTS

The hydrogeologic and land systems resource interpretation results for the Arusha Region are displayed as reduced-scale overlays and line drawings with color LANDSAT basemaps in Figures 4-1, 4-2, 4-3, 4-4, 4-5, 4-6, 4-7 and 4-8 on the pages following. Land Unit overlays for each of the eight (8) regional LANDSAT basemaps contain more detailed information than can be meaningfully represented in overlay form at a reduced scale, and therefore these overlays have been reproduced in the form of line drawings for the report.

The Arusha Region has effectively been subdivided on the basis of descriptive resource characteristics (vegetation, physiographic landforms, geology, soils, current land use, etc.) into 36 Land Systems; these Land Systems have in turn been further differentiated through LANDSAT data interpretation into approximately 550 Land Unit areas. Each individual Land Unit represents a specific land area which displays a relatively homogeneous set of, or repetitive pattern of, landforms, soils and vegetation, and manifests a relatively uniform land use capability potential at the regional level.

Land Unit, and in some instances, Land System boundaries may be taken to define the areal extent of candidate agricultural and rangeland development areas at the regional planning level, and may additionally be used as a basis for scoping and planning semi-detailed resource development surveys at the District level.

GROUNDWATER EXPLORATION GUIDE MAP LEGEND

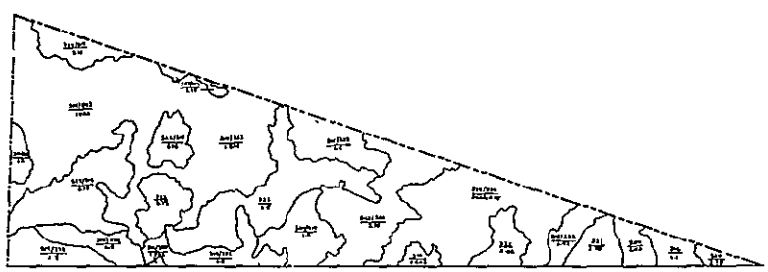
FRACTURES FROM LANDSAT IMAGERY

	FRACTURE
	FOLIATION
	OUTCROP TRACE OF LAYERED ROCKS
	INTERSECTION OF FRACTURES
	INTERSECTION OF FRACTURES AND THE GROUNDWATER FLOW DOWN A SLOPE TIC MARK INDICATES THE DOWNTHROWN SIDE LINE ENCLOSING A DOTTED AREA INDICATES AN AREA OF PARTICULAR INTEREST.
	HIGHLY FRACTURED AREA SHOWN AS AN AREA OF PARTICULAR INTEREST
	AREAS OF PARTICULAR INTEREST FOR GROUNDWATER.
	PRECAMBRIAN SHEAR ZONES
A,B,C,D,E,F,G	PRIMARY OBJECTIVES FOR FURTHER GROUNDWATER EXPLORATION.
?	FRACTURE, QUESTION MARK WHERE UNCERTAIN TIC MARK INDICATES THE DOWNTHROWN SIDE.

OTHER FEATURES

O	TORRS
M	MBUGAS
•	SPRINGS
	CRATER RIM
	OPEN DEPRESSION

FIGURE 4-A



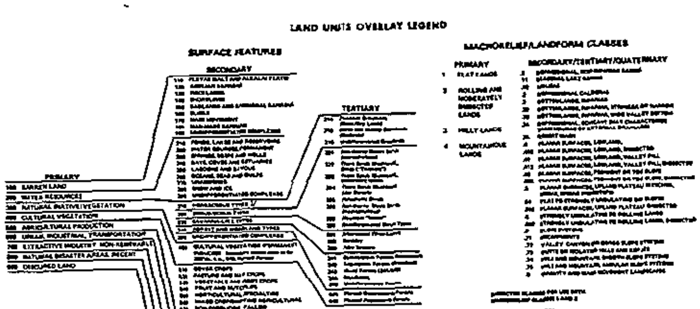
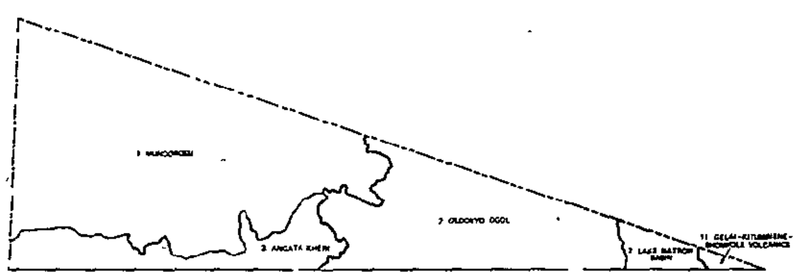

LAND UNITS OVERLAY LEGEND
SURFACE FEATURES
SECONDARY
PRIMARY
TERTIARY
MACRORELIEF/LANDFORM CLASSES
LAND UNITS OVERLAY

FIGURE 4-1B



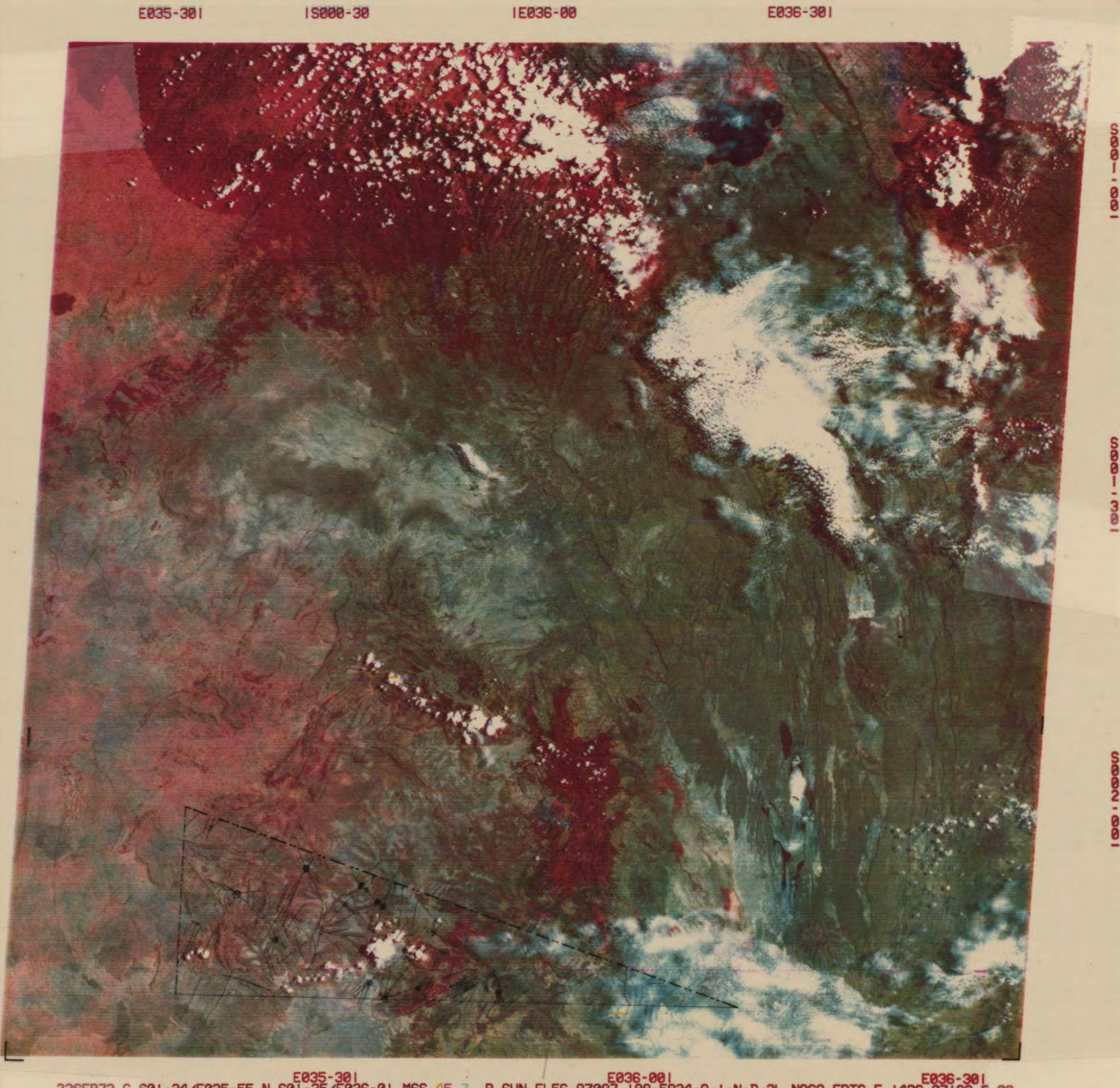
LAND SYSTEMS OVERLAY LEGEND

SEE "TABLE OF LAND SYSTEMS DESIGNATORS" IN TEXT

LAND SYSTEMS OVERLAY

SHEET 1 OF 8

FIGURE 4-1A



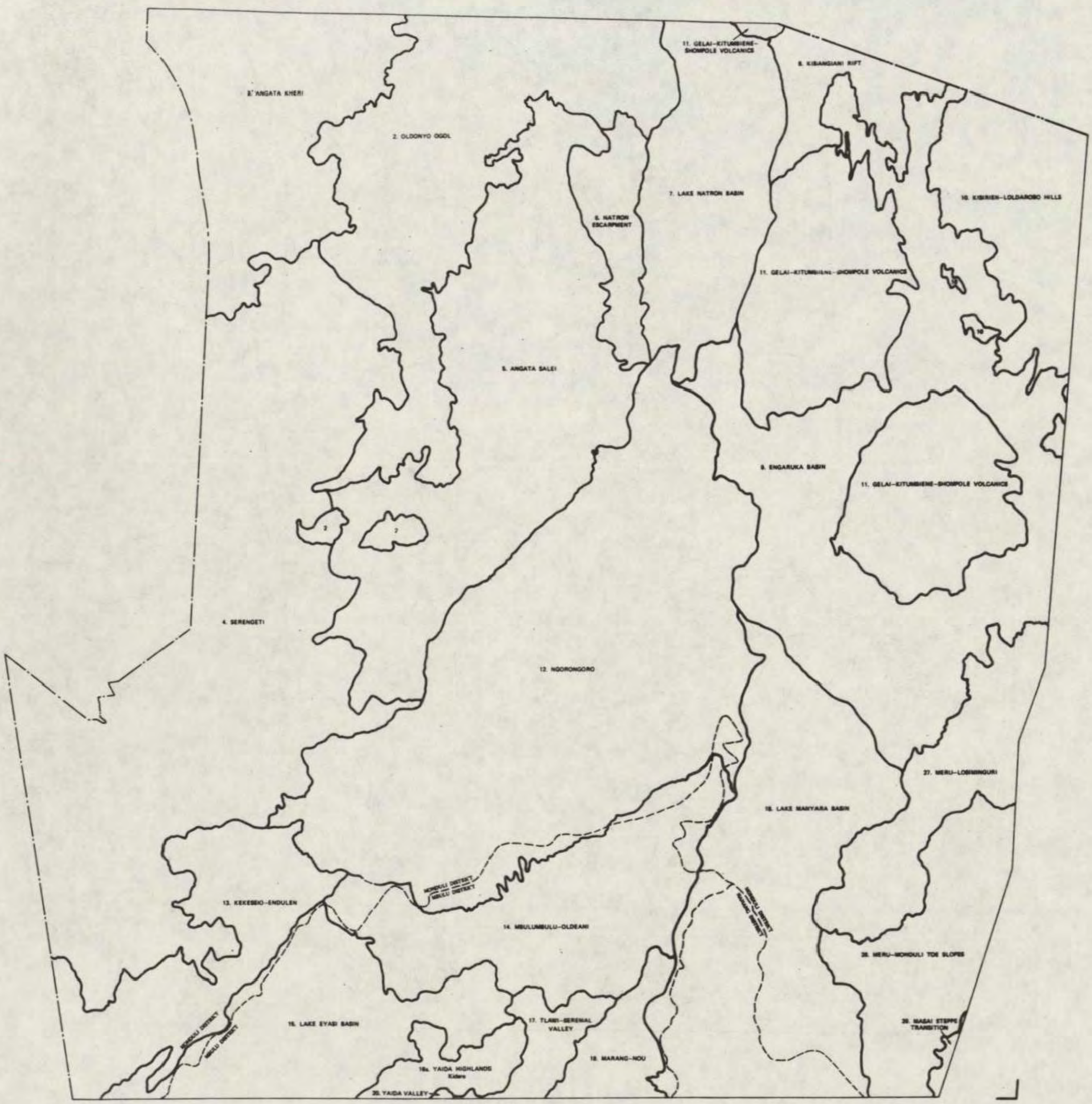
POTENTIAL GROUNDWATER AND LAND RESOURCE ANALYSIS

ARUSHA REGION OF THE UNITED REPUBLIC OF TANZANIA

GROUNDWATER EXPLORATION GUIDE MAP

LAND UNITS OVERLAY LEGEND
SURFACE FEATURES
SECONDARY
TERTIARY
PRIMARY
100 BARREN LAND
200 WATER RESOURCES
300 NATURAL (NATIVE) VEGETATION
400 CULTURAL VEGETATION
500 AGRICULTURAL PRODUCTION
600 URBAN, INDUSTRIAL, TRANSPORTATION
700 EXTRACTIVE INDUSTRY, NON-RENEWABLE
800 NATURAL DISASTER AREAS, RECENT
900 OBSCURED LAND
MACRORELIEF/LANDFORM CLASSES
PRIMARY
SECONDARY/TERTIARY/QUATERNARY
1 FLAT LANDS
2 ROLLING AND MODERATELY DISSECTED LANDS
3 HILLY LANDS
4 MOUNTAINOUS LANDS
LAND UNITS OVERLAY

FIGURE 4-2B



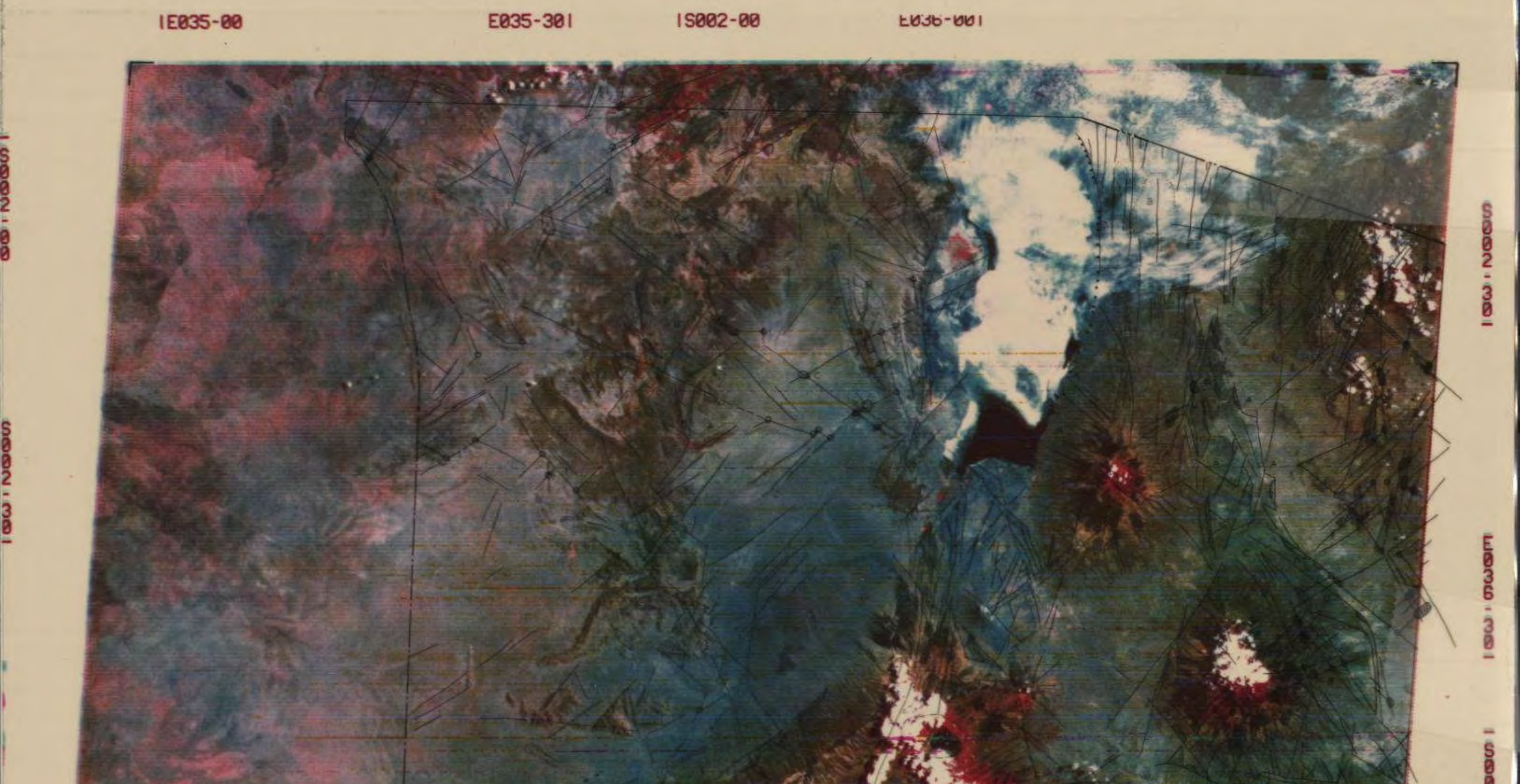
LAND SYSTEMS OVERLAY LEGEND

SEE "TABLE OF LAND SYSTEMS DESIGNATORS" IN TEXT.

LAND SYSTEMS OVERLAY

SHEET 2 OF 8

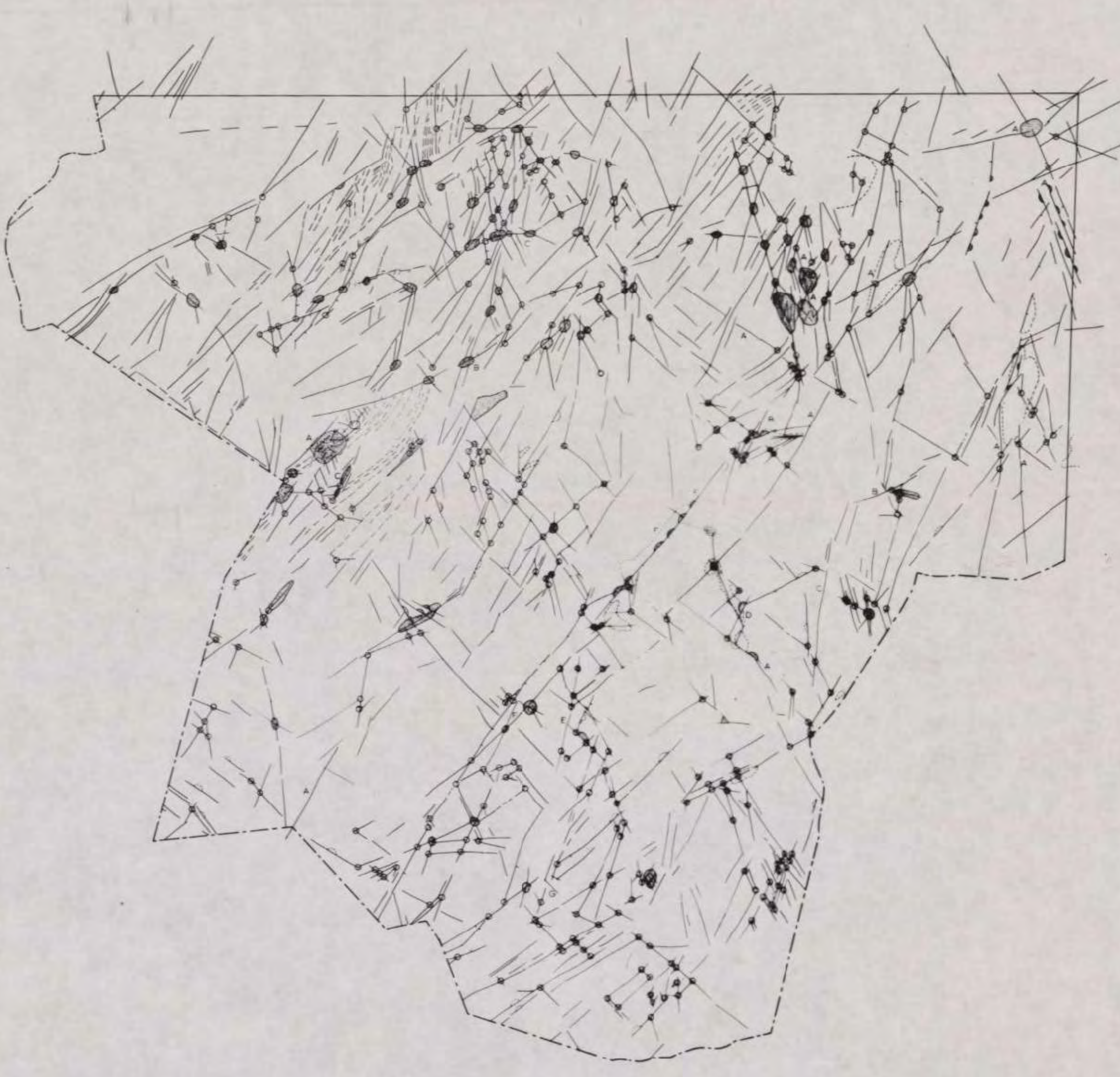
FIGURE 4-2A



POTENTIAL GROUNDWATER AND LAND RESOURCE ANALYSIS

ARUSHA REGION OF THE UNITED REPUBLIC OF TANZANIA

GROUNDWATER EXPLORATION GUIDE MAP



POTENTIAL GROUNDWATER AND LAND RESOURCE ANALYSIS

ARUSHA REGION OF THE UNITED REPUBLIC OF TANZANIA

GROUNDWATER EXPLORATION GUIDE MAP

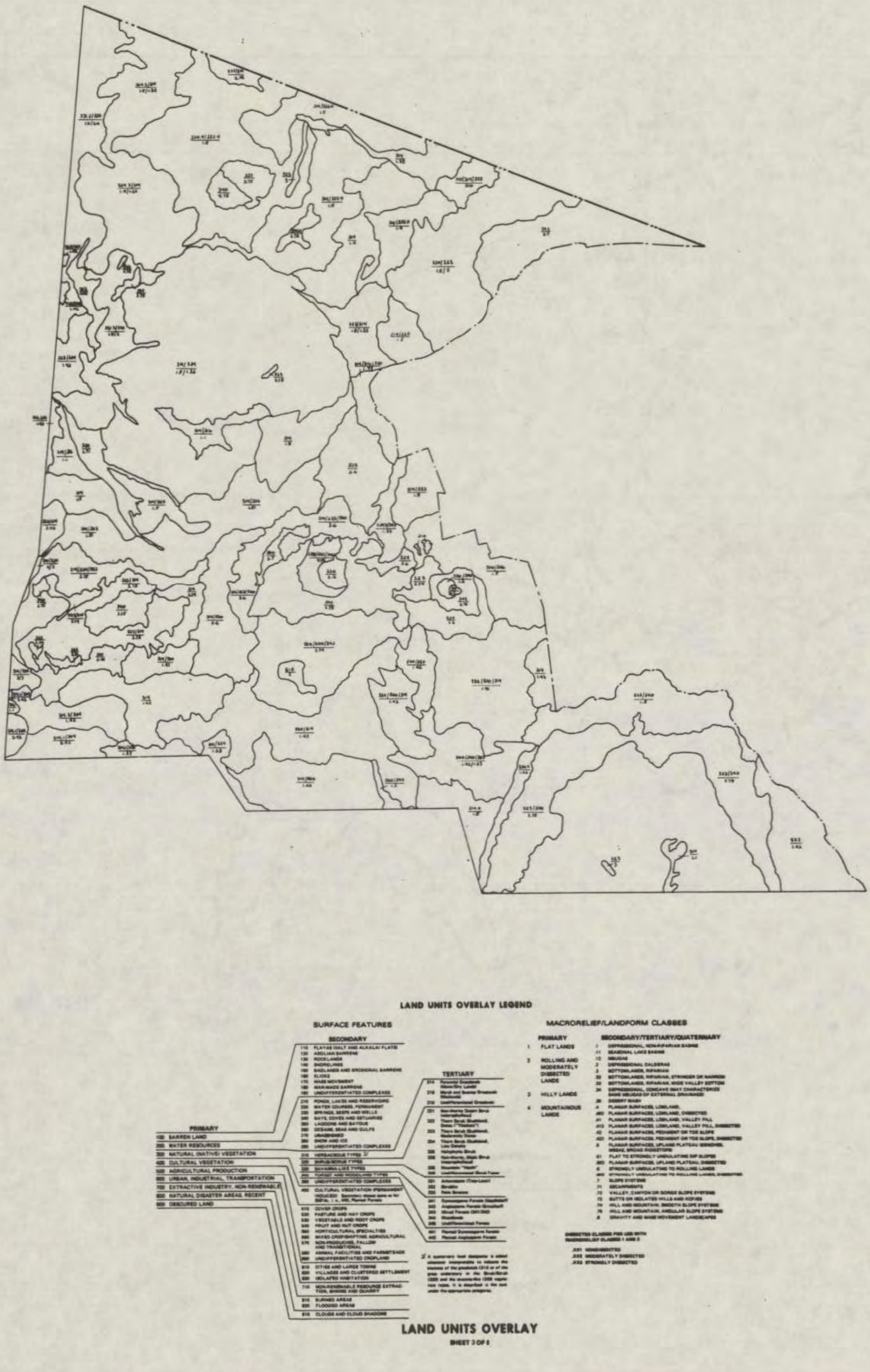
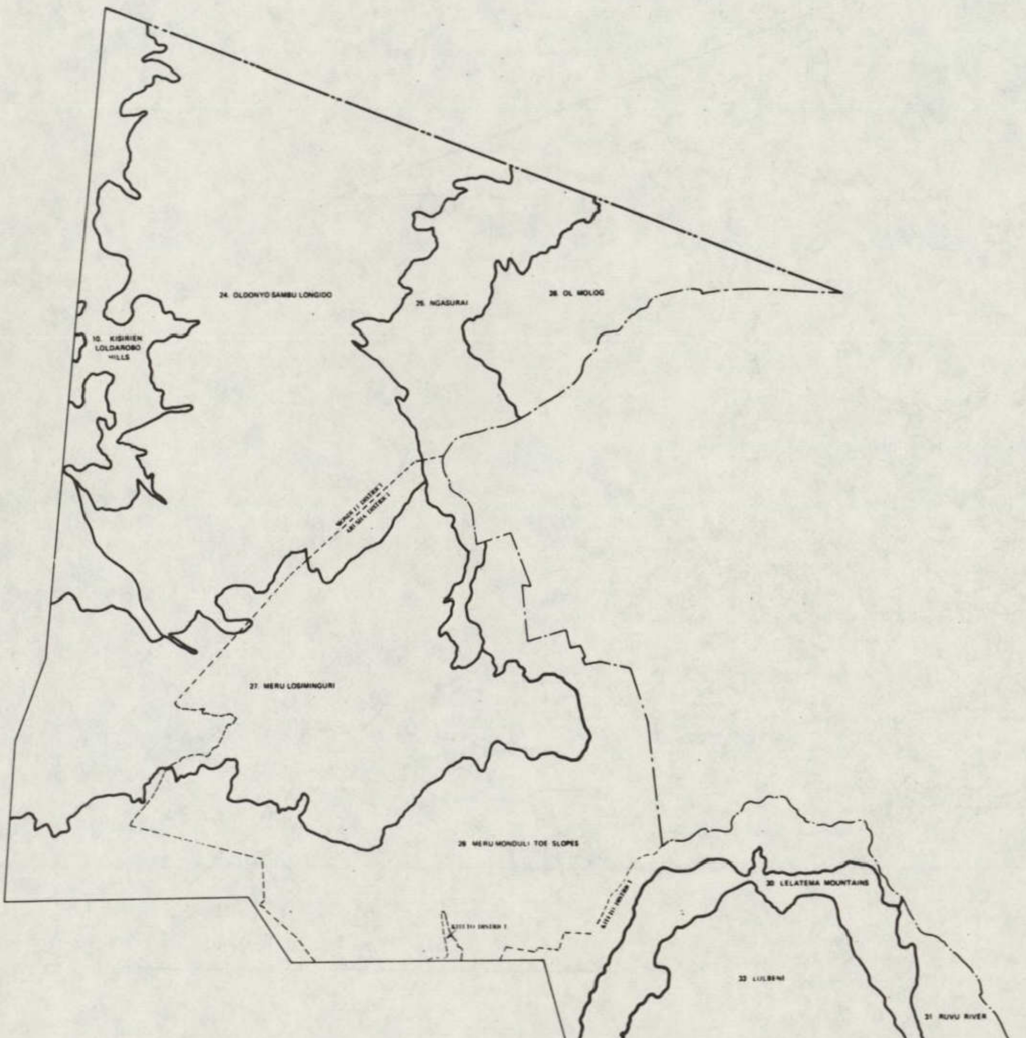

LAND UNITS OVERLAY LEGEND
SURFACE FEATURES
SECONDARY
TERTIARY
PRIMARY
100 BARREN LAND
200 WATER RESOURCES
300 NATURAL (NATIVE) VEGETATION
400 CULTURAL VEGETATION
500 AGRICULTURAL PRODUCTION
600 URBAN, INDUSTRIAL, TRANSPORTATION
700 EXTRACTIVE INDUSTRY, NON-RENEWABLE
800 NATURAL DISASTER AREAS, RECENT
900 OBSCURED LAND
MACRORELIEF/LANDFORM CLASSES
PRIMARY
SECONDARY/TERTIARY/QUATERNARY
1 FLAT LANDS
2 ROLLING AND MODERATELY DISSECTED LANDS
3 HILLY LANDS
4 MOUNTAINOUS LANDS
LAND UNITS OVERLAY
SHEET 3 OF 5

FIGURE 4-3B

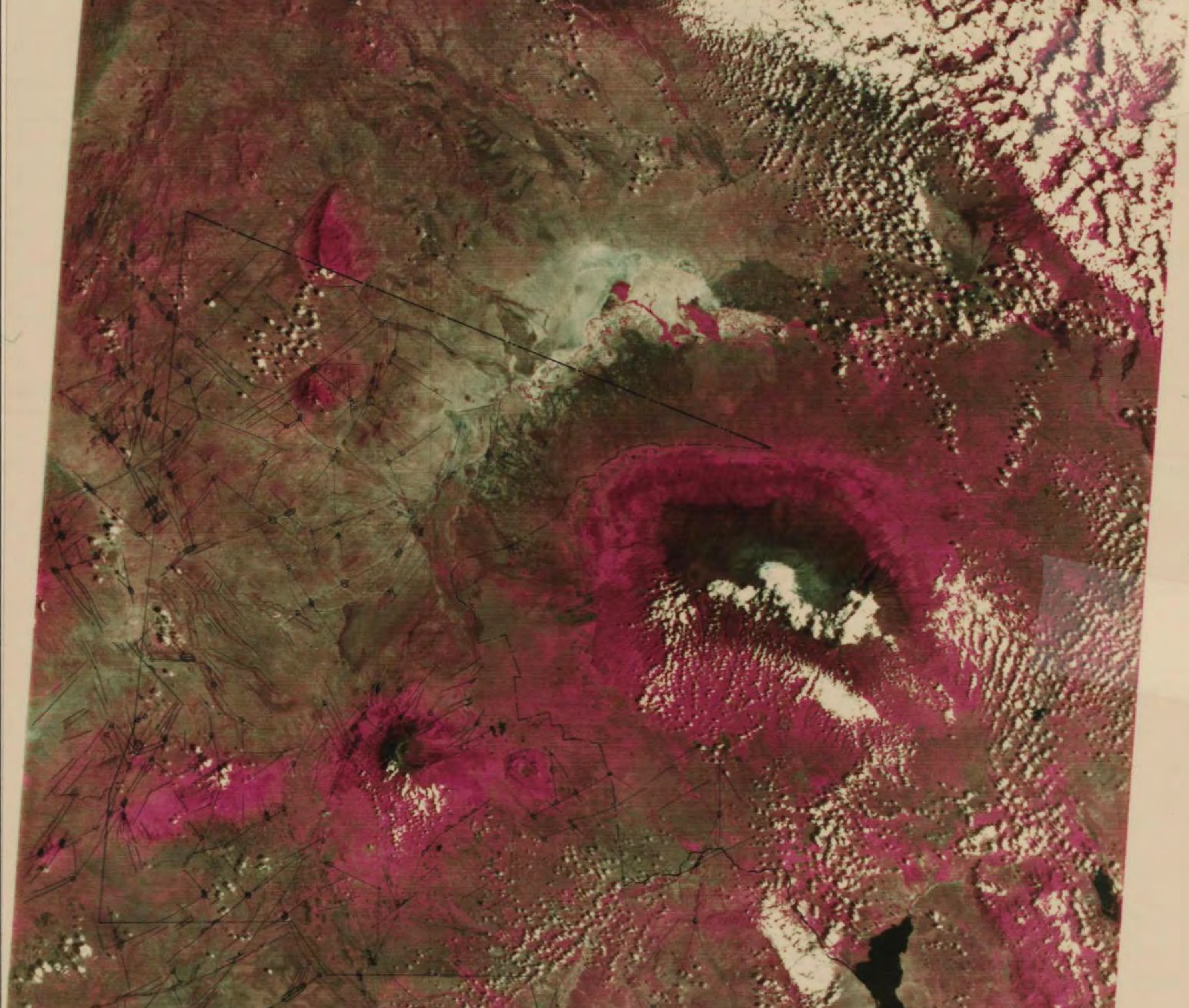


LAND SYSTEMS OVERLAY LEGEND

SEE "TABLE OF LAND SYSTEMS DESIGNATORS" IN TEXT.

LAND SYSTEMS OVERLAY

FIGURE 4-3A



POTENTIAL GROUNDWATER AND LAND RESOURCE ANALYSIS

ARUSHA REGION OF THE UNITED REPUBLIC OF TANZANIA

GROUNDWATER EXPLORATION
GUIDE MAP

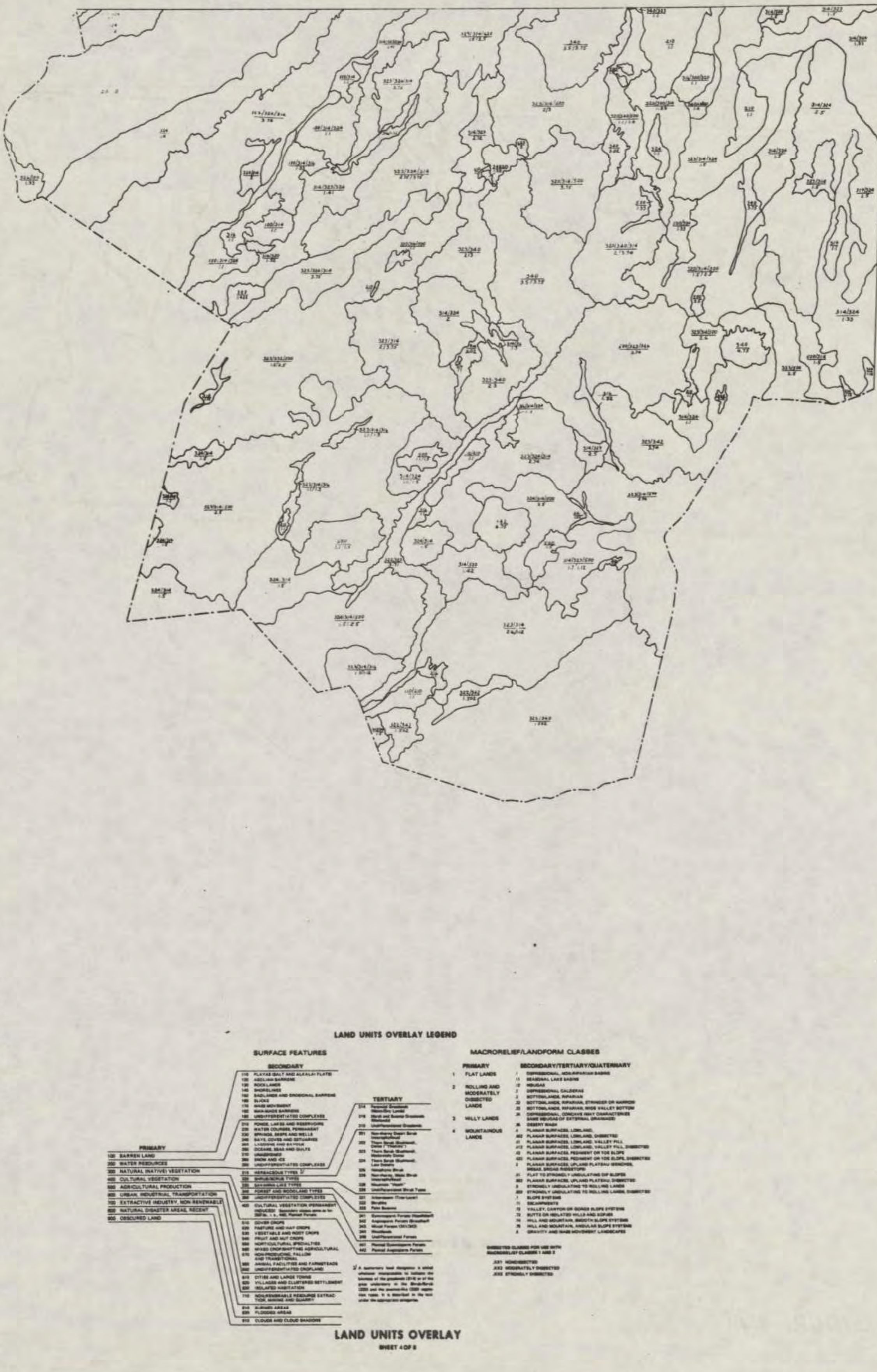
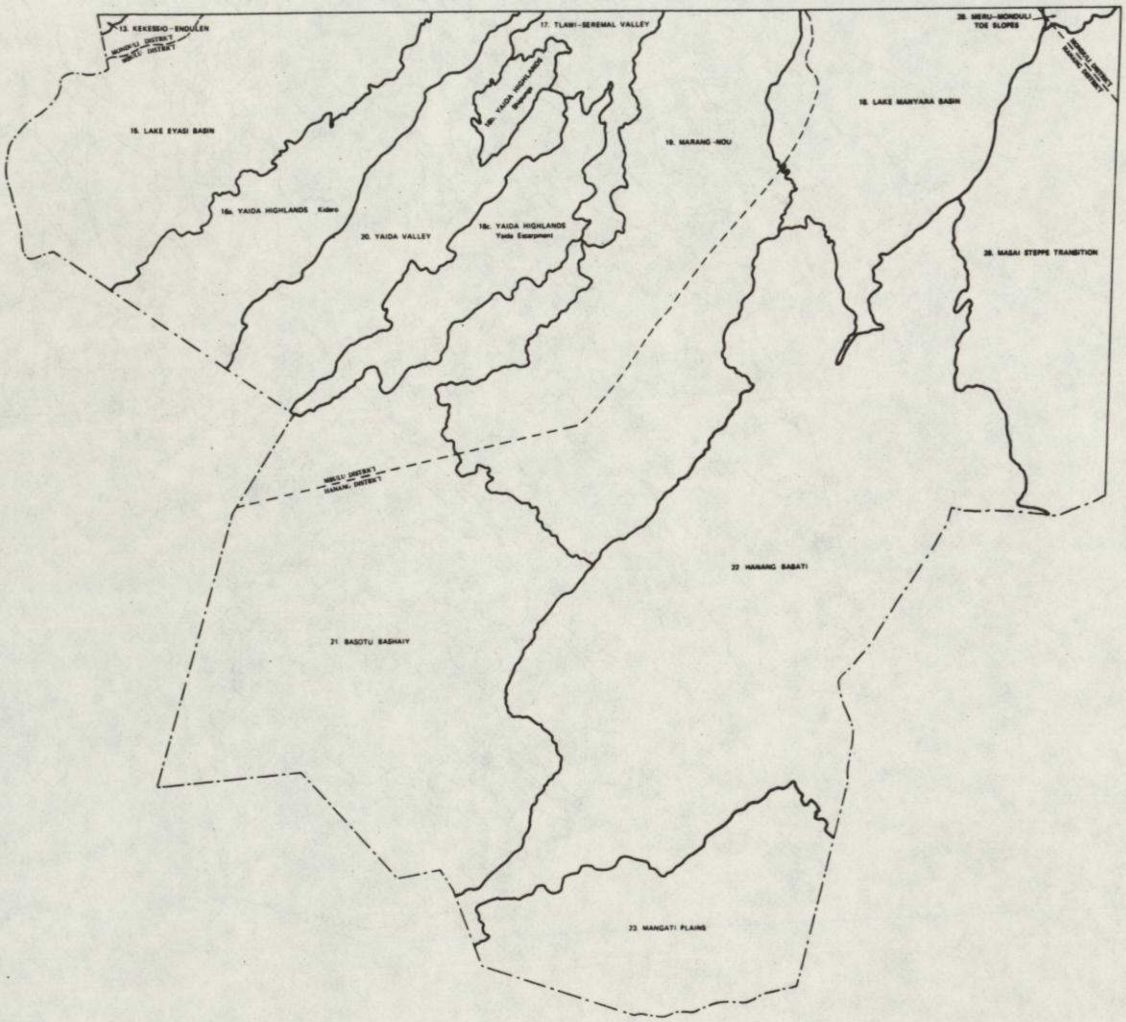

LAND UNITS OVERLAY LEGEND
SURFACE FEATURES
PRIMARY
100 BARREN LAND
200 WATER RESOURCES
300 NATURAL (NATIVE) VEGETATION
400 CULTURAL VEGETATION
500 AGRICULTURAL PRODUCTION
600 URBAN, INDUSTRIAL, TRANSPORTATION
700 EXTRACTIVE INDUSTRY, NON RENEWABLE
800 NATURAL DISASTER AREAS, RECENT
900 OBSCURED LAND
SECONDARY
TERTIARY
MACRORELIEF/LANDFORM CLASSES
PRIMARY
1 FLAT LANDS
2 ROLLING AND MODERATELY DISSECTED LANDS
3 HILLY LANDS
4 MOUNTAINOUS LANDS
SECONDARY/TERTIARY/QUATERNARY
LAND UNITS OVERLAY

FIGURE 4-4B



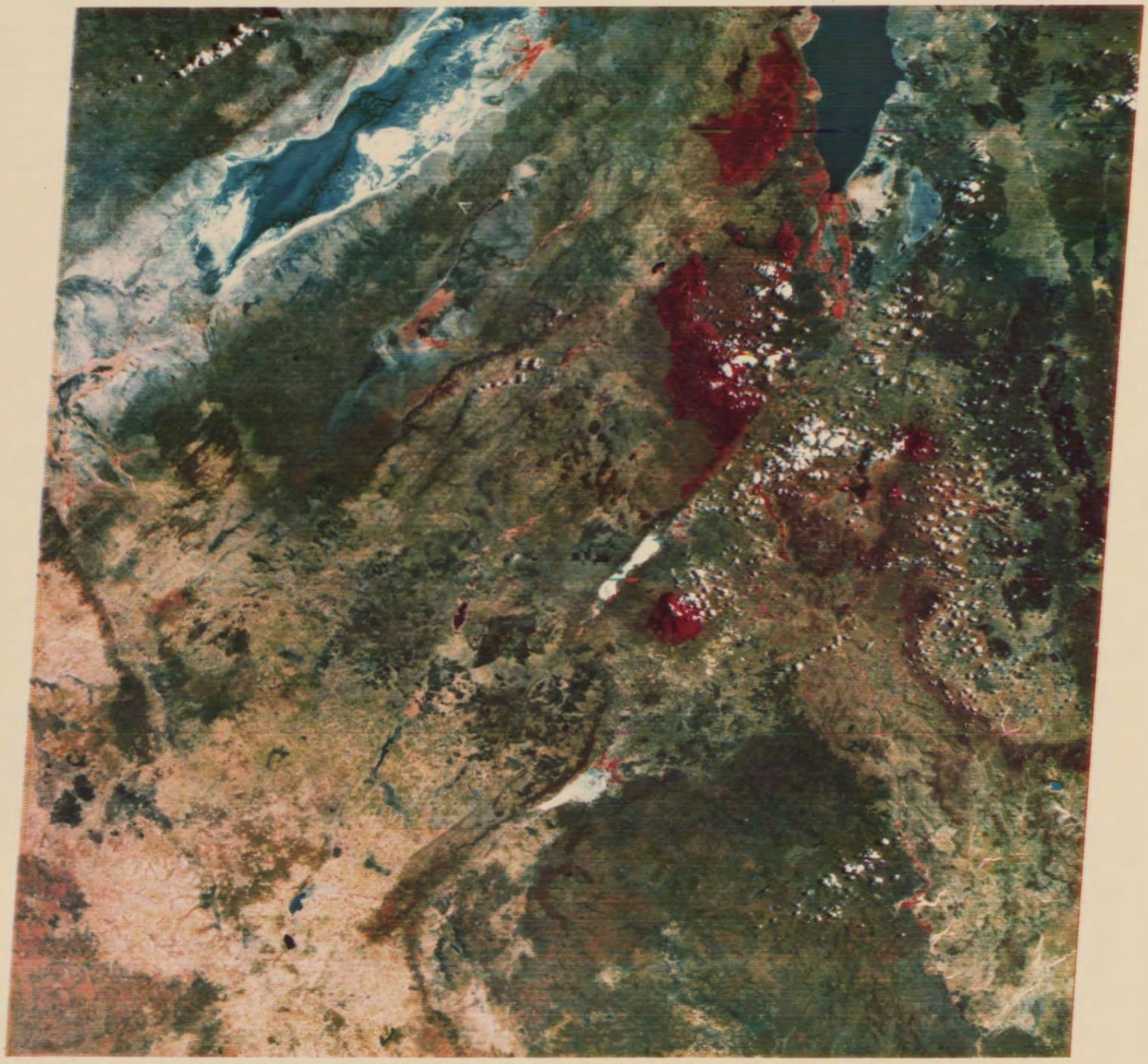
LAND SYSTEMS OVERLAY LEGEND

SEE "TABLE OF LAND SYSTEMS DESIGNATORS" IN TEXT.

LAND SYSTEMS OVERLAY

SHEET 4 OF 8

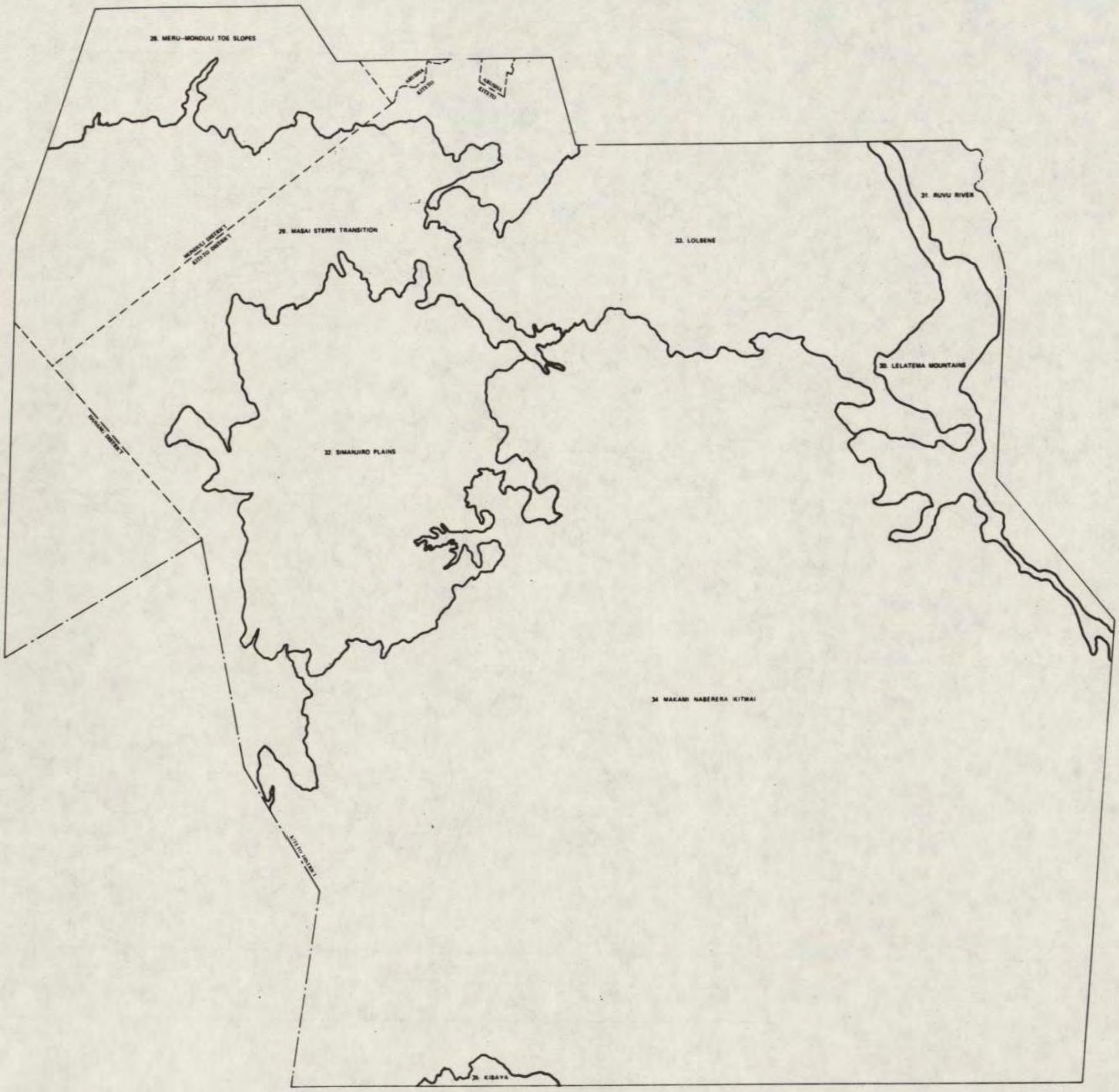
FIGURE 4-4A



22SEP73 C S04-17/E035-15 N S04-19/E035-21 MSS 4 5 7 R SUN EL56 AZ082 188-5934-A-1-N-D-2L NASA ERTS E-1426-07171-5 02


LAND UNITS OVERLAY LEGEND
SURFACE FEATURES
SECONDARY
TERTIARY
PRIMARY
100 BARREN LAND
200 WATER RESOURCES
300 NATURAL (NATIVE) VEGETATION
400 CULTURAL VEGETATION
500 AGRICULTURAL PRODUCTION
600 URBAN, INDUSTRIAL, TRANSPORTATION
700 EXTRACTIVE INDUSTRY, NON-RENEWABLE
800 NATURAL DISASTER AREAS, RECENT
900 OBSCURED LAND
210 PONDS, LAKES AND RESERVOIRS
220 WATER COURSES, PERMANENT
230 SPRINGS, SEEPS AND WELLS
240 BAYS, COVES AND ESTUARIES
250 LAGOONS AND BAYOUS
260 OCEANS, SEAS AND GULFS
280 SNOW AND ICE
290 UNDIFFERENTIATED COMPLEXES
320 SHRUB/SCRUB TYPES
330 SAVANNA-LIKE TYPES
340 FOREST AND WOODLAND TYPES
390 UNDIFFERENTIATED COMPLEXES
510 COVER CROPS
520 PASTURE AND HAY CROPS
530 VEGETABLE AND ROOT CROPS
540 FRUIT AND NUT CROPS
550 HORTICULTURAL SPECIALTIES
570 NON-PRODUCING, FALLOW AND TRANSITIONAL
590 UNDIFFERENTIATED CROPLAND
610 CITIES AND LARGE TOWNS
620 VILLAGES AND CLUSTERED SETTLEMENT
630 ISOLATED HABITATION
710 NON-RENEWABLE RESOURCE EXTRACTION, MINING AND QUARRY
810 BURNED AREAS
820 FLOODED AREAS
910 CLOUDS AND CLOUD SHADOWS
MACRORELIEF/LANDFORM CLASSES
PRIMARY
SECONDARY/TERTIARY/QUATERNARY
1 FLAT LANDS
2 ROLLING AND MODERATELY DISSECTED LANDS
3 HILLY LANDS
4 MOUNTAINOUS LANDS
LAND UNITS OVERLAY
SHEET 1 OF 8

FIGURE 4-5B



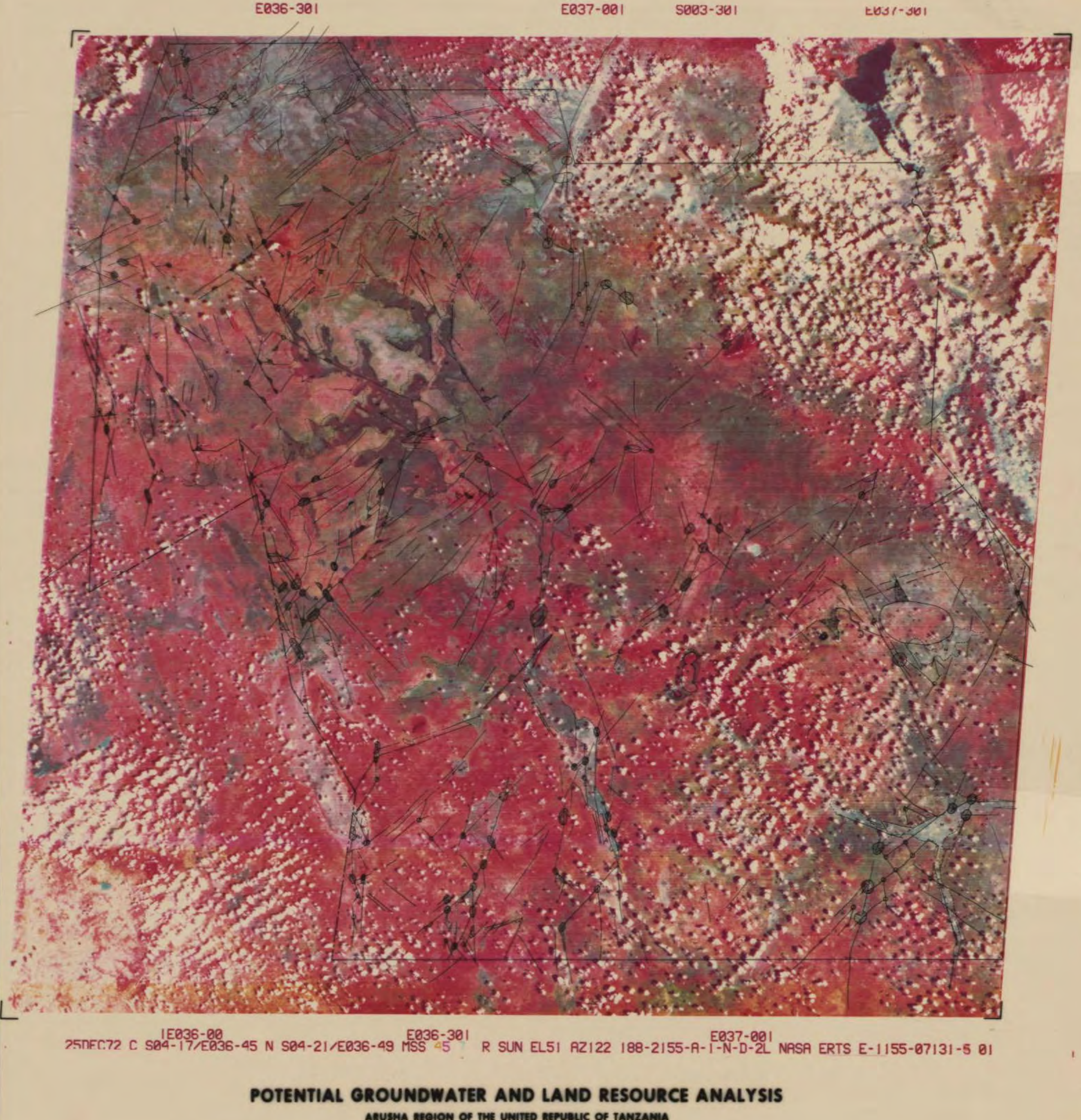
LAND SYSTEMS OVERLAY LEGEND

SEE "TABLE OF LAND SYSTEMS DESIGNATORS" IN TEXT.

LAND SYSTEMS OVERLAY

SHEET 5 OF 8

FIGURE 4-5A



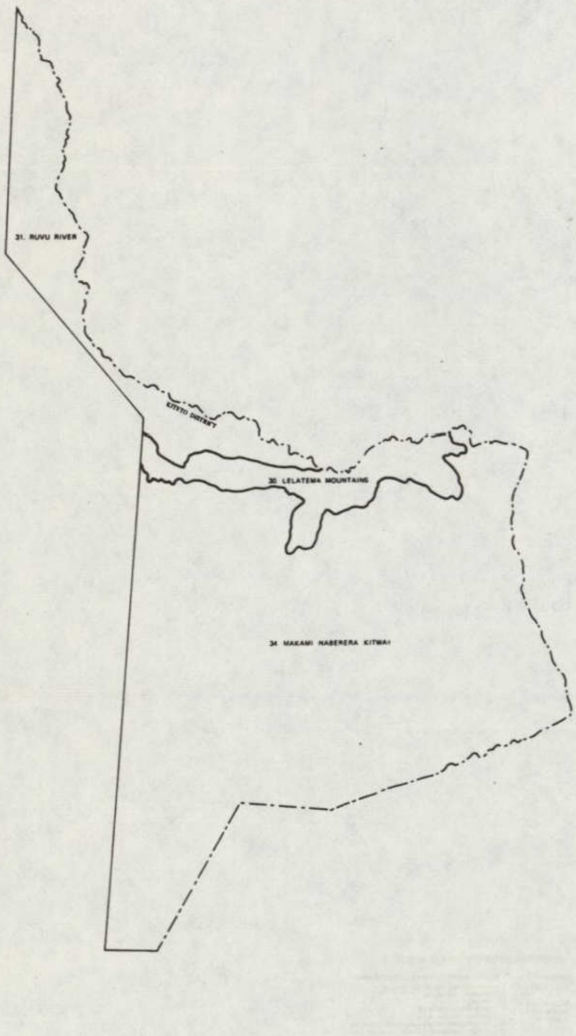
POTENTIAL GROUNDWATER AND LAND RESOURCE ANALYSIS

ARUSHA REGION OF THE UNITED REPUBLIC OF TANZANIA

GROUNDWATER EXPLORATION GUIDE MAP


LAND UNITS OVERLAY LEGEND
SURFACE FEATURES
SECONDARY
PRIMARY
TERTIARY
MACRORELIEF/LANDFORM CLASSES
PRIMARY
SECONDARY/TERTIARY/QUATERNARY
LAND UNITS OVERLAY

FIGURE 4-6B

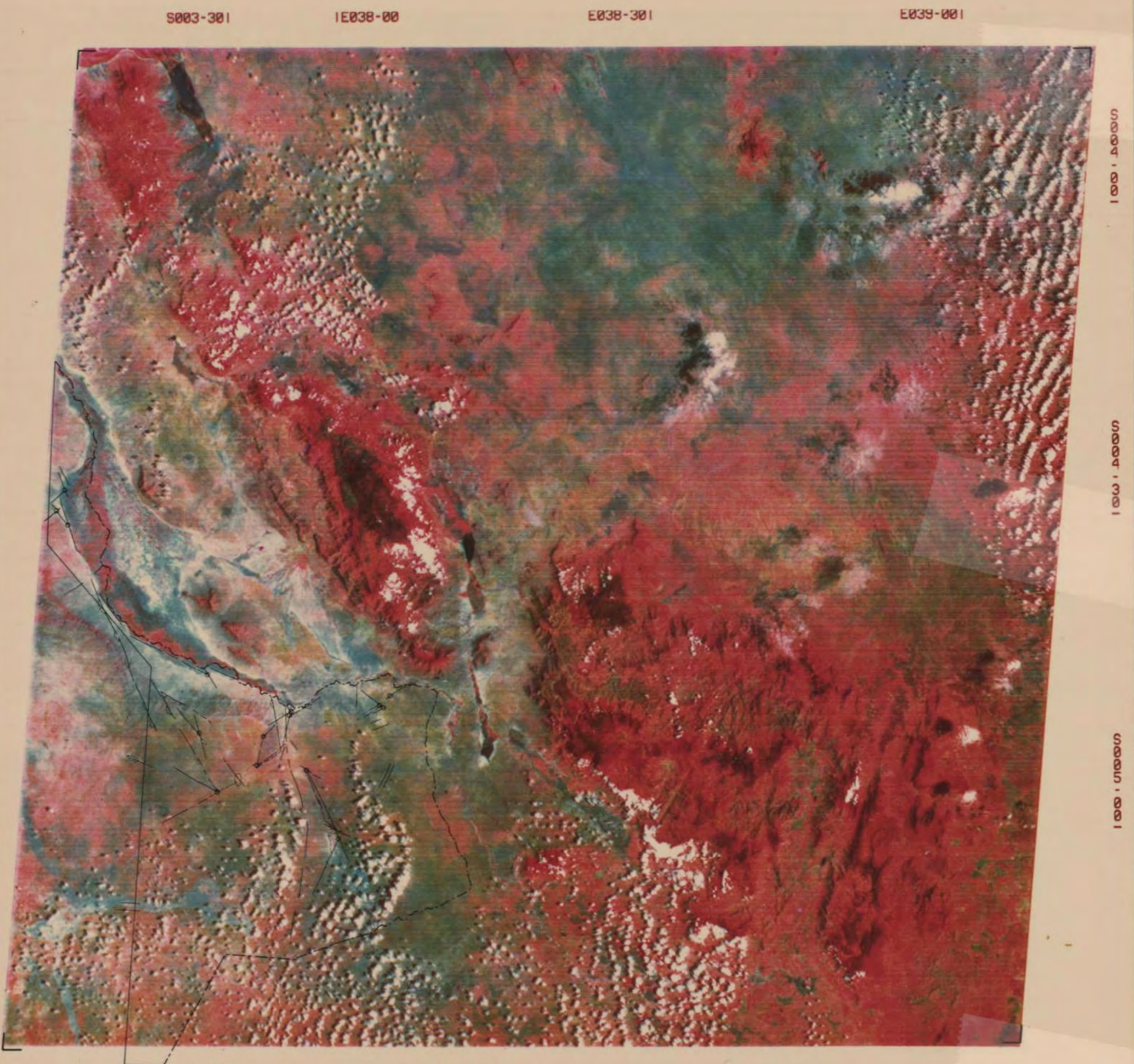


LAND SYSTEMS OVERLAY LEGEND

SEE "TABLE OF LAND SYSTEMS DESIGNATORS" IN TEXT.

LAND SYSTEMS OVERLAY

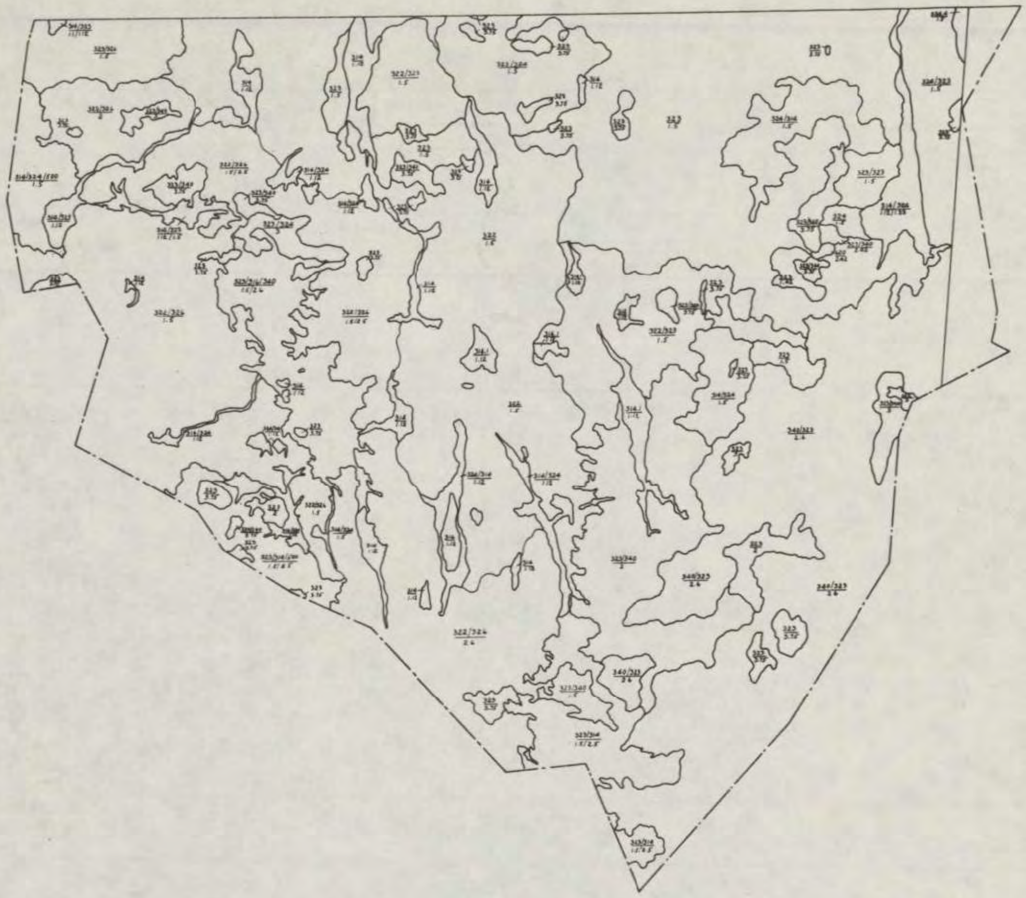
FIGURE 4-6A



POTENTIAL GROUNDWATER AND LAND RESOURCE ANALYSIS

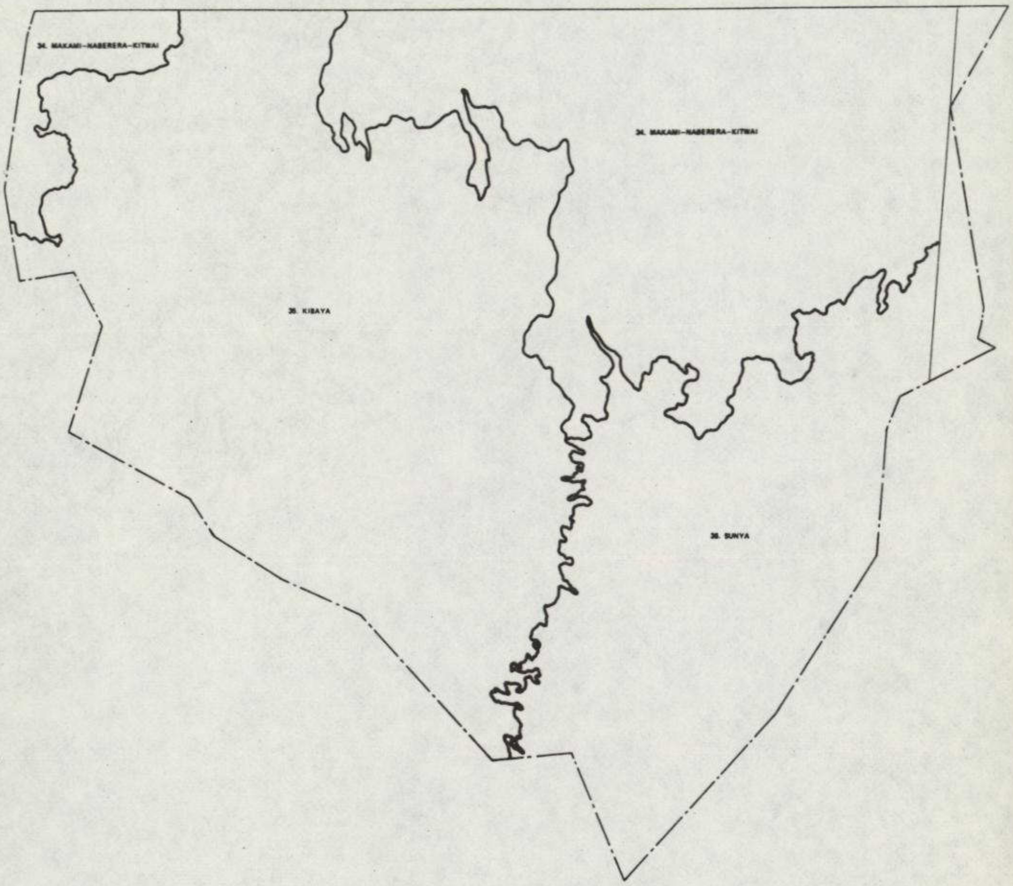
ARUSHA REGION OF THE UNITED REPUBLIC OF TANZANIA

GROUNDWATER EXPLORATION GUIDE MAP




LAND UNITS OVERLAY LEGEND
SURFACE FEATURES
PRIMARY
100 BARREN LAND
200 WATER RESOURCES
300 NATURAL (NATIVE) VEGETATION
400 CULTURAL VEGETATION
500 AGRICULTURAL PRODUCTION
600 URBAN, INDUSTRIAL, TRANSPORTATION
700 EXTRACTIVE INDUSTRY, NON-RENEWABLE
800 NATURAL DISASTER AREAS, RECENT
900 OBSCURED LAND
SECONDARY
TERTIARY
MACRORELIEF/LANDFORM CLASSES
PRIMARY
1 FLAT LANDS
2 ROLLING AND MODERATELY DISSECTED LANDS
3 HILLY LANDS
4 MOUNTAINOUS LANDS
SECONDARY/TERTIARY/QUATERNARY
LAND UNITS OVERLAY
SHEET 7 OF 8

FIGURE 4-7B



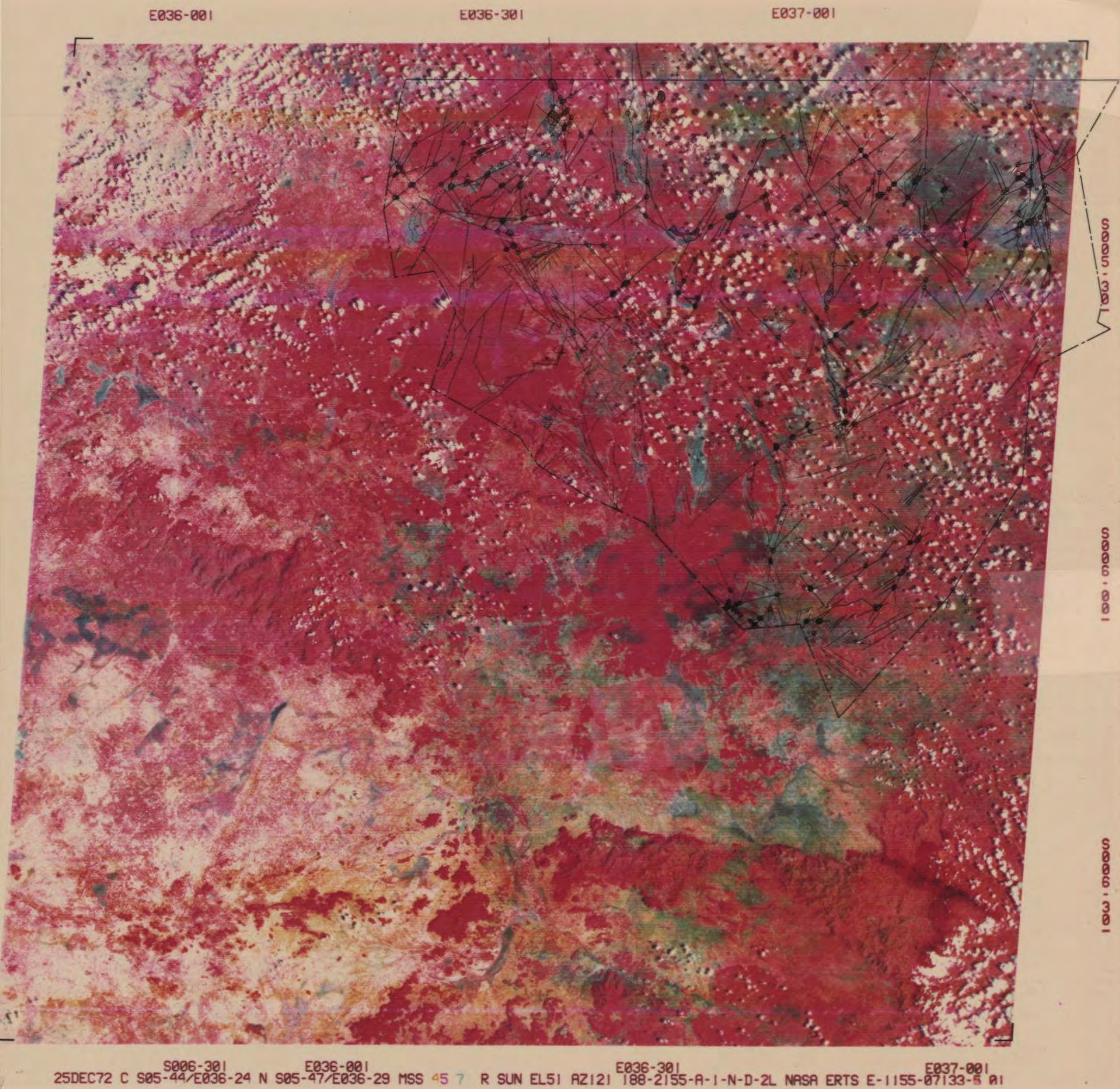
LAND SYSTEMS OVERLAY LEGEND

SEE "TABLE OF LAND SYSTEMS DESIGNATORS" IN TEXT.

LAND SYSTEMS OVERLAY

SHEET 7 OF 8

FIGURE 4-7A



POTENTIAL GROUNDWATER AND LAND RESOURCE ANALYSIS

ARUSHA REGION OF THE UNITED REPUBLIC OF TANZANIA

GROUNDWATER EXPLORATION GUIDE MAP

FIGURE 4-8

IS006-30 E037-30I E038-00I
06JAN74 C S05-45/E037-49 N S05-48/E037-53 MSS 45 R SUN EL50 AZ118 188-7412-A-1-N-D-2L NASA ERTS E-1532-07042-5 01

POTENTIAL GROUNDWATER AND LAND RESOURCE ANALYSIS

ARUSHA REGION OF THE UNITED REPUBLIC OF TANZANIA

LAND UNITS OVERLAY

4.1 Regional Geohydrologic Information Summary

The results of geohydrologic analysis performed from interpretation of computer enhanced LANDSAT imagery during the course of Phase I are represented on Ground Water Exploration Guide Map overlays for each of the Arusha Region basemaps. These guide maps for ground water exploration were compiled from interpretation of geologic, vegetative and geomorphologic information contained in LANDSAT imagery, supplemented with available regional geologic and hydrologic data.

The exploration guide maps do not attempt to predict directly without further investigation the presence of ground water. Rather, these maps identify areas where large scale photointerpretation then will, in all probability, be most effective. The Guide Maps represent a means of targeting or focusing a conventional ground water exploration program. The ground water Guide Map can provide a significant increase in the efficiency (savings in time and money) in the search for good quality ground water. In addition, the use of LANDSAT imagery as a working base for refinement and presentation of the hydrogeologic analysis will enhance the understanding and communication of ideas and planning concepts among people responsible for ground water prospecting in the Arusha Region.

The logical sequence of steps which should be followed in applying the results of the geohydrological analyses performed during Phase I to the task of locating specific water well drilling sites is given below:

1) Relate the initial LANDSAT analysis to all available ground water data and experience not already integrated into the study.

2) Rank the exploration targets in relation to areas of priority interest which have been determined from land resource characteristics, land use capability assessments and agriculture and range development plans and projects.

3) Proceed with large scale stereo aerial photointerpretation (where photo's exist) and then resistivity and related conventional detailed studies in order to locate specific drilling sites.

The LANDSAT-derived ground water exploration guide maps will provide directly useful ground water resource development information for locating productive ground water aquifers capable of supplying water for domestic consumption, livestock use and agricultural crop irrigation. Focusing ground water exploratory efforts in those target areas which are likely to be most favorable with respect to geologic and hydrologic considerations.

Although the majority of the 36 Land Systems of the Arusha Region have some relatively favorable target areas for ground water exploration, some areas show very little indication of ground water potential. These areas of low ground water potential may impose severe limitations for new agricultural or village development.

A tabulation of identified target areas within all regional Land Systems is presented in Table 4-1. The geohydrologic information in Table 4-1 represents a narrative summary of the graphic ground water exploration data contained on the geohydrologic overlays which have been prepared for each of the Arusha Region LANDSAT basemaps.

TABLE 4-1: RESULTS OF GROUNDWATER INVESTIGATIONS BY LAND SYSTEM

LAND SYSTEM	RANK OF PROSPECTS WITHIN SYSTEM	BRIEF OESCRIPTION OF GROUNDWATER PROSPECTS	COMMENTS
1. Mundorossi	A	-Fault or fracture intersections	Superior faults, fractures or fault or fracture intersections have been labeled (A) on the overlay. Springs are known from corollary data to occur at the foot of the quartzite ridges in the system.
2. Oldonyo Olgol	A B	-Alluvial fans -Fault or fracture intersections, especially close to the highlands -Faults or fractures near to the highlands	Recharge probably is satisfactory, It seems likely that at the base of the scarp should deposit sufficient fans or other coarse textured alluvium to contain groundwater, but this expectation should be confirmed by ground study

TABLE 4.1 (continued)

LAND SYSTEM	RANK OF PROSPECTS WITHIN SYSTEM	BRIEF DESCRIPTION OF GROUNDWATER PROSPECTS	COMMENTS
3. Angata Kheri	No rank	-Fault or fracture intersection	
4. Serengeti	No rank	-Faults or fracture intersections and large faults	
5. Angata Salei	A B C	-Alluvial fans (labeled A on the overlay) -Element B - (slightly north of element A has a deflected stream which may have accumulated coarse textured alluvium -Major faults and fault or fracture intersections	
6. Natron Escarpment	A B	-Fault or fracture intersection (labeled A on the overlay) -Other fault or fracture intersections	-Intersections appear to have acted in concert with a fault parallel trapping water on upper-slope side
7. Lake Natron Basin			Salt Basin

TABLE 4.1 (continued)

LAND SYSTEM	RANK OF PROSPECTS WITHIN SYSTEM	BRIEF DESCRIPTION OF GROUNDWATER PROSPECTS	COMMENTS
8. Kibangiani Rift	No rank	This area appears to have little promise	-The Trachytes in this land use system are densely fractured, but recharge is problematical.
9. Engaruka Basin	A	-Alluvial fans - (labeled A on the overlay)	-These fans have pronounced seepage from their bases, and this is reflected by salt accumulations in seepage zone. Recharge may be a problem for a stable supply;therefore this is not considered a primary site
	B	-Northwest extension into the Kibangaini area (fault bounded lowland pocket of sand with local gravel and screes).	-Recharge is from the north-trending faults transecting the adjacent volcanics. It appears to be a basin of salt accumulation, and the water is most likely saline; therefore, this may be a low priority area unless fresh water can be encountered at depth
		-Swamp areas south of and bordering the eastern slopes of both reserves	-The swamp areas may be fault controlled. Fresh water possibly could be obtained in deep wells located in these areas, especially if coarse textural materials are found at depth
		-North of the Olbalbal Ngarirat swamp are large alluvial fans which should be checked for groundwater	
10. Kisirien - Loldarobo Hills		-This area appears to have little promise	-The gneissic uplands are highly fractured, but recharge is problematical and the potential for finding much groundwater in any single fracture is slight

TABLE 4.1 (continued)

LAND SYSTEM	RANK OF PROSPECTS WITHIN SYSTEM	BRIEF DESCRIPTION OF GROUNDWATER PROSPECTS	COMMENTS
11. Gelai-Kitumbiene-Shompole Volcanics	A	The permeable volcanic slope of Essimingor contains water that can be obtained approximately two-thirds of the distance down the slope	Recharge potential is favorable in all the elements noted, as the source of the water is in the higher rainfall upland areas
	B	Eastern slopes of the Kitumbiene and Gelai reserve along the northwest and northeast trending faults transecting the permeable volcanics (labeled B on the overlay)	-In these reserves, surface runoff from the slopes seeps underground and reappears as springs encircling the base of the slope. (This seepage is especially evident on the western flanks of Gelai; and adjacent to Lake Natron, where a spring "bloom" of vegetation bordered the lake). The coast downward from these springs is a saline zone; groundwater from all of the slopes must be obtained farther up from the base of these springs
	C	Alluvial fans south of the Olbalbal Ngarirat Swamp may be potential sites for water concentration (labeled C on the overlay)	
	D	Between the volcanic uplands and the linear swamp on the eastern slopes of the reserve are pockets of outwash sands with local gravel and screes. Moreover, if the swamps are fault controlled, water could be backed up favorably. (Labeled D on the overlay)	It seems to be an excellent area for ground water reconnaissance. Streams flowing from the Katumbiene Uplands disappear upon reaching the pocket between the Uplands and the Ngusero Swamp. Also, streams from the acid gneiss Uplands to the east flow toward this linear swamp and disappear into the gravelly pocket; therefore, this must be a fairly long and deep zone of ground water accumulation. Element D has also been noted on the west side of the Katumbiene Forest Reserve where the area appears to have ample recharge.

TABLE 4.1 (continued)

LAND SYSTEM	RANK OF PROSPECTS WITHIN SYSTEM	BRIEF DESCRIPTION OF GROUNDWATER PROSPECTS	COMMENTS
12. Ngorongoro	No rank	-Highlands -Eastern slope of Elanairobi	The highlands in the area abound with plentiful water; there are many springs seeping out from the side of the crater; water could be piped from these lush rainfall areas to the lowlands. Also, on the eastern slope of Elanairobi are some linearities which could be due to water being ponded by extensive faulting. These linearities should be investigated.
13. Kekessio-Endulen	No rank	Springs from faults or fractures in the Precambrian rocks	
14. Mbulumbulu-Oldeani	No rank	Fault or fracture intersections	This system is in agriculture
15. Lake Eyasi Basin	A	Intersecting fractures in the drainage westward from the Kidero Mountains	
16.a Yaida Highlands-Kidero	No rank	Intersecting fractures in the highlands	
16.b Yaida Highlands-Shipunga	No rank	Intersecting factures in the Kidero Mountains	

TABLE 4.1 (continued)

LAND SYSTEM	RANK OF PROSPECTS WITHIN SYSTEM	BRIEF DESCRIPTION OF GROUNDWATER PROSPECTS	COMMENTS
16.c Yaida Highlands- Yaida Escarpment	A B C	Intersecting fractures in the highlands Intersecting fractures in the highlands Intersecting fractures in the highlands	
17. Tlawi-Seremal Valley	A	Intersecting fracture bounding Lake Tlawi	

TABLE 4.1 (continued)

LAND SYSTEM	RANK OF PROSPECTS WITHIN SYSTEM	BRIEF DESCRIPTION OF GROUNDWATER PROSPECTS	COMMENTS
18. Lake Manyara Basin	A	-Lake bed over limestone, bounded by NW-trending faults and permeable volcanic extrusives. Approximately 7km wide lowland just east of Lake Manyara (labeled A on the overlay). Also, between limestone lowlands and uplands is a zone of outwash sands, gravels, and local screes, approximately 2km in width	-Surface drainage from highlands abruptly terminates upon reaching limestone lowland contact, and drainage faults are natural concentrations of percolating groundwater. Delta fan development is minimal on East Shore Lake because of underground to underwater seepage. On the bordering outwash sands, gravels, and screes drilling may be prudent because this is the first landform to absorb the water from the uplands. Moreover, the water may be of a higher quality than that found in the limestone. (One of the faults seems to transect this zone). Recharge is excellent, as the source of the groundwater is the well-watered Essimingor highlands.
	B	-Northwestern boundary of this land system has a scarp separating the volcanic highlands from the lowlands lying to the east of that escarpment. Four delta fans along the eastern edge of this system are attractive prospecting sites (labeled B on the overlay).	-A number of springs have been mapped along the scarp, and it is in general a favorable place for groundwater to be found. Concentrate on more permeable fans. Care must be taken when drilling in the fans near the lake level to avoid encountering salinity problems.
	C	Northwest-trending faults in the northern part of this system. (Labeled C on the overlay).	-These are significant and may bear water. Unsure of recharge capacity.

TABLE 4.1 (continued)

LAND SYSTEM	RANK OF PROSPECTS WITHIN SYSTEM	BRIEF DESCRIPTION OF GROUNDWATER PROSPECTS	COMMENTS
19. Marang-Nou	A	Intersecting fractures in the highlands of the Marang and Nou Forest Reserves	
	B	Intersecting fractures in the lower area	
	C	Single fractures	
20.	A	Alluvium in the Sirola River Valley	
Yaida Valley	B	Intersection fractures in the valleys of the two rivers draining into the end of the Yaida Valley from the northwest	
	C	Intersecting fractures northwest of the Yaida Swamp	Likely to be saline
21. Basotu-Bashaiy	A	Intersecting fractures in vegetational anomalies labeled A, B, C on the overlay. All are about equally promising.	

TABLE 4.1 (continued)

LAND SYSTEM	RANK OF PROSPECTS WITHIN SYSTEM	BRIEF DESCRIPTION OF GROUNDWATER PROSPECTS	COMMENTS
22. Hanang-Babati	A	-Fractures controlling and intersecting the surface drainage off the northern slope of Kwaraka (labeled A on the overlay)	
	B	-Fracture system along the Manyara Escarpment in the northwestern part of the system (labeled B on the overlay)	
	C	-Fractures along and south of Lake Babati (labeled C on the overlay)	
	D	-Intersecting fractures in the general areas of the Managhat Swamp (labeled D on the overlay)	-The Managhat Swamp and other swamps are localized along fractures. The water accumulated in this and other swamps nearby comes from surface drainage basin, and is likely to be fresher, and the best areas for prospecting are at the intersections of fractures in the region of D.
	E	-Fractures on the western and southern flanks of Hanang (labeled E on the overlay)	-The fractures appear to have ponded ground water up slope of them and are prime candidates for further exploration.
	F	-Fractures along the Manyara Escarpment northwest of Lake Balandiga and about four miles northeast of Lake Balandiga (both labeled F on the overlay)	
	G	-Fractures northeast of Lake Balangida Lelu (labeled G on the overlay)	

TABLE 4.1 (continued)

LAND SYSTEM	RANK OF PROSPECTS WITHIN SYSTEM	BRIEF DESCRIPTION OF GROUNDWATER PROSPECTS	COMMENTS
23. Mangati Plains	A	-Fracture intersections along drainages into swamps	
	B	-Fractures along drainages	
24. Oldonyo-Sambu-Longido	A	-Faults or fractures transecting the highland slopes (labeled A on the overlay)	
	B	-Alluvial fans and talus debris on the base of Longido (labeled B on the overlay)	-The permeability, and therefore the water containment potential of these fans, is speculative.
25. Ngasurai	No rank	Alkalinity a problem. Alkaline water collects at the lowland toe slopes of Kilamanjaro. Poor area for groundwater acquisition.	
26. Ol Molog	A	This area appears to have little promise, except in the fault intersections (labeled A on the overlay)	-Parts of this system are undesirable because they receive the more saline runoff from Mount Kilimanjaro. Drilling must be pursued as far up the highland slopes as possible to avoid encountering accumulations of saline surface runoff.
27. Meru-Losiminguri	A	-Faults or fractures transecting the highland slopes.	-Recharge should not be a problem.

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TABLE 4.1 (continued)

LAND SYSTEM	RANK OF PROSPECTS WITHIN SYSTEM	BRIEF DESCRIPTION OF GROUNDWATER PROSPECTS	COMMENTS
33. *Lolbene*	No rank	Fracture and fault intersections. Recharge may be a *problem; not a high probability* area	
34. Makami-Naberera-Kitwai	A	-Fractures mear mbugas	Little recharge and therefore generally a poor prospect for groundwater. In this land system the primary targets are fault controlled elongated mbugas. Attention should also be given to mbugas aligned along major fault intersections.
35. Kibaya	A	-Faults near elongate mbugas	Contains many large mbugas associated with linear faults. Although many mbugas have accumulations of surface water, salinity *within the mbugas may* be a problem. It may be beneficial to drill in the faults connecting the mbugas to intersect the fresher ground water before it reaches the surface.
36. Sunya	No rank	Fracture and fault intersections in metamorphics	

In accordance with the sequence of steps previously described, ground water resistivity surveys should be focused on the best potential target areas in the same or near vicinity of identified development sites. General target areas which have been identified for resistivity surveys from the 1:250,000 scale ground water exploration guide map overlays may be followed through to the choice of highly specific local sites for conduct of field work by making use of the existing 1:50,000 scale topographic map series and 1:40,000 scale black-and-white photography. Specific locations within any Land System may be identified on corresponding topographic map sheets by use of the Regional Topographic Map Index overlay which was prepared by EarthSat and delivered in working copy form with other Phase I products. Each of the topographic maps, in turn, directly indexes by number the specific 1:40,000 scale black-and-white aerial photographs which pertain to each portion of the land area representated on the map.

4.2 Regional Land Use Capability Evaluation

The primary capability analysis task for development planning in Phase I and Phase II of the Arusha Region Study is to identify and differentiate land areas manifesting cropland agricultural development potential from those areas where a management program and policy of rangeland use represents the most appropriate use capability alternative; and further to distinguish rangeland areas offering range improvement use potential from those which might be best managed as unimproved natural forage areas.

Reconnaissance level assessments of land use capability alternatives made on a regionwide scale are necessarily generalized and are intended to be further refined and made more site specific as semi-detailed surveys within the most promising of Phase I Vegetation/Soil Systems proceeds throughout the course of Phase II and in further work to be done by professionals in Tanzania.

4.2.1 Capability Evaluation Criteria and Assessment Procedure

The most important elements of descriptive resource information which are required under ideal circumstances to support land use capability assessments are discussed in Section 5.0, and therefore will be only briefly mentioned here. Such ideal capability assessment parameters include numerous specific data elements related to climate, and hydrology, geology, physiography, soils, vegetation and ecological and mineralogy factors. The large quantities of highly detailed resource information in all these various categories needed to make site specific local land use capability assessments are at present not widely available within the Arusha Region and will not be until Phase II and other follow-on semi-detailed and detailed surveys have been undertaken and completed.

Climatic limitations are thought to be a key determinate of land use capability in the Arusha Region and may be used to distinguish between various classes of agricultural application and range application such as: low risk candidate agricultural development areas, moderate-to-high risk areas marginal for agricultural development and areas unsuited for agriculture or between good, fair, and poor rangeland use areas. However, the available climatic information is much too limited, sketchy and generalized to be used directly for location and definition of specific boundaries between areas of differing land use capability throughout the Region.

The key climatic criteria for assessment of agriculture and rangeland capability potential was chosen to be a climatic threshold of 600 mm annual precipitation. 600 mm was chosen for use as the cutoff value below which cropland agricultural development should be disregarded as a land use alternative without investment in irrigation, and where the permanent rangeland alternative should be recommended. The basis for this threshold choice is presented in Appendix D.

LANDSAT image interpretation for land resource information during Phase I resulted in separate location and delineation of approximately 550 Vegetation/Soil Systems and complexes (Land Units) within the 36 Arusha Region Land Systems. Vegetation/Soil Systems and Complexes form natural land capability planning units because they represent areas which manifest recurring patterns of vegetation, soils, physiographic landforms, and geology subject to a relatively uniform climate.

Regional land use capability assessments at the Land Systems level were performed by broadly relating the Vegetation/Soil System and Land Unit delineations to available, but very generalized, climatic information.

The actual location of climaticly-related agricultural land use capability boundaries was therefore approximately determined by direct use of Vegetation/Soil Land Unit and Land System delineation boundaries.

Vegetation/Soil Systems were related to climatic data by overlaying the best available isohyetal map and a map of predicted drought onto the 1:1,000,000 LANDSAT color mosaic and studying the broad indications of weather pattern in relation to the 36 Land Systems and some 550 Land Units defined on the basis of LANDSAT vegetation-landform interpretations. We next evaluated each Land System area on the basis of what the vegetation-landforms mapping and presently sketchy soils information suggested about land capability.

Regional land use capability judgments, although based primarily on the general relationship between vegetation complexes delineated from LANDSAT image analysis and corresponding climatic regimes associated with each vegetation complex, were also supported by the results of LANDSAT geohydrologic, physiographic and current land use analysis, and whenever possible by other existing information (maps, reports, etc.) on geology, hydrology, physiography, ecology and soils..

The general procedure used for regional land use capability evaluation is diagrammatically represented in Figure 4-9. The results of regional land use capability evaluation are presented and briefly summarized in Section 4.2.2 following.

4.2.2 Capability Evaluation Results

The results of regionwide agriculture and range land use capability evaluation are presented in graphic form in

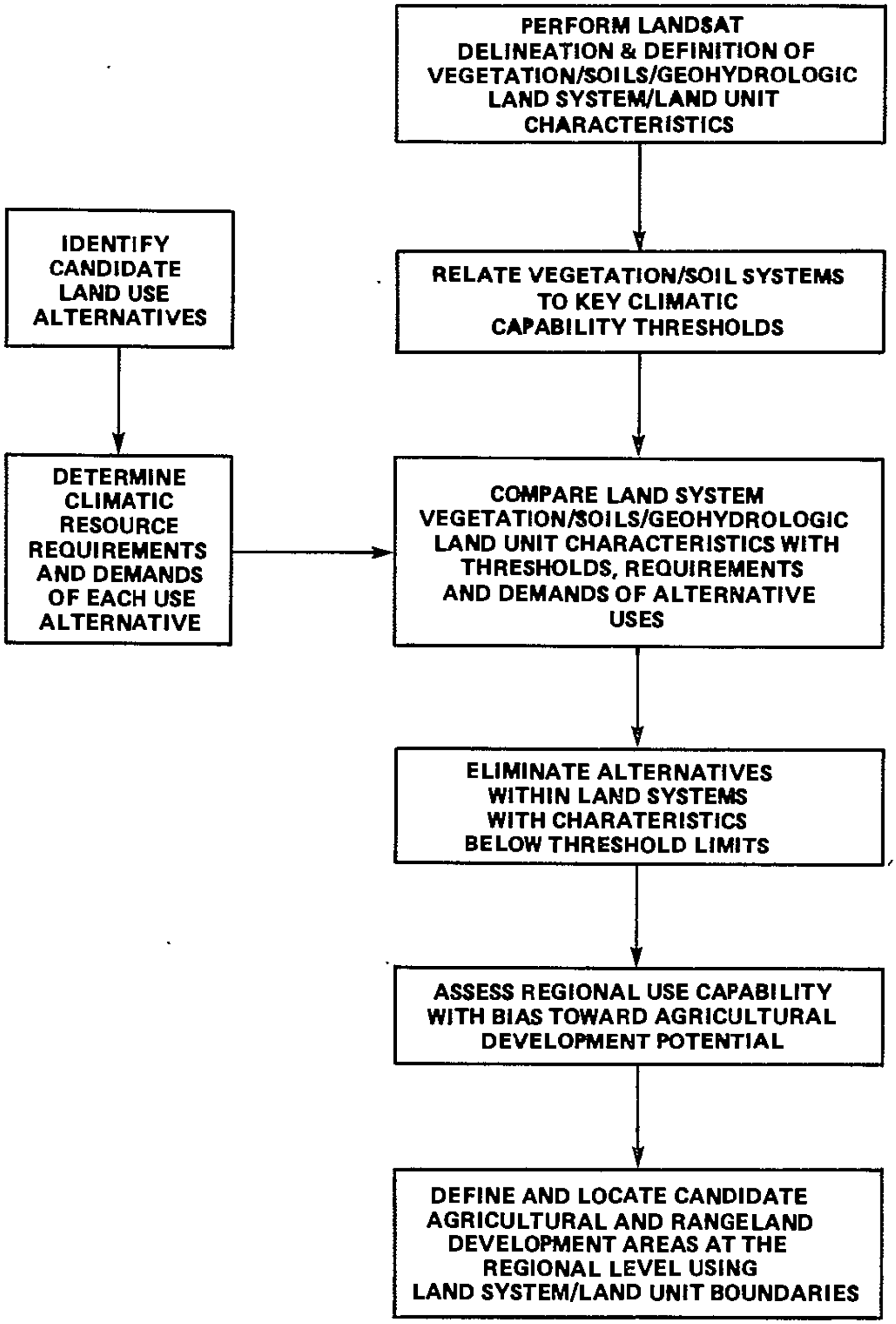


FIGURE 4-9. Regional Land Use Capability Evaluation Procedure

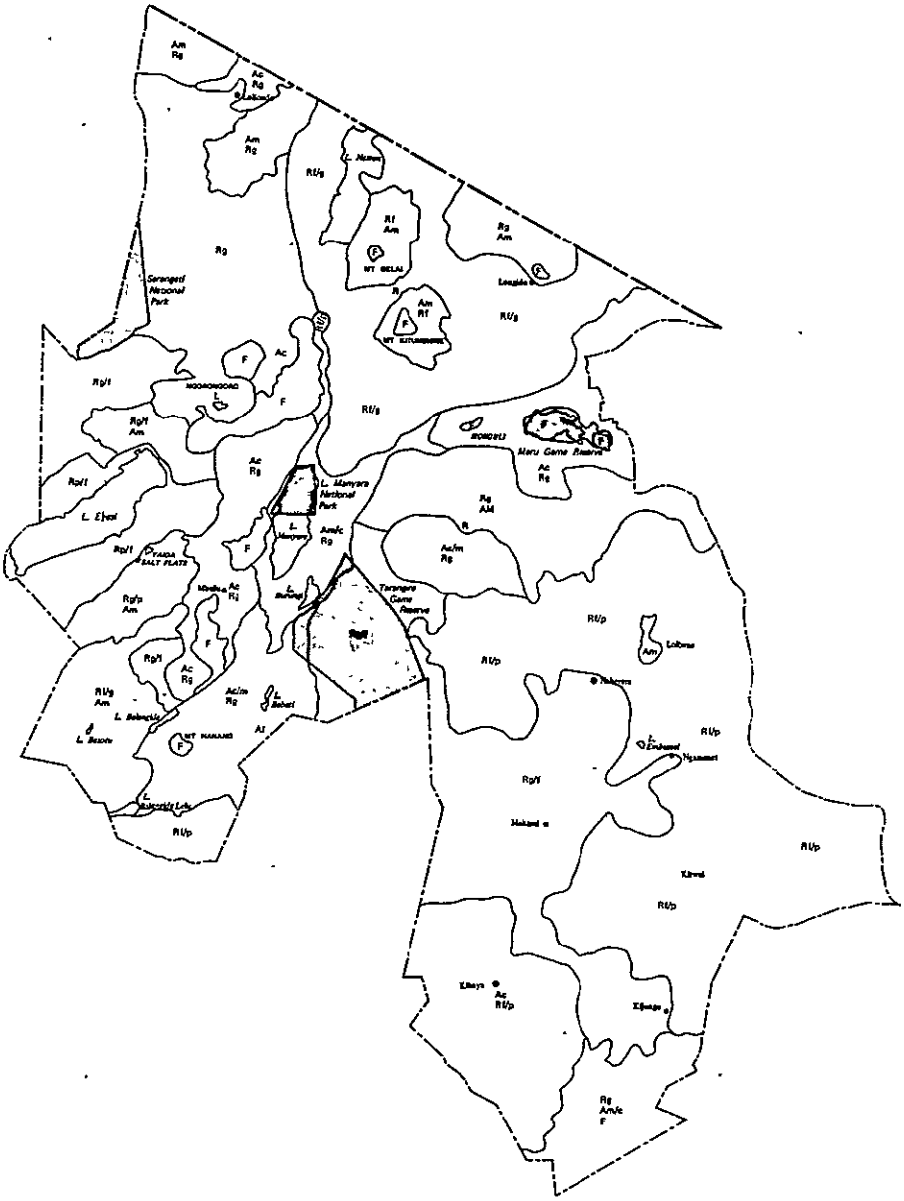
Figure 4-10. Figure 4-10 is a reduced size representation of a 1:1,000,000 scale overlay for the Arusha Region LANDSAT color mosaic (see EXECUTIVE SUMMARY for illustrative reproduction of the overlays and color mosaic).

As stated previously, the primary objective in Phase I land use capability analysis at the regional level is to locate and identify land areas offering varying degrees of cropland agricultural development potential, and to differentiate such areas from lands best used and managed as either improved or as unimproved rangelands. Areas which have been identified as candidates for agricultural development are then to the extent possible to be subjected to closer scrutiny during Phase II by detailed ground and aerial photo interpretation required to make site specific capability statements.

In the kinds of fragile environments that typify most of the Arusha Region, land resource development decisions must provide for adequate mitigative management in order to prevent any acceleration of the rate of change toward desertification, reduction in livestock carrying capacity and wildlife habitat, deterioration of herd size and quality, or possible elimination of the food producing capacity of the land itself.

It is with these thoughts in mind that we have approached a first approximation of agricultural land use candidate areas which will be further refined and updated throughout the course of Phase II and beyond.

In reaching capability assessment decisions, a conscious effort has been made to lean toward candidacy for agricultural

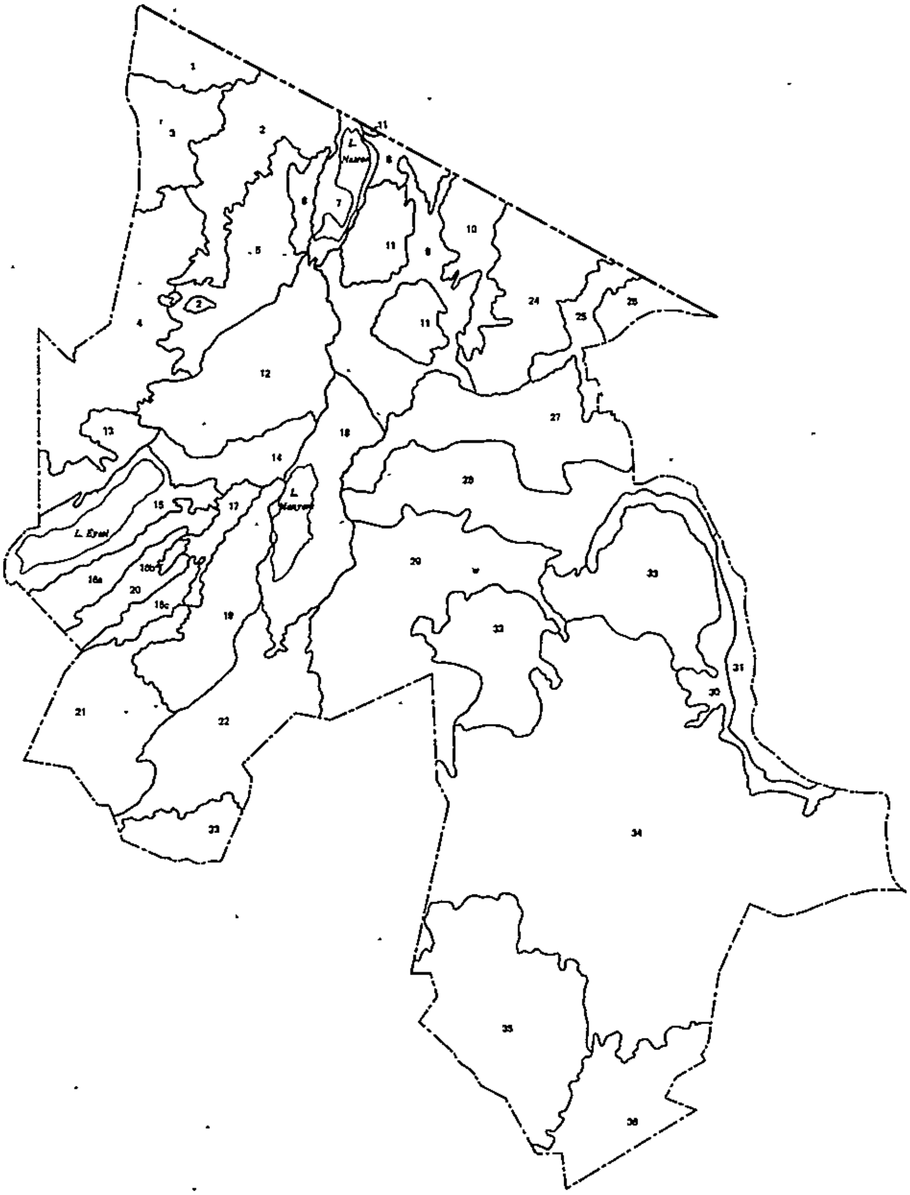


LAND CAPABILITY INTERPRETATION OVERLAYLEGEND

A	AGRICULTURE	c	candidate area
R	RANGE	m	marginal for agriculture
F	FORESTRY	g	good range potential
▭	GAME RESERVES AND NATIONAL PARKS	f	fair range potential
		p	poor range potential

OVERLAY FOR
LAND CAPABILITY INTERPRETATION
(AGRICULTURAL DEVELOPMENT CANDIDATE AREAS)

FIGURE 4-10B



LAND SYSTEMS OVERLAY LEGEND

SEE "TABLE OF LAND SYSTEMS DESIGNATORS" IN TEXT

LAND SYSTEMS OVERLAY

FIGURE 4-10A

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NO. 38

development so that attention would not be directed away from any major areas manifesting significant agricultural potential. Within areas which have been designated for range (R) or for forest (F) use alone, there are specific locations at the local level suitable for agriculture, or for range within the forest areas. In general, however, these local cases would tend to be classified as Am, or subsistence agriculture, when located within the drier range areas or within areas peripheral to mountain or hill systems.

In reaching these decisions on candidacy at the regional level, major emphasis was placed on vegetation/climatic relationships; relatively less emphasis was given to detailed consideration of ground water overlay information because that data is relevant to site specific programs rather than to broad general applications.

The land use capability classification scheme which has been employed for regional capability evaluation is described fully in Appendix B, and will be only briefly summarized here. The recognized capability classes include the following:

Ac - Candidate agricultural development areas where a significant proprotion of Class I, II, and III (and in some cases IV) land may be found.

Am - Marginally suitable for agricultural development because of high management risk, low flexibility of options or high costs and technical difficulty of mitigating measures needed to avoid resource deterioration.

- Unsuited for agricultural development by virtue of falling below one or more of the best available threshold values (areas unsuited for agriculture have been given only a Range capability class designator)

Rg - Good rangeland use potential (some areas may presently be in a deteriorated condition but yet have good potential).

Rf - Fair rangeland use potential.

Rp - Poor rangeland use potential, mainly where limiting climatic factors suggest a fragile range ecology easily subject to deterioration.

F - Forest use area for wood, lumber or charcoal.

Most areas possessing both agricultural and range use potential on this regional scale are given multiple A and R capability designators. Capability classes for range and agriculture have also been used in combination to show variability. In these instances, the first listed designator represents a judgment of the more prominent condition, e.g., Am/c = primarily marginal for agricultural development, but with some candidate areas of Class AI, AII, or AIII soils. A significant portion of 13 of the 36 Arusha Region Land Systems have been designated as areas for candidate agricultural development as shown in Figure 4-10. The numbers, names, and land use capability designators for these 13 Land Systems are listed below:

Land System Number	Land System Name	Portion of System in Candidate Area	Capability Designation
1	Mundorossi	Southeast portion	Ac, Rg
2	Oldonyo Ogol	Northwest portion	Ac, Rg
12	Ngorongoro	Entire System	Ac
14	Mbulumbulu-Oldeani	East portion	Ac, Rg
17	Tlawi-Seremal Valley	Entire portion	Ac, Rg
18	Lake Manyara Basin	Central and south portion	Am/c, -Rg
19	Marang-Nou	Central, North and Southcentral portions	Ac, Rg
22	Hanang-Babati	Entire System	Ac/m, Rg
25	Ngasurai	Southeast portion	Ac, Rg
26	Ol Molog	Entire System	Ac, Rg
27	Meru-Losiminguri	Central and East portion	Ac, Rg
29	Masai Steppe Transition	Southwest portion	Am/c, Rg
35	Kibaya	Entire System	Ac, Rf/p
36	Sunya	Entire System	Am/c, Rg, F

The regional land use capability analysis results displayed in Figure 4-10 represent only a first iteration toward definition of land use potential; delineation lines are broadly generalized at the regional scale, and the reader is referred to the 1:250,000 scale Land System and Land Unit overlay series for a more precise presentation of descriptive Land System and Unit boundary lines.

4.3 Description of Arusha Region Land Systems

The application of LANDSAT land resource interpretation procedures throughout Phase I of the present study has resulted in delineation of 36 distinct Land Systems areas across the whole Arusha Region. An effort is made in this section of the report to briefly describe and summarize land resource characteristics of the majority of the Land Systems, drawing upon both the LANDSAT-derived geohydrologic and Land Unit legend information which has been developed and presented in map overlay form, and other existing information sources for relevant material.

Each Land System displays broadly variable but recurring patterns of vegetation, landforms, geology and soils; these units effectively form the first logical sub-regional level of resource and development planning and management units. Recognition of land resource and land capability distinctions at the Land Systems level is a logical first step toward development of more site-specific land resource information and capability assessments at the Land Unit and local development project levels.

Land Systems are described in accordance with a concise standard format, using short, criptic phases wherever possible; information is organized under a sequence of descriptive headings which permits the user to quickly reference specific kinds of information.

The Land System, and ultimately the Land Unit descriptions are never written in final form. Their preparation is an iterative process starting from the initial regional view and then progressively updating and revising as more and more is learned about each area and its resource characteristics and development potential.

Land System descriptions developed during Phase I of the present study are intended only as a very brief summary of the land resource and geohydrologic data which has been developed and delivered in map overlay form, and of the available correlary background data. (reference materials are listed in the SELECTED BIBLIOGRAPHY)

4.3.1 Expanded Land System/Land Unit Descriptions for Hanang District

The narrative Land System descriptions for two contrasting Land Systems in the Hanang District have been prepared in greater detail than those for the remainder of the Arusha Region. These descriptions were prepared under an expanded format in order to: 1) better illustrate the actual level of descriptive resource information which can be extracted from the LANDSAT basemap overlays developed during the course of Phase I; 2) illustrate the potential utility of the computer reprocessed and enhanced LANDSAT imagery used in geohydrologic analysis and delivered with this report for definition of the current extent and status of agricultural land use and development. These expanded descriptions better reflect the full information content of Phase I basemap overlays through presentation of individual Land Unit legend descriptors and their associated square mile areas as they occur within the total Land System; descriptions presented in this manner are likely to be found of greater utility at the District development planning level. Descriptions have been prepared specifically for the Hanang-Babati Land System (No. 22) and the Basotu-Bashaiy Land System

(No. 21) in the Hanang District. These two Land Systems were chosen because they illustrated a contrast between two Land Systems which were identified in Phase I Land Use capability analysis as Fair/Good Candidate Rangeland and Candidate Agricultural Development Areas, respectively. These areas also are not included among previously identified Phase II priority areas and will therefore be likely to receive less attention during semi-detailed survey operations; Land Systems 21 and 22 consequently represent candidate agricultural and moderate rangeland development areas where expanded Phase I information will be particularly useful because less expansion of resource information is contemplated for these particular areas during Phase II. Descriptions were developed through focus of special attention by our entire multidisciplinary working group on these two areas and will provide an example for multidisciplinary Tanzanian teams to follow in producing similar Land System summaries of Phase I overlay information integrated with their own more detailed local knowledge.

A completed set of Land System descriptions, particularly when augmented by additional resource survey information at the semi-detailed level, will prove to be a very valuable and highly useful body of organized knowledge to help guide both the regional and district phases of land use planning, resettlement, and resource development and management.

The work of the Canadian Soils Team in the Basotu Wheat Scheme area (see Figure 21-1 in Land System description No. 21) shows how semi-detailed land use capability analysis on a site specific level can be integrated with this work. Field and inventory work such as that done near Basotu should be considered as a Phase III activity. It is at this latter level that the results have the greatest impact on the local problems of each District and of the priority areas for resettlement, improved range management, and resource development.

During Phase II of this project, EarthSat hopes to assist the Tanzanians in working toward a refinement and more complete characterization of all of the Land Systems and a strengthening of the data base. We also hope to make substantial steps toward a soils mapping system and legend integrated with Phase I vegetation/Soils System descriptions that can be carried into all of the priority areas of the Arusha Region to determine land use capability on a local, site specific basis.

4.3.1.1 Current Agricultural Land Use Interpretation

As part of the expanded description of two Land Systems in the Hanang District in the Southwest portion of the Arusha Region, an analysis of current agricultural land use was performed as a cartographic theme separate from physiographic landforms and other descriptive land cover and land surface information. Digital computer reprocessed and specially enhanced LANDSAT imagery was used for interpretation of current agricultural production areas. LANDSAT band 7, edge-enhanced, black-and-white photographic basemaps at a scale of 1:250,000 were used for agricultural land use analysis according to the image interpretation key shown in Figure 4-11.

KEY TO AGRICULTURAL DELINEATION FROM BAND 7 COMPUTER ENHANCED LANDSAT IMAGERY OF SOUTHWEST ARUSHA REGION

A	Smooth, uniform textures and natural patterns and boundaries; natural vegetation/land features dominate the scene	
A_1	Playas (Salt and Alkaline Flats)	(110)
A_2	Lakes, ponds, and Reservoirs	(210)
A_3	Natural vegetation	(300)
A_4	Perennial Grasslands	(314)
A_5	Marsh and Swamp Grasslands	(316)
A_6	Shrub/Scrub	(320)
A_7	Clouds and Cloud Shadows	(910)
AA	Textures, shapes and patterns show modified landscape; natural vegetation/land features do not dominate the scene	
B	Signature indicates high habitation density, dominates the scene; habitation density is greater than agricultural field density	
C_1	Isolated habitation (point data, generally not evident at scales smaller than 1.50,000)	(601)
C_2	Strip settlement, linear features along roads and tracks, generally in uplands or crossing riparian lowlands generally not evident on LANDSAT	(602)
C_3	Strip settlement, linear features along riparian ways generally not evident on LANDSAT	(603)
C_4	Cluster settlement and villages; marginally evident on LANDSAT if one knows where to look	(604)
C_5	Larger towns and cities; street patterns often evident	(605)
BB	Signature, as in AA, indicates habitation density is less than agricultural field density.	(D)
D	Field patterns small; patterns, edges and corners indistinct; few straight edges, if so very short; angular corners often indistinct; generally a dot and small blob, stippled "salt and pepper" tone and texture on LANDSAT	(E)
E	Isolated individual to very small cluster field patterns, confidence low, often near lost in noise at scales below 1:100,000 (LANDSAT); usually discernable at scales of 1:100,000 and larger, usually less than 20% of landscape. Mixed-crop, shifting agriculture, scattered	(501)
EE	Not isolated, very small cluster fields with a fine "salt and pepper" tone and texture.	(F)
F	Salt and pepper 20 to 69% of landscape. Usually mappable only as complex with naturally vegetated landscape. Mixed-crop, shifting (usually hoe) agriculture, low density	(300/502) (502/300)
FF	Salt and pepper 70%+ of landscape; mixed-crop, shifting (usually hoe) agriculture, high density	(503)
DD	Field patterns larger, distinct, regular in outline, many straight edges and angular corners; not a stippled, "salt and pepper" tone and texture. Interpretive confidence very high. Usually clearly evident at LANDSAT scales	(G)
G	Field patterns easily discerned and recognized; but patternssuggests mixed cropping and mechanical tillage, intensive, large-field mechanical agriculture.	(504)
GG	Field patterns extremely large, suggesting very extensive, uniformly cropped or planted fields; very long, straight field edges, plantation agriculture.	(505)

This key approximates the dichotomous keys used in the natural sciences. It is dichotomous in the major decisions and works by an iterative process, proceeding from general to specific classification. Major headings and subheadings organize the classification into criteria illustrating salient differences between the major classes. For example, this key begins by separating natural landforms essentially unmodified by man (A) from those landscapes modified by man (AA) through agricultural or settlement activities. Subsequent choices under each of the major subheadings continue to refine a classification until a specific category or series of categories is defined.

The letter headings to the left of the key index the progression of classes and subclasses. Letters to the right guide the user to the next alternative. Numeric designators are the final step in the keying process; they indicate specific land use classifications matching each alternative choice.

FIGURE 4-11

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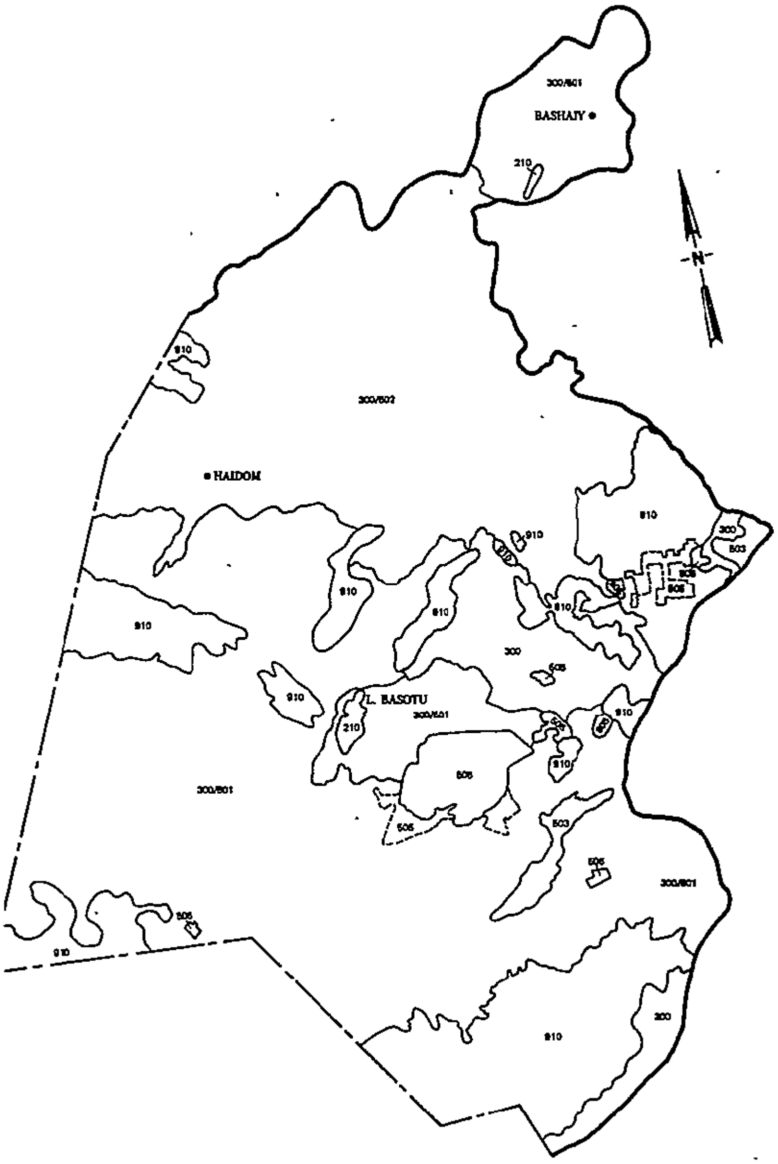
NO. 4-46

Current agricultural production area interpretations for the Basotu-Bashaiy Land System and the Hanang-Babati Land System are presented in the form of reduced scale map illustrations in Figure 4-12 and Figure 4-13, respectively.

Interpretations of current agricultural land use (similar to those used here) could be used as a basis for projections of present agricultural production potential and for current year estimates of the amount of production of key crops. This might be accomplished with greatest effectiveness, using cloud free coverage from LANDSAT-2 selected in an optimum season for detection. This kind of imagery, together with the interpretations of agricultural land area like those shown in Figure A-11 is the first essential parameter in crop production estimation.

Another important ingredient of crop yield involves agroclimatological analysis and predictions of water budget. These can be based on information EarthSat has the capability to extract from weather satellite data. These data are modeled to derive a geographic water budget estimate on a 12.5 or a 25 nautical mile grid throughout the country for input into growth models to predict crop yield.

A program combining these innovative features might provide useful information about food supply and distribution problems by giving better estimates of how much, and from which sections of the country, the



KEY TO AGRICULTURAL DELINEATION FROM BAND 7 COMPUTER ENHANCED LANDSAT IMAGERY OF SOUTHWEST ARUSHA REGION

A Smooth uniform textures and natural patterns and boundaries, natural vegetation/land features dominate the scene

- A_1 Playas (Salt and Alkaline Flats) (110)
- A_2 Lakes ponds and Reservoirs (210)
- A_3 Natural vegetation (300)
- A_4 Perennial Grasslands (314)
- A_5 Marsh and Swamp Grasslands (318)
- A_6 Shrub/Scrub (320)
- A_7 Clouds and Cloud Shadows (910)

AA Textures, shapes and patterns show modified landscape natural vegetation/land features do not dominate the scene

- B Signature indicates high habitation density, dominates the scene habitation density is greater than agricultural field density
  - C_1 Isolated habitation (point data, generally not evident at scales smaller than 1 50,000) (601)
  - C_2 Strip settlement linear features along roads and tracks, generally in uplands or crossing riparian lowlands generally not evident on LANDSAT (602)
  - C_2 Strip settlement, linear features along riparian ways generally not evident on LANDSAT (603)
  - C_4 Cluster settlement and villages, marginally evident on LANDSAT if one knows where to look (604)
  - C_5 Larger towns and cities; street patterns often evident (605)
- BB Signature as in AA, indicates habitation density is less than agricultural field density (D)
  - D Field patterns small patterns edges and corners indistinct, few straight edges if so very short, angular corners often indistinct, generally a dot and small blob, stippled "salt and pepper" tone and texture on LANDSAT (E)
    - E Isolated individual to very small cluster field patterns; confidence low, often near loss in noise at scales below 1 100,000 (LANDSAT) usually discernable at scales of 1 100,000 and larger usually less than 20% of landscape Mixed-crop shifting agriculture, scattered (501)
    - EE Not isolated, very small cluster fields with a fine "salt and pepper" tone and texture (F)
      - F Salt and pepper 20 to 69% of landscape. Usually mappable only as complex with naturally vegetated landscape Mixed-crop shifting (usually hoe) agriculture low density (300/502) (502/300)
      - FF Salt and pepper 70%+ of landscape mixed-crop shifting (usually hoe) agriculture, high density (503)
  - DD Field patterns larger distinct regular in outline many straight edges and angular corners, not a stippled, "salt and pepper" tone and texture Interpretive confidence very high, Usually clearly evident at LANDSAT scales (G)
    - G Field patterns easily discerned and recognized but patternsuggest mixed cropping and mechanical tillage intensive large-field mechanical agriculture. (504)
    - GG Field patterns extremely large suggesting very extensive uniformly cropped or planted fields, very long, straight field edges, plantation agriculture. (505)

This key approximates the dichotomous keys used in the natural sciences. It is dichotomous in the major decisions and works by an iterative process, proceeding from general to specific classification. Major headings and subheadings organize the classification into criteria illustrating salient differences between the major classes. For example, this key begins by separating natural landforms essentially unmodified by man (A) from those landscapes modified by man (AA) through agricultural or settlement activities. Subsequent choices under each of the major subheadings continue to refine a classification until a specific category or series of categories is defined

The letter headings to the left of the key index the progression of classes and subclasses Letters to the right guide the user to the next alternative Numeric designators are the final step in the keying process, they indicate specific land use classifications matching each alternative choice.

BASOTU - BASHAIY LAND SYSTEM

prepared for
U S AGENCY FOR
INTERNATIONAL DEVELOPMENT

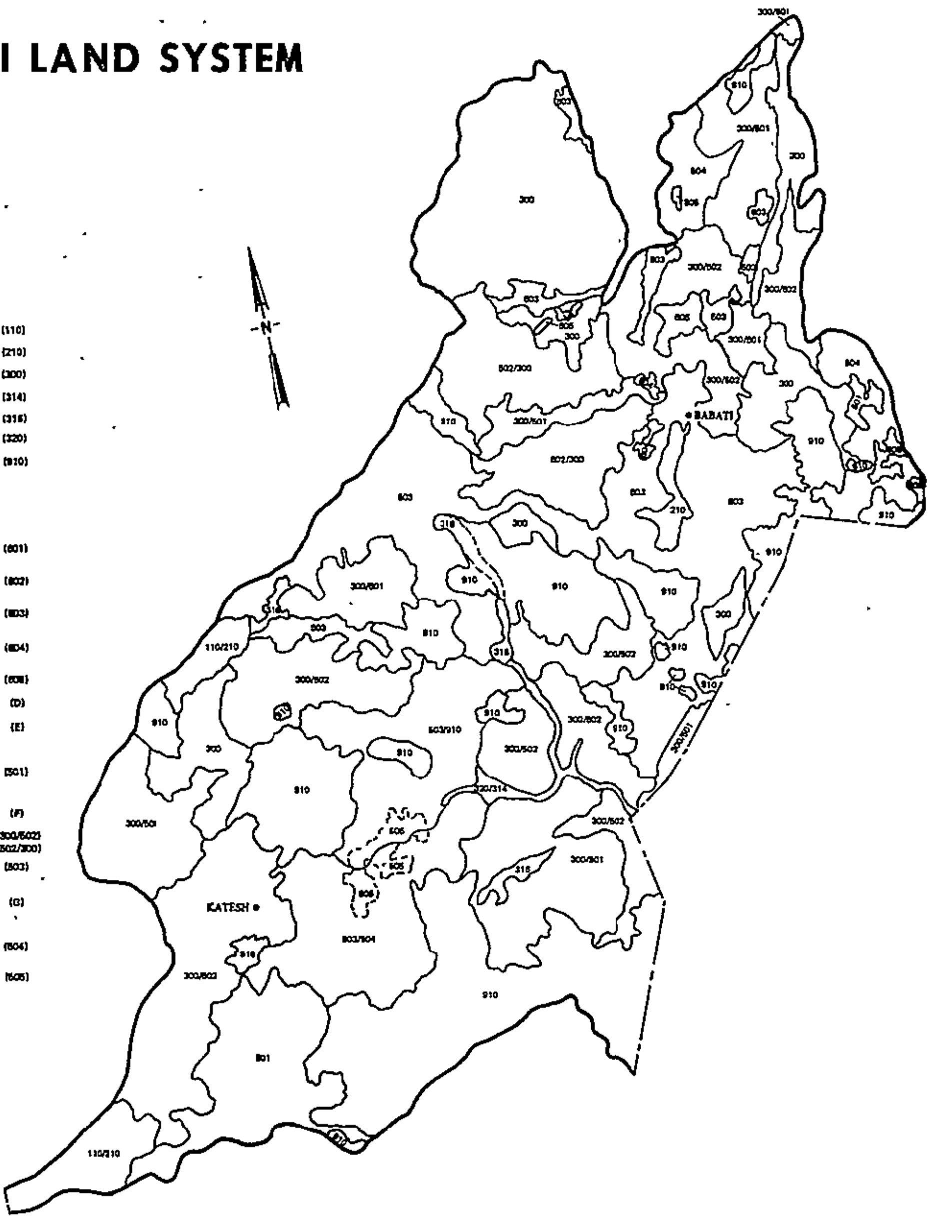
AGRICULTURAL INTERPRETATION FROM 1 250,000 BAND 7
SPECIAL PROCESSED BLACK AND WHITE IMAGERY

Scale 1:250,000
5 0 5 10 15 20 Statute Miles
5 0 5 10 15 20 25 30 Kilometers

Earth Satellite Corporation
Washington, D C.

FIGURE 4-12

HANANG BABATI LAND SYSTEM



KEY TO AGRICULTURAL DELINEATION FROM BAND 7 COMPUTER ENHANCED LANDSAT IMAGERY OF SOUTHWEST ARUSHA REGION

A Smooth, uniform textures and natural patterns and boundaries, natural vegetation/land features dominate the scene

- **A_1** Playas (Salt and Alkaline Flats) (110)
- **A_2** Lakes ponds and Reservoirs (210)
- **A_3** Natural vegetation (300)
- **A_4** Perennial Grasslands (314)
- **A_5** Marsh and Swamp Grasslands (315)
- **A_6** Shrub/Scrub (320)
- **A_7** Clouds and Cloud Shadows (910)

AA Textures, shapes and patterns show modified landscape natural vegetation/land features do not dominate the scene

- **B** Signature indicates high habitation density dominates the scene habitation density is greater than agricultural field density
  - **C_1** Isolated habitation (points dots generally not evident at scales smaller than 1 80,000) (601)
  - **C_2** Strip settlement linear features along roads and tracks generally in uplands or crossing riparian lowlands generally not evident on LANDSAT (602)
  - **C_3** Strip settlement, linear features along riparian ways generally not evident on LANDSAT (603)
  - **C_4** Cluster settlement and villages marginally evident on LANDSAT if one knows where to look (604)
  - **C_5** Larger towns and cities, street patterns often evident (605)
- **BB** Signature as in AA indicates habitation density is less than agricultural field density (D)
  - **D** Field patterns small; patterns, edges and corners indistinct, few straight edges, if so very short angular corners often indistinct, generally a dot and small blob stippled "salt and pepper" tone and texture on LANDSAT (E)
    - **E** Isolated individual to very small cluster field patterns confidence low often near lost in noise at scales below 1 100,000 (LANDSAT) usually discernable at scales of 1 100,000 and larger usually less than 20% of landscape Mixed-crop shifting agriculture, scattered (501)
    - **EE** Not isolated, very small cluster fields with a fine "salt and pepper" tone and texture (F)
      - **F** Salt and pepper 20 to 69% of landscape. Usually mappable only as complex with naturally vegetated landscape Mixed-crop shifting (usually hoe) agriculture low density (300/502) (502/300)
      - **FF** Salt and pepper 70%+ of landscape mixed-crop, shifting (usually hoe) agriculture high density (503)
  - **DD** Field patterns larger distinct, regular in outline many straight edges and angular corners, not a stippled "salt and pepper" tone and texture. Interpretive confidence very high. Usually clearly evident at LANDSAT scales. (G)
    - **G** Field patterns easily discerned and recognized but patterns suggest mixed cropping and mechanical tillage, intensive large-field mechanical agriculture. (504)
    - **GG** Field patterns extremely large suggesting very extensive uniformly cropped or planted fields; very long, straight field edges; plantation agriculture. (505)

This key approximates the dichotomous keys used in the natural sciences. It is dichotomous in the major decisions and works by an iterative process proceeding from general to specific classification. Major headings and subheadings organize the classification into criteria illustrating salient differences between the major classes. For example this key begins by separating natural landforms essentially unmodified by man (A) from those landscapes modified by man (AA) through agricultural or settlement activities. Subsequent choices under each of the major subheadings continue to refine a classification until a specific category or series of categories is defined.

The letter headings to the left of the key index the progression of classes and subclasses. Letters to the right guide the user to the next alternative. Numeric designators are the final step in the keying process, they indicate specific land use classifications matching each alternative choice

prepared for
U S AGENCY FOR
INTERNATIONAL DEVELOPMENT

Scale 1:250,000
5 0 5 10 15 20 Statute Miles
5 0 5 10 15 20 25 30 Kilometers

Earth Satellite Corporation
Washington, D.C.

FIGURE 4-13

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NO. 4-48 4-49

greater crop yields were likely to come each year, as well as where food crop deficiencies are likely in any given season and area of the country because of an unfavorable water balance.

The Land System and Land Unit maps which have been produced in Phase I constitute the initial resource stratification that would be necessary for this kind of an economically significant follow-on study. Land Units represent Vegetation/Soil Systems which often effectively integrate and represent areas having relatively homogeneous climatic conditions and associated crop development and yield potential when soil characteristics are known.

4.3.1.2 Basotu-Bashaiy and Hanang-Babati Land Systems Descriptions

Expanded descriptors for the Basotu-Bashaiy (No. 21) and Hanang-Babati (No. 22) Land Systems are presented in this section. The descriptive information is organized according to the following subject outline format:

Geographic Location:

Climate:

Land Units:

Including a Table of Land Unit descriptors, their meaning, location and approximate areas in square miles.

Geology:

Vegetation/Soil Systems:

Infrastructure and Present Land Use:

- Transportation
- Urban
- Agriculture
- Range

Land Use Capability:

The name and number of each Land System, together with a map insert showing the location of the system within the Arusha Region, appear at the top of the first page of each Land System description.

Land System: BASOTU-BASHAIY -- No. 21, 1030 sq. mi.

Geographic Location: Extreme southwest corner of Hanang District; village of Basotu is in center of the Land System area. Comprises the plateau or dip slope between the regional boundary and the Yaida Escarpment and the Malbadow Escarpment on the southeast. Northern border marked by 6,000 foot contour where important change in geology and landform occurs. Narrow extension reaches Bashaiy vicinity in the north.

Climate: Closest weather station is in Singida, about 25 miles to the southwest. There ppt. averages 660 mm (26 in.) per an. generally adequate for cropping but falling in a one-season pattern; distributed 20% in each of December and January, 14-19% each in February and March; 9-13% in April, and 5-8% in November, May to October very dry. Southwest side of Land System area is driest. In northeast and mountain areas, ppt. probably ranges from 800-to-1,000 mm. In southeastern 1/3 of the area, less than 250 mm per an. expected 1 year in 10. For remainder, expectations are a minimum between only 250-to-500 mm 1 year in 10. For this latter area, climate would probably not be serious limitation to agricultural development except on coarse textured and shallower soils. Whenever December to March ppt. drops to 300 mm, crop failures and poor range productivity expected; is likely in more than 1 year in 10. Area lies near a critical drought center around Lake Eyasi and the Yaida Basin where both short and long-rain drought is documented in climatic records.

Land Units: This Land System has a generally flat to rolling plateau or dip slope landscape surrounded by hills escarpments as above. The northern extension follows a narrow valley bordered by the Haidom-Maghang Escarpment on the west and a series of hill systems on the east. The southern portion is flatest, giving a lowland appearance with frequent mbugas or mbuga-like depressions. Some isolated, low hills in the southeast; northerly becoming more rolling except in the northeast corner where the flatland aspect repeats. The elevations range from 1524-to-1829 m (5000-to-6000 ft.). Some small hill systems in the central plain rise slightly over 1830 meters. The lowest elevation is at the Mpambaa Dam. The Land Units support primarily the Thorn Scrub/Bush, Moderately Dense (323) on flatlands and undulating to gently rolling uplands (1.5 - 2.5). The escarpments (3.71) generally support Dense and Moderately Dense Thorn Scrub/Bush (322 and 323). Also on the uplands (1.5 - 2.5), Grasslands (314) alternate in varying complexes with Low Density Thorn Scrub/Bush (324) on both uplands with very low relief (1.5) and in drainage ways, mbugas, and larger basins (1.32, 1.12, 1.11). The grassland complexes tend to occur on the gentler relief where most of the agricultural development has also taken place. The Land Units within the Basotu-Bashaiy Land System may be summarized in Table 21-1.

Table 21-1

Land Units Comprising the Basotu-Bashaiy Land System in the Arusha Region, Tanzania

Land Unit Symbol	Description	Relative Location	Approximate Area, sq. mi.
323/332/500 1.5/2.5	Moderately dense bush to shrub savanna, agriculture complex, flat to rolling plateau	Northwest to North	280
323/314/500 2.5	Moderately dense bush-grassland, agriculture complex, rolling plateau	West Central	355
324/314/500 1.5/2.5	Open bush-grassland, agriculture, flat to rolling plateau	South	121
500 1.1/1.5	Agriculture, low areas and flat plateau (some mbugas)	Central and Northeast	47
324/314 1.5	Open bush-grassland on flat to undulating plateau	West and Southwest	104
322/323 3.71	Dense to moderately dense bushland on escarpments	Eastern Margin	41
323/314/316 1.5/1.12	Moderately dense bush-grassland, wetland grasses, flat plateau with mbugas	South	31
323/314/316 1.1/1.3	Moderately dense bush-grasslands and wetlands in riparian and non-riparian depressional systems	Central	11
314/324 1.1/1.5	Grassland to open bushlands, non-riparian depressions and flat plateaus	Northeast	31
314 1.12	Grassland mbuga	West	5
320/316/500 1.1	Bushland, wetlands, agricultural complex, non-riparian lowland	North	4
210	Lakes and ponds	North and South Central	3

BASOTU-BASHAIY, No. 21 (continued)

Geology: Geologically this Land System has some of the oldest soils in the world, residual from precambrian rock with no fertility recharge from volcanics. Sediments have been eroded, redeposited, and re-eroded so that low soil fertility prevails generally in the western- and northwestern-most Land Units. The plateau Land Units to the east have volcanic influenced soils and higher potential fertility. These latter areas include many clay-rich mbuga soils (Vertisols). The northern upland area near Haidom is underlain primarily by gneisses, while much of the remaining area consists of granites and calcareous tuffs.

Ground and Surface Water: On the overlay of groundwater candidate areas, three sets of intersecting fractures in vegetational anomalies (labeled A1, A2, and A3) are all about equally promising. Lake Basotu lies within this Land System. Free-flowing surface water is very limited except in the rainy season. Within this Land System, particularly on the graben side of the northeast-southwest trending Yaida Escarpment, the LANDSAT color infrared imagery indicates a high frequency of narrow drainage ways supporting lush-growing, water-tolerant vegetation. This suggests high water tables in these situations. These areas may provide shallow wells or developable seeps for better livestock, game and culinary water. These sources might provide some water for limited irrigation of crops in their immediate vicinity. The particular locations have not been mapped because the lines, in most cases, would completely obscure the feature; and they are visually evident to the officials who will be applying the results of this study. Intersecting fractures in these drainages have been identified as promising areas for ground water exploration on the geohydrologic overlay for this Land System.

Vegetation-Soil Systems: Refinement of details in this section will come from subsequent work, primarily by Tanzanian scientists and District personnel. The following can be said on the basis of work by Sheehy and Green (undated ms.). (1973). The bushland vegetation (320) is predominantly *Acacia-Commiphora*, *Acacia-Combretium*, and *Acacia-Cordia* bushlands. *Hyparrhenia-Acacia* bushed grassland (generally 324) and tall *Hyparrhenia-Sacciolepis* grasslands (314) are important. Seasonally waterlogged grasslands (314) of Hyparrhenia occur in many mbuga areas. On the limited escarpments within the Land System, *Brachystegia spiciformis-Commiphora schimperi* woodlands are found. The prominent bush species are *Acacia drepanolobium*, *A. stuhlmannii*, *A. tortilis*, *A. kinionge*, *A. xanthophloea*, *A. sieberiana*, *Commiphora schimperi*, *C. ugogensis*, and *Cordia ovalis*. The more prominent grasses are *Hyparrhenia rufa*, *H. filipendula*, *Sacciolepis palustris*, and *Themeda triandra*. While the only useable LANDSAT imagery was dry season taken in and after extensive range and field burning had taken place, the imagery does suggest numerous lowland areas, mbugas and narrow drainage ways vegetated by species that remain green into late September. These are where the grasslands (314) predominate.

The best available estimate of the soils in the area as a whole are derivable from the Tanzanian Atlas. This suggests that the most extensive soils are Ferrisols derived from crystalline rocks, Kc. Complexes of Hydromorphic mineral soils and Vertisols are common, NaDj. There are some Ferruginous tropical soils derived from crystalline, acidic rocks, chiefly granite and also some derived from lavas and rocks rich in ferromagnesian minerals, Jc and Jb. There are extensive Vertisols, Dj, where grasslands are most typical; and in the escarpment areas colluvium and lithosols derived from acidic rocks and lavas and from gneisses are common, Ac and Aa. The soil survey of the Basotu Wheat Scheme area, shown in Figure 21-1, is probably quite representative of the Land Unit in which it falls (323/500//2.5/1.5). This illustration effectively demonstrates the high level of local variability in soils capability classes which may be found within many regional Land Systems and Land Units; this illustration further demonstrates that valid regional Land Unit capability generalization may have clear exceptions at the local, semi-detailed information level.

Infrastructure and Present Land Use: Transportation: The main Singida-Babati road extends along the entire southeast edge of the Land System for about 15 miles. Graded road to Basotu, south to the border and north to Dongobesh and with a road southwestto Haidom. There are numerous interconnecting tracks and, for the region, transportation is reasonably good. Urban: There are two main centers, Basotu to the south and Bashaiy to the northwest. Agriculture: Major agricultural development is in the southeasternmost Land Unit where the Basotu Wheat Scheme was developed. Here approximately one-third of the Land Unit is cropland producing beans, maize, and other food crops (Sheehy and Green). The wheat scheme and other large developments cover at least 52 square miles. Subsistence agriculture is scattered more or less throughout the Land System with concentrations around lakes and other permanent water sources, especially in some of the lowlands. Using especially enhanced LANDSAT imagery we analyzed the extent of current agricultural cropping in this Land System. Interpretation of this imagery revealed an even pattern of scattered, small-scale agriculture in the northern half of the Land System. This small-scale pattern gives way to either rangeland or to large plantation and development schemes in the south, particularly to the southwest. The map of agricultural land use is presented in Figure 21-3. This is suggestive of what could be done to update the land use picture and determine the impact of population pressure on soil and fodder resources since the last aerial photography was taken in the 1950's and 1960's. Range: Practically all of the Land System not in crops is grazed by pastoralists. Special game reserves or parks do not impinge on the Land System. The main areas of Kondoa rock paintings may include some of the southern and western edge of the area and dry lake basins may be a source of salt. There are no forests of consequence in the Land System although much of the bush and some of the riparian woods are a potential source of charcoal. Most of the area falls in a "less than 3 and 3-to-6 month's transmission period" for malaria and is essentially free of serious tsetse problems except in the denser bushed areas on the extreme west and in the southeast corner of the Land System area.

BASOTU WHEAT SCHEME

AGRICULTURAL LAND USE CAPABILITY

Land Use Capability: Except in the Basotu Wheat Scheme area, for which there is a 1:50,000 scale soil survey, presently available information is adequate to permit only a general overview of land use capability. Except for escarpments, "salt flats," and swampy areas, all of the Land System is good to very good for range, RI to RIII. The swampy areas and escarpments would be mostly in classes RIV and RV. The low relief essentially eliminates erosion as a risk in range use if management is reasonable and stocking rates not excessive. Wildlife and recreational value of lakes are potentially significant considerations.

For agricultural development, climate is limiting because of the probability of drought, particularly in the south and central Land Units and toward the Yaida Basin to the northwest. As one approaches the mountains and near the upland portions of this Land System, climate is not limiting. Drought, together with granitic-derived soils, make for unsuitability, or at best capability AIII and AIV in these soils areas--evidenced by most of the agricultural development being in basins and major drainage ways, and in the areas influenced by igneous rock types and volcanic soil-forming materials. Capabilities determined from the Basotu Wheat Scheme soil survey are probably quite representative of much of the southeastern part of the Land System, but not at all of the western and northern Land Units. Based on the Tanzanian Atlas, the most important soils are probably Ferrisols from crystalline rocks, Kc (AIII, AII); complexes of Mineral, Hydromorphic Soils and Vertisols (Black Cotton Soils); NaDj (AIII, AIV, some AII for former soils); Ferruginous Tropical Soils from crystalline, acidic rock, chiefly granite, Jc (AIII, AII); Valley-bottom Vertisols, Dj (AIII, AIV, rarely AII); and Raw Mineral Soils and rock debris from lavas and gneisses and from acidic rocks, Aa and Ac (AV).

Taken as a sample of the land units which immediately surround it, the soil survey of the Basotu Wheat Scheme shows 32% of the land in Agricultural Capability Class I and II; 63% in Classes III and IV; and 5% in Class V.

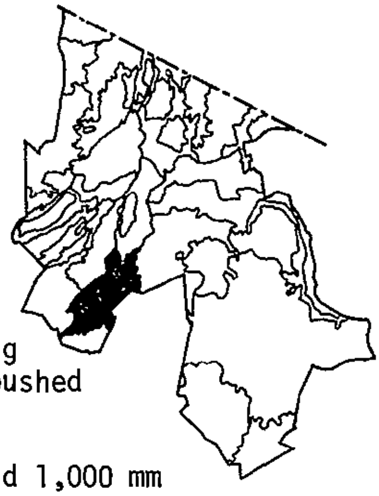
It would appear that in the context of regional priorities, this Land System may not warrant additional agricultural development in the near term. Consideration might be given to improving and increasing benefits from the better and returning the poorer of the agricultural developments to improved rangeland. Range use in this area is generally of sufficient importance to warrant much increased attention along with integration of crop and animal agricultural as new management schemes are developed.

Land System No. 21 lies in Agro-Economic Zones 015.1 and 014.3, and in Zonal Groups 14a and 4b, respectively. Relevant information descriptive of this Land System has been extracted from the Agro-Economic Zones study of Tanzania, and is presented in Table 21-2 below.

TABLE 21-2: Agro-Economic Data for the
Basotu-Bashaiy Land System

Agro-Economic Zone Zonal Group	014.3 4b	015.1 14a
Population density	medium/dense	very low
Migration	-	-
Tribe(s)	Iraqw	Iraqw,Mang'a
Settlement pattern	dispersed	dispersed
Social cohesion	low	low
Land availability	shortage	plenty
Land tenure	permanent	permanent
Area cultivated	medium	large(varied)
Cash crops(1)	-	-
Cash crops(2)	-	wheat,seed bean
Cash crops(3)	maize,millet	maize, millet
Food crops(1)	beans	beans
Food crops(2)	low	-
Double cropping	mainly flat	mainly flat
Tillage	high	high
Manure	-	-
Mulch, compost	-	-
Artificial fertilizer	low	-
Water control	low	low
Social conservation	low	low
Mechanisation - ox	-	low
Mechanisation - tractor	-	low
Hired labour	high	high
Cooperative labour	-	-
Pastoralists	-	some
Cattle ownership	high	high
Herd size	medium	medium
Improved stock	-	-
Economic uses of cattle	milk(s),manure	milk(s),manure
Social value of cattle	high	high
Small stock	high	high
Donkeys	high	low
Poultry	high	medium
Other livestock	pigs	-
Husbandry practices	both/males	both/males
Other rural activities	-	-
Estates/ranches	-	-
Urban influence	-	-
Communications	poor	poor

Land System: HANANG-BABATI -- No. 22, 1240 sq. mi.



Geographic Location: In southeast portion of the Hanang District from the Lake Balangida Lelu depression north to but excluding the Lake Manyara depression; below and east of the Malbadow Escarpment including Mt. Hanang and Mount Kwaraha east of Babati; excluding the heavy bushed thicket lands south of Mt. Hanang.

Climate: Mean annual ppt. 600+ mm to 800 mm in the north and 1,000 mm or more in the mountains (24 to 40 inches). The northwest lobe of the Land System may extend into a region receiving below 500 mm ppt. 1 year in 10. In terms of seasonal ppt., all of the area receives adequate rainfall in both the long and short rains on the average although the northern end of the Land System verges on the droughty region. Truly adequate data on seasonal precipitation probabilities were not available at time of writing. Where soils are good, however, rainfall appears non-limiting.

Land Units: This Land System lies entirely below the Malbadow Escarpment on the west. It includes two major volcanic mountain areas with the rolling to hilly intervening landscape. This sharply contrasts it with the plateau Land Systems to the west and south. It grades more subtly into Manyara and Masai Steppe Land Systems to the north and northeast. Elevations range from 945 m to general hill land levels of 1,370 to 1,860 m and the more mountainous areas ranging to 2,200 and 3,400+ m (3,100 to 11,212 feet). The Land Units support a highly diverse vegetation, and because of the relief and topography it occurs in intricate patterns that often cannot be uniquely mapped at small scales. Thus a larger percentage of the Land Units are complexes of vegetations and soils rather than representing essentially pure types. Woodlands (340, 342) typify the mountains and higher hills (4.75, 3.75, 3.74). The area includes insufficient dense bush to map, but areas of Moderately Dense and Open Thorn Scrub/Bush (323, 324) are common throughout the area. These are abundantly interspersed with grasslands (314) and Marsh or Wet Grasslands (316) commonly found in the gentler relief and depressional areas of drainage ways (1.1, 1.3, 1.4). The Land Units within the Hanang-Babati Land System are summarized in Table 22-1.

Geology: Granitoid gneisses and quartzites form the hills and ridges of this Land System (with the exception of the volcanic centers, Kwaraha in the northern and Hanang in the southern part). Kwaraha consists of superposed tuffs with some agglomerate and nephelinite, and Hanang consists of nephelinite with some calcareous tuffs on the basement complex.

Table 22-1

Land Units Comprising the Hanang-Babati Land System In the Arusha Region, Tanzania[1/]

Land Unit Symbol	Description	Relative Location	Approximate Area, sq. mi.
320/340/314 / 2/3.74	Bush and forested areas, grasslands, rolling lands with smooth-sloped hills	Northwest	72
320/314/500 / 1.5/2.5	Bush-grasslands with agriculture on flat to rolling plateau	North	132
323/342 / 3.74	Moderately dense bush, woodlands on smooth-sloped hill system	East Central	82
323/314/500 / 2.6	Bush-grassland with agricultural land use on strongly undulating to rolling lands	Central	15
500/232/326 / 2.74	Agriculture and moderately dense shrub-scrub and macrophyllous bushlands, grass understory, undulating, smooth hill-like slope systems	West to Central	162
323/500 / 2.5	Moderately dense bushland, agriculture, rolling plateau	Northeast	22
314/323 / 2.5	Grassland with moderately dense bush, rolling, plateau-like	Central	11
323/324/314 / 2.74	Moderately dense to open bush-grassland, undulating to rolling land, smooth slope systems	West Central	112
324/314/500 / 2.5	Open bush-grassland, agriculture, on rolling plateau	South Central	62
314/500 / 1.42	Grassland and agriculture on toe slope	South	47
314/324 / 1.1	Grassland with open bush cover in non-riparian depression	East Central	22

Table 22-1

(Continued)

Land Unit Symbol	Description	Relative Location	Approximate Area, sq. mi.
314/323/500 / 1.7/1.12	Grasslands, moderately dense bush, agriculture, on flat to undulating slope system, mbugas in low areas	Southeast	37
323/314 / 2.6/1.12	Moderately dense bush-grassland, strongly undulating to rolling landscape, mbugas in low areas	South	182
323/314 / 1.5	Moderately dense bush-grassland on flat to undulating plateau	Southwest	23 2/
323/314/500 / 2.74	Moderately dense bush-grasslands, agriculture, rolling lands with smooth, hilly slope systems	Southeast	103
500 / 1.33	Agricultural land in riparian drainage system	North Central	10
500 / 2.5	Agriculture on rolling plateau	South Central	4
500 / 1.5	Agriculture on flat plateau	South Central	13
340 / 4.75	Forest cover on angular mountain slope system	Northeast	19
342 / 4.75	Broadleaf forest on angular mountain slope system	Southwest	23
340 / 3.75	Forest cover on angular hill slope system	Northeast and East Central	20 2/
110/210 / 1.1	Lake and alkaline flat systems	Southwest West	26 2/

Table 22-1

(Continued)

Land Unit Symbol	Description	Relative Location	Approximate Area, sq. mi.
210 / 1.1	Lake System	North Central	8
316 / 1.1/1.32	Papyrus Marsh in riparian basin	Central	8
316 / 1.32	Marshland, wetland grasses in narrow riparian basin	South	4
316 / 1.1	Marsh and wetland grasses in non-riparian depressional areas	South, Southwest Southeast	13 2/
316/314/324 / 1.1	Marsh swamp grassland systems, open bush in non-riparian basin	West	6

1/ Land unit list follows a general top to bottom trend dividing land units into the following four major groups:

- Bushlands and grasslands, with agriculture and forests or woodlands included in some of the classifications
- Agriculture dominant
- Forest and woodland vegetation on hill and mountain macrorelief
- Lakes, ponds, lowland marshes and riparian systems

2/ Combines land area of several similar land units

Ground and Surface Water: Unranked areas with groundwater potential are as follows. These we believe to have equally good potential for additional resistivity and related ground work.

- Fractures controlling and intersecting the surface drainage off the northern slope of Kwaraha.

- Fracture system along the Manyara Escarpment in the northwestern part of the system.

- Fractures along and south of Lake Babati.

- Intersecting fractures in the general areas of the Managhat Swamp (labeled A-4 on the overlay). The Managhat Swamp and other swamps are localized along fractures. The water accumulated in this and other swamps nearby comes from surface drainage in this interior drainage basin, and is likely to be saline. Again, however, water in the fractures underground is likely to be fresher, and the best areas for prospecting are at the intersections of fractures.

- Fractures on the western and southern flanks of Hanang (labeled A on the overlay). The fractures appear to have ponded groundwater up slope of them and are prime candidates for further exploration.

- Fractures along the Manyara Escarpment northwest of Lake Balangida and about four miles northeast of Lake Balangida (both labeled A-6 on the overlay).

- Fractures northeast of Lake Balangida Lelu.

Vegetation-Soil Systems: No semidetailed or reconnaissance level soils surveys have been conducted in this land system unless being currently done by the Canadian Soils Team. Thus intensification of information in both the areas of soils and vegetation will come from subsequent work in this highly promising and productive land system. The following can be said of the vegetation from work of Sheehy and Green (undated ms.). The Woodland units (340) in the southeast are dominated by Brachystegia speciformis-Schlerocarya caffera. Associated species are Commiphora schimperi, C. fischeri and Euphorbia candelabrum. To the north the woodlands include Brachystegia boehmii and in the upland dry forests common species are Ekbergia sp., Pygenum africanum and Albizzia gummifera. The Moderately Dense Thorn Scrub/Brush (323) is dominated by Acacia tortilis-Commiphora schimperi. Other important shrub species are Acacia seyal, A. drepanolobium, A. stuhlmannii, and Balanites aegyptiaca. On the southeast, Terminalia sericea, T. kilimandscharica and Ostryoderris stuhlmannii are more important in the bush. The Acacia-Commiphorabushland also continues to the north where it tends to occur on soils of volcanic origin. The Open Thorn Schrub/Bush (324) is similar to the Bushed Grassland of other writers. The most prominent type is dominated by Hyparrhenia-Acacia. Important grass species in the Land System are Hyparrhenia rufa, H. filipendula, Themeda triandra and Pennisetum mezianum in the area south of Mt. Hanang. In the central part and to the north Andropogon gayanus and Aristida sp. are important and also occur along with Hyparrhenia rufa as understory in the upland dry forest at its lower elevational extent.

The best available soils information at this time is the Soils Map of Tanzania. It suggests that the most prominent soils are Ferrisols from crystalline rocks, Kc, wherever they are derived from the basement complex and uninfluenced by volcanics. Eutrophic Brown soils, Ha, occur on volcanic ash, lava and pumice on and near the tops of the volcanos. Tropical Soils developed from ferromagnesian minerals and lavas, Jb, are prominent on the lower slopes of the volcanic mountains. Ferrisols from sandstones, sandy sediments and sandy colluvium, Kd, are found in the area along with Ferrunginous Tropical Soils, Jd, (the latter especially in the north). Hydromorphic mineral soils, Na, and complexes of these soils with Vertisols, Na-Dj, are common in the lowlands.

Infrastructure and Present Land Use: Transportation: This Land System is transected by approximately 145 miles of "all weather" road and approximately 65 miles of main track, dry weather road. The intervening areas are traversed by predominantly low density of subordinant tracks and trails except that two topographic quadrangles (Hanang and North Bubu-Bereku) show moderate to high density of subordinant tracks and trails. Except for the black-top rock areas elsewhere in the Region, this Land System has good to excellent ground transportation as compared to most other Land Systems. Urban: The three main village and population centers are Babati, Dareda and Katesh. The habitation density as judged from the topographic sheets ranges from none in many square km areas to 6 to 19 habitations per km^2. Agriculture: Agricultural development is generally heavy throughout the central and northern part of the Land System. It includes large scale sisal and wheat plantations and commercial farms as well as the usual array of small-field and subsistence agriculture (figure 4-12). Peripheral to most of the mountain areas and on the better of the volcanic soils as well as in many of the wet valley bottoms, cropland development is intensive. The higher densities of agricultural development are in the northern end of the Land System, except for the large field, commercial agriculture (wheat and maize) south and southeast of Mt. Hanang. In the extreme southern end of the Lad System, there is little agricultural cropping. Range: Practically all of the Land System not in crops is grazed by mixed herds of the pastoralists. The Tarangire Game Reserve extends into the northeastern corner of the Land System south of Lake Burungi. This land system is very important for both the development of grazing and cropland agriculture and offers many opportunities for the integrated management of these two land uses for the benefit of each. Forestry: There are approximately 62 square miles of mountainous and hilly forest land and two Forest Reserves in the area. Significant amounts of woodland are complexed with 154 square miles of thorn/scrub and grassland. Disease Limitations: Most of the Land System falls in a 3- to 6-months transmission period for malaria and is mostly free of tsetse fly and sleeping sickness except for the northern area both east and west of Babati where Glossinae morsitans is common and sleeping sickness is also reported. The Kondoa rock painting archeological area has been noted to extend into the Hanang-Babati Land System on its southeast side.

Land Use Capability: The agricultural land capability is generally high (AI to AIII) on all volcanic soils surrounding the mountains and in the north of the Land System. The entire Land System is indicated as "candidate" to "marginal" for agricultural development with the poorest of the agricultural land potential in the extreme south. The entire area is generally good for Range except in the steep forested mountain areas and on valuable watersheds where domestic livestock use should be limited. This Land System includes many developed agricultural areas where attention should be directed to increasing the productivity of existing agriculture and further expansion into remaining Class AI and AII soils before concentrating great expenditures of funds and manpower on less promising areas.

Grazing is sufficiently important throughout, that integrated planning for both uses should be the guideline in this Land System. On good soils, rainfall generally appears non-limiting for cropland agriculture--and by the same measure would tend to provide consistently good and dependable fodder resources for animal agriculture.

Based on the Tanzanian Atlas the most important soils likely to be found in this are are Ferrisols from crystaline rocks, Kc, (Capability AIII and AII), Eutrophic Brown Soils of Tropical Regions from Volcanic ash, lava, and pumice (Capability I and II where steepness of slope and position on the mountain cones does not preclude development); Ferruginous Tropical Soils from Ferromagnesian soils forming materials and lavas, Jb, (Capability AIII and AII, surrounding the volcanic mountains on their lower slopes); some Hydromorphic Mineral soils, Na, (Capability AIII, AIV, and some AII); along with complexes of these Hydromorphics with Vertisols of topographic depressions, Dj, (Capability AIII, AIV, and some AII with the Vertisols generally in the AIV class).

Present indications are that this Land System should receive increased attention for Integrated Resource Planning and Development with a view to balancing cropland and animal agriculture, restoring and maintaining range values through proper stocking and good range management, and the development of such forest resources as do not lower watershed values through denudation.

4.3.2 Generalized Land System Descriptions

Generalized Land Systems descriptions for several of the Land Systems which have been designated as candidate agricultural development areas are presented in this section.

The geographic location of each Land System is shown by a shaded area on the map insert in the upper right hand corner of each page; the name, number and square mile area of each Land System also appears at the top of each page.

Descriptive information is organized according to the following subject outline:

Geographic Location:

Climate:

Land Units:

Geology:

Ground and Surface Water:

Infrastructure and Present Land Use:

Land Use Capability:

Table 4-2 summarizes the map designator numbers, names, and appropriate areas (square miles) of all 36 Land Systems in the Arusha Region. The areas of each Land System were carefully determined from the 1:1,000,000/color mosaic overlay of Land Systems. For technical reasons they may not perfectly represent the true area of the Arusha Region or of the individual Land Systems, but they are sufficiently accurate to provide information on the relative areal importance of each Land System.

TABLE 4-2

Approximate Areas of the Land Systems in the Arusha Region, Tanzania.

Land System Number	Name	Approximate Area (sq. mi.)
1	Mundorossi	410
2	Oldonyo Ogol	900
3	Angata Kheri	550
4	Serengeti	1,350
5	Angata Salei	820
6	Natron Escarpment	150
7	Lake Natron Basin	370
8	Kibangiani Rift	170
9	Engaruka Basin	1,000
10	Kisirien-Loldarobo Hills	440
11	Gelai-Kitumbiene-Shompole Volcanics	650
12	Ngorongoro	1,226
13	Kekessio-Endulen	380
14	Mbulumbulu-Oldeani	450
15	Lake Eyasi Basin	830
16a	Yaida Highlands-Kidero	360
16b	Yaida Highlands-Shipunga	30
16c	Yaida Highlands-Haidom	180
17	Tlawi-Seremal Valley	180
18	Lake Manyara Basin	1,050
19	Marang-Nou	800
20	Yaida Valley	270
21	Basotu-Bashaiy	1,030
22	Hanang-Babati	1,205
23	Mangati Plains	320
24	Oldonyo-Sambu-Longido	920
25	Ngasurai	300
26	Ol Molog	220

TABLE 4-2 (Continued)

Approximate areas of the Land Systems in the Arusha Region, Tanzania.

Land System Number	Name	Approximate Area (sq. mi.)
27	Meru-Losiminguri	1,200
28	Meru-Monduli Toe Slopes	1,300
29	Masai Steppe Transition	1,850
30	Lelatema Mountains	500
31	Ruvu River	270
32	Simanjiro Plains	800
33	Lolbene	1,050
34	Makame-Naberera-Kitwai	6,501
35	Kibaya	1,750
36	Sunya	860
	TOTAL:	32,650

Land System: MUNDOROSSI -- No. 1, 410 sq. mi.

Geographic Location: Extreme northeast corner of Arusha Region and north of the Ongatageri Plain Subregion.

Climate: Precipitation from 635 - 762 mm (25 to 30+"), increasing as one moves to the northwest. Probability of 500 mm 1 year in 10.

Land Units: About 60% of the area is flatland macrorelief and 40% hilly. The former are planar surfaces, upland plateaus and are both dissected and nondissected. Elevations range from 1,830 to 2,290 m (6,000 to 7,500 feet). The land units are defined by the following vegetation-landform types:

(1) Thorn Scrub/Bush, Moderately Dense (323) predominate in the hill systems.

(2) Complexes of Grasslands (314) with inclusions and complexes of Thorn Scrub/Bush (323) predominate in the plateau areas.

(3) Dense Thorn Scrub/Bush (322) or Thorn-tree Forest (Woodland) (342.3) dominate the drainages.

Geology: A basement complex of rock types underlies most of the area. Hills are generally quartzitic schists and quarzites, some gneiss on higher hills. Would produce high-silica soils and stringer soil types high in muscovite (potassium mica).

Ground and Surface Water: Some perennial and seasonal springs occur at the foot of quartzite ridges. Said to be well watered for dry season grazing. Gordon and O'Rouke indicate geohydrological analysis has identified several promising faults, fractures and fault on fracture intersections for potential ground water development.

Infrastructure and Present Land Use: Surface travel difficult, roads poor. Habitation small clusters, little social cohesion. Farming subsistence, very small cultivated areas. Primarily domestic livestock and game use. Borders Serengeti National Park on the west. In Loliondo Game Controlled Area. Tsetse fly moderate to low; malarious none or only near water.

Land Use Capability: Climate appears non-limiting. Primarily domestic and wild animal grazing. Limited agricultural development. Soils suggest Cropland Capability Classes AIII, AIV, AV, and some AI and AII. Rangeland Capability mostly RI, RII, and RIII. Soils classes: Reddish Brown Soils of Semi-arid Regions, older rocks, chiefly gneiss, Gc (AV, IV); Weakly developed Lithosols, basic parent materials, lavas and gneiss, Ba (AV, IV); Vertisols of topographic depressions, Dj (AIV, III); Ferruginous Tropical Soils, ferromagnesian rich, Jb (AIII, II); and Humic ferrisols of high altitudes, Ka (AI, II).

Land System: OLDONYO OGOL -- No. 2, 900 sq. mi.

Geographic Location: West of Lake Natron extending across the Kenya border. Its southern extension separates the northern portion of the Serengeti plain from the Angata Kheri plain. The land system is bordered on the east by the abrupt north-south Rift Valley scarp.

Climatic Characteristics: Rainfall in this area varies between 430 and 900mm (17" to 35") with the lower precipitation levels prevailing to the south and corresponding to the somewhat lower elevation hills. Precipitation in general tends to increase as one moves from the southeast toward the northwest. The lowest estimate of probable precipitation is approaching 500mm 1 year in 10.

Land Units: This area is predominately (90%) 3.7, hilly slope systems, and about 10% 1.5, flatlands. Relief within this land system generally becomes greater and greater as one moves toward the east and eventually drops off into the Rift Valley. Elevation changes from approximately 1,830 to 2,530 meters (6,000 to 8,300 feet).

About 85% of this area is characterized as 323, Thorn Scrub (Bush) of Moderate Density, and about 15% as 314, Grassland. It is a bushed grassland complex of grassland and thorn scrub. The latter complexes tend to occur on the gentler relief. A small portion of the area is classified 324, Thorn Scrub (Bush) Low Density. Quite a number of the stinger valleys indicate moisture-loving, phreatophytic vegetation. All are small and constitute inclusions as the Land Units were mapped.

Geology: This hill system is generally Precambrian siliceous rocks including quartzitic schists, quartzites and some muscovite (potassium mica) schists and gneiss. Adjacent to the Rift there are some young volcanic alkalic and calcalkalic rocks. As the Rift Valley is approached the likelihood of encountering saline or high flourine content waters increases. Gray brown calcareous tuffs occur at higher elevations associated with the volcanics.

Ground & Surface Water: The groundwater exploration areas are not ranked. They consist of alluvial fans and fault or fracture intersections, especially close to the highlands. Recharge probability is satisfactory. Gordon and O'Rourke indicate a number of both temporary and permanent springs throughout the mountain range and one successful and one dry borehole within the land system.

Our fracture and groundwater analysis shows a moderate density of fractures trending in both a northeast-southwest and northwest-southeast direction but relatively small numbers of them intersect in a manner to suggest high likelihood of enhancing the availability of groundwater. There are a number of areas in the valleys where phreatophytic vegetation suggests permanent surface or shallow groundwater. At the north end of the land system, there are some foliated layers in the crystal rocks, evidenced by the vegetation, that may contain groundwater. Over the entire area there may be some small, shallow reservoirs of groundwater in the weathered crystalline rocks. This is especially true at the bases of scarps around the hill areas where it is likely that deposits of course-textured alluvium may contain groundwater.

In summary, this land system is probably not rich in groundwater except in locations where phreatophytic vegetation or the foliated crystalline rocks suggest the possibility of the groundwater reservoir. There may be numerous locations throughout the land system where surface water storage would be feasible. These locations can be most effectively selected and initially evaluated from the interpretation of small-scale aerial photography. Erosional basins or basins with low erosion potential should be given highest priority in site selection.

Infrastructure & Present Land Use: The unit is presently being used primarily for grazing of livestock and game. Most of the agricultural cropping is subsistence agriculture. The main center is Loliondo, and one poor road system runs more or less north and south through the unit. The Land System includes one forest reserve near Loliondo. There is an airport, hospital and schools at Loliondo and also schools and churches at other outlying villages within the Land System. A poor road and track net connects the existing settlements.

The northern portion of this land system includes the major part of the Loliondo priority area of the Masai Livestock Project.

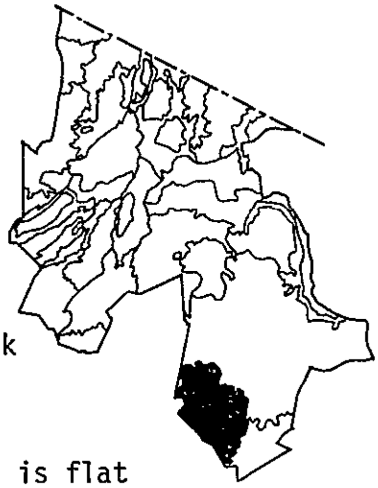
The Oldonyo Ogol Land System is in Conyers (1973) Agroeconomic Zone 013.3 Zonal Group 14a. This places the area in the more or less typical Masai livestock culture with very small-field agriculture limited essentially to maize and bean production at a subsistence level. The better of the agricultural areas are in the uppermost highlands.

Land Use Capability: The primary potential of this area is for grazing of domestic livestock and game. Small scale subsistence and possibly low volume commercial agriculture may be feasible on the very best soils, but these are also the best rangelands in many cases. While much of the area has a fair to good agricultural potential, shallow soils and a relatively low rainfall are limiting. The dissected landscapes pose severe limitations to large scale agriculture. There are sharp climatic limitations to agriculture between the lowlands to the west and the better uplands. The major soil classes of the area, as shown on the Soils Map of Tanzania, are Ferruginous

Tropical Soils from rock rich in ferromagnesian minerals including lavas, Jb, (Classes AIII and AII), humic ferrisols of high altitudes Ka, (Classes AI and AII with some AIII). Particlularly in the south are found Brown and Reddish Brown Soils of Semi-arid Tropical Regions from older rocks, chiefly gneiss, Ge, (Classes AV and AIV). Weakly developed, undifferentiated Lithisols with low agricultural potential, Ba, (Classes AV and AIV), are indicated within the hill system. Also in the south small areas of Vertisols in topographic depressions, Dj, (Classes AIII and AIV) are indicated by the Soils Map of Tanzania. There is apparently a limited forest potential in the area. A more critical examination through interpretation of appropriate larger scale aerial photography may reveal expanded opportunity for economic use of the woodlands. On the other hand, forestry and cropland agriculture may be competing alternatives but with less potential conflict than in the cropland-range interface.

Resource Management Needs: One of the greatest potential problems in this area is soil erosion, particularly on the steeper slopes and the quartzitic soil areas. On many of these kinds of soils, once the turf is broken, a chain reaction of very severe erosion begins that is difficult to arrest. Some of the primary problems of the area may well involve efforts to maximize compatability between subsistent cropland agriculture and livestock grazing. Increased opportunities may exist to improve the utilization of crop aftermath and crop waste in domestic animal production during the dry season. It probably is not feasible to convert potential cropland to pasture. In the subsistence farming context it may be feasible to harvest natural fodder during the latter part of the rainy season and the beginning of the dry season, storing it for animal use late in the dry season.

Land System: KIBAYA -- No. 35, 1759 sq. mi.



Geographic Location: Extreme southern end of the Arusha Region, lying between the Makami Depression and the Regional Boundary. It includes the Kibaya priority area of the Masai Livestock Program, the Kibaya Livestock Association Area, and the western one-third of the Sunya Livestock Association Area.

Land Units: Except for a few isolated hill systems, the area is flat to undulating. Many of the hills, while qualified by virtue of relief, are very gentle and smooth in contour giving the impression of a strongly rolling land form. Elevations range from 1160 to 1945 meters (3,800 to 6,380 feet). Grassland (314) Mbuga, on depressional landforms, 1.12, are common in this land system but smaller and less numerous than in the land systems to the east and north. The uplands generally support dense bush (322/323) and the hills are wooded (340). Typified by thickets as classified in other literature. Approximately 60 to 70 percent of the land system supports this kind of vegetation (322). The depressional mbugas support 314, Grassland, and Grassland/Bush Thickets (314/322). The latter occur as small patches throughout and commonly on the periphery of the mbugas. There are a few mbugas identified as 324, Low Density Thorn Scrub. In some areas the thicket and bush is complexed with woodlands (340), that is, taller forest trees. Generally speaking the latter do not form a closed canopy but are interspersed as patches with the grasslands and/or the thickets and bushland.

Climate: Average percipitation throughout this land system is in the vicinity of 635 mm (25") with a probable range of 550 to 700 mm (21 to 28").

Geology: This area is underlaid by rocks of the basement complex, mainly gneiss, granulite, schist, quartzite and marble. Moving to the south one trends toward a granite area; typical hills of these rocky materials protrude through the gently undulating to rolling landscape to form the isolated ridges and hill systems. There are substantial fault scarps to the west of this land system that give rise to very gentle east-facing dip slopes within the western edge of the Kibaya Land System.

Ground and Surface Water: This land system is intricately dissected by a high-density network of faults. The best potential is in faults near elongate mbugas. Contains many large mbugas associated with linear faults. Although many mbugas have accumulations of surface water, salinity within the mbugas may be a problem. It may be beneficial to drill in the faults connecting the mbugas to intersect the fresher ground water before it reaches the surface.

Gordon and O'Rourke (1973) indicate two existing surface water catchments in the land system and nine boreholes of which six are dry. They also show some permanent springs in the vicinity of Kibaya. In the vicinity of Dosidosi they show three successful and two unsuccessful boreholes. Van Voorthuizen (2) indicates that dams constructed by W.D. & I.D. show no signs that they ever held much water," but he goes ahead and suggests emphasis on surface water storage.

Infrastructure and Present Land Use: Traversed east to west by one graded road, partially surfaced in critical areas, running from Korogwe through Kijungu to Kibaya and on west. From this road "fair-weather tracks" run north into the Masai Steppe and a good road runs south to Dosidosi. There are a few jeep tracks interconnecting.

The area lies within Agroeconomic Zone 013.3 and in Zonal Group 14a of Conyers (1973). This places it in an area of typical Masai culture, although this land system has a growing proportion of settled agriculture--much more than is typical of the Masai Steppe to the northeast. Strong evidence of settled agriculture making inroads into the thickets and on mbuga fringes in this land system; substantial changes since the early to mid 1960s. Present land use predominately grazing; settled agriculture is in a predominately subsistence mode; evidence of increasing field sizes, some increasing potential for semi-commercial production, particularly of maize.

Land Use Capability: Agricultural potential of this area appears fair to good. May be limited by moderately deep soils having low fertility and low water-holding capacity. According to the Tanzanian Soils map, the most prominent soil of the area is the Reddish-brown soil of semi-arid tropical regions derived from older rocks, chiefly gneisses, Gc (Classes AV and AIV). Others are weekly developed Lithosols from basic rocks, Ba (Classes AV and AIV). The Vertisols, Dj, in mbuga areas are said to have agricultural capability from AIII to AIV with occasional AII areas, but these are very hard soils to work agriculturally, and generally provide some of the best late season grazing so that their range value would be capability Class RI and RII.

Severe, current limitation to the development of commercial agriculture in this area is the availability of water. There may be significant potential for improvement, at least to provide more adequate water for direct human and animal use. Reservoir storage potential remains to be determined.

Local experience seems to be demonstrating the feasibility of replacing the thicket vegetation on the better soils by cultivated agriculture. Little land use conflict likely from this practice because the dense bush problem; although from the air, the entire bush area appears heavily trailed and grazed. Improved maize production on the west; especially to the south, castor beans are produced as a cash crop; expansion in this area may be feasible.

Mbugas liberally scattered throughout the area are an important, dry-season grazing resource for the continuation of livestock agriculture. Livestock production could be substantially improved by better husbandry and by improving water distribution through a widely planned borehole program managed to improve range condition and productivity.

The woodlands do not seem to have economic potential beyond charcoal production.

Resource Management Needs: The primary resource management needs of this area are for improved range management and the enhancement of the animal agriculture with careful integration of cultivated agriculture and animal programs. If the full economic potential of this region and lands to the west is realizable, better transportation must be provided out of the region. The soil fertility limitation suggests another management problem which could best be approached through simple soil fertility and residue mulch programs.

Land System: Sunya No. 36, 360 square miles

Geographic Location: In the extreme southeastern corner of the Arusha Region and east of the Kibaya Land System. Includes the Sunya Priority Area of the Masai Livestock Project, the eastern two-thirds of the Sunya Livestock Association area, and approximately the southeastern one-half of the Talamai Livestock Association area.

Climate: Precipitation in this Land System ranges from about 460 to 635 mm (18 to 25"). It lies in the rain shadow of the Nguru Mountains, where drought between 250 and 500 mm can be expected at least 1 year in 10.

Geology: Rocks of the basement complex, mainly gneiss, granulite, schists, quartzite, and marble underlie this Land System. Additionally, in the land systems of Sheehy and Green (undated ms.) part of the area may fall within an area that includes some granite in the basement complex.

Land Units: This Land System was defined as strongly undulating, 2.6, with inclusions of hills, 3.7, and some nearly flat to gently undulating relief areas, 1.5. The Sunya Land System seems to be transitory between the flatter Masai Steppe and the extensive hill land (Nguru Mountains) to the southeast in Tanga Province. The drainage is essentially out of the Arusha Region to the east. The elevations range from slightly under 970 to 1,935 m (3,200 to 6,349 ft.).

About 40 to 50% of this Land System is classified as Shrub/Scrub, 320. The remainder is either Woodland, 340, or complexes of Moderately Dense Thorn Scrub (Bush), 323, with Woodland, 340. The hilly areas tend to be woodland and dense scrub or thicket, and the lowlands somewhat more open. While we did not consider grasslands and bushed grasslands extensive enough to map, they do constitute inclusions within the lower elevations and more gentle relief areas on the west. There are in addition a few grassland mbugas that occur as inclusions in the flatlands and lowlands (1.5).

The bushland species are Commiphora, Combretum, and Acacia mellifera. Woodlands and wooded grasslands are dominated by Brachystegia sp., Albizzia harveyi and Adansonia digitata. The grassland and bushed areas are dominated by Themeda and Pennisetum mezianum. In the woodlands Cenchrus ciliaris, Cynodon sp., Digitaria sp., Eragrostis superba, Heteropogon contortus, Hyparrhenia sp., Panicum maximum, and Setaria sphacelata are common. These reflect the good grazing qualities of the area.

Ground & Surface Water: There is an intricate complex of fracture systems in the extreme southwest corner of this Land System where it joins the Kibaya Land System. Another series of fractures runs more or less north and south along the west boundary of the Land System. A third fracture system arches eastward and northeast across the Land System, with a fourth set of fractures extending to the extreme southern tip of the Arusha Region. Areas of highest groundwater potential are probably where these fractures bound or cross mbugas. Fault and fracture systems in the metamorphics are likely. The northeastern portion of this Land System did not show extensive fracturing.

Gordon and O'Rourke (1973) show two surface water impoundments, one northeast and one southwest of Sunya, one seasonal spring, and a short pipeline at Pakini in the southern end of the Land System.

The more distinctive drainage pattern and the hill systems within this area suggest a potential for additional surface water storage. Examination of the area on larger scale aerial photography could provide an adequate initial assessment of this likelihood. Extreme importance should be attached, however, to the erosional stability of any watershed feeding a contemplated impoundment.

The Tanzania soils map indicates the possibility that some Ferrisols of the class "ferrisols of sub-humid regions chiefly on crystalline rocks" may occur within this Land System along with limited examples of "mineral hydromorphic soils" and possibly some Ferruginous Tropical Soils of the class "ferroginous tropical soils on rocks rich in ferromagnesian minerals, including lavas," on the extreme southeastern edge of the Land System as it becomes typically more hilly and more densely forested.

Sheehy and Green (undated ms.) describe the soils on the south and west side of this Land System as predominately "very dark grayish brown sandy loams over reddish yellow sandy loams which are strongly acid and usually less than 150 centimeter in depth. Included are areas of deep, medium acid, dark reddish brown loams over dark red clay loams and deep cracking black sandy clays. The latter occur in depressions and adjacent to streams. These soils often contain calcium carbonate nodules." On the somewhat drier east side and northern end of the Land System, they describe predominate soils as "moderately deep reddish brown to red sandy loams and sandy clays." They say the soils in this area are stony, and the landscape is often interspersed with bedrock exposures and with Vertisols or deep brown sands in the valleys.

Infrastructure & Present Land Use: Not well serviced by all-weather roads. A landing strip is indicated north of Mbjak Mbugu about 25 kilometers northwest of Sunya. Sunya is the major settlement within the Land System.

Used primarily for livestock grazing but there are a few subsistence farms producing maize. On the moderately deep reddish brown to red sandy loams and sandy clays of the eastern and northern portion, there is a higher proportion of maize and other food crop cultivation, but still on a subsistence farming basis. Castor beans produced as a cash crop. The remainder of the land is grazed by livestock, but limited somewhat by fly problems.

Land Use Capability: The agricultural potential of this area is indicated by Sheehy and Green as fair, but limited by marginal soil depths, low water holding capacity, and low fertility of some of the soils. As one moves to the east, agricultural potential drops because of the broken nature of the landforms as well as more marginal soil depths and low fertility. The soils map of Tanzania shows no marked difference between the soils of this Land System and of the Kibaya Land System to the west or the Makame-Naberera-Kitwai to the north. The more important soils appear to be reddish-brown soils of semi-arid tropical regions from older rocks, chiefly gneisses, Gc (Classes AV and AIV). Others are weakly-developed Lithosols from basic rocks, Ba (Classes AV and AIV). The Vertisols, Dj, in mbuga areas are said to have agricultural potential, but they are very difficult to handle and fall in Classes AIII and AIV with some limited areas of AII. The range capability of these same areas is RI and RII--especially valuable for late season grazing and much in need of maintenance for this exclusive use. Except for problems with tsetse flies, best use of the area appears to be for livestock grazing. Whether or not the woodland areas could provide a substantial source of charcoal is yet to be determined. Such could provide cash income if road systems were improved.

Resource Management Needs: The primary resource management needs of this area would appear to be (1) improved range and livestock management; (2) improvement of available water through surface storage, drilling programs, or both; (3) brush control with a view to improving livestock production and range management; (4) improvement of agricultural practice, initially on a subsistence basis, with encouragement of cash cropping where feasible (castor beans); and (5) improvement of the road system within and tributary to the unit.

5.0 INTERPRETATION OF LAND USE POTENTIAL

5.1 Introduction

Land use capability analysis involves a process of progressive refinement of resource information and technologic information, with the objective of perfecting development and management decisions related to optimum uses of the land resource. This present land use capability task is undertaken as one necessary initial step toward providing a framework for analysis, and a methodology that may be used for years to come by professionals engaged in land capability analysis in Tanzania. This program is designed to provide a platform, based upon a regional view of land use potential, from which more detailed work can be accomplished in a far less costly and a more time effective fashion than is traditional.

An objective of this project is to establish a basis for developing a multi-stage, hierarchical perspective for use in analysis and planning. The goal of such a perspective is the traditional one, to know the potentials and alternatives for each acre of high value land and each area of useful land. The route and order of attainment of this goal has changed because of the availability of LANDSAT data. In the approach we herein use one first develops regional perspective. The region is broken into macro components that share key environmental system features. Following this organization of data, and after a more thorough analysis and a better organization of information relevant to decision making, one may set regional priorities. Given a set of land priorities in regional perspective, traditional forms of semi-detailed (1:50,000) or detailed resource mapping programs can be efficiently undertaken using, where possible, multi-stage sampling techniques.

5.2 Definition of Terms and Concepts: Land Use Capability vs. Land Use Suitability

The determination of land use capability, and subsequently of suitability or feasibility, is an interpretive process. Decisions are based on integration of a variety of corollary data and resource information, and the same considerations are involved whether one is working at the regional or the detailed project planning levels. Judgments must, therefore, be somewhat subjective and limited by the best information available at the time. The decision processes usually represent a series of approximations, iteratively derived, each one of which places the decision maker in a position of greater certainty about the accuracy of interpretation. As the amount of organized support data relative to resources and climate increases, the character of the process necessarily changes. It can reach a point where classifications may be based on both qualitative and quantitative scores for each land unit (Storie, 1937, 1964), and land units may even be modeled in the mathematical sense.

The notion of "Land Capability" has inherent in it the concept of quality and the concept of risk. The characteristics of the land and its climatic setting, as they relate to a particular use or development alternative, are stated qualitatively as are the risks inherent in imposing upon the land a series of uses. While the characteristics of the land are fixed, they have different values when different use alternatives are considered. Obviously, most land areas have more than one use alternative, and as the quality of land improves the multiple or alternative-use capability increases also.

Ideally, a given area of land should have a separate capability score for each candidate use. Standard agricultural land use capability assessment procedures commonly used during the past decades have tended toward a single scoring system. Such scoring systems deny the decision maker information needed to assess trade-offs. The approach used in this Arusha Region Land Use Study provides, insofar as time and information permit, individual interpretations of land use capability for agriculture crop production and for range production. A similar evaluation procedure can be developed and added for other candidate uses.

Land capability assessments cannot be made absent assumptions about investment levels and/or levels of technology to be applied. Some lands that can sustain agricultural use at a subsistence level will not retain their agricultural use under moderate or high inputs of mechanical technology without substantial investments, such as as those represented by contour terracing, grassed waterways, etc. Without substantial capitalinvestment, such land must be classified as UNSUITABLE for other than subsistance agriculture even though it has greater potential capability, given adequate investment in technology and necessary preventative and management treatment. In some cases, planners may have an option to vary the amount of technological input from subsistance to moderate or high (maximum productive inputs). In other cases the land itself in its ecosystem dictates that minimum input levels are absolutely required to achieve and perpetuate site productivity.

As more detailed data are obtained, one may approach land and resource development from three levels of technological and economic intensity: subsistance, moderate, or high (maximum productive input). For purposes of this study, the Land Use Capability Rating or classification assumed a level of technological input, which if applied will prevent the loss of basic site qualty or productive capacity. It did not assume major investments to change the existing ecosystem, which in turn requires additional inputs of capital, management, and technology to achieve implementation and to counteract ecological effects.

Land suitability starts with the notion of capability, and advances to include the consequences of applying a specified alternative. Determination of the suitability of land for alternative uses requires the evaluation of economic, social, and even political tradeoffs involved in such uses, in addition to the evaluation of quality and risks that is a part of the capability definition.

Following are some of the general areas that are evaluated in deciding feasibility or suitability of a candidate land use:

1. Economic and social short-term vs. long-term goals, and the possible impact of all irreversible allocations of resources on these goals.
2. Tradeoffs among alternative or multiple-use options, and their impact on the goal to optimize the contribution of each land area toward meeting development objectives on a sustained yield basis.
3. Downstream problems, such as demands for new infrastructure or dislocation of other segments of the economy, that may arise from the decision to favor a particular land use or set of uses.
4. Capability of society to afford the costs in the form of education, extension, and social adjustments necessary to insure success, as well as the benefits of the land use and resource allocation options.

The criteria and determinants of land use capability and of land suitability are different. Capability determinants must be matched with the suitability/feasibility criteria for each area, and a decision made on the optimum land use or combination of uses in each planning area. Planners and managers must then recommend and implement these decisions to achieve the resource development goals within the environmental constraints that are determined by fundamental ecological principles and the allowable risk limitations associated with development.

5.3 Ideal Information Requirements for Determination of Land Use Capability

Considerable quantities of relatively detailed resource information are required to support local, site-specific land use capability assessments.

To the extent that the data are available, one can decide land capability by matching detailed resource characteristics with the requirements of alternative uses.

The approach used during Phase I to achieve the first iteration of land use capability evaluation has been to use the LANDSAT-derived Land Systems and Land Unit delineations and descriptors as the resource characteristics (regional level), and to use the climatic threshold as the primary requirement for agricultural capability. The judgments are also supported by all the other data relating to the full range of quality and risk factors called for in an ideal analysis, but only to the extent that that information is presently available. These other ideally required but frequently not available forms of quality and risk information descriptive of the land resource include the following parameters:

A. Climate

   a. Amount and seasonal distribution of precipitation.

   b. Likelihood and severity of drought, probability of specified drought frequencies.

   c. Temperature characteristics, growing season minima and maxima; likelihood of frost.

d. Evapotranspiration and moisture balance during the growing season.

B. Geology

a. Tectonics in relation to structural stability, availability of ground water, and mineralization.

b. Lithology and minerology in relation to soil development, maintenance of fertility, and erosion.

C. Soils

a. Depth.

b. Texture and/or stoniness (surface and subsoil).

c. Profile morphology (horizonation, structure, permeability, freedom from pans and restrictive layers).

d. Fertility/salinity/alkalinity.

e. Soil forming material and nature of the underlying substratum.

f. Moisture holding capacity in relation to effective ppt or moisture balance.

g. Susceptibility to erosion and deterioration.

D. Vegetational Ecosystems

a. Kinds of plant community types, vegetation associations.

b. Vegetation-soil-landform relationships.

c. Autecology (environmental requirements) of key plant indicators.

d. Vegetation (plant community) climatic relationships.

e. Seral status and successional relationships among community types.

f. Inherent stability or fragility of the ecosystem, successional recovery potential.

Environmental and resource requirements of the alternative land uses constitute the corresponding information posed on the other side which must be compared with the land resource characteristics to make capability assessments. These latter parameters involve a knowledge of crop ecology on the agricultural side, and on the range, wildlife, and forestry side they call for an accumulation and summary of resource development and management experience in relation to each specific land unit or natural vegetation-soil system.

5.4 Basis and Procedure for Arusha Regional Capability Interpretation

The process of land use capability assessment involves a comparison between the land resource characteristics and the corresponding resource requirements of the alternative uses being considered.

As has been pointed out in earlier sections, much of the detailed, descriptive, land resource information required under ideal circumstances to make site specific land use capability evaluations is simply not available at this point in time for the Arusha Region.

The LANDSAT satellite imagery interpretation approach to regional capability evaluation depends upon several premises:

1. Regional land resource characteristics can be spacially defined (land unit and land system delineations) through the combined image interpretation, background data assimilation and ground checking process;
2. Inadequately known elements of important essential resource information needed for capability analysis can be broadly inferred to a sufficient degree from the covariant Land Systems and Land Units area descriptions.
3. The large number of differences in land resource characteristics recognized in the course of image analysis and delineation (i.e., 550 land units, voluminous geohydrologic information throughout the Arusha Region) and used initially in the Regional capability interpretation, will find continued application later in development planning and ongoing resource management at the District and semi-detailed levels. Land units differentiate areas of potentially different land use development capability, and geohydrologic data has site specific applicability.

The validity of the approach to land classification which begins with a general resource description and then proceeds to more detailed resource surveys within priority areas has been demonstrated elsewhere. When the Canadians began the comprehensive Canada Land Inventory and the land capability assessment of their undeveloped territories, they brought together a group of 44 natural resources leaders who investigated approaches to land classification and resource allocation throughout the world. In terms of approach and procedure they concluded:

> "Discussions . . . have led to the general agreement that a land classification that begins with a broad aerial appraisal of land resources and provides a summary of data that sets the stage for more detailed work on those areas that warrant closer attention is the most practical one [for a large developing country] (Lacate, 1969)."

The most important, inadequately known characteristic, which was in effect inferred and generalized from the LANDSAT-derived land systems and land unit delineations descriptions was the operative climatic regime across the region, with special emphasis on the most likely extent of areas above and areas below the 600 mm mean annual precipitation threshold.

The results of regional capability interpretation were described previously in Section 4.0.

The capability judgments made in Phase I are interpreted at a reconnaissance level (Scale 1:1,000,000) so that a perspective of the entire Region can be seen. The primary goal is to define and classify areas as: (1) low-risk candidate areas for agricultural development; (2) probable high-risk candidate areas for development; and (3) areas predominately unsuited to agricultural development which should remain in pastoral (animal agriculture), wildlife, or forest use. Decisions are binary with respect to agricultural vs. range, and binary (high risk/low risk) within the agricultural category.

Because of the complexity of individual landscapes in terms of the point to point capability of the land, any attempt during Phase I to refine capability designations beyond that of broad "candidate areas" for which more detailed quantitative studies should be justified is presumptious.

5.5 Requirements and Thresholds for Land Use Alternatives

The regional, agriculture versus range use capability interpretation was performed in Phase I by comparing all known and inferred descriptive resource information with corresponding climatic, soils, and physiographic requirements and thresholds. A brief discussion of agricultural and rangeland use requirements and thresholds is presented below.

5.5.1 Climatic Thresholds

A discussion of the basis for selection of a mean annual precipitation threshold below which agricultural development would likely be of prohibitively high risk is presented in Appendix D.

Climate, and particularly the amount and timing of precipitation, is thought to be the most important single determinant of land use capability potential on the Regional level. After considering all available climatic data as described in Appendix D, a climatic threshold of 600 mm mean annual precipitation was chosen as a climatic threshold for agricultural capability assessment. By using a 600 mm cutoff point, one would tend to push the agricultural fringe further than prudent judgment may allow. This would, however, encompass the majority of areas where compensating soil or landform characteristics would permit isolated agricultural development in preference to pastoral or animal agriculture. At the same time, this places the responsibility directly on the land use planner and development officer to be sure that new cropping is restricted to the better class soils when proposing new developments or agricultural expansion in the high risk area below more conservative climatic guidelines which have been recognized by Heady and others.

5.5.2 Soil Parameters and Thresholds

With a few exceptions, soils information at an adequate level of detail for meaningful, location-specific interpretations of land capability is lacking except for the land systems as a complex. In characterizing the land systems and in projecting candidate areas for agricultural development, a method was devised based on the soils classification and land use capability groupings used in the Tanzanian Atlas. These criteria (Table 5-1) were applied together with climatic and elevational information at a land system level. This constitutes a major refinement over previous atlases and small-scale regional treatments.

TABLE 5-1: LAND USE CAPABILITY GROUPINGS BASED ON THE SOILS AND CAPABILITY UNITS AS DESCRIBED IN THE ATLAS OF TANZANIA

	Major Soil Groups Included		
Agricultural Capability	Symbol	Name	Derived From
I and II (III)	Ha	Eutrophic Brown Soils of Tropical Regions	Volcanic ash lava and pumice
	Ka	Ferrisols	Humid, of high altitudes
	Kb	Ferrisols	Humid, from crystaline rocks
III and II	Jb	Ferruginous tropical soils	Ferromagnesian minerals & lavas
	Jc	Ferruginous tropical soils	Crystaline, acidic rock, chiefly granite
	Kc	Ferrisols	Subhumid, crystaline rocks
III and IV (II)	Bo	Juvenile Soils on Recent Deposits	Riverine & lacustrine alluvium
	Dj	Vertisols	Topographic depressions
	Hc	Eutrophic Brown Soils of Tropical Regions	On alluvial deposits
	Me	Halomorphoric Soils	Solonetz & Solodized Solonetz
	Na	Hydromorphic Soils	Mineral
	Nb	Hydromorphic Soils	Organic
III	La	Ferrallitic Soils, yellow-brown	Sandstones and sandy sediments
	Ls	Ferrallitic Soils, Humic of high altitudes	various
	Lx	Ferrallitic Soils, yellow and red	various

TABLE 5-1: (CONT'D)

Capability	Major Soil Groups Included: Symbol	Major Soil Groups Included: Name	Derived From
IV	Ca	Calcimorphic Soils, Rendzinos, brown or red-brown	Limestones & corals
	Cd	Calcimorphic Soils, brown	Volcanic tuff, ash or lacustrine sediments
	Fa	Podzolic Soils, Pseudo-podzolic	high veldt
	Gb	Brown Soils of Semi-arid Tropical Regions	Volcanic ash or lava
	Jd	Ferruginous Tropical Soils	Undifferentiated but many on sandy SFM
	Kd	Ferrisols	sandstones, sandy sediments, sandy colluvium
V and IV	Ba	Weakly Developed Soils, Lithosols	Basic rocks, chiefly lavas and gneiss
	Cb	Calcimorphic Soils w/Calcaveous Pan	Volcanic ash, tuff or lacustrine sediments
	Ea	Podzolic Soils	various
	Gc	Reddish-brown Soils of Semi-arid Tropical Regions	Older rocks, chiefly gneisses
V	Aa	Raw Mineral Soils, Rocks and Rock Debris	Lavas and gneisses
	Ac	Raw Mineral Soils, Rocks and Rock Debris	Acidic rocks
	Bd	Weakly Developed Lithosols	Acidic rocks
	Bn	Juvenile Soils or Recent Deposits	Volcanic ash often wind sorted

TABLE 5-2

LAND USE CAPABILITY GROUPINGS

FROM THE MONDULI AND BASOTU AREA

SURVEYS (from work of Presant, 1974)

Soil Class	Agriculture Capability Class
Eutrophic Brown (Inceptisols) (>600mm)	I, II, (III)*
Calcimorphic Brown (Mollisols) (400-600mm)	(II), III, IV
Vertisols, Calcareous Rock, Raised	III, (IV)
Vertisols, Topographic Depressions	(III), IV
Lithosols (Entisol, Orthents)	(IV), (III), V
Alluvial Soils (Entisols)	(II), III, IV
Raw Mineral Soils (Limestone,	V
Ferruginous Soils (Alficols & Ultisols)	II, III, IV
Mineral Hydromorphic Soils	II, III

* Capability class designators in parentheses indicate that the soil class only rarely falls within the capability class so designated.

There are a few semi-detailed, site-specific, soil surveys and land use capability projections in the Arusha Region (Presant, 1974a, 1974b). This work, being done as background for wheat production schemes, is currently in progress, and additional areas have been inventoried since the two initial areas near Monduli and Basotu were completed. The information in these latter studies (Table 5-2) was cross-checked with the guidelines derived from the Atlas, and some minor adjustments were made where necessary.

The following additional useful information relating to land use capability was abstracted from the work of the Canadian team:

> Soil depths of 30 cm or less are generally severely restricting for agricultural production, resulting in land use Class V, nonagricultural; (although they may be Class II or III rangeland).
>
> Upland vertisols are better drained and some are represented in agricultural capability Class III.
>
> "Lithosols .... over bedrock .... or on strongly sloping land .... are better left unbroken or planted to improved forages."
>
> Shallow soils over bedrock, 30 to 75 cm in depth, are frequently restricting, and would result in assignment to a low agricultural capability class unless compensated by climate or other soil characteristics that improve their moisture holding and release characteristics.
>
> Class I soils are generally found in areas of 800 to 1,000 mm mean annual precipitation.
>
> Soil areas that slope between 2 and 5% are generally in agricultural capability Class II because of erosion risk,, [but these slopes would have negligible impact on rangeland capability].

> "Unless good land is scarce, Vertisols are probably better left untilled." [They are valuable dry season grazing grounds in Rangeland capability Class II or III.]

Several studies both within and peripheral to the Region were also examined where discussion of soils, soil-vegetation, and climatic relationships are indicated (Sheehy and Green, undated report circa 1968; Herlocker, 1972; van Voorthuizen, 1971). These studies were highly general in their treatment, except for Herlocker, and in some cases were found to be conflicting, so that confirming checks would be desirable before depending on them to clarify vegetation-soil-climate relationships relevant to land use capability questions. Currently available information related to soils and vegetation-soil relationships in the Arusha Region will be substantially expanded during the course of Phase II of the present study.

5.5.3 Topographic Tresholds

Because we must often infer climate and other capability parameters from covariant data and information, an elevation guideline would be useful if applied with constraint. Such a threshold has been suggested by Curry-Lindahl (1974) when he observed that most crops in the East African Highlands are raised above 1,500 meters (m) elevation. Comparisons with contour maps of the Arusha Region suggest that this may be a fair guideline when used with other data, at least for the southern Masai Steppe. Recognizing that temperature, precipitation, and evapotranspirational losses are related to elevation, Heady (1960) also suggested elevation as a factor of some, but limited, relevance in defining East African rangelands. He indicated that the majority of crop production in the area was found above 1,524 to 1,829 m elevation.

In making capability interpretations, mountain and hill systems may also affect their immediate surroundings by orographic influence or by producing rain shadow effects on the prevailing storm tracks. These should be taken into account.

For cropland applications, it is rare that a soil sloping over 5% will not be limited below class III or lower because of erosion risk, particularly from mechanical plowing. Steeper slopes can be effectively managed and utilized without deterioration under hoe agriculture, however, so the contemplated technology input is a strong determinant of the true capability. At the same time, in northern Tanzania the best of the agricultural land generally is found in the hilly and mountainous regions. This is partly due to the impact of these land systems on the local climate and additionally to the kinds of soils generally found in the hill and mountain areas--often being of more recent volcanic origin. Even here, however, the highest land capability for agricultural crop production is going to be on the gentler slopes (which are defined by microrelief rather than 1:250,000 scale macrorelief) and on the deep, loamy, more fertile soils.

Similarly, with respect to grazing use by domestic animals, effective utilization can be made of productive rangelands on slopes as steep as about 30 to 35%, provided the soils are not subject to high erosion risks. On soils derived from granites, however, grazing of domestic livestock has to be carefully managed, and large reserves of grass left for erosion protection. Where the slopes of these soils exceed about 20% or 30% slope, a cutoff point is reached above which domestic livestock grazing should be excluded because of the erosion risk. This point is even more critical under Tanzanian close-herding methods than it would be under the more open herd management typical of the temperate regions where livestock are handled under open range or in fenced paddocks without the close attendance of a herder.

6.0 GUIDELINES FOR CONTINUING USE AND REFINEMENT OF THE REGIONAL RESOURCE INFORMATION BASE

This regional resource and land use study has produced a characterization of the Arusha Region and organized the information for easy comprehension according to the Land System and Land Units method of analysis. It obviously has not answered all of the questions, but it has made clearer some of the environmental constraints and limitations within which one must work as one makes decisions about the land and its resources.

Animal agriculture and wildlife are the dominant land uses over the majority of the Arusha Region. This is not so much determined by Man and his desires as by the environment of the region. It is dominantly a pastoral environment; and through time, the pastoralists have gravitated to this region where nomadic and seminomadic pastoralism have been found most compatible with the variable climate and resources of the region. Where it applies, this fact, confirmed in long years of practice, cannot be ignored without serious consequences.

As the Government moves to meet the impacts of population pressure and to provide more crop food production, it is extremely important to recognize the environmental limitations and the needs of the pastoralists when making land use decisions that may favor agricultural cropping. A balanced agricultural economy and food production program must make adequate provision for animal protein production on a sustained basis.

After this comprehensive study of "Range Management in East Africa," Heady (1960) summed the matter up most appropriately when he said that the areas typified by the Masai Steppe do lie on the cropping fringe. He emphasized that a balanced economy and sound social structure as well as a dependable food production program cannot be built on policies and development programs that do not recognize the importance of also reserving some highly productive rangeland for animal agriculture. Providing for this balance in decision making is one of the main reasons why we have proposed and used in our first Land-Use-Capability Approximation a scheme that rates the land use potential for both crop and animal agriculture.

As land use decisions and plans for development are made from this Phase I study, its subsequent elements, and other supporting data, it is vital that the responsible officials always evaluate the tradeoffs and side effects of decisions that irreversibly commit the resources of the project area. The side effects are not always limited to the immediate environs or to the obvious direct costs. If one is aware of and carefully evaluates the undesirable side effects, satisfactory mitigating actions can often be taken that bring these effects within economically, socially, and biologically tolerable limits.

These statements emphasize the consequences and importance of adhering to certain guidelines as the results of this work are used as background for decisions and planning. The guidelines may be more precisely listed as follows:

1) The Phase I Study was not intended to provide all of the information needed for planning and program implementation. It should be recognized that some decisions will require more information. That information should be obtained; generalized, regional information should not be overextended to local planning and program implementation.
2) New information should be organized and built into the same Land System format as is established by this regional study.
3) In the quest for increased food production to alleviate hunger, the role and requirements of animal agriculture should not be overlooked. Opportunities to more effectively integrate crop and animal agriculture for mutual benefit and profitability should be sought.
4) The control and limitations inherently imposed on land use change by the characteristics of the environment and the soil-vegetation resource by each ecosystem should be recognized and planned.
5) In each and every decision involving land use change and an irreversible or long-term commitment of resources, each land use alternative should be carefully evaluated in terms of its side effects and long-term consequences.
6) A multiple-use mix in resource development should be strived for through "Integrated Land Use Planning" that is fully compatible with environmental limitations.

The program reported herein, has the primary purpose of supporting regional and land use planning resource development and management. Since this report treats Phase I results in a two-phase program of investigation, two key questions are: "What are the primary, useful products of Phase I?"; and "Where do we go from here?."

6.1 Phase I Results and Land Use Planning in the Arusha Region

Addressing the first question, the Phase I work has produced an excellent set of Ground Water Exploration Guide Maps, at a scale of 1:250,000, that should result in substantial savings in the costly ground surveys of resistivity and other observations and measurements that lead to even more costly drilling. Specific candidate areas, or focal points, for directing this exploratory attention have been identified; and in many cases, a prioritization of these candidate areas has been made. The Ground Water Exploration Guide Map will also be directly useful in the initial stages of land use planning as it is consulted for a first-look assessment of the likelihood of additional ground water resources as new candidate areas for agriculture and resettlement are being evaluated.

Because these kinds of developments are so strongly water dependent, this can save many costly hours of planning in otherwise suitable areas where the likelihood of adequate water supplies is remote.

Grazing management programs are also highly water dependent. These Ground Water Exploration Guide Maps can also aid these programs by providing a first estimate of the potential for improving water distribution as an aid in grazing management.

In this connection, some recent work from a large international symposium sponsored by the Food and Agriculture Organization of the United Nations, provided a critically important guideline. Their report conceived a new program for "The Ecological Management of Arid and Semi-Arid Rangelands in Africa and the Near East. This group of approximately 100 scientists and resource management specialists emphatically pointed out that many water development and animal health programs have "tended to be counter-productive" except where they have resulted in marketing of more animals than they have produced and where accompanied by an acceptable and effective program for control of livestock numbers and application of sound grazing management principles to insure continued resource productivity. (FAO, 1974, 1975) Thus, the GUIDELINE:develop new water sources for use by livestock and game only as an integral and accepted part of a program of range resource management, improvement, and maintenance through application of the principles of plant ecology and physiology in animal use and management.

In further response to the first question, Phase I has also produced a first iteration of a land use capability map for the whole Arusha Region, at a scale of 1:1,000,000. This map rates the landscape for both agricultural and range use. Similar to the Ground Water Exploration Guide Maps, it also provides a guide to the areas that should receive first priority attention in Phase II and in the development of detailed plans for resettlement and cropland agricultural development, for animal agriculture and range management, as well as in promoting other land use developments such as wildlife and tourism, forestry, watershed, urbanization, and the expanded infrastructure that will be required as economic development expands.

As an essential step in developing a regional land use capability assessment, the study has also created the best existing land resource map of homogeneous landscape units as determined by the physiognomic and structural characteristics of the vegetation types and the land forms on which each is found. These Land Unit delineations total 552 within the region. They range in size upward from 2- to 3-square mile delineations and average about 62 square miles each. This is a map that can, with additional ground work, be converted into a very accurate region-wide map of the present vegetational cover as well as a reconnaissance soils map at a scale of 1:250,000. After determining the vegetation-landform classes that comprise the Land Units, they were grouped into relatively homogeneous Land Systems that are clearly defined and accurately bounded on the LANDSAT photomaps. This Land System classification provides an improved method of organizing all land use and natural resources information throughout the region. It is a substantial improvement upon the earlier work of Sheehy and Green (undated ms.).

As was discussed in Section 4.0, a systematic format for characterizing and describing each Land System was demonstrated at two levels of intensity. These illustrate the reiterative growth and refinement of the resource data base for land use planning and resource management. In each iteration, the categories are treated only to the extent that available information warrants. They thus draw together in a single place, and under a consistent organizational framework, essentially all that is known and important to the politician planner, and manager.

Similarly, as an essential step to land use capability projections, a large amount of correlary data was assembled, analyzed, and presented as the best currently available criteria for land use capability assessment. As more refined information about the resources and land conditions of the Arusha Region becomes available, many of these same criteria can be applied to refine and update the land use capability projections on a more local and site-specific basis.

The LANDSAT photomap base, with its respective overlays, has provided a perspective of the resources, their uses and potentials, and their limitations for development that has heretofore been unavailable to the Government Officials in Tanzania. Being on a photobase, much of the information is much more easily comprehended than when presented on planimetric or topographic base maps. The photographic view of the whole region also enables users to relate to the landscape and to interrelate problems with maximum effectiveness.

These results and maps will also find usefulness in prioritizing, planning, conducting and researching by agencies, such as BRALUP at the University of Dar es Salaam, and other groups sponsored by donor nations and organizations and by the United Nations.

It is also anticipated that this project will provide most of the working and demonstration materials for a training program to achieve technology transfer in remote sensing, resource analysis, and land use capability interpretations to Tanzanian officials, scientists, and resource managers.

6.2 Where We Go from Here

Rather than to plan and implement a comprehensive regional coverage at the next more intensive level with small scale aerial photography, the second phase work should concentrate on priority areas and specific problem situations. In doing this, a number of options are open which will generally be determined by urgency of the problem, time available for a solution, and funds and manpower available to accomplish the stated goals.

The first option is already decided by virtue of the contract between USAID and Earth Satellite Corporation. Beginning in November 1975, a soil scientist will take up residence in the Arusha Region to perform soils-related tasks associated with the Arusha Livestock Project and the Resettlement Program. Part of his time will be devoted to soils studies in priority areas and for this he will use the 1:250,000 scale maps from Phase I for the initial stratification in his studies. This work will be directed to refinement and improvement of soils information for site-specific land use capability determinations and development of soil classes and legends for a more intensive Phase III soils inventory of designated priority areas.

Other candidate follow-on activities include:

1) A more comprehensive training program for Tanzanians to increase their participation in subsequent work and designed eventually to independently carry on the resource development and management program.

2) Completion and refinement of the Land System and Land Unit descriptions. This can and should move ahead concurrently with Phase II as it is presently envisaged.

3) Complete the current agricultural lands inventory using specially processed Band 7 (near infrared) black-and-white LANDSAT imagery or, if funds are available, using color reconstituted imagery from specially processed Bands 4, 5, and 7. This can be completed by EarthSat or Tanzanian technicians who could complete the work after the training program and under the supervision of BRALUP. Because of its contribution to the Swedish aid (SEDA) work in land use planning and to the further characterization of the Land Units as to Agricultural Potential, this work should also be completed during Phase II.

4) Vegetation-Soil-Current Land Use reconnaissance and documentation to refine the Land Use Capability Interpretations. This work involves mostly ground examination using the LANDSAT mapping as a first stratification for selection of sampling points. The current Land Use sampling and documentation can be done much more economically and effectively

by aerial overflight, especially if supported by 35 to 70 mm oblique photography from the aircraft. These photos can be interpreted and correlated with the ground observations to increase the total effectiveness of the study. Some of the soils part of these observations are currently scheduled in Phase II. It is much more efficient to do both the vegetation and soils work together. This could be accomplished by putting a qualified Tanzanian botanist or range officer with EarthSat's soil scientist after the training period in Item 1.

5) Climatological studies are needed to improve both agricultural and range potential determinations. They are important in setting long-term range productivity levels and critically important in the management of food supplies, storage and distribution. While yield and land suitability/capability are determined by a multiplicity of factors, not the least of which is soil, the current and expected climatic conditions are often overriding and thus may be used as the first order determinant in decisions about land capability -- particularly as one approaches semi-arid and arid conditions. Critical deficiencies exist in the climatological data base available for the Arusha Region. The number of observational records are too few and the available data has not been interpreted sufficiently to present:

a. An adequately high density of precipitation isohyets with the region.

b. Better rainfall likelihood probabilities calculated separately for the two rainy seasons.

c. Predictions of probability and frequency of precipitation below agronomically important thresholds for crop production and reasonable levels of range forage and browse production -- by rainy seasons.

d. Useful projections of water balance for key environments and locations throughout the region.

Available climatological data has been assembled on magnetic tape by the East African Meterological Department in Nairobi, Kenya, and are readily available to workers in Tanzania. In addition, the work of Dr. H.M.H. Braun at the National Agricultural Laboratories, Nairobi, Kenya, has pointed a way to the more effective use of climatological data as a criterion of agricultural land use capability. (WMO, 1974)

In addition, Dr. Earl Merritt, Meteorologist and Director of the Food Production Group at EarthSat, has pioneered and thoroughly tested a new technology that uses information derived from meteorological satellite data to fill gaps in climatic records and to make water balance predictions which he has then successfully modeled to produce good estimates of the yield of certain food crops of world importance.

BRALUP, at the University of Dar es Salaam, has an active interest and capability in climatology. It is our understanding that they have already acquired the data bank on magnetic tape and are conducting studies. BRALUP represents the essential on-site agency to do an effective job of strengthening the climatological data base and focusing it on the land use planning and resource development goals of the Nation.

An alternative solution with substantial merit would be to design a cooperative program whereby the new weather satellite technology to estimate water balance and predict crop yields could be brought to bear on the problem. It would be logical to accomplish this through the joint efforts and contribution of EarthSat and BRALUP under the leadership of the latter agency. This approach could also be of vital significance in the National food import, storage, and distribution problem presently being handled and researched through a separate USAID program which sponsors expatriate help from the National Millers Association (USA). We understand that this program is giving particular attention to food storage and distribution. Better yield predictions have already been identified as one of the critical needs of this program to cut food crop losses in periods of high production, to anticipate importation requirements, and to effect better distribution to areas of human need. This would all seem to place high priority on the early design and initiation of climatological studies in the whole of Tanzania.

6) Range productivity and condition inventories and management planning needs to be stpped up beyond the one-man effort in the present Arusha Livestock Project. Some new technology could be adapted and brought to bear on this problem by

attacking it in conjunction with the climatological work and by using weather satellite data, especially the processed LANDSAT data acquired in multi-season coverage, together with subsample aerial photography and an appropriate but minimum amount of ground observation and measurement.

7) Current land use inventory, with emphasis on change since the new resettlement program began, is vital to the comprehensive land use planning program. These needs will be partially met from Item 3; but in some priority areas and for urban studies, the analysis of new aerial photography will be required.

8) Detailed soil-vegetation surveys in all top priority areas where development and resettlement programs are scheduled for implementation. These should be conducted with good quality aerial photography at scales of not less than 1:40,000 and in cases of the highest quality of land and intensities of development at scales of 1:8,000 to 1:10,000. A multi-stage program starting with additional work on the LANDSAT imagery, Item 4 above, and ending with the largest scales of new aerial photography is truely the most cost-effective and rapid program the Tanzanian Government and the donor agencies can employ to insure the soundest and most successful development program.

9) Carry parallel similarly phased programs into the other regions of Tanzania with higher levels of participation by

Tanzanians following the training needed for increasing capability and achieving a well understood transfer of the technology.

10) Monitor range and crop productivity and condition with LANDSAT-2 imagery if it becomes sufficiently available with the timely, multi-season delivery that would be required for this work.

Implementation of the above candidate programs, somewhat in the priority and order as suggested, will not only meet the resource information needs of the Tanzanian Government officials but insure full benefit from the investment of USAID to implement these first two phases of the current land use study. The value of the present work will be found only in its use and application in the solution of national, regional, district, and eventually local problems of relating the activities of Man and his animals to the resources that sustain them.

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APPENDIX A

DESCRIPTIVE MAPPING LEGEND, ARUSHA REGION

<u>Resource and Land Use Features</u>

APPENDIX A

DESCRIPTIVE MAPPING LEGEND, ARUSHA REGION

Resource and Land Use Features

Primary Classes

100 - BARREN LAND: Barren land is somewhat relative but it is intended to cover all situations where the earth's surface is essentially barren rock, stones and gravel, or mineral soil. It is impossible to specify a vegetational cover percentage or threshold for barren land. For example, a talus slope with a few shrubs around the periphery or rarely within the talus would still be mapped in a barren land class. Desert or sparse steppe vegetation causes the greatest problem. If the natural ecosystem in a desert climate is sparsely vegetated, it would fall into one of the vegetated desert classes, usually symbol 320, even though total percentage ground cover may be well under 10 percent. Experience has shown that barren land subclasses should never go beyond tertiary level and frequently it is unnecessary to go beyond secondary. To do so makes the barren land class redundant with geological information where the latter is assessed as a component of the physical environment or land surface.

200 - WATER RESOURCES: Includes areas covered by natural or man-made water surfaces--streams, lakes, reservoirs, snow and ice, canals, enclosed aqueducts, and other water bodies lacking a surface vegetational cover. This class includes lakes and ponds with heavy "algal bloom" but not ponds with a floating or moderately dense, emergent vegetational covering.

300 - NATURAL VEGETATION: This class includes natural or native vegetation consisting of essentially indigenous species or introduced species that have become essentially naturalized to the region and that have found an ecological niche as though they were a part of the original vegetation. This class includes all successional stages in the natural vegetation. In mapping and identification, one should avoid trying to map the presumed "climax" or eventual equillibrium vegetation. Map and identify vegetation as it exists at the time imagery was obtained. The postulation of climax areas comes later as an interpretation of the basic inventory. This basic vegetation legend was modified to fit the Arusha region environment after consulting several sources describing or illustrating the various vegetation classification systems being used in East Africa.

Many vegetation classifications, at varying levels of detail, have been developed for Tanzania since the turn of the century. They have included floristic, structural and physiognomic approaches. A physiognomic vegetation map of Tanzania compiled in 1966 from information supplied by the Ministry of Agriculture, Forests and Wildlife contains eight major vegetation classes--forests, woodlands, brushlands and thickets, wooded grasslands, grasslands, permanent swamps, deserts and semi-deserts and actively induced vegetation (introduced by man).

The most recent 1:50,000 topographic map series of Tanzania carries a symbolic vegetation key for 13 types of vegetation or vegetation habitat, eleven of which are found in the Arusha region--forest, woodland, scattered trees, scrub, palms, grassland, tree swamp, marsh, seasonal swamp, and plantation.

This primary legend class includes all of these except the "actively induced vegetation" and "plantation" classes which fall into classes 400 or 500 below.

<u>400 - CULTURAL VEGETATION</u>: This class provides for the culturally introduced and intensively managed vegetation where the management objective is maintenance of a permanent stand that is managed and manipulated according to ecological rather than agronomic principles. The class is designed primarily to provide for seeded range where the intention is permanency of stand and the planted forest, e.g., grass seedings in a shrub steppe or savanna land, and planted coniferous forests in a hardwood forest area.

Some would argue this class should be in primary category 500, agricultural production. We prefer the class 400 because, generally, foresters and range managers identify these intensively treated areas as forests and rangeland respectively.

Removal of woody overstory species on potential rangeland, range seedings and clear-cut forests allowed to revert by natural succession are classed in the appropriate 300 category. These types are treated as seral natural vegetation. If, however, such areas were additionally planted to exotic species not initially natural to the site but which were the stand dominants, they would be classed under the appropriate 400, cultural vegetation, category.

500 - AGRICULTURAL PRODUCTION: These are land areas cleared of the natural vegetation and managed by agronomic principles for production of food, fiber or fodder crops. The class includes any land areas or structures and facilities directly related to agricultural practices (subsistence to intensive). These agricultural lands are characterized by the relatively constant manipulation by man through manipulation of the vegetation and microenvironment (fertilization, mulching, irrigation, etc.).

The class also includes permanent pasture managed for maximum yield by fertilization, irrigation and periodic renovation. These are pastures generally included within or in juxtaposition with the crop field boundary.

Forests or woodland windbreaks and woodlots included within the cropland area would be treated by the appropriate 300 or 400 subclass if the units are of mappable size. Agricultural activities were mapped in this project at primary (500) level; however, description of secondary and tertiary mapping levels is included in the event refinement at larger scales is desired.

600 - URBAN INDUSTRIAL AND TRANSPORTATION: Without a long title, semantics leads to misunderstanding about this class. It includes all urban, industrial and transportation centers and arteries.

Natural areas of mappable size located within urban areas would be treated under the appropriate 300 class. If they were planted forests or woodlands used as open space or for screening with the urban-industrial environment, they would be treated as appropriate 400, cultural vegetational subclasses.

700 - EXTRACTIVE INDUSTRY: This class includes open-pit mining, gravel quarries or any type of non-renewable resource extraction that has altered the natural landscape.

900 - OBSCURED LAND: This class is intended to provide for those portions of remotely sensed imagery in which the earth's surface is essentially obscured by clouds and other atmospheric obstruction. It is used primarily where it becomes necessary to account for 100% of the image frame area and where cloud or other atmospheric interference prevents meaningful statements about the area beneath.

Secondary Classes:

100 - BARREN LAND: Practically all of the secondary classes under 100 are self-explanatory. Problems most frequently arise with class 150 badlands and class 180 man-made barrens or land fills. Badlands are generally best identified by their intricate drainage patterns and usually irregular slopes and relief although many present a smoothly sloping relief. This class is intended to provide primarily for those barren lands derived from silty and clayey materials or from relatively easily weathered rocks that may produce smoothly sloping barrens or intricately grotesque or spire-like series of relief features.

Class 180 should be restricted to man-made land fill and not confused with extractive industry classes that typically generate barren lands, e.g., open pits mining, which fall under class 660, an industrial category.

200 - WATER RESOURCES: These secondary subclasses are all self-explanatory or defined in standard dictionaries. Large ponds, lakes and reservoirs (210) have been mapped to the secondary level. Completely seasonal or ephemeral water bodies or collection basins carry the macrorelief/landform designator 1.11 and either a barren land, 110, or a water body designator, 210, depending on whether the basin was dry when imaged. Permanent water courses, 220, are not mapped because streams in the region are not sufficiently large at the working scale. These kinds of features are indicated by the appropriate riparian bottomland designator and a riparian vegetational symbol when the feature is of mappable size within the guidelines set forth above.

300 - NATURAL VEGETATION:

310 - HERBACEOUS TYPES: That vegetation (annual, biennial, or perennial) which in aspect is dominantly herbaceous--including any or all grasses, grass-like plants, forbs, and non-vascular or vascular cryptogams. Other growth forms of vegetation may be present but they are decidedly subordinate in terms of aspect.

320 - SHRUB/SCRUB TYPES: All types of shrubs are the prominent vegetation. These may or may not form a closed layer; however, in this classification, the herbaceous layer is subordinate. The herbaceous ground layer of this vegetation is highly variable but can be important. The aspect is one of a relatively low woody vegetation.

330 - SAVANNA-LIKE TYPES: The world literature in no way agrees on the definition of a savanna. We have thus been somewhat arbitrary in phrasing the following descriptive definition that seems to

fit most temperate and many tropical situations where the expression savanna has been used to describe a unique community of plants. In contrast to some tropical writers, we are not including the tall grass, sparse overstory with a dense shorter grass understory as savanna. This latter belongs in the 310, herbaceous class, e.g., elephant grass. Vegetation consists of sparse, taller woody plants interspersed somewhat regularly throughout by a more dense low shrub or herbaceous layer to give a distinct two-storied community with the lower layer the more prominent.

We have tested many percentage cover thresholds in the tall woody layer to differentiate or characterize the savanna. Most of these have been difficult to apply consistently because of variation in the size of the individuals in the tall layer. The larger the size, the more widely they can be dispersed and still present an accurate savanna-like aspect. We therefore prefer not to specify such thresholds but to say that the vegetations should be savanna-like in their appearance or aspect to match as closely as possible the intent of the above description.

340 - FOREST and WOODLAND TYPES: The tree layer forms the dominant vegetational feature. This layer often forms a closed canopy over a variety of subordinate vegetation layers.

400 - CULTURAL VEGETATION: The secondary classes for cultural vegetation are the same as those presented above for class 300.

500 - AGRICULTURAL PRODUCTION:

510 - WHEAT, CORN, SISAL, SORGHUM: Cover crops - field, fiber and seed.

520 - PASTURE AND HAY CROPS: Any intensively managed land (fertilized, irrigated and/or renovated or appropriate) utilized for grazing or browsing, with or without periodic mechanical harvest. A pasture may be harvested as a "permanent" crop or managed as a temporary lay in a crop rotation plan.

530 - VEGETABLE CROPS: Legumes, leafy vegetables, roots, tubers, bulbs, cucurbit, solanaceous, and perennial vegetable crops (including herbaceous fruit crops) are in this category.

540 - FRUIT AND NUT CROPS: Fruit, nut, and beverage crops with tree and shrub, growth forms.

550 - HORTICULTURAL SPECIALTIES: Artifically planted and maintained flower, shrub, or tree stock. This includes nursery stock, flowers (whether grown for seed, rootstocks, corns, bulbs, tubers, or blooms), and other herbaceous horticultural plants occurring in various sized production lots.

560 - SUBSISTENCE/MIXED-CROP/SHIFTING AGRICULTURE: Small cultivated plots close to bomas generally used only one or two years. Crops include maize, millet, sorghum, beans, sweet potatoes, etc.

570 - NON-PRODUCING AND TRANSITIONAL CROPLAND: Fallow; plowed, hoed (or variously worked), and leached cropland including harvested fields; included here are abandoned or idle croplands, fields, and

ERRATA

A list of corrigenda for this volume is now in preparation. Identified corrigenda are expected to include:

1) A complete listing of grammatical, punctuation and spelling errors;
2) Geographical place name references in Swahili where an uncommon usage form may have been used;
3) Transposition of Land System, Land Unit and Groundwater map overlay digits/descriptors in textual references to same.

pastures as well as entrapped lands that are isolated from effective agricultural production by being surrounded or blocked from access by class 600 lands. The question, "When does abandoned land revert back to class 300?" must remain somewhat a judgemental factor. As long as plant succession is at a stage where it could easily be put back to crop and the cover contrasts strongly with the surrounding natural vegetation, it is appropriate to retain the 570 designator.

580 - ANIMAL FACILITIES AND FARMSTEADS: At all but the largest of inventory scales, these features usually represent point data of non-mappable size but they may be particularly important to annotate, especially in complete land-use inventories. Structures and facilities utilized for animal production and farming make up this category. Barns, sheds, holding pens, and farm buildings are examples.

600 - URBAN

610 - CITIES: The primary urban centers which distribute goods and services to the outlying areas. Residential, industrial, institutional, and commercial distinguish a city.

620 - VILLAGES: Collection centers for the isolated bomas and through which the raw products may be transported to the cities. Mainly agriculturally oriented. More settled agricultural cultivation.

630 - ISOLATED BOMAS: Primitive, scattered, isolated, small villages or single dwellings usually moving to another area, one in three years. Small plot subsistency crops are grown. Not observable on LANDSAT imagery.

Tertiary Classes:

310 - HERBACEOUS TYPES:

314 - GRASSLAND, STEPPE, AND PRAIRIE: Any land area dominated by grass vegetation. Tall grass prairies, short grass prairies, desert grasslands, "midgrass plains", bunchgrass, and grass dominant steppes are all included in this category. The 314 category herbaceous vegetation is often a dominant plant association in mbuga areas.

If carried to the quaternary level of classification, an estimated biomass cover figure is added to the designator where interpretable on the imagery. Biomass classification levels are: .1, high; .2, medium; .3, low; .4, deteriorated. Hence, a grassland of medium biomass would carry a 314.2 designator.

316 - GRAMINACEOUS MARSHES: Hygric (very wet) vegetation dominated by mixtures or dense stands of individual grasses, rushes and sedges.

320 - SHRUB/SCRUB TYPES: Shrub and scrub types may include a quaternary level designator indicating an herbaceous understory biomass cover. Designators are the same as those for the quaternary level of the grassland, steppe and prairie class (314).

321 - NON-THORNY DESERT SCRUB (MICROPHYLLOUS): Small-leaved unarmed shrubs usually growing in the very driest regions.

322 - THORN SCRUB (BUSH), DENSE: Small-leaved, thorny scrub species occur as the dominant overstory vegetation. This category includes desert thorn scrub predominantly. Very dense.

323 - THORN SCRUB (BUSH), MODERATELY DENSE: Moderately dense, small leaved thorny scrub species.

324 - THORN SCRUB (BUSHLAND) LOW DENSITY: Small leaved thorny scrub species of low density. This category is often included as a plant component in mbuga areas.

325 - HALOPHYTIC SHRUB: Salt tolerant shrubs occurring as dominant vegetation type predominantly salt flats, alkali flats and other soils with high salt contents.

326 - NON THORNY MESIC SHRUBS: Deciduous or semi-deciduous unarmed macrophyllous (large leaved) shrubs.

328 - MOUNTAIN HEATH: A highland plant community consisting in general of a ground cover of low dense shrubs or herbaceous vegetation.

330 - SAVANNA-LIKE TYPES:

331 - ARBORESCENT (TREE-LAYER): Vegetation consisting of sparse, taller trees, e.g., acacia tori torillis, interspersed throughout a more dense low shrub or herbaceous layer to give a distinct two storied community.

332 - SHRUBBY: Similar in many respects to the arborescent savanna-like type except for the dominance of a shrub-like woody plant overstory in place of the tree-like forms of the arborescent savanna. Commiphora and the smaller Acacia species are logical woody plant forms in this association, not to be confused with types where acacia-commiphora are dense enough to be classified as bushlands.

333 - PALM SAVANNAS: Savanna-like types where palm trees are the taller vegetation in the association. Generally found along the margins of the lake areas and extending a short distance upland.

All of the above defined savanna-like vegetation types may have a quaternary level designation for herbaceous biomass similar to those of the 310 and 320 classifications.

340 - FOREST TYPES:

341 - GYMNOSPERM FOREST TYPES: Forested areas of needle leaved, cone-bearing trees dominated by any Coniferales or Taxales.

342 - ANGIOSPERM FOREST TYPES: Deciduous, semi-deciduous, or evergreen broad leafed angiospermous (flowering) forest species.

343 - MIXED FORESTS: Mixtures in any proportion of 341 and 342 with the minor component 20 percent or more of the total cover.

344 - WOODLANDS: Woodlands are generally represented by the *Brachystegia-Isoberlinea* associations located in the southeastern tip of Arusha region. For the purposes of this survey, it is understood that this plant association constitutes a "Miombo woodland." Though *Acacia* were included peripheral to and within the Miombo woodland, Extensive *Acacia* woodlands were not sufficiently common or extensive to warrant a separate classification.

440 - CULTURED FORESTS:

441 - PLANTED CONIFEROUS FORESTS: Intensively managed cone bearing trees.

442 - PLANTED BROADLEAVED FORESTS: Deciduous or semi-deciduous trees intensively managed. Eucalyptus plantation were noted in several areas, but were not of a sufficient size to be mapped.

610 - CITIES AND LARGE TOWNS: Except for Arusha, these were point data and mapped only at primary level. Following are useful subclasses where scale permits their mapping.

611 - RESIDENTIAL: Single and multiple unit dwellings including secondary structures, driveways, and landscaped areas. Sparse residential land-use should be treated as point data within that land use or resource class throughout which they are dispersed.

612 - TRADE AND SERVICES: Areas used predominantly for the sale, storage, and handling of products and services. Warehouses, office buildings, parking lots, and intensively developed resort sites are examples of this category.

613 - TRANSPORTATION, COMMUNICATIONS, AND UTILITIES: Highways and railways make up the two basic transportation means that require stationary routings visible on remote sensing images. Facilities related to all transportation types are included in this category (seaports, airports, runways, railroad terminals, bus terminals, highways, roads, etc.) Resource (or utility) transportation facilities that move nonvehicular products are also included in this category (oil pipelines, gas, and electricity).

620 - VILLAGES AND CLUSTER SETTLEMENT:

621 - CLUSTER VILLAGES: Domiciles in relatively concentrated units.

622 - STRIP VILLAGES: Generally located along transportation routes or riparian systems.

Macrorelief Classes

Mapping Symbol	Technical Meaning	Description
1.	Flat Lands	A generally flat landscape with prominent slopes less than 10%. The landscape is essentially smooth. Dissection is minimal. The regional slope in this class is nearly always between 0 and 3%.
2.	Rolling and moderately dissected lands	A rolling or moderately dissected landscape with prominent slopes 10 to 25% (side slopes may exceed that figure in the case of dissected planar surfaces).
3.	Hilly lands	The landscape is hilly to submountainous; slopes are moderate to steep, predominantly exceeding 25%. Relief is generally over 100 feet but less than 1,000 feet; the landform system appears to be relatively simple - with smooth slopes. Drainage basins generally are simple in drainage pattern; usually lack a strong vegetational zonation pattern.
4.	Mountainous lands	The landscape is mountainous, having high relief, usually over 1,000 feet. Slopes are

moderate to steep, frequently exceeding 50%. The landform and drainage systems are usually complex, with drainage systems having multiple and local base levels quite independent of one another. Vegetational zonation is usually clearly evident.

Landform Features

Secondary to Quaternary Level:

Mapping Symbol	Description
.1	Depressional, non-riparian basins
.11	Seasonal lake basins
.12	Mbugas
.2	Depressional calderas
.3	Bottomlands, riparian
.32	Bottomlands, riparian, stringer or narrow
.33	Bottomlands, riparian, wide valley bottom
.34	Depressional, concave (may characterize same mbugas of external drainage)
.35	Desert wash
.4	Planar surfaces, lowland
.402	Planar surfaces, lowland, moderately dissected

.41 Planar surfaces, lowland, valley fill

.412 Planar surfaces, lowland valley fill, moderately dissected

.42 Planar surfaces, pediment or toe slope

.422 Planar surfaces, pediment or toe slope moderately dissected

.5 Planar surfaces, upland plateau (benches, mesas, broad ridgetops)

.51 Flat to strongly undulating dip slopes

.502 Planar surfaces, upland plateau, moderately dissected

.6 Strongly undulating to rolling lands

.602 Strongly undulating to rolling lands, moderately dissected

.7 Slope systems

.71 Escarpments

.72 Valley, canyon or gorge slope systems

.73 Butte or isolated hills and kopjes

.74 Hill and mountain, smooth slope systems

.75 Hill and mountain, angular slope systems

.8 Gravity and mass movement landscapes

Dissected Classes for Use With Macrorelief Classes 1. and 2. and with any of classes .3, .4, .5, and occasionally class .6 above.

.XX1 = Nondissected

.XX2 = Moderately Dissected

.XX3 = Strongly Dissected

For more intensive inventories at larger scale a slope class may also be added at a fifth level, thus X.XXX2.

Diagrammatic examples of the application of this legend are shown in Figure A-1.

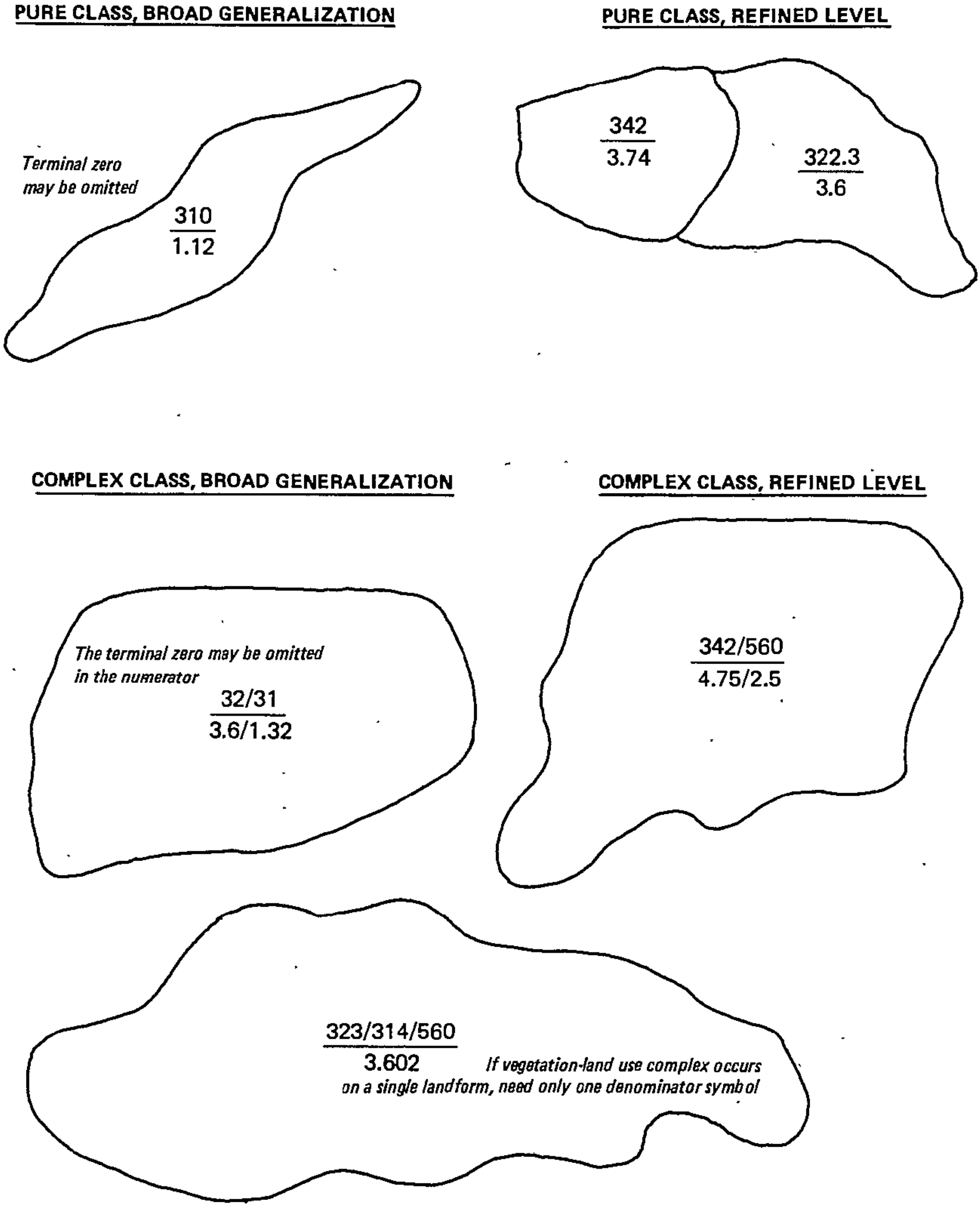

FIGURE A-1. Examples of use of the Legend Symbolization

APPENDIX B

LAND USE CAPABILITY CLASSES

APPENDIX B

LAND USE CAPABILITY CLASSES

As pointed out in the body of this report, we strongly urge the assignment of multiple capability scores or classes to each parcel of land. Ideally, a separate score should be assigned to each candidate use of the land so that the decision maker can better appreciate the trade-offs (gain and losses or secondary problems that may arise) when a land use and resource allocation decision is made.

We attempted to devise a scoring method to aid the decision process in land use capability assessment. A system involving individual/arithmetic ratings based on "a percentage of ideal" for each parameter and combination of these into a single score by progressive multiplication of ratings has been successfully used for many years by a leading soil scientist in the United States (Storie, 1937, 1964). We discarded this idea for want of sufficiently detailed information, particularly about soils. The numerical scores resulting from such a "quantitative" approach would have engendered undue confidence in the first-approximation ratings on the part of users who did not fully appreciate the background and inadequacies of supporting data.

Land Capability Classes for Reconnaissance Analysis

It was our decision to use a subjective evaluation for the entire Arusha Region as a first approximation and as a guide to Regional and District officials as they seek to provide for the information deficiencies, ultimately to make site specific decision, and enable a more quantified approach to land use capability on the local level. For our first approximation interpretations we used the following classes and criteria:

Capability Class	Definition
Ac	A candidate area for potential agricultural development or for expansion of the use of land for crop production. Present indications are that soils in the Ac class fall in agricultural capability classes AI, AII, and AIII. There may be some areas of AIV soil but it is not predominantly an AIV and AV soil area. There are no apparent climatic limitations to development for cropping and the likelihood of finding large areas suitable for agriculture is good. There is reasonable likelihood of being able to find ground water, at least for human use, within the area.
Am	A marginal candidate area for agricultural development. Present indications are that most of the soils in Am areas will be in agricultural capability classes AIII, AIV, and AV. There is no apparent climatic limitation and there is reasonable likelihood of ground-water for human use.
R	Rangeland, non-agricultural, in agricultural capability class AV. The land should remain in pastoral or improved and developed rangeland use. The R lands may include small areas around isolated hill and mountain ranges where the land is either now being used for subsistence agriculture or where it has the potential of such use. The size and quality of such lands is not sufficient to warrant priority attention in near term, development programs. Generally the value of R land is sufficient for animal agriculture that any improvement potential should be directed toward range improvement and the production of animal feed.

Land Capability Classes for Semi-detailed and Detailed Analysis

Priorities justify the work and where good soils information is available to permit a more intensive analysis, it is appropriate to use the following capability classes. Each candidate use of the land should be given its own appropriate rating preceded by a notation designating the land use option. In this project we have focused on cropland agriculture, A; and range uses, R. Lands could be rated as well for specific kinds of wildlife, for urban or village development, for tourism, recreation and scenic values, and even watershed and mineral development whenever the available background data would make such rating meaningful.

Capability Classes	Definition
I	No significant limitations to the contemplated use. Adaptability is high, the environment non fragile; and it is easy to maintain basic productivity of land use under the subject use. Flexibility of options in application of the subject use is high. Only normally accepted, sound practices of management are required.
II	Moderate limitations exist to the contemplated use. Adaptability is good but somewhat more limited than in class I. The environment may be slightly susceptible to damage under the contemplated use. Does require some mitigating or preventative actions to avoid deterioration of site productivity. These usually are achievable at relatively low capital, labor or technological inputs above the normal, standard practice typical of the subject use.
III	Moderately severe limitations to the contemplated use. Adaptability is severely limited, but the limitations are correctable at rather high capital, labor, or technological inputs. The environment is moderately susceptible to deterioration under the contemplated use.
IV	Severe limitations to the contemplated use. Highly subject to damage or deterioration under the designated use. Diversity of application of technology (e.g., cropping options) is severely restricted by site characteristics. Will require very high capital, labor and/or technological inputs to maintain productivity. Some limitations may be doubtful of removal; and the site may be marginal for the contemplated use on a high proportion of years, borderline economic feasibility as long as other land use alternatives exist.
V	Limitations so severe that the contemplated use is not feasible or the ecosystem is simply unsuited to the specified use.

In addition to the above major classes, one may add a subscript or other notation to indicate the dominant limiting factor in the land use capability decision. These may be such factors as climate, c; soils, s; and topographic or relief limitations, t. One may, if desired, be more specific in the capability designators by specifying such limitations as frequent drought, seasonally wet or poorly drained soils, high or perched water tables, heavy or unusually light textured soils, erosion risk due to relief or to surface textures subject to blowing, infertile soils, saline/alkali soils, stoniness, or soils shallow to bedrock or to hardpans.

For this study and the future application of its results, we are recommending the first three broader subscript notations: Climate c; Soils, s; and Topographic, t; wherever they are appropriate.

APPENDIX C

CATALOG

OF AVAILABLE ARUSHA REGION

LANDSAT I AND LANDSAT II

IMAGERY

TYPE COVERAGE	TYPE / SIZE / FILM SOURCE	PHOTO/SCENE IDENTIFICATION	QUALITY (4 5 6 7 ERTS)	CLOUD COVER	DATE ACQUIRED	LATITUDE / LONGITUDE (CENTER/FIRST FRAME COORDINATE)	SCALE OF IMAGERY	ALTIT	OVERLAP	FIRST FRAME	LAST FRAME	NO OF FRAMES	CASSETTE	FRAME
IDENTIFICATION			DATA CHARACTERISTICS							PHOTO STRIP INFO			MICROFILM	

FIRST LINE OF ACCESSION INFORMATION

COMPUTER PRINTOUT DECODING SHEET

FOR INTERPRETATION OF IMAGERY FROM EROS DATA CENTER

SHEET 1

INSTRUCTIONS:

This decoding sheet is used in conjunction with the enclosed computer listing to interpret characteristics of imagery available from the EROS Data Center.

From interpretation of choices listed individual photographic accessions can be evaluated and appropriate order forms selected for ordering.

The computer listing may list several possible images available over your area of interest. Each will be described by two printed lines indicating in detail parameters of the individual image or photograph accession.

Detailed data can be read by aligning the scale on the top and bottom of this sheet with the upper and lower lines of each accession on the computer listing, noting characteristics for each data item.

TYPE COVERAGE for each accession indicates the correct ORDER FORM to be used. FILM TYPE SIZE dictates products available from the table at the bottom of the respective order forms.

Descriptions and code breakdown for data fields are shown on the right. A further breakdown of selected data fields is itemized on supplemental sheet 2.

Note that special procedures are required for imagery accessed by photo index or photo strip.

CODE EXPLANATIONS (REFER TO SHEET 2 FOR FURTHER BREAKDOWN)

TYPE COVERAGE

- DESIGNATES TYPE AND SOURCE OF PHOTOGRAPHIC COVERAGE LISTED
- INDICATES ORDER FORM TO BE USED

FILM SOURCE

- INDICATES TYPE AND SIZE OF MASTER REPRODUCIBLE FILM. REFER TO STANDARD PRODUCT TABLE ON ORDER FORM TO DETERMINE PRODUCTS AVAILABLE

B & W = BLACK AND WHITE
COL = COLOR
CIR = COLOR INFRARED
FCC = ERTS FALSE COLOR COMPOSITE
SIZE = IMAGE SIZE ON FILM

PHOTO / SCENE IDENTIFICATION

- COLUMN 1 – SOURCE AGENCY

CODE	AGENCY	AIRCRAFT	SPACE
1	USGS	x	
2	BUREAU OF RECLAMATION	x	
4	US BLM	x	
5	NASA-AMES	x	
6	NASA-JSC	x	
7	APOLLO/GEMINI		x
8	ERTS		x
A	AMS	x	
D	AIRFORCE	x	
G	SKYLAB		x

- SEE SHEET 2 FOR DETAILED BREAKDOWN

QUALITY

- AIRCRAFT/SKYLAB
  A/C = IMAGE QUALITY WHERE 0 = INFERIOR TO 9 = EXCELLENT
- ERTS
  MSS - (B & W)
  4567 = INDIVIDUAL AVAILABILITY AND QUALITY FOR MSS BANDS 4 5 6, & 7
- ERTS COLOR COMPOSITES
  A/C = OVERALL QUALITY OF AVAILABLE COMPOSITES WHERE 0 INFERIOR TO 9 = EXCELLENT
  4567 = ENTRY IN RESPECTIVE BANDS INDICATES THOSE USED FOR THE COMPOSITE

CLOUD COVER

- CLOUD COVER IN 10'S OF PERCENT

00% NO CLOUD COVER
TO
90% 90% OR LESS CLOUD COVER

DATE ACQUIRED

- DATE OF EXPOSURE FOR THIS IMAGE

CENTER / FIRST FRAME COORDINATE

- SCENE-CENTER OF SCENE
- PHOTO STRIP-CENTER OF FIRST FRAME
- PHOTO INDEX-CENTER OF ENTIRE PHOTO INDEX

SCALE OF IMAGERY

- SCALE OF IMAGERY FOR THIS ACCESSION

ALTITUDE

- HEIGHT FROM WHICH EXPOSURE WAS MADE (IN HUNDREDS OF METERS)

OVERLAP

- FORWARD OVERLAP IN TENS OF PERCENT

PHOTO STRIP INFORMATION

- FIRST LAST FRAME NUMBER OF THIS PHOTO STRIP ON FILM (USE FOR ORDERING)
- NUMBER OF FRAMES IN THIS PHOTO STRIP

MICROFILM

- LOCATION OF THIS IMAGE IN MICROFILM LIBRARY

TYPE ACCESSION

- INDICATE WHETHER COVERAGE DESCRIBED IS SCENE OR PHOTO (SINGLE IMAGE), PHOTO STRIP (2 OR MORE ADJOINING FRAMES) OR PHOTO INDEX (MOSAIC OF MANY INDIVIDUAL PHOTOS)

CORNER POINT COORDINATES

- SCENE/PHOTO-COORDINATES OF SCENE OR PHOTO
- PHOTO STRIP-COORDINATES OF ENTIRE STRIP (SEVERAL SCENES)
- PHOTO INDEX-COORDINATES OF ENTIRE PHOTO INDEX (MANY SCENES)

SENSOR CODES

- (SEE SHEET 2)

SENSOR CLASS

- SEE SHEET 2)

IMAGE CLASS

- (SEE SHEET 2)

FILTER CODE

- (SEE SHEET 2)

FILM CODE & COLOR

- 100 199 - B & W
- 200 - 299 - COLOR
- 300 - 399 - B & W IR (INFRARED)
- 400 - 499 - COLOR IR (INFRARED)
- SEE SHEET 2 FOR DETAILED CODES

FORMAT SIZE

- LENGTH AND WIDTH OF IMAGE ON FILM MASTER IN MILLIMETERS

12/09/74

SECOND LINE OF ACCESSION INFORMATION

TYPE ACCESSION	CORNER POINT COORDINATES								SENSOR	SNS CLASS	IMG CLASS	FILTER	FILM CODE	FORMAT SIZE (MM)	
	LATITUDE	LONGITUDE	LATITUDE	LONGITUDE	LATITUDE	LONGITUDE	LATITUDE	LONGITUDE						LENGTH	WIDTH

DETAILED CODE INTERPRETATION
SHEET 2
SUPPLEMENT FOR DETAILED INTERPRETATION OF SHEET 1

PHOTO ID CODING

COLUMN 1 = 1

USGS (GEOLOGICAL SURVEY)
- ID = 1PPPPPCCCFFFFOO
  - 1 = USGS
  - PPPPP = PROJECT
  - CCC = MICROFILM CASSETTE
  - FFFF = FRAME
  - OO = UNUSED

COLUMN 1 = 2

BUREAU OF RECLAMATION
- ID = 1PPPPPCCCFFFFOO
  - 1 = USGS
  - PPPPP = PROJECT
  - CCC = ROLL
  - FFFF = FRAME
  - OO = UNUSED

COLUMN 1 = 4

USBLM (BUREAU OF LAND MGT.)
- ID = 4PPPPPPPRRSSSOO
  - 4 = USBLM
  - PPPPPP = PROJECT
  - RR = ROLL
  - SSS = STRIP
  - OO = UNUSED

COLUMN 1 = 5

NASA-AMES RESEARCH CENTER
- ID = 5YYORRRRRFFFFOO
  - S = NASA-AMES
  - YY = YEAR
  - O = UNUSED
  - RRRRR = ROLL
  - FFFF = FIRST FRAME
  - OO = UNUSED

COLUMN 1 = 6

NASA-JSC (JOHNSON SPACECRAFT CENTER)
- ID = 6MMMMRRRSFFLLBB
  - 6 = NASA-JSC
  - MMMM = MISSION
  - RRR = ROLL
  - S = SENSOR
  - FF = FLIGHT
  - LL LINE
  - BB BREAK

COLUMN 1 = 7

NASA-APOLLO/GEMINI MANNED SPACECRAFT
- ID = 7MMMMAANNNNOOOO
  - 7 = APOLLO/GEMINI
  - MMMM = MISSION
  - AA = MAGAZINE
  - NNNN = ROLL
  - OOOO = UNUSED

COLUMN 1 = 8

ERTS (EARTH RESOURCE TECHNOLOGY SATELLITE)
- ID = 81DDDHHMMS2AOOO
  - 8 = ERTS
  - 1 = ERTS-1, 2 = ERTS-2
  - DDD = DAYS SINCE LAUNCH
  - HHMM = HOURS/MIN. SINCE LAUNCH
  - S = TENS OF SECONDS
  - 2 = RBV, 5 = MSS
  - A = ALASKA, N = GODDARD, G = GOLDSTONE, B = BRAZIL
  - 0 = BULK, 1 = PRECISION, 2 = COLOR COMP., 3 = COLOR COMP. PRECIS.
  - OO = UNUSED

COLUMN 1 = A

AMS (ARMY MAP SERVICE)
- ID = APPPPPCCCFFFFOO
  - A = AMS
  - PPPPP = PROJECT
  - CCC = MICROFILM CASSETTE
  - FFFF = FRAME
  - OO = UNUSED

COLUMN 1 = B

AIRFORCE
- ID = BPPPPPCCCFFFFOO
  - B = AIRFORCE
  - PPPPP = PROJECT
  - CCC = MICROFILM CASSETTE
  - FFFF = FRAME
  - OO = UNUSED

COLUMN 1 = G

SKYLAB (MANNED SPACECRAFT)
- ID = G2OAMMMFFFOOOOO
  - G = SKYLAB
  - 2 = SKYLAB 2, 3 = SKYLAB 3, 4 = SKYLAB 4
  - O = UNUSED
  - A = S190-A, B = S190-B
  - MMM = MAGAZINE
  - FFF - FRAME
  - OOOOO - UNUSED

SENSOR CODES

CAMERAS (MM)

- C01 = HR-732C
- C02 = HR-732R
- C03 = RC-10
- C04 = PAN-307
- C31 = WILD RC-8 (152)
- C32 = T-11
- C33 = APS
- C34 = K-17CHI AER (457)
- C35 = K-17NIKON DATA (70)
- C36 =ZEISS (305)
- C37 = ZEISS, RMK 30/23 (305)
- C38 - ZEISS, RMK 15/23 (152)
- C39 = HASS (40)
- C40 = ITEK M-BAND (100)
- C41 - ITCK M-BAND (150)
- C42 = HASS A (50)
- C43 = HASS B (80)
- C44 - HASS C (120)
- C45 = HASS D (150)
- C46 = HASS'E (250)
- C47 = HASS F (500)
- C48 = KA62 A (76)
- C49 = KA62 B (76)
- C50 = KA62 C (76)
- C51 = KA62 D (76)
- C52 = S190
- C53 = KA50 A (44)
- C54 = VINTEN (44)
- C55 = SMITH (152)
- C56 = FAIRCHILD (152)
- C57 = HURD (152)
- C58 = PARK (152)
- C59 = WILD RC-5 (152)
- C60 = K17 (152)
- C61 = AERO 69 (152)
- C62 = AEROGON (152)
- C63 = KAROL (152)
- C64 = AEROGON ENG-152
- C65 = WILD (152)
- C66 = AERO VIEW (152)
- C67 = KAROL K-17 (152)
- C68 = KAROL T-12 (152)
- C69 = WILD RC-9 (88)
- C70 = AERO (304)
- C71 = I S (100)
- C72 = RC8/4L (152)
- C73 = RC8/4R (152)
- C74 = RC8/4L (305)
- C75 = RC8/4R
- C76 = ITEK 9
- C77 = MPMR (35)
- C78 = M S
- C79 = P-220
- C80 = RFR
- C81 = KB8
- C82 = RC8 #1
- C83 = RC8 #2
- C84 = RC-10
- C85 = S190-A
- C86 = S190-B
- C87 = DA50 A
- C88 = K-12
- C89 = AAD-2
- C90 = KA-2
- C91 = AMP
- C92 = C24
- C93 = K224
- C94 = NIKON
- C95 = HC-730V
- C96 = HC-730W
- C97 = HC-730R
- C98 = HR-732
- C99 = HR-732F

SCANNERS (ANGLE)

- S01 = AAS-5UV
- S02 = BENDIX 24 CH (80)
- S03 = UM
- S04 = RECON-4 (60)
- S05 = RS-7 (100)
- S06 = RS-14 (80)
- S07 = RS-310
- S08 = RS-314
- S09 = S192
- S10 = RBV
- S11 = MSS
- S12 = APD-97
- S13 = DPD-2 (SLAR)
- S14 = HP-3070 (130)
- S15 = DP #6

FILTER CODES

A	= 57A
AA	= 0.5 - 0.6
BB	= 0 6 - 0.7
BL	= BLUE (USGS-5)
CA	= CLEAR AV
CC	= 0.7 - 0.8
CL	= CLEAR
DD	= 0.8 - 0.9
EE	= 0.5 - 0 88
FF	= 0.4 - 0 7
F0	= 1.000 - .000
F1	= 0.000 - .925
F2	= 0.000 - .324
F3	= 0.000 - 227
F4	= 0.000 - 111
F5	= 0.515 - 315
F6	= 0 350 - 400
GG	= 0.4 - 0.5
HH	= 0.425 - 0.475
HF	= HF/2
H3	= HF3
H4	= HF4
II	= 0 525 - 0.575
JJ	= 0 625 - 0.675
KK	= 0 725 - 0.775
LL	= 0.825 - 0.875
MM	= 0.35 - 0.60
M4	= MSS-4
M5	= MSS-5
M6	= MSS-6
M7	= MSS-7
M8	= MSS-8
NN	= 0 475 - 0.525
OO	= 0.575 - 0.625
PP	= 0.675 - 0.725
P1	= 400
P2	= 1.6
P3	= 13.3
P4	= 1.420
P5	= 10.625
P6	= 22.235
P7	= 22 355
P8	= 31.4
P9	= 10.69
PA	= 16.5
QQ	= 0.775 - 0.825
RR	= 0,875 - 0.925
R1	= RBV-1
R2	= RBV-2
R3	= RBV-3
SA	= 1 20 - 1.30
SB	= 1 55 - 1.75
SC	= 2.10 - 2 35
SD	- 10 2 - 12 5
SE	= SE
S1	= 0 41 - 0.46
S2	= 0 46 - 0.51
S3	= 0 52 - 0.56
S4	0 56 - 0.61
S5	- 0 62 - 0 67
S6	0 68 - 0 76
S7	0 78 - 0 88
S8	= 0 98 - 1 08
S0	= 1 09 - 1.19
T1	= 3 0 - 5.50
T2	= 0.3 - 0.55
T3	= 1.0 - 1.30
T4	= 1 5 - 1.8
T5	= 2 0 - 2.8
T6	= 1.0 - 1.30
T7	= 0.7 - 0.9
T8	= 8 - 14
T9	= 8 - 10.5
UV	= UV -17
U1	= 10.0 - 12.0
U2	= 10.2 - 12.5
U3	= 10M - 515
U4	= 10M - .52
V1	= .475 - .575
V2	= .580 - .680
V3	= .510 - .900
W1	= W-1
W5	= W-15
W8	= W58A
ZA	= ZEISS A
ZB	= ZEISS B
ZC	= ZEISS C
ZD	= ZEISS D
0B	= 80B
07	= 0.7 MICRONS
1B	= 18B
1M	= 10M
2A	= 2A
2E	= 2E
3	= 3
3B	= 30B
3R	= 30R
5A	= 25A
5B	= 80B
5G	= 15G
6A	= 65A
7A	= 47A
7B	= 47B
8A	= 82A
8B	= 58B
9B	= 89B
12	= 12
15	= 15
18	= 1 8
20	= 2 0 AV
21	= W21
22	= W22
24	= W24
25	= 20
38	= 38
47	= 47
48	= 48
50	= W500
53	= W530
56	= W156
57	= 57
58	= 58
78	= W78A
70	= W700
88	= IR WR88A
89	= W89

FILM CODES

B & W FILM

- 100 = 8401
- 101 = 8403
- 102 = 2405
- 103 = 2402
- 104 = 2403
- 105 = 2485
- 106 = 2498
- 107 = 3400
- 108 = 8425
- 109 = 3401
- 110 = 5401
- 111 = XX
- 112 = 2404
- 113 = SO467
- 114 = 5498
- 115 = SO-206
- 116 = SO-243
- 117 = SO-349
- 118 = SO-357
- 119 = SO-380
- 120 = 2401
- 121 = 3404
- 122 = SO-022
- 123 = 2479
- 124 = SO-267
- 125 = SO-355
- 126 = 3414
- 127 = RAR 2490

COLOR

- 220 = 8442
- 221 = 8448
- 222 = 2450
- 223 = SO-121
- 224 = SO-118
- 225 = SO-368
- 226 = SO-397
- 227 = D-500
- 228 = 0-1000
- 229 = SO-271
- 230 = SO-360
- 231 = SO-276
- 232 = 267
- 233 = -C
- 234 = SO-168
- 235 = SO-242
- 236 = SO-356
- 238 = 2445
- 239 = 5389
- 240 = SO-224
- 241 = 4109
- 456 = SO-356

B & W INFRARED

- 340 = SO-246
- 341 = 2424
- 342 = 8424
- 343 = -I
- 344 = FE-3215

COLOR INFRARED

- 450 = 8443
- 452 = SO-117
- 453 = SO-180
- 454 = 2443
- 455 = 2448
- 457 = 3443
- 458 = SO-131

SENSOR CLAS

- 01 = VERT. CARTO
- 02 = VERT. RECON
- 03 = SLAR
- 04 = THERMAL
- 05 = PANORAMIC
- 09 = PPI
- 10 = MICROWAVE
- 16 = L. OBLIQUE
- 17 = H. OBLIQUE
- 37 = RBV
- 38 = MSS

IMAGE CLASS

- 06 = BULK
- 07 = PRECISION
- 08 = COLOR COMP
- 11 = PANCHROMAT
- 12 = IR (B & W)
- 13 = IR (COLOR)
- 14 = COLOR
- 15 = MULTISPECTR.
- 16 = LOW OBLIQUE
- 17 = HIGH OBLIQUE
- 18 = RECTILINEAR
- 19 = NON-REC
- 20 = SLANT RANGE
- 21 = GROUND RANG
- 22 = NON-IMAGE
- 23 = OTHER IMAGIN
- 24 = BLACK & WHIT
- 31 = HASSELBLAD
- 32 = HASSELBLAD
- 33 = HASSELBLAD
- 34 = HASSELBLAD
- 35 = HASSELBLAD
- 36 = HASSELBLAD

GEOR 8 57 S024500 E373000 S050000 E381500 S060000 E370000 S050000 E350000 S034500 E344000 S014000 E351000
110 ACCESSIONS
LIST FOR JEH 51000144

TYPE COVERAGE FILM SOURCE PHOTO/SCENE ID QUAL CLD DATE CENTER/1ST FRAME CTR SCALE ALT OLAP 1ST LAST NOF MICROFILM CCT

ERTS-1 (MSS) 8&W-02.2" 81048071845N000 8 00% 720909 S05 45 27 E034 59 07 3369000 9100 10% 0
SCENE (S06 33 43,E033 46 08)(S06 49 32,E035 57 11)(S04 41 06,E034 01 02)(S04 57 11,E036 11 45) S11 3806 M5 113 55 53

ERTS-1 (MSS) 8&W-02.2" 81192071925A000 8888 30% 730131 S05 40 12 E034 56 33 3369000 9135 10% 200140441
SCENE (S05 01 19,E035 56 53)(S04 47 30,E034 20 22)(S06 32 52,E035 32 52)(S06 18 59,E033 56 05) S11 3806 M5 113 55 53

ERTS-1 (MSS) 8&W-02.2" 81408071805A000 8888 20% 730904 S05 42 01 E034 52 02 3369000 9095 10% 200281480
SCENE (S05 03 17,E035 52 06)(S04 49 34,E034 15 59)(S06 34 26,E035 28 12)(S06 20 40,E033 51 51) S11 3806 M5 113 55 53

ERTS-2 (MSS) 8&W-02.2" 82152070735000 8588 20% 750623 S05 50 59 E034 54 59 3369000 9109 10% 200091272
SCENE (S05 12 58,E035 55 40)(S04 57 57,E034 19 35)(S06 44 00,E035 30 32)(S06 28 55,E033 54 11) S11 3806 M5 113 55 53

ERTS-1 (MSS) 8&W-02.2" 01065071255G000 8888 50% 720926 S05 49 51 E036 27 53 3369000 9153 10% 200041567
SCENE (S05 11 14,E037 28 31)(S04 56 52,E035 51 54)(S06 42 48,E037 03 58)(S06 28 23,E035 27 07) S11 3806 M5 113 55 53

FRTS-1 (MSS) B&W-02.2" 81119071345A000 8888 70% 721119 S05 48 19 E036 18 22 3369000 9176 10% 200080584
SCENE (S05 09 20,E037 19 01)(S04 55 20,E035 42 03)(S06 41 16,E036 54 47)(S06 27 12,E035 17 35) S11 3806 M5 113 55 53

ERTS-1 (MSS) B&W-02.2" 81155071335A000 2888 30% 721225 S05 44 23 E036 24 19 3369000 9078 10% 200110763 Y
SCENE (S05 06 02,E037 24 29)(S04 51 50,E035 48 37)(S06 36 55,E037 00 09)(S06 22 39,E035 24 02) S11 3806 M5 113 55 53

ERTS-1 (MSS) B&W-02.2" 81533071005A000 8888 50% 740107 S05 44 42 E036 23 31 3369000 9114 10% 200340873
SCENE (S05 06 13,E037 23 55)(S04 51 55,E035 47 41)(S06 37 26,E036 59 28)(S06 23 05,E035 22 59) S11 3806 M5 113 55 53

ERTS-1 (MSS) 8&W-02.2" 81154070755A000 8888 50% 721224 S05 45 12 E037 48 34 3369000 9079 10% 200130086
SCENE (S05 06 39,E038 48 37)(S04 52 45,E037 12 42)(S06 37 36,E038 24 34)(S06 23 39,E036 48 24) S11 3806 M5 113 55 53

ERTS-1 (MSS) 8&W-02.2" 81172070735A000 8888 30% 730111 S05 50 33 E037 52 08 3369000 9083 10% 200120686 Y
SCENE (S05 11 56,E038 52 00)(S04 58 02,E037 16 02)(S06 43 02,E038 28 23)(S06 29 04,E036 52 09) S11 3806 M5 113 55 53

ERTS-1 (MSS) 8&W-02.2" 81532070425A000 8888 30% 740106 S05 45 19 E037 48 58 3369000 9117 10% 200350042 Y
SCENE (S05 06 48,E038 49 23)(S04 52 32,E037 13.06)(S06 38 03,E038 24 57)(S06 23 45,E036 48 25) S11 3806 M5 113 55 53

ERTS-2 (MSS) 8&W-02.2" 821860655450000 5555 00% 750727 S05 41 59 E037 51 59 3369000 9052 10% 0
SCENE (S05 04 15,E038 52 20)(S04 49 16,E037 16 52)(S06 34 41,E038 27 14)(S06 19 39,E036 51 32) S11 3806 M5 113 55 53

ERTS-1 (MSS) 8&W-02.2" 81049072405A000 8888 00% 720910 S04 21 34 E033 53 40 3369000 9098 10% 200030171
SCENE (S03 43 06,E034 53 50)(S03 28 55,E033 17 56)(S05 14 11,E034 29 30)(S04 59 57,E032 53 24) S11 3806 M5 113 55 53

ERTS-1 (MSS) 8&W-02.2" 81067072355A000 8888 10% 720928 S04 17 56 E033 56 01 3369000 9154 10% 200041773
SCENE (S03 39 03,E034 56 25)(S03 25 04,E033 19 54)(S05 10 45,E034 32 14)(S04 56 44,E032 55 31) S11 3806 M5 113 55 53

ERTS-1 (MSS) 8&W-02.2" 81373072405A000 8888 00% 730731 S04 14 54 E033 44 18 3369000 9198 10% 200261464
SCENE (S03 35 51,E034 44 59)(S03 21 47,E033 08 00)(S05 07 59,E034 20 41)(S04 53 53,E032 43 31) S11 3806 M5 113 55 53

ERTS-2 (MSS) B&W-02.2" 821530712550000 8588 10% 750624 S04 23 59 E033 48 59 3369000 9104 10% 0
SCENE (S03 46 01,E034 49 32)(S03 30 58,E033 13 42)(S05 16 59,E034 24 23)(S05 01 53,E032 48 21) S11 3806 M5 113 55 53

ERTS-1 (MSS) 8&W-02.2" 81120071905A000 8888 50% 721120 S04 20 21 E035 14 20 3369000 9171 10% 200080668
SCENE (S03 41 35,E036 14 58)(S03 27 17,E034 38 18)(S05 13 24,E035 50 28)(S04 59 02,E034 13 36) S11 3806 M5 113 55 53

ERTS-1 (MSS) B&W-02.2" 81156071855A000 8888 60% 721226 S04 14 21 E035 19 08 3369000 9074 10% 200110871
SCENE (S03 35 57,E036 19 07)(S03 21 52,E034 43 28)(S05 06 48,E035 54 54)(S04 52 41,E034 19 04) S11 3806 M5 113 55 53

ERTS-1 (MSS) B&W-02.2" 81192071855A000 8888 10% 730131 S04 12 41 E035 17 22 3369000 9131 10% 200140440 Y
SCENE (S03 33 53,E036 17 36)(S03 19 58,E034 41 19)(S05 05 22,E035 53 30)(S04 51 25,E034 17 02) S11 3806 M5 113 55 53

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GEOR 8 57 S024500 E373000 S050000 E381500 S060000 E370000 S050000 E350000 S034500 E344000 S014000 E351000
110 ACCESSIONS
LIST FOR JEH 51000144

 TYPE COVERAGE      FILM SOURCE  PHOTO/SCENE ID  QUAL CLD  DATE  CENTER/1ST FRAME CTR  SCALE  ALT OLAP  1ST LAST NOF MICROFILM CCT

ERTS-1 (MSS)        B&W-02.2" 81408071745A000  2888 30% 730904 S04 15 18 E035 12 23 3369000 9093 10%                200281479
 SCENE      (S03 36 25,E036 12 37)(S03 22 36,E034 36 14)(S05 07 59,E035 48 37)(S04 54 07,E034 12 03) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82152070715O000  8885 30% 750623 S04 23 59 E035 15 00 3369000 9109 10%                200091271
 SCENE      (S03 45 58,E036 15 33)(S03 30 58,E034 39 38)(S05 16 59,E035 50 26)(S05 01 57,E034 14 20) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81119071325A000  8888 70% 721119 S04 22 45 E036 39 08 3369000 9174 10%                200080583
 SCENE      (S03 43 51,E037 39 43)(S03 29 43,E036 02 59)(S05 15 44,E037 15 23)(S05 01 33,E035 38 27) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81155071315A000  2888 30% 721225 S04 17 22 E036 44 48 3369000 9076 10%                200110762 Y
 SCENE      (S03 39 02,E037 44 51)(S03 24 48,E036 09 12)(S05 09 53,E037 20 29)(S04 55 36,E035 44 39) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81533070945A000  8802 30% 740107 S04 18 00 E036 43 58 3369000 9113 10%                200340872 Y
 SCENE      (S03 39 39,E037 44 40)(S03 25 18,E036 08 38)(S05 10 40,E037 19 23)(S04 56 17,E035 43 10) S11 3806 M5 113   55  53

ERTS-1 (RBV)        B&W-02.2" 81010070632A000  888  60% 720802 S04 17 55 E038 12 06 3369000 9102 10%                200011069
 SCENE      (S03 39 17,E039 07 15)(S03 24 20,E037 31 26)(S05 11 28,E038 52 53)(S04 56 28,E037 16 52) S10 3706 R2 113   55  55

ERTS-1 (MSS)        B&W-02.2" 81010070645A000  8888 70% 720802 S04 49 09 E038 04 53 3369000 9102 10%                200011070
 SCENE      (S04 11 09,E039 05 25)(S03 56 11,E037 29 32)(S05 42 06,E038 40 19)(S05 27 05,E037 04 14) S11 0615 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81154070725A000  8888 40% 721224 S04 19 06 E038 09 14 3369000 9077 10%                200130085
 SCENE      (S03 40 38,E039 09 12)(S03 26 38,E037 33 30)(S05 11 32,E038 45 03)(S04 57 29,E037 09 10) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81172070715A000  8888 10% 730111 S04 24 50 E038 12 51 3369000 9079 10%                200120685 Y
 SCENE      (S03 46 22,E039 12 51)(S03 32 20,E037 37 07)(S05 17 17,E038 48 41)(S05 03 13,E037 12 46) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81226070755A000  8888 50% 730306 S04 08 43 E038 01 43 3369000 9212 10%                200161301
 SCENE      (S03 29 23,E039 02 20)(S03 15 41,E037 25 09)(S05 01 44,E038 38 23)(S04 48 00,E037 01 01) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81532070405A000  8888 40% 740106 S04 18 12 E038 09 30 3369000 9116 10%                200350041
 SCENE      (S03 39 43,E039 09 49)(S03 25 25,E037 33 45)(S05 10 57,E038 45 20)(S04 56 36,E037 09 05) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82060065545G000  5858 60% 750323 S04 21 59 E038 18 59 3369000 9062 10%                200030553
 SCENE      (S03 44 07,E039 19 20)(S03 29 19,E037 43 54)(S05 14 38,E038 54 10)(S04 59 48,E037 18 33) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82096065535N000  8888 60% 750428 S04 21 59 E038 12 59 3369000 9211 10%                200060279
 SCENE      (S03 43 28,E039 14 18)(S03 28 28,E037 37 17)(S05 15 29,E038 48 47)(S05 00 26,E037 11 35) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82132065535A000  5558 50% 750603 S04 26 59 E038 09 59 3369000 9200 10%                200071537
 SCENE      (S03 48 32,E039 11 14)(S03 33 31,E037 34 20)(S05 20 26,E038 45 45)(S05 05 22,E037 08 39) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82186065515O000  5855 10% 750727 S04 15 00 E038 12 59 3369000 9048 10%                        0
 SCENE      (S03 37 16,E039 13 11)(S03 22 17,E037 37 57)(S05 07 40,E038 48 08)(S04 52 39,E037 12 42) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82222065435O000  8888 50% 750901 S04 16 59 E038 17 59 3369000 9187 10%                        0
 SCENE      (S03 38 31,E039 18 58)(S03 23 35,E037 42 13)(S05 10 22,E038 53 51)(S04 55 23,E037 16 55) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81139072425A000  8888 40% 721209 S03 04 32 E034 08 06 3369000 9109 10%                200100781
 SCENE      (S02 26 12,E035 08 22)(S02 11 44,E033 32 30)(S03 57 20,E034 43 45)(S03 42 49,E033 07 45) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82097070055A000  8888 50% 750429 S03 00 59 E037 05 59 3369000 9210 10%                200060429
 SCENE      (S02 22 30,E038 07 13)(S02 07 28,E036 30 20)(S03 54 29,E037 41 42)(S03 39 26,E036 04 42) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82133070055N000  8588 60% 750604 S03 00 59 E037 03 59 3369000 9195 10%                200080496
 SCENE      (S02 22 33,E038 05 07)(S02 07 34,E036 28 24)(S03 54 24,E037 39 39)(S03 39 23,E036 02 47) S11 3806 M5 113   55  53
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GEOR 8 57 S024500 E373000 S050000 E381500 S060000 E370000 S050000 E350000 S034500 E344000 S014000 E351000
110 ACCESSIONS
LIST FOR JEH 51000144

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 TYPE COVERAGE      FILM SOURCE  PHOTO/SCENE ID  QUAL CLD  DATE  CENTER/1ST FRAME CTR  SCALE  ALT OLAP  1ST LAST NOF MICROFILM CCT

ERTS-1 (MSS)        B&W-02.2" 81010070625A000  8888 50% 720802 S03 22 21 E038 24 59 3369000 9101 10%          200011068
 SCENE      (S02 44 20,E039 25 25)(S02 29 24,E037 49 41)(S04 15 16,E039 00 21)(S04 00 18,E037 24 28) S11 0615 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81046070625A000  8888 70% 720907 S03 00 13 E038 28 18 3369000 9088 10%          200021840
 SCENE      (S02 21 31,E039 28 09)(S02 07 49,E037 52 24)(S03 52 35,E039 04 16)(S03 38 51,E037 28 23) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81049072335A000  8888 00% 720910 S02 54 12 E034 13 48 3369000 9054 10%          200030170
 SCENE      (S02 15 45,E035 13 51)(S02 01 36,E033 38 06)(S03 46 47,E034 49 33)(S03 32 37,E033 13 41) S11 3806 M5 113   55  53

ERTS-1 (MSS)        FCC-07.3" 81049072335A200 58G R 00% 720910 S02 54 12 E034 13 48 1000000 9094 00%          200030170
 SCENE      (S02 15 45,E035 13 51)(S02 01 36,E033 38 06)(S03 46 47,E034 49 33)(S03 32 37,E033 13 41) S11 3808 M5 500  185 178

ERTS-1 (MSS)        B&W-02.2" 81067072335A000  8888 40% 720928 S02 51 06 E034 16 10 3369000 9149 10%          200041772
 SCENE      (S02 12 15,E035 16 27)(S01 58 18,E033 40 06)(S03 43 54,E034 52 17)(S03 29 55,E033 15 48) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81373072335A000  8888 00% 730731 S02 48 10 E034 04 04 3369000 9196 10%          200261463
 SCENE      (S02 08 46,E035 05 06)(S01 54 40,E033 27 28)(S03 41 38,E034 40 43)(S03 27 31,E033 02 57) S11 3806 M5 113   55  53

ERTS-1 (MSS)        FCC-07.3" 81373072335A200 68G R 00% 730731 S02 48 10 E034 04 04 1000000 9196 00%          200261463
 SCENE      (S02 08 46,E035 05 06)(S01 54 40,E033 27 28)(S03 41 38,E034 40 43)(S03 27 31,E033 02 57) S11 3808 M5 500  185 178

ERTS-2 (MSS)        B&W-02.2" 82153071235000O  8888 00% 750624 S02 57 59 E034 08 59 3369000 9104 10%                  0
 SCENE      (S02 20 01,E035 09 27)(S02 04 59,E033 33 44)(S03 50 58,E034 44 19)(S03 35 55,E033 08 28) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81048071755N000  2828 10% 720909 S02 52 07 E035 39 44 3369000 9092 10%          200030053
 SCENE      (S02 13 36,E036 39 43)(S01 59 35,E035 03 59)(S03 44 39,E036 15 32)(S03 30 36,E034 39 41) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81120071835A000  8888 40% 721120 S02 54 00 E035 34 50 3369000 9170 10%          200080667
 SCENE      (S02 15 18,E036 35 24)(S02 00 55,E034 58 53)(S03 47 04,E036 10 50)(S03 32 40,E034 34 11) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81156071825A000  8888 70% 721226 S02 46 25 E035 39 00 3369000 9072 10%          200110870
 SCENE      (S02 07 57,E036 38 51)(S01 54 00,E035 03 20)(S03 38 48,E036 14 44)(S03 24 49,E034 39 05) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81174071815A000  8888 50% 730113 S02 55 20 E035 40 17 3369000 9078 10%          200120894
 SCENE      (S02 16 39,E036 40 03)(S02 03 01,E035 04 24)(S03 47 38,E036 16 15)(S03 33 58,E034 40 28) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81192071835A000  8888 10% 730131 S02 45 34 E035 38 14 3369000 9126 10%          200140439 Y
 SCENE      (S02 06 53,E036 38 25)(S01 52 50,E035 02 20)(S03 38 17,E036 14 12)(S03 24 12,E034 37 59) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81408071715A000  8828 60% 730904 S02 48 47 E035 32 29 3369000 9092 10%          200281478
 SCENE      (S02 10 05,E036 32 22)(S01 56 21,E034 56 35)(S03 41 11,E036 08 26)(S03 27 25,E034 32 32) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82044070655A000  8585 60% 750307 S02 58 59 E035 43 59 3369000 9041 10%          200020065
 SCENE      (S02 21 14,E036 44 07)(S02 06 25,E035 09 02)(S03 51 32,E036 19 00)(S03 36 42,E034 43 47) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82062070645A000  8588 40% 750325 S02 57 59 E035 46 59 3369000 9064 10%          200031016
 SCENE      (S02 20 11,E036 47 16)(S02 05 15,E035 11 57)(S03 50 43,E036 22 05)(S03 35 45,E034 46 39) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82080070645G000  8888 50% 750412 S02 58 59 E035 37 59 3369000 9139 10%          200031337
 SCENE      (S02 20 44,E036 38 46)(S02 05 57,E035 02 37)(S03 52 01,E036 13 25)(S03 37 12,E034 37 09) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82134070645A000  8888 40% 750605 S02 53 59 E035 38 59 3369000 9192 10%          200080666
 SCENE      (S02 15 38,E036 40 05)(S02 00 32,E035 03 26)(S03 47 26,E036 14 37)(S03 32 18,E034 37 50) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82152070645000O  8888 30% 750623 S02 57 59 E035 34 59 3369000 9107 10%          200091270
 SCENE      (S02 19 58,E036 35 28)(S02 05 00,E034 59 42)(S03 50 58,E036 10 21)(S03 35 58,E034 34 27) S11 3806 M5 113   55  53
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GEOR 8 57 S024500 E373000 S050000 E381500 S060000 E370000 S050000 E350000 S034500 E344000 S014000 E351000
110 ACCESSIONS
LIST FOR JEH 51000144

TYPE COVERAGE    FILM SOURCE  PHOTO/SCENE ID  QUAL CLD  DATE   CENTER/1ST FRAME CTR  SCALE  ALT OLAP  1ST LAST NOF MICROFILM CCT

ERTS-2 (MSS)        B&W-02.2" 8217007063500000  5558 40% 750711 S02 49 59 E035 36 59 3369000 9046 10%                         0
 SCENE      (S02 12 11,E036 37 03)(S01 57 22,E035 01 55)(S03 42 36,E036 12 07)(S03 27 45,E034 36 52) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 822060705450000  5585 60% 750816 S02 50 59 E035 45 00 3369000 9107 10%                         0
 SCENE      (S02 12 52,E036 45 24)(S01 58 04,E035 09 36)(S03 43 54,E036 20 26)(S03 29 04,E034 44 31) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81245071315A000  8882 40% 730325 S02 44 14 E036 53 47 3369000 9189 10%                 200200129
 SCENE      (S02 05 06,E037 54 15)(S01 51 16,E036 17 27)(S03 37 11,E037 30 10)(S03 23 19,E035 53 15) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81155071245A000  2888 50% 721225 S02 50 38 E037 05 13 3369000 9074 10%                 200110761
 SCENE      (S02 12 22,E038 05 13)(S01 58 05,E036 29 42)(S03 43 10,E037 40 48)(S03 28 52,E036 05 10) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81515070945A000  8888 30% 731220 S02 48 08 E037 02 13 3369000 9171 10%                 200340845
 SCENE      (S02 09 21,E038 02 45)(S01 55 06,E036 26 12)(S03 41 09,E037 38 17)(S03 26 53,E036 01 37) S11 3806 M5 113   55  53

ERTS-1 (MSS)        FCC-07.3" 81515070945A200  8BG R 30% 731220 S02 48 08 E037 02 13 1000000 9171 00%               200340845
 SCENE      (S02 09 21,E038 02 45)(S01 55 06,E036 26 12)(S03 41 09,E037 38 17)(S03 26 53,E036 01 37) S11 3808 M5 500  185 178

ERTS-1 (MSS)        B&W-02.2" 81533070915A000  8888 20% 740107 S02 50 51 E037 04 05 3369000 9112 10%                 200340871 Y
 SCENE      (S02 12 30,E038 04 42)(S01 58 11,E036 28 48)(S03 43 31,E037 39 25)(S03 29 09,E036 03 23) S11 3806 M5 113   55  53

ERTS-1 (MSS)        FCC-07.3" 81533070915A200  6BG R 10% 740107 S02 50 51 E037 04 05 1000000 9112 00%               200340871
 SCENE      (S02 12 25,E038 04 19)(S01 58 05,E036 28 25)(S03 43 36,E037 39 48)(S03 29 14,E036 03 47) S11 3808 M5 500  185 178

ERTS-2 (MSS)        B&W-02.2" 82061070055A000  5888 40% 750324 S02 58 59 E037 08 59 3369000 9061 10%                         0
 SCENE      (S02 21 12,E038 09 15)(S02 06 15,E036 33 58)(S03 51 42,E037 44 05)(S03 36 44,E036 08 40) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82079070105G000  8888 70% 750411 S02 55 59 E037 04 59 3369000 9135 10%                 200031304
 SCENE      (S02 17 44,E038 05 44)(S02 02 59,E036 29 38)(S03 48 59,E037 40 24)(S03 34 12,E036 04 10) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82115070045A000  8888 60% 750517 S02 54 59 E037 09 59 3369000 9235 10%                 200070327
 SCENE      (S02 16 23,E038 11 22)(S02 01 20,E036 34 14)(S03 48 38,E037 45 48)(S03 33 33,E036 08 32) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 821690700550000  5888 40% 750710 S02 50 59 E037 02 59 3369000 9050 10%                 200100310
 SCENE      (S02 13 09,E038 03 04)(S01 58 22,E036 27 53)(S03 43 35,E037 38 09)(S03 28 48,E036 02 51) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 822050700050000  8888 30% 750815 S02 50 59 E037 10 59 3369000 9104 10%                         0
 SCENE      (S02 12 55,E038 11 24)(S01 58 04,E036 35 39)(S03 43 54,E037 46 23)(S03 29 01,E036 10 31) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 822230659450000  5555 70% 750902 S02 48 59 E037 12 59 3369000 9185 10%                         0
 SCENE      (S02 10 34,E038 13 55)(S01 55 35,E036 37 19)(S03 42 23,E037 48 44)(S03 27 22,E036 12 00) S11 3806 M5 113   55  53

ERTS-1 (RBV)        B&W-02.2" 81010070612A000  888  50% 720802 S02 51 07 E038 32 13 3369000 9100 10%                 200011067
 SCENE      (S02 12 30,E039 27 16)(S01 57 34,E037 51 34)(S03 44 39,E039 12 55)(S03 29 43,E037 37 06) S10 3706 R2 113   55  55

ERTS-1 (MSS)        B&W-02.2" 81154070705A000  8888 50% 721224 S02 53 29 E038 29 29 3369000 9075 10%                 200130084
 SCENE      (S02 15 04,E039 29 23)(S02 01 01,E037 53 50)(S03 45 56,E039 05 11)(S03 31 51,E037 29 30) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81172070645A000  8888 50% 730111 S02 57 58 E038 33 37 3369000 9076 10%                 200120684
 SCENE      (S02 19 36,E039 33 35)(S02 05 27,E037 58 01)(S03 50 27,E039 09 17)(S03 36 17,E037 33 36) S11 3806 M5 113   55  53

ERTS-1 (MSS)        FCC-07.3" 81172070645A200  5BG R 40% 730111 S02 57 58 E038 33 37 1000000 9076 00%               200120684
 SCENE      (S02 19 36,E039 33 35)(S02 05 27,E037 58 01)(S03 50 27,E039 09 17)(S03 36 17,E037 33 36) S11 3808 M5 500  185 178

ERTS-1 (MSS)        B&W-02.2" 81190070705G000  8828 70% 730129 S02 44 11 E038 31 37 3369000 9120 10%                 200140142
 SCENE      (S02 05 34,E039 31 48)(S01 51 29,E037 55 46)(S03 36 53,E039 07 31)(S03 22 46,E037 31 23) S11 3806 M5 113   55  53
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GEOR 8 57 S024500 E373000 S050000 E381500 S060000 E370000 S050000 E350000 S034500 E344000 S014000 E351000
110 ACCESSIONS
LIST FOR JEH 51000144

 TYPE COVERAGE      FILM SOURCE  PHOTO/SCENE ID  QUAL CLD  DATE  CENTER/1ST FRAME CTR  SCALE  ALT OLAP  1ST LAST NOF MICROFILM CCT

ERTS-1 (MSS)        B&W-02.2" 81226070725A000  8888 30% 730306 S02 42 41 E038 22 02 3369000 9209 10%              200161300
 SCENE      (S02 03 23,E039 22 35)(S01 49 39,E037 45 34)(S03 35 42,E038 58 34)(S03 21 55,E037 21 25) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82060065515G000  5858 70% 750323 S02 54 59 E038 38 59 3369000 9058 10%              200030552
 SCENE      (S02 17 08,E039 39 14)(S02 02 21,E038 03 58)(S03 47 36,E039 14 04)(S03 32 48,E037 38 41) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82078065515G000  8888 30% 750410 S02 56 59 E038 36 59 3369000 9130 10%              200031228
 SCENE      (S02 18 46,E039 37 42)(S02 04 00,E038 01 39)(S03 49 58,E039 12 23)(S03 35 10,E037 36 12) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82096065515N000  8888 50% 750428 S02 55 59 E038 32 59 3369000 9207 10%              200060278
 SCENE      (S02 17 30,E039 34 12)(S02 02 31,E037 57 21)(S03 49 27,E039 08 41)(S03 34 26,E037 31 43) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 821500655150000  5888 20% 750621 S02 55 59 E038 26 59 3369000 9118 10%              200091050
 SCENE      (S02 17 50,E039 27 29)(S02 02 59,E037 51 34)(S03 48 59,E039 02 28)(S03 34 06,E037 26 26) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 821680655150000  8885 40% 750709 S02 57 59 E038 26 59 3369000 9052 10%                      0
 SCENE      (S02 20 09,E039 27 05)(S02 05 21,E037 51 53)(S03 50 37,E039 02 09)(S03 35 47,E037 26 50) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 821860654550000  8855 10% 750727 S02 47 59 E038 32 59 3369000 9044 10%                      0
 SCENE      (S02 10 16,E039 33 05)(S01 55 20,E037 58 00)(S03 40 37,E039 08 02)(S03 25 40,E037 32 50) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 822040654250000  5555 40% 750814 S02 51 59 E038 35 59 3369000 9100 10%                      0
 SCENE      (S02 13 53,E039 36 20)(S01 59 07,E038 00 37)(S03 44 51,E039 11 25)(S03 30 03,E037 35 35) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81049072315A000  8888 10% 720910 S01 27 35 E034 34 08 3369000 9091 10%              200030169
 SCENE      (S00 49 10,E035 34 09)(S00 34 59,E033 58 30)(S02 20 10,E035 09 48)(S02 05 58,E033 34 05) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81067072305A000  8888 30% 720928 S01 24 27.E034 36 27 3369000 9145 10%              200041771
 SCENE      (S00 45 39,E035 36 42)(S00 31 39,E034 00 27)(S02 17 14,E035 12 30)(S02 03 14,E033 36 11) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81139072405A000  8888 20% 721209 S01 37 54 E034 28 17 3369000 9108 10%              200100780
 SCENE      (S00 59 36,E035 28 31)(S00 45 06,E033 52 44)(S02 30 42,E035 03 52)(S02 16 12,E033 28 00) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81193072355N000  8888 10% 730201 S01 20 12 E034 31 29 3369000 9125 10%              200140584
 SCENE      (S00 41 28,E035 31 36)(S00 27 31,E033 55 33)(S02 12 52,E035 07 27)(S01 58 54,E033 31 20) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82045071215N000  5558 60% 750308 S01 32 59 E034 37 59 3369000 9038 10%              200021258
 SCENE      (S00 55 18,E035 38 03)(S00 40 24,E034 03 05)(S02 25 34,E035 12 56)(S02 10 39,E033 37 53) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82063071205A000  5888 10% 750326 S01 33 59 E034 35 59 3369000 9063 10%              200040308
 SCENE      (S00 56 14,E035 36 13)(S00 41 14,E034 00 59)(S02 26 45,E035 11 02)(S02 11 43,E033 35 44) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 82081071205A000  8888 10% 750413 S01 34 59 E034 31 59 3369000 9139 10%              200031427
 SCENE      (S00 56 46,E035 32 43)(S00 41 55,E033 56 39)(S02 28 03,E035 07 22)(S02 13 11,E033 31 13) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 821530712050000  8888 10% 750624 S01 30 59 E034 28 59 3369000 9104 10%                      0
 SCENE      (S00 53 01,E035 29 25)(S00 38 01,E033 53 45)(S02 23 58,E035 04 16)(S02 08 57,E033 28 32) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 822070711050000  5888 20% 750817 S01 23 59 E034 39 59 3369000 9107 10%                      0
 SCENE      (S00 45 52,E035 40 21)(S00 31 05,E034 04 37)(S02 16 54,E035 15 24)(S02 02 06,E033 39 36) S11 3806 M5 113   55  53

ERTS-2 (MSS)        B&W-02.2" 822250710550000  5888 30% 750904 S01 21 59 E034 39 59 3369000 9189 10%                      0
 SCENE      (S00 43 29,E035 40 51)(S00 28 37,E034 04 15)(S02 15 21,E035 15 46)(S02 00 28,E033 39 06) S11 3806 M5 113   55  53

ERTS-1 (MSS)        B&W-02.2" 81048071725N000  2828 10% 720909 S01 25 20 E035 59 49 3369000 9088 10%              200030052
 SCENE      (S00 46 50,E036 59 44)(S00 32 50,E035 24 06)(S02 17 50,E036 35 33)(S02 03 49,E034 59 51) S11 3806 M5 113   55  53
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GEOR 8 57 S024500 E373000 S050000 E381500 S060000 E370000 S050000 E350000 S034500 E344000 S014000 E351000
110 ACCESSIONS
LIST FOR JEH 51000144

 TYPE COVERAGE     FILM SOURCE  PHOTO/SCENE ID  QUAL CLD  DATE  CENTER/1ST FRAME CTR  SCALE  ALT OLAP  1ST LAST NOF MICROFILM CCT

ERTS-1 (MSS)          B&W-02.2" 81156071805A000  8888 70% 721226 S01 19 28 E035 59 09 3369000 9070 10%              200110869
 SCENE       (S00 41 02,E036 58 57)(S00 27 04,E035 23 30)(S02 11 51,E036 34 50)(S01 57 53,E034 59 20) S11 3806 M5 113    55  53

ERTS-1 (MSS)          B&W-02.2" 81192071805N000  8888 10% 730131 S01 19 24 E035 58 57 3369000 9122 10%              200140438
 SCENE       (S00 40 50,E036 59 08)(S00 26 39,E035 23 10)(S02 12 09,E036 34 46)(S01 57 57,E034 58 44) S11 3806 M5 113    55  53

ERTS-1 (MSS)          FCC-07.3" 81192071805N200 5BG R 10% 730131 S01 19 24 E035 58 57 1000000 9122 00%              200140438
 SCENE       (S00 40 50,E036 59 08)(S00 26 39,E035 23 10)(S02 12 09,E036 34 46)(S01 57 57,E034 58 44) S11 3808 M5 500  185 178

ERTS-1 (MSS)          B&W-02.2" 81516071505A000  8888 10% 731221 S01 21 18 E035 54 47 3369000 9167 10%              200340994 Y
 SCENE       (S00 42 18,E036 54 58)(S00 28 22,E035 18 28)(S02 14 13,E036 31 08)(S02 00 16,E034 54 35) S11 3806 M5 113    55  53

ERTS-1 (MSS)          FCC-07.3" 81516071505A200 88G R 10% 731221 S01 21 18 E035 54 47 1000000 9167 00%              200340994
 SCENE       (S00 42 21,E036 55 09)(S00 28 24,E035 18 39)(S02 14 11,E036 30 58)(S02 00 13,E034 54 24) S11 3808 M5 500  185 178

ERTS-1 (MSS)          B&W-02.2" 81534071435A000  2888 10% 740108 S01 25 37 E035 56 51 336900C 9107 10%              200340861
 SCENE       (S00 47 06,E036 56 56)(S00 32 58,E035 21 06)(S02 18 16,E036 32 36)(S02 04 07,E034 56 43) S11 3806 M5 113    55  53

ERTS-2 (MSS)          B&W-02.2" 82080070625G000  8558 60% 750412 S01 31 59 E035 58 59 3369000 9135 10%              200031336
 SCENE       (S00 53 46,E036 59 42)(S00 38 58,E035 23 40)(S02 25 00,E036 34 21)(S02 10 11,E034 58 15) S11 3806 M5 113    55  53

ERTS-2 (MSS)          B&W-02.2" 82134070615A000  5888 50% 750605 S01 27 59 E035 58 59 3369000 9191 10%              200080665
 SCENE       (S00 49 39,E037 00 02)(S00 34 32,E035 23 27)(S02 21 27,E036 34 33)(S02 06 19,E034 57 54) S11 3806 M5 113    55  53

ERTS-2 (MSS)          B&W-02.2" 821520706250000  8888 50% 750623 S01 30 59 E035 54 59 3369000 9107 10%              200091269
 SCENE       (S00 52 59,E036 55 26)(S00 38 00,E035 19 43)(S02 23 58,E036 30 18)(S02 08 59,E034 54 31) S11 3806 M5 113    55  53

ERTS-2 (MSS)          B&W-02.2" 821700706150000  5558 40% 750711 S01 22 59 E035 56 59 3369000 9046 10%                      0
 SCENE       (S00 45 11,E036 57 00)(S00 30 23,E035 21 55)(S02 15 35,E036 32 05)(S02 00 47,E034 56 57) S11 3806 M5 113    55  53

ERTS-1 (MSS)          B&W-02.2" 81174071745A000  8888 50% 730113 S01 29 33 E036 00 36 3369000 9075 10%              200120893
 SCENE       (S00 50 56,E037 00 19)(S00 37 14,E035 24 46)(S02 21 52,E036 36 26)(S02 08 09,E035 00 50) S11 3806 M5 113    55  53

ERTS-2 (MSS)          B&W-02.2" 82044070635A000  8585 40% 750307 S01 31 59 E036 03 59 3369000 9039 10%              200020064
 SCENE       (S00 54 16,E037 04 04)(S00 39 26,E035 29 05)(S02 24 32,E036 38 56)(S02 09 41,E035 03 53) S11 3806 M5 113    55  53

ERTS-2 (MSS)          B&W-02.2" 82062070615A000  5588 40% 750325 S01 30 59 E036 07 59 3369000 9060 10%              200031015
 SCENE       (S00 53 14,E037 08 12)(S00 38 15,E035 33 00)(S02 23 43,E036 43 01)(S02 08 43,E035 07 45) S11 3806 M5 113    55  53

ERTS-2 (MSS)          B&W-02.2" 821880705550000  5555 00% 750729 S01 23 59 E036 00 59 3369000 9044 10%                      0
 SCENE       (S00 46 19,E037 01 04)(S00 31 19,E035 26 02)(S02 16 39,E036 35 58)(S02 01 39,E035 00 53) S11 3806 M5 113    55  53

ERTS-2 (MSS)          B&W-02.2" 822060705250000  5588 70% 750816 S01 23 59 E036 04 59 3369000 9104 10%                      0
 SCENE       (S00 45 53,E037 05 19)(S00 31 06,E035 29 38)(S02 16 53,E036 40 23)(S02 02 05,E035 04 38) S11 3806 M5 113    55  53

TOTALS  ERTS- 110, MANNED SPACECRAFT-     , NASA-AIRCRAFT-     , AERIAL MAPPING-
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APPENDIX D

Discussion of Climatic Thresholds
for Agricultural Development

APPENDIX D

Discussion of Climatic Thresholds for Agricultural Development

A review and discussion is presented in this Appendix Section of the report of the relationships between climate and agricultural potential in the Arusha Region which led to selection of 600 mm mean annual precipitation as a threshold value below which agricultural development is extremely risky and possibly unwise.

A summary of crop ecology information was prepared in order to shed light on the climatic thresholds beyond which agricultural cropping may not be feasible. These data were drawn largely from Brown and Cocheme (1973) and Acland (1971). The most salient information is presented in Table D-1. From these data, it is possible to postulate some useful climatic thresholds for region-wide interpretation as well as subsequent site-specific decisions when more local resource information (particularly about soils) becomes available.

The data from Table D-1 suggests that a threshold of 500 to 600 mm mean annual precipitation marks the cut-off point below which agricultural development is extremely risky and possibly unwise. Braun (1974) has suggested that precipitation below 300 mm in any one rainy season is generally inadequate to mature a crop--thus marking a seasonal precipitation threshold.

In his comprehensive and thorough studies of East African Rangelands, Heady (1960) characterized "rangelands" by many criteria, one of which was climatic. He classed as range those areas receiving an annual average between 762 and 889 mm of precipitation and where the expectance

TABLE D-1: CROP ECOLOGY DATA USEFUL IN LAND USE CAPABILITY PROJECTIONS FOR THE ARUSHA REGION

Crop	Units H_2O per Unit D.M.	Growing Season mm. ppt.	Min. $\bar{x}$ ann.ppt.	Max. or Optimum ann.ppt.	Optimum Gro.Seas. ppt.	Range of Elevation	Temperature Requirements	Remarks
			mm	mm	mm	m	°C	
TEFF			625	M973	200-300	1700-2000m	Frost sens.	Mainly in Kenya and Ethopia
(*Eragrostis tef*)						Some 2400	15.2-20°	Frost tolerance, 1 year in 5 or less
						2500+	1-2° lethal	White seeded, best below 2,400 meters
							> 14° < 40°	Drought resistant after 6-leaf stage
			600---	------	------	------	------	-In Acacia-Commiphora thornbush areas
								Varieties 60 to 150 days (most 90 to 120) planting to maturity
			500---	------	------	------	------	-As nurse crop with other grasses
								Grows on 15-30cm of soil
								Will grow on heavy black soils
								Planted in peak rains, June-July
MAIZE	350	300-1800	600	M1200		0-4000	> 10°	Planted mid-March through April, earlier generally better
(*Zea mays*)							Opt.20-26°	
			500	M5000			Crit.min. 8°	ppt. has linear affect on yield $r^2 = .44$ (p = 0.01
				<800---	------	------	------	-Caused yield depression below 5-year moving average
							45° fatal	
						> 2400---	------	-Cuzco variety from Peru.
						≲ 2200---	------	-White flat complex
						≲ 1500---	------	-Caribbean flint, most Tanzanian production is below 1,500 meters
				Opt. 750---	------	------	------	-For 150-day varieties, April to August
								Yield depreciation rapid below 825mm
			500	M825-1225				At these low and high points yield is only 1/4 optimum
								Varieties available for 2 short rain periods, 80 days to maturity
								Not suited to black cotton soils
		300---	------	------	------	------	------	-In long rains for early maturing varieties
		1800---	------	------	------	------	------	-For late maturing varieties
			625					Serious depreciation of yield at 625mm

TABLE D-1: CROP ECOLOGY DATA USEFUL IN LAND USE CAPABILITY PROJECTIONS FOR THE ARUSHA REGION (cont.)

Crop	Units H_2O per Unit D.M.	Growing Season mm ppt.	Min. $\bar{x}$ ann.ppt.	Max. or Optimum ann.ppt.	Optimum Gro.Seas. ppt.	Range of Elevation	Temperature Requirements	Remarks
			mm	mm	mm	m	°C	
WHEAT (<u>Triticum aestivum</u>)	542-557		600	M1250-1375		2000-3000	-2°to 3°	Mildly frost resistant
							0°	No growth
						<2000		Rusts are serious problems and ppt. unreliable below 2,000 meters
							Opt. 20-25°	Degree days T. requirements, 2,914°F to 4,311°F
							Germ @ 3.5-5.5°	110 to 130-day wheat, transpires 250 to 400 mm
			580					With summer fallow west of Kilimanjaro
		100-150					Max. 35°	Some fast maturing varieties
BARLEY (<u>Hordeum sativum</u>)	518		700	M1200		2500-4000	-5 to -8 at night min. 0° day not lim. by high temp.	Wider ecological tolerance than any other cereal, especially as to temperature Maturity 106 to 121 days at low elevations 140 to 150 days at high elevations, some in 87 days Some in July in Kenya, matures 120 days Not grown on black cotton soils; on red loams best
		500						Kenya malting barleys Requires reliable ppt, periods of drought bad
BEANS (<u>Phaseolus vulgaris</u>)			600+			2000		Crop life 3-5 months Not drought resistant
PYRETHRUM (<u>Chrysanthemum cenerareifolium</u>)			875	M1250-1500		1800-2000		Requires chilling to initiate flowering Needs some ppt. each month
			900			1800		@ 1800m, ppt. rarely below 900mm 90% shade yield by 50% Irrigation uneconomic
COFFEE (<u>Coffea canephora</u>)			900 1000	2100				Yield pos. related to ppt. and elevation

TABLE D-1: CROP ECOLOGY DATA USEFUL IN LAND USE CAPABILITY PROJECTIONS FOR THE ARUSHA REGION (cont.)

Crop	Units H_2O per Unit D.M.	Growing Season mm ppt.	Min. $\bar{x}$ ann.ppt. mm	Max. or Optimum ann.ppt. mm	Optimum Gro.Seas. ppt. mm	Range of Elevation m	Temperature Requirements °C	Remarks
SORGHUM (Sorghum vulgare)	304	300-380	650					Will grow on heavy clays Very drought resistant Grows well in Central Tanzania at this ppt. level
FINGER MILLET (Elusine caricana)			900			>900		Requires steady ppt. at 900mm
COTTON (Glossipyum hirsutum)		450						Growth December to March, 5 months of adequate, uninterrupted ppt. required. Is drought tolerant once established
CASTOR (Ricinus communis)			500-625			0 - 2100		Adapted to dry areas
GROUNDNUTS (Arachis hypogea)						1500m and below		Requires 3 months wet season, good distribution of ppt. and soil moist to harvest time.
GENERAL CROPS		300						HMM Braun

of less than 508 mm was between 1 to 6 years in 20 and less than 762 mm in 3 years out of 4. He based his analysis largely on the work of J. Grover and his associates (1957, 1953a, 1953b, 1954). He stated further:

> "The risk of crop failure due to scanty rains or those with unfavourable seasonal distribution becomes greater at a rapid rate from 35- [889mm] to 25-inch [635mm] rainfall areas. On the other hand, the risk of failure of grass is not great."

A general threshold under 600 mm per annum precipitation is also supported by work of the Canadian soils team investigating suitability of lands for wheat production. They suggest that on Calcimorphic Brown soils, the threshold is at 400 to 600 mm and 600+ on Eutrophic Brown soils. They suggest that nearly all Class I soils (suitable for agriculture without constraint or special management precautions) fall in an 800 to 1,000 mm precipitation range. These guidelines support Heady's suggestion of a 762 mm threshold where 3 out of 4 years could be expected to fall below this level.

In marking the climatic fringe of arable cropland (in the absence of irrigation) many writers have emphasized the normally expected extremes of precipitation that make risks of agricultural development unbearable. Heady (1960) summarized climatic data to show variability at four stations within or peripheral to the Arusha Region (Table D-2).

Studies in adjacent Kenya show, for instance, that the precipitation in the two rainy seasons may vary as widely as 190 to 960 mm in the March - May rains and 130 to 1120 mm during the October - December rains (Braun, 1974). In addition, probability calculations show that

TABLE D-2

AN ANALYSIS OF RAINFALL VARIABILITY WITHIN AND PERIPHERAL TO THE ARUSHA REGION, TANZANIA (Heady, 1960)

Location	Years of Record	Annual Precipitation			Percentage of Years Below		
		Mean	Least	Most	254mm	508mm	762mm
Tsavo, Kenya	26	362	62	590	19	88	100
Loliondo	23	859	468	1241	0	13	39
Engaruka	17	377	203	604	18	82	100
Dodoma	25	580	308	1083	0	32	88

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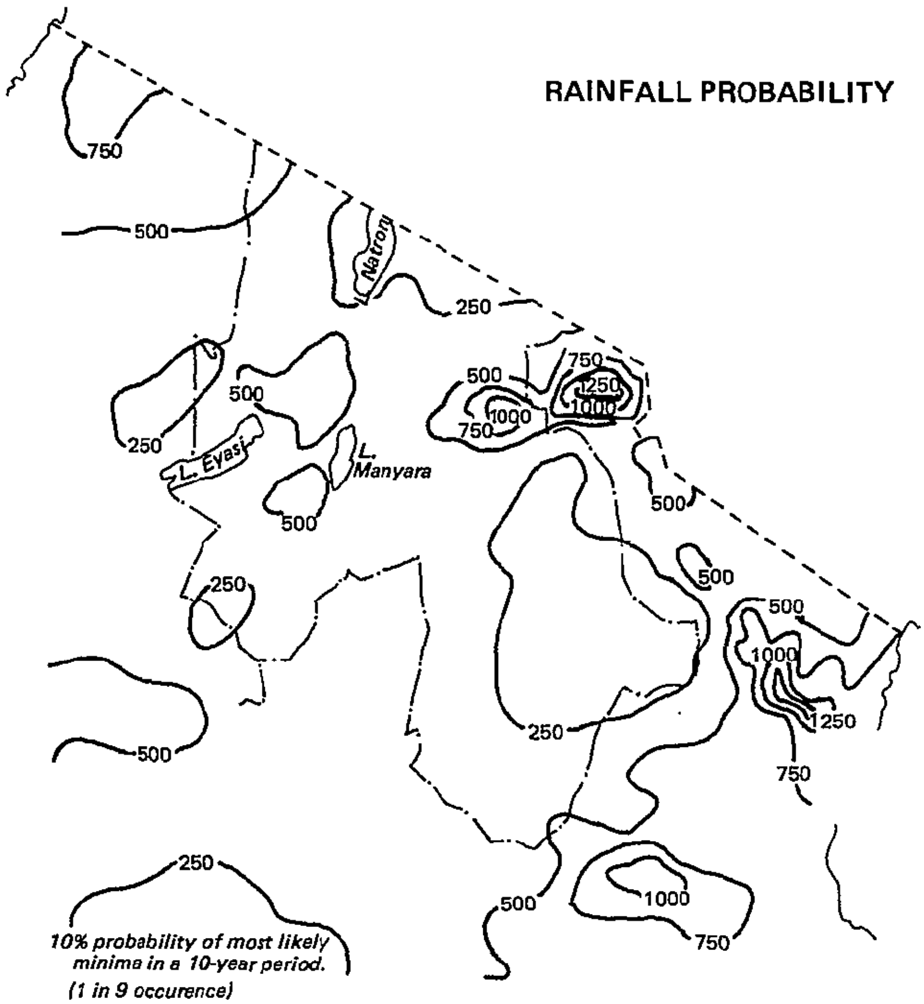
NO. D-7

a substantial portion of the Masai Steppe is likely to receive 250 mm or less per annum in 1 year out of 10. Since this defines extremely serious drought conditions, the area subject to extreme drought problems in crop production is no doubt much larger than that indicated by the 250 mm probability isohyet. A sound development program would suggest eliminating this entire area from consideration for new agricultural development in the first approximation (Figure D-1).

Since there is only one climatological station within the Arusha Region for which probability statistics have been calculated, the Arusha, Olmotony Forest station, 40-year record (Lawes, 1969), it is very difficult to consider the climatic parameter with the refinement that should be technologically feasible. One additional station, Tabora, located more or less directly south of Lake Victoria and approximately 165 miles southwest of Lake Eyasi, may be somewhat representative of the dryer, single season precipitation areas in the Arusha Region even though its mean annual precipitation is considerably higher than the driest of the Arusha Region (906.7 mm mean annual precipitation). Drawing upon these two sets of data, some important points can be made with respect to probability and severity of drought in the Arusha Region (Table D-3).

If one assumes that approximately 100 mm precipitation per month is essential for optimum yield of many crops grown in the Arusha Region, this is the equivalent of 67 mm per 20-day period used by Lawes in calculating his probabilities. On this basis, for the Arusha station in 1 year our of 4, none of the time periods between 21 December and 10 March reached this threshold and all periods but one (the first) will have less than one-third the requirement. They will have less than one-



Ppt. mostly in March-May.
Arusha & Moshi $\bar{x}$ = 800 - 1000mm.
Same & Mombo 800mm,
marked hot & cool seasons.
Ppt. peaks in April (Mar-May)
& in Nov (highs in Oct-Dec)

		$\bar{x}$	Max
Arusha	182 rainy days coolest ca	20° C	27°
Moshi	87	25° C	30°
Same	66	25° C	30°
Mombo	114	27° C	32°

FIGURE D-1

TABLE D-3

EXPECTED DEVIATION FROM NORMAL BY 20-DAY PERIOD FOR

ARUSHA (MAppt. 964.7mm) AND TABORA (MAppt. 906.7mm) TANZANIA

(Adapted from Lawes, 1969)

Begin Period Date	Sequence 20-Day Periods	Mean ppt. for Period		Lower ppt. Limit Not Exceeded			
				1 yr. in 4		1 yr. in 10	
		Tabora	Arusha	Tabora	Arusha	Tabora	Arusha
21 Dec	01	111.2	57.5	67.5	23.6	45.4	9.5
	02	94.9	47.3	53.4	18.9	33.6	6.9
	03	91.7	49.6	54.3	17.1	36.0	4.6
	04	85.6	53.1	55.1	15.1	38.8	1.9
	05	91.8	48.7	60.8	18.7	43.8	6.2
	06	88.6	45.3	56.3	16.7	39.6	4.7
	07	85.7	57.3	58.1	19.9	42.6	5.7
1 Mar	08	107.5	68.2	69.4	28.6	49.3	12.6
	09	127.1	89.3	78.8	39.3	54.5	19.5
	10	114.6	132.3	62.8	63.6	39.3	36.2
	11	94.5	180.9	47.9	89.6	27.9	54.2
	12	84.8	190.3	32.2	116.0	18.8	81.7
	13	54.4	167.4	15.3	87.5	2.5	53.7
	14	27.0	113.9	5.7	47.5	NIL	23.3
	15	16.6	53.3	0.3	21.4	NIL	8.1
21 May	16	5.5	24.8	NIL	8.0	NIL	0.1
1 Oct	29	8.1	8.1	0.5	NIL	NIL	NIL
	30	14.3	25.8	3.7	4.9	NIL	NIL
	31	24.7	42.1	7.7	12.4	0.2	1.3
	32	47.0	62.5	17.6	24.2	6.0	9.5
	33	75.4	89.9	31.5	37.1	14.9	17.4
	34	101.8	97.8	48.4	46.9	27.0	25.9
1 Dec	35	115.4	90.5	70.5	41.2	48.0	21.4

sixth the required amount in one year out of ten for all of the time periods. Thus, in keeping with common planting practices, this December to March time period cannot be expected to produce enough reliable precipitation for planting.

In the long rain season from about the first of March to early June, the mean annual precipitation for Arusha exceeds the above mentioned threshold in the first seven of the intervening nine time periods. However, the first three time periods and the last three can be expected to fall below the threshold one year out of four. Only the middle three time periods, approximately 1 April through 10 May, can be expected to exceed the 67 mm threshold on all years. On one year out of 10 at Arusha, only the latter half of April can be expected to exceeed the threshold. Eight time periods out of nine in the long rain season will fail to reach the threshold of 67 millimeters per 20-day period on 1 year in 10.

In the short rain season from October through November or early December mean precipitation for only the last three time periods, 11 November through 20 December will reach the threshold. All earlier periods fall below the 67 mm presumed threshold. None of the time periods will reach this threshold in one year out of four with the best period being approximately one half of the presumed requirement. On one year out of ten, the expectation is, of course, worse with five of the time periods being extremely low and only two of them, the last two, reaching approximately one-third of the presumed threshold.

One might assume that the Tabora record will shed some light on the drought risk characteristics of the slightly drier, single-season precipitation areas of the Arusha Region. The November to May precipitation at Tabora averages 824 mm with maximum precipitation 1 year in 4 of 475 mm or less (58 percent of normal) and with a 1 in 10 maximum of 312 mm (only 38 percent of normal) for the same period. Depending on the specific pattern of rainfall, these conditions could adversely affect crop production at least one year out of four and be quite severe on one year out of ten.

This information is perhaps most meaningful if placed in the context of the minimum expected deviation below normal (the best one can expect) on a specified frequency. This combines into a single figure both the severity and expected frequency of drought. Based on the work of Lawes (1969), we calculated the minimum percent deviation below normal that could be expected for the Arusha vicinity in one year out of four (Table D-4). These were calculated from the confidence limits at a 50% probability level (P = 0.5) by 20 day incremental periods for the short rains, the long rains, and the interim rainy period December through February. This table shows that during the long rain period one should expect less than half normal rainfall one year out of four and that in the short rain period one can expect to receive only about one-third or less of normal precipitation at the same frequency of occurrence. When judging land use potential, these figures emphasize the importance of conservatism because, while 300 mm of precipitation per rainy period of 600 per annum may satisfactorily grow a crop, the risks of agricultural development are exceedingly high where the above amount and frequency of deficiency is anticipated. As one approaches the biological limit or threshold in rainfall amount, the risk becomes even more serious and of greater consequence where errors are made in land development that converts from pasture to cropland agriculture.

TABLE D-4

EXPECTED MINIMUM DEVIATION IN PERCENT BELOW

NORMAL, BY 20-DAY PERIODS, ON ONE YEAR OUT OF FOUR

[Based on Arusha, Olmotonyi Forest, 40-year record, (Lawes, 1969)]

Item	Expected Minimum Deviation Below Normal, 1-year in 4		
	Interim Rains Dec-Mar	Long Rains Mar-June	Short Rains Oct-Nov
No. 20-day Periods	(8)	(9)	(7)
Min. % Below Normal	62.5	54.3	68.3
Standard Error	1.85	2.74	6.49

Figure D-2: Long Rains Droughty Areas. These isohyets were derived by overlaying monthly mean precipitation maps (Tomsett, 1969) and delineating the area that did not exceed 100 mm in any one of the months and designating by "D" the isohyet where 100 mm was exceeded on only one month out of the long rain season. The cross-hatched area in Figure D-2 receives 100 or more mm precipitation on three of the four months and is thus judged non-limiting on an average year.

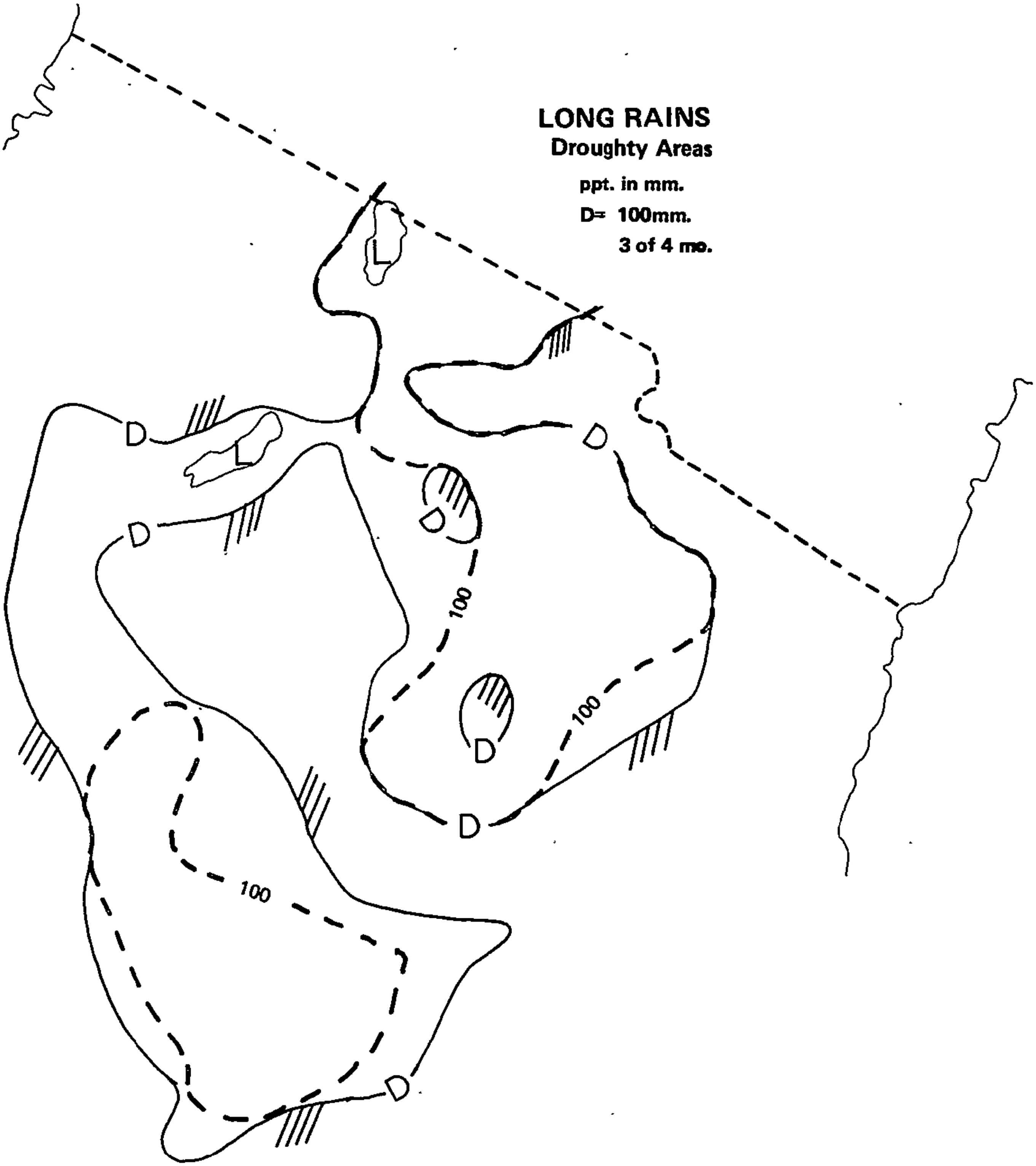
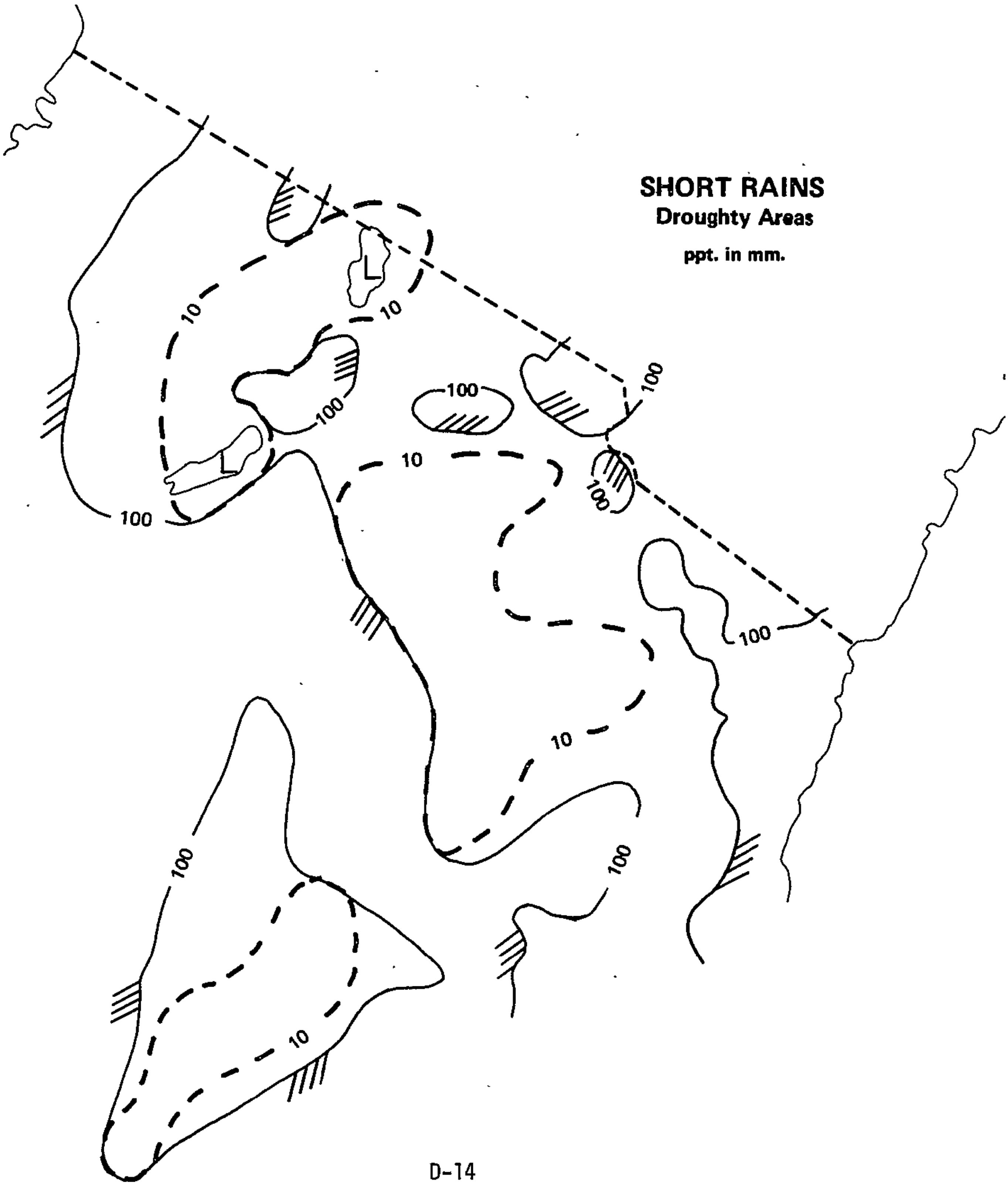


Figure D-3: Short Rain Droughty Areas. These isohyets were derived by overlaying monthly mean precipitation maps (Tomsett, 1969) and delineating the area that received less than 10 mm and less than 100 mm of precipitation during each of the short rain months. The cross-hatched area outside of the 100 mm isohyet is considered non-limiting on an average year.



We derived a particularly useful set of isohyetal maps from the mean monthly precipitation maps prepared by the East African Meteorological Department, Nairobi (Tomsett, 1969). Our derived maps show the normal-year droughty areas in and around the Arusha Region (Figures D-2 and D-3). These were derived for the Long Rains by overlaying the mean-monthly maps and delimiting the area that did not exceed 100 mm in any one of the months and also designating the peripheral area where 100 mm of precipitation was exceeded in only one month out of the Long Rains season. For the Short Rains, the mean monthly maps were similarly overlayed and the area receiving less than 10 mm and less than 100 mm for the whole season were defined. It is our general feeling and recommendation that lands falling within these droughty areas must be classified as high risk areas for agricultural development and also recognized as very sensitive areas in grazing management. Obviously, the lines may not be accurate because of the paucity of stations on which they are based, but the concept is sound; and, with the refinement of isohyetal maps of northern Tanzania, could be a most useful basis for discriminating non-agricultural land areas and drought sensitive environments.

APPENDIX E

LANDSAT- (ERTS) PROGRAM

LANDSAT - (ERTS) PROGRAM

Earth Resources Technology Satellite

1. Background of the program:

   a) Successful application of satellites for meteorology, telecommunications, navigation.

   b) Successful imaging of earth surface from manned (Gemini, Apollo) satellites in earth orbit.

   c) Existence of basic component sub-systems - vehicle, power, sensors, recording, telemetry.

   d) Recognized need for image/data information for many regions and many applications fields - especially natural resources, land use, cartography.

   e) Recognized benefit potential of large area, synoptic, repetitive, multispectral imagery.

   f) Program initiated 1969; world-wide participation invited 1970; ERTS-A (=1) launched July 1972. LANDSAT-2 January 1975.

   g) Several hundred experimental projects; 3 dozen countries participating.

2. Objectives of the program:

   a) To apply rocket, satellite, and R/S technology in advancing man's capability for responsible management of earth resources and human environment.

   b) To determine experimentally what types of satellite-derivable data are most valuable.

   c) To determine experimentally what combinations of component sub-systems (especially sensors) yield the most useful information.

   d) To develop optimum systems for data acquisition and processing.

   e) To help the user communities prepare to utilize the imagery/data.

3. Sectors or fields of application:

   a) Agriculture and range; soils; crops.

   b) Forest products.

c) Mineral and fuel resources; geologic hazards, engineering.

d) Hydrology, water resources, flood control.

e) Oceanography, fishing, marine resources, coastal engineering.

f) Land use inventory, urban and regional planning.

g) Geography, cartography, thematic mapping.

h) Energy and transport infra-structure.

i) Environmental conservation.

4. LANDSAT (ERTS) - an exceptional opportunity:

a) For developing regions ("undeveloped," "developing," "interior"): mineral and oil resources, fishing, forest products, range, agriculture, energy, transport.

b) For over-developed regions ("developed," "industrialized," "urbanized"): urban sprawl control, water, pollution, inter-urban corridor transport, planning.

c) For transition regions or zones of interaction: regional land-use planning and management; highways, waterways, airports, railroads, power distribution; rural-urban integration.

5. LANDSAT (ERTS) - system in brief:

a) An earth-orbiting, stabilized observatory.

b) Multi-sensor instrumented.

c) Solar powered.

d) With on-board data processing, recording and telemetry.

e) Three ground stations for tracking, command, and receipt of image data. (Also Canada, Brazil, Italy; in development stages Zaire, Iran, etc.).

f) Ground facilities for conversion of image data to images.

g) Expected lifetime-one year.

6. Sensor sub-systems:

a) Return beam vidicon (TV) cameras (3).

(1) Spectral bands:

1.	0.475-0.575	microns,	Blue-Green
2.	0.580-0.680	" ,	Green-Yellow
3.	0.698-0.830	" ,	Red - IR

(2) Acquisition mode: combined, framing + image plane scanning.
(3) Vidicon image tube: structure and operation.
(4) Lens focal length: 126 mm
(5) Exposure time: variable 4-16 ms, in 5 steps; (shutter)
(6) Exposure frequency: every 25 secs.
(7) Scanning readout time: 3.5 secs.
(8) Number of scan lines: 4,125
(9) Ground area imaged: 185x185 km (34,000 km^2)
(10) Spatial resolution: approximately 100 m (varies with contrast).
(11) Radiometric fidelity: error 9%±1 (film)

b) Multi-spectral scanner.

(1) Acquisition mode: mechanical-optical object plane scanning.
(2) Detector elements: photomultiplier tubes (bands 4, 5, 6); silicon photodiodes (band 7); HgCdTe at 100° K (band 8)
(3) Spectral bands:

4.	0.5-0.6	microns,	Green
5.	0.6-0.7	" ,	Yellow-Red
6.	0.7-0.8	" ,	Red
7.	0.8-1.1	" ,	Infrared

(4) MSS structure and operation.
(5) Performance parameters: spatial resolution, radiometric resolution, geometric fidelity, registration.
(6) Spatial resolution: 100 to 200 m (varies with contrast).

7. Vehicle and navigation sub-systems:

a) A conical structure 1.5 m diameter by 3 m high.

b) Stabilized environment (20° ± 10°C) - by radiation (±) and electric heating.

c) Stabilized attitude, i.e., earth-pointing:

(1) Radiometric (14-16 micron) horizon sensing, to ± 1 mr.
(2) Gyro sensing of yaw attitude and rate.
(3) Attitude control (by reaction jets) to within:

± 7 mr of local vertical (about pitch and roll axes)
± 10 mr of velocity vector (about yaw axis)

d) Orbit adjust by 3 orthogonal propellant jets to:

(1) Correct in-plane orbital injection;
(2) Correct orbital plane inclination;
(3) Correct orbital perturbations - drag and gravitational.

e) Ground station tracking and doppler orbit determination; orbital adjust commands by telemetry.

8. Power sub-system:

   a) Two solar cell arrays (paddles), sun-seeking, approx. 1x3 m. (Solar radiation at 1,000km altitude approx. 1.4 Kw/m^2)

   b) Each array generates 550 watts. (~10% eff.)

   c) 8 NiCd batteries - capacity 4.5 amps each.

   d) Max. output 980 w, 24 V, regulated.

   e) Scheduled drain 480 w real time mode, 521 w on record mode.

   f) Half of each orbit is in eclipse - no solar energy.

   g) Overall capacity: 20 mins full load per orbit.

   h) Electrical interface sub-system controls switching, fusing, timing, etc.

9. ERTS orbital parameters:

   a) Circular orbit (eccentricity $6x10^{-4}$).

   b) Altitude approx. 900km (semi-major axis 7286-6360=926).

   c) Inclination 99° (descending node 81°).

   d) Period 103 mins. Sub-satellite track velocity 390 Km/min.

   e) Sun-synchronous - 09:42 local suntime, descending node.

   f) Orbits per day: 14.

   g) Repeat cycle: 18 days (251 revolutions).

   h) Distance between tracks (at equator) 159.4 Km.

   i) Possible coverage - entire earth 81°N lat to 81°S.

   j) Successive orbit separation 2,870 Km at equator.

   k) Swath width 185 Km.

   l) Sidelap 14% at equator 25.6% at 30° lat, 34.1% at 40° lat.

   m) See ephemeris for longitude of descending nodes.

10. Geometry of the imagery:

   a) Quasi-orthographic:

      (1) Very small effective aperture 11-1/2%. (925/185 = 200mr)
      (2) Relief displacement per 1,000m same order as resolution
      (3) Compare wide angle (120°) airphoto displacement

b) Sun-synchronous: 09:42 local mean solar time.

(1) Grossly uniform illumination, morning sun.
(2) But sun altitude (elevation angle) and azimuth vary with season and latitude (and hour). Example for 30°N lat, 09:42 local mean solar time-

Season	Declination	Altitude	Azimuth
Summer solstice (Jun)	+23°27'	60°	90°
Equinoxes (Mar, Sep)	0°	45°	125°
Winter solstice (Dec)	-23°27'	28°	145°

(3) Thus shadowing azimuth and angle will vary, but only slightly day-to-day (adjacent swaths); and only a max 6° (elev angle) within one 18-day cycle, and a max 7° variation of azimuth (over 25°.8 longitude).

c) Overlap and stereo-viewing:

(1) RBV frames forward-lap (along track) 10%, stereoscopic, synoptic.

(2) MSS continuous raster along track, cut into frames with apparent forward-lap 10% to match RBV, but not stereoscopic (each scan line different position); quasi-synoptic in time (25 secs), but not in viewing position.

(3) Swath sidelap variable with latitude: 14% at equator, 34% at 40° lat, 85% at 80° latitude.

(4) Both RBV and MSS stereoscopic for laterally adjacent images.

11. Geometric fidelity:

a) Basically, the accuracy of geographic (lat long) position of any image point:

(1) Within one scan line (relative)
(2) Within one frame or one swath (relative)
(3) Within a mosaic (relative)
(4) With respect to earth geodetic position (absolute)

b) Errors due to uncertainty of vehicle location:

(1) S/C ephemeris -- orbit uncertainties (± 1,12m rms)
(2) Exposure time uncertainty 6500 m/s (± 28m) =±4 ms

c) Errors due to uncertainty of pointing:

(1) Attitude uncertainties, non-nadir (± 680m)
(2) Sensor alignment to S/C axes (± 191m)

d) Errors due to distortions internal to sensor:

(1) RBV (see table F-12) net positional uncertainty ($\pm$ 1,355m)
(2) MSS (see table F-13) net positional uncertainty ($\mp$ 26m)

e) Combined internal and external uncertainities:

(1) RBV input to ground data-processing facility 1,536m
(2) MSS input to ground data-processing facility 710m

f) Errors introduced in image-data processing (NDPF):

(1) EBR inaccuracies, film and paper distortion, scale change, enlarger distortions, registration misalignment.
(2) Computer imprecision and data base errors
(3) Model imprecision -- flat earth assumption, non-compensation for non-nadir pointing

g) Errors reduced or removed during "bulk" processing:

(1) Scale variations due to altitude variations (RBV and MSS)
(2) Systematic internal (sensor) distortions (RBV and MSS)
(3) Dynamic imaging variations: attitude; orbital velocity (MSS)
(4) Image skew due to earth rotation during scan (MSS)
(5) Scan differentials (MSS mirror vs. EBR); non-linear mirror scan (MSS)

h) Bulk processed output, residual errors (rms):

(1) RBV film and paper products, position: 775m
(2) MSS, film and paper products, positional accuracy:750m

i) Precision processing of bulk 70mm film products.

(1) Removes residual distortions in RBV/MSS bulk outputs
(2) Performs photogrammetric spatial resection based on identifiable control geopoint data to correct geographic coordinates.

j) Precision processed output, residual errors (rms).

(1) RBV positional mapping accuracy, film, paper: $\backsim$ 100m
(2) MSS positional mapping accuracy, film, paper: $\backsim$ 245m

k) Preliminary observed internal geometric accuracies:

(1) RBV bulk $\backsim$ 70m; precision $\backsim$ 50m.
(2) MSS bulk $>$ 300m; precision $\backsim$ 50m.

l) Registration accuracies:

(1) RBV bulk 336m; RBV precision 118m.
(2) MSS bulk 159m; MSS precision 154m.

12. Radiometric fidelity:

a) RBV fidelity: a complex function of many error sources.

(1) Optical elements: vignetting, imperfections
(2) Photoconductor element: non-uniformity, imperfections
(3) Electron optics: beam error, space charge anomalies
(4) Electronic elements: random noise
(5) Shading correction circuits: over or under correcting
(6) Non-linearity of light transfer characteristics
(7) Exposure time and saturation effect
(8) Variation of modulation transfer function with spatial frequency
(9) Errors introduced in data recording, transmission, processing to film, etc.

b) MSS radiometric fidelity (amplitude resolution) depends on:

(1) Signal-to-noise ratio S/N, which is affected by:

a. Instantaneous field of view ($\sim$ 0.1 mr)
b. Photocathode sensitivity, photomultiplier tube sensitivity enhancement factor, noise factor of PMT
c. Electrical Bandwidth, optical efficiency, etc.

c) Net radiometric errors:

(1) RBV bulk products: film/prints 10%; computer compatible table 30%.
(2) RBV precision products: T/P 8%; CCT 7%.
(3) MSS bulk products: T/P 6%; CCT 2%.
(4) MSS precision products: T/P 6%; CCT 6%.

d) For more accurate radiometry use: MSS bulk CCT. (MSS digital data not subject to VTR or transmission distortions).

13. Image-data recording and processing sub-system:

a) ERTS operates in two modes:

(1) Real time telemetry of data when within reach of any one of three ground stations (North America)
(2) Record and store data (of all other areas) on board for subsequent readout and telemetry during later pass

b) Wideband Video Tape Recorder sub-system:

(1) Two WBVTR's, capacity 30 mins each, for:

a. 3.2 MHz video analog data from RBV, or
b. 15 Mbps digital data from MSS

(2) Record, VTR selection, and readout by command

c) On board data processing includes:

(1) Frequency modulation and demodulation
(2) Switching, clocking, rephasing

14. Telemetry, tracking, and command sub-systems:

a) Wideband telemetry for data recovery.

(1) 2 channels 2229.5 and 2265.5 MHz.
(2) Accepts/processes/transmits data from RBV, MSS, VTRs.
(3) Two 20 watt S-band transmitters; shaped beam antennas

b) Narrowband telemetry, tracking and command.

(1) Collects and transmits S/C and sensor housekeeping data
(2) Provides tracking signals, implements commands on board
(3) Pulse code modulates (PCM) the data
(4) 2 S-band channels (1 in, 1 out), and 2 VHF (154 and 138 MHz)

LAND UNITS OVERLAY LEGEND

SURFACE FEATURES

PRIMARY

- 100 BARREN LAND
- 200 WATER RESOURCES
- 300 NATURAL (NATIVE) VEGETATION
- 400 CULTURAL VEGETATION
- 500 AGRICULTURAL PRODUCTION
- 600 URBAN, INDUSTRIAL, TRANSPORTATION
- 700 EXTRACTIVE INDUSTRY, NON-RENEWABLE
- 800 NATURAL DISASTER AREAS, RECENT
- 900 OBSCURED LAND

SECONDARY

- 110 PLAYAS (SALT AND ALKALAI FLATS)
- 120 AEOLIAN BARRENS
- 130 ROCKLANDS
- 140 SHORELINES
- 150 BADLANDS AND EROSIONAL BARRENS
- 160 SLICKS
- 170 MASS MOVEMENT
- 180 MAN-MADE BARRENS
- 190 UNDIFFERENTIATED COMPLEXES

- 210 PONDS, LAKES AND RESERVOIRS
- 220 WATER COURSES, PERMANENT
- 230 SPRINGS, SEEPS AND WELLS
- 240 BAYS, COVES AND ESTUARIES
- 250 LAGOONS AND BAYOUS
- 260 OCEANS, SEAS AND GULFS
- 270 *UNASSIGNED*
- 280 SNOW AND ICE
- 290 UNDIFFERENTIATED COMPLEXES

- 310 HERBACEOUS TYPES 1/
- 320 SHRUB/SCRUB TYPES
- 330 SAVANNA-LIKE TYPES
- 340 FOREST AND WOODLAND TYPES
- 390 UNDIFFERENTIATED COMPLEXES

- 400 CULTURAL VEGETATION (PERMANENT INDUCED) Secondary classes same as for 300's, i. e., 440, Planted Forests

- 510 COVER CROPS
- 520 PASTURE AND HAY CROPS
- 530 VEGETABLE AND ROOT CROPS
- 540 FRUIT AND NUT CROPS
- 550 HORTICULTURAL SPECIALTIES
- 560 MIXED CROP/SHIFTING AGRICULTURAL
- 570 NON-PRODUCING, FALLOW AND TRANSITIONAL
- 580 ANIMAL FACILITIES AND FARMSTEADS
- 590 UNDIFFERENTIATED CROPLAND

- 610 CITIES AND LARGE TOWNS
- 620 VILLAGES AND CLUSTERED SETTLEMENT
- 630 ISOLATED HABITATION

- 710 NON-RENEWABLE RESOURCE EXTRACTION, MINING AND QUARRY

- 810 BURNED AREAS
- 820 FLOODED AREAS

- 910 CLOUDS AND CLOUD SHADOWS

TERTIARY

- 314 Perennial Grasslands (Moist/Dry Lands)
- 316 Marsh and Swamp Grasslands (Wetlands)
- 319 Undifferentiated Grasslands

- 321 Non-thorny Desert Scrub (microphyllous)
- 322 Thorn Scrub (Bushland), Dense ("Thickets")
- 323 Thorn Scrub (Bushland), Moderately Dense
- 324 Thorn Scrub (Bushland), Low Density
- 325 Halophytic Shrub
- 326 Non-thorny, Mesic Shrub (macrophyllous)
- 328 Mountain "Heath"
- 329 Undifferentiated Shrub Types

- 331 Arborescent (Tree-Layer)
- 332 Shrubby
- 333 Palm Savanna

- 341 Gymnosperm Forests (Needleleaf)
- 342 Angiosperm Forests (Broadleaf)
- 343 Mixed Forests (341/342)
- 344 Woodlands
- 349 Undifferentiated Forests

- 441 Planted Gymnosperm Forests
- 442 Planted Angiosperm Forests

1/ A quaternary level designator is added whenever interpretable to indicate the biomass of the grasslands (314) or of the grass understory in the Shrub/Scrub (320) and the savanna-like (330) vegetation types. It is described in the text under the appropriate categories.

MACRORELIEF/LANDFORM CLASSES

PRIMARY

- 1 FLAT LANDS
- 2 ROLLING AND MODERATELY DISSECTED LANDS
- 3 HILLY LANDS
- 4 MOUNTAINOUS LANDS

SECONDARY/TERTIARY/QUATERNARY

- .1 DEPRESSIONAL, NON-RIPARIAN BASINS
- .11 SEASONAL LAKE BASINS
- .12 MBUGAS
- .2 DEPRESSIONAL CALDERAS
- .3 BOTTOMLANDS, RIPARIAN
- .32 BOTTOMLANDS, RIPARIAN, STRINGER OR NARROW
- .33 BOTTOMLANDS, RIPARIAN, WIDE VALLEY BOTTOM
- .34 DEPRESSIONAL, CONCAVE (MAY CHARACTERIZE SAME MBUGAS OF EXTERNAL DRAINAGE)
- .35 DESERT WASH
- .4 PLANAR SURFACES, LOWLAND,
- .402 PLANAR SURFACES, LOWLAND, DISSECTED
- .41 PLANAR SURFACES, LOWLAND, VALLEY FILL
- .412 PLANAR SURFACES, LOWLAND, VALLEY FILL, DISSECTED
- .42 PLANAR SURFACES, PEDIMENT OR TOE SLOPE
- .422 PLANAR SURFACES, PEDIMENT OR TOE SLOPE, DISSECTED
- .5 PLANAR SURFACES, UPLAND PLATEAU (BENCHES, MESAS, BROAD RIDGETOPS)
- .51 FLAT TO STRONGLY UNDULATING DIP SLOPES
- .502 PLANAR SURFACES, UPLAND PLATEAU, DISSECTED
- .6 STRONGLY UNDULATING TO ROLLING LANDS
- .602 STRONGLY UNDULATING TO ROLLING LANDS, DISSECTED
- .7 SLOPE SYSTEMS
- .71 ESCARPMENTS
- .72 VALLEY, CANYON OR GORGE SLOPE SYSTEMS
- 73 BUTTE OR ISOLATED HILLS AND KOPJES
- .74 HILL AND MOUNTAIN, SMOOTH SLOPE SYSTEMS
- .75 HILL AND MOUNTAIN, ANGULAR SLOPE SYSTEMS
- .8 GRAVITY AND MASS MOVEMENT LANDSCAPES

DISSECTED CLASSES FOR USE WITH MACRORELIEF CLASSES 1 AND 2

- .XX1 NONDISSECTED
- .XX2 MODERATELY DISSECTED
- .XX3 STRONGLY DISSECTED

FIGURE 3-2. Hierarchial Land Unit legend scheme for identification of land cover and land use features in the Arusha Region