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APPLICABILITY OF SPACECRAFT REMOTE SENSING TO THE MANAGEMENT OF FOOD RESOURCES IN DEVELOPING COUNTRIES

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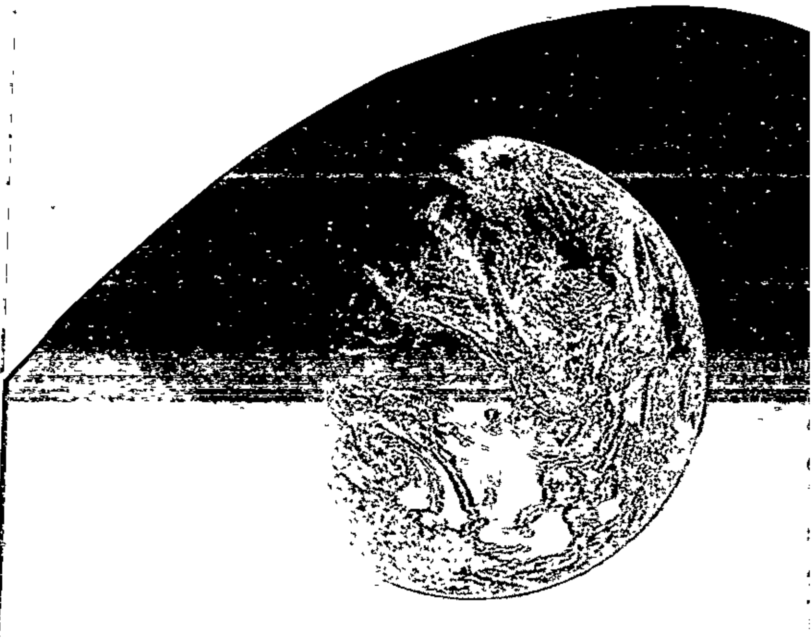

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APPLICABILITY OF SPACECRAFT REMOTE SENSING TO THE MANAGEMENT OF FOOD RESOURCES IN DEVELOPING COUNTRIES

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CONTENTS

1 0 Introduction

The objective of this report is to review and evaluate the applicabilit of spacecraft remote sensing techniques to map and inventory food resources and related features of developing countries, including a summar of on-going and planned remote sensing activities by international and U S agencies in developing countries

Remote sensing technology seems to provide a cost-effective tool to collect and use resource data that is badly needed by developing countries to plan the execution of development programs in food production, water resources management, range and forest management, land-use planning, and mineral exploration This is an important role for satellite remote sensors to play particularly in the development process of emerging countries where the problem of acquiring adequate data on earth resource systems has been a major limiting factor to successful development planning There are strong indications that utilization of resource data acquired from spacecraft can reduce efforts and expense ordinarily devoted to conventional gathering of data using aircraft or ground surveys

Remote sensing technology cuts across a broad range of scientific disciplines and requires close communication and cooperation between these disciplines to provide useful applications in mapping and monitoring the land, vegetation, water and mineral resources of our planet Aerial photography, one kind of remote sensing, has been used in many areas of the world for decades as a base on which to map soils, to prepare land use inventories, to identify and measure crop areas, to delineate conditions of crop stress and to make other observations of the earth's surface Since 1960, many new sensors have been developed and great advances have been made in analysis and interpretation techniques

In July 1972, the National Aeronautics and Space Administration launched Landsat-1, a satellite in polar orbit designed to study earth resources from an altitude in excess of 900 kilometers. Landsat-2, a duplicate of Landsat-1, was placed into polar orbit in January 1975 Each satellite has a remote sensor device, called a multispectral scanner (MSS), which scans the earth's surface every 18 days, and a return beam vidicon (RBV) system (Figure 1-1). The MSS measures four wavelength intervals or bands of energy radiating from the surface of the earth These bands have the following wavelengths

Band 4 0 5-0 6 Micrometers (Visible green)

Band 5 0 6-0 7 Micrometers (Visible red)

Band 6 0 7-0 8 Micrometers (Reflective infrared)

Band 7 0 8-1 1 Micrometers (Reflective infrared)

Research results have shown that each of these bands has particular utility for separating certain features From the different bands of radiation data, shown above, which are transmitted to receiving stations and recorded on magnetic tape, images or pictures can be produced The smallest area which the Landsat scanners can resolve or see on the earth's surface is approximately half a hectare or about 1 10 acre This is equivalent to about 70 meter ground resolution While this resolution is poorer than that attainable from aircraft, it is better than that of any non-military satellite In comparison, the Nimbus III High Resolution Infrared Radiometer which maps surface temperatures has a resolution of 10 km, while NOAA-2 can resolve 1 km with its thermal scanner

Each frame or image from Landsat covers an area 185 by 185 km, known as a "scene" It takes just 25 seconds to collect the data for one frame The orbit was designed to obtain multispectral data at approximately the same local time each day in every location In considering the total land area of the world and cloud probability statistics a mid-morning data acquisition time was selected

A single Landsat image contains about 8 million picture elements or pixels per wavelength band Each pixel represents 5 hectare or approximately 1 10 acre To process such a vast amount of data extensive computer operations are required Specific computer systems have been developed to use special purpose circuitry for extracting thematic information from multispectral scanning data Four examples of such computer systems are the Bendix Multispectral Data Analysis System (MDAS), General Electric's Image-100, Environmental Research Institute of Michigan's Multivariate Interactive Digital Analysis System (MIDAS), and the Laboratory for Applications of Remote Sensing, Purdue University (LARS) system

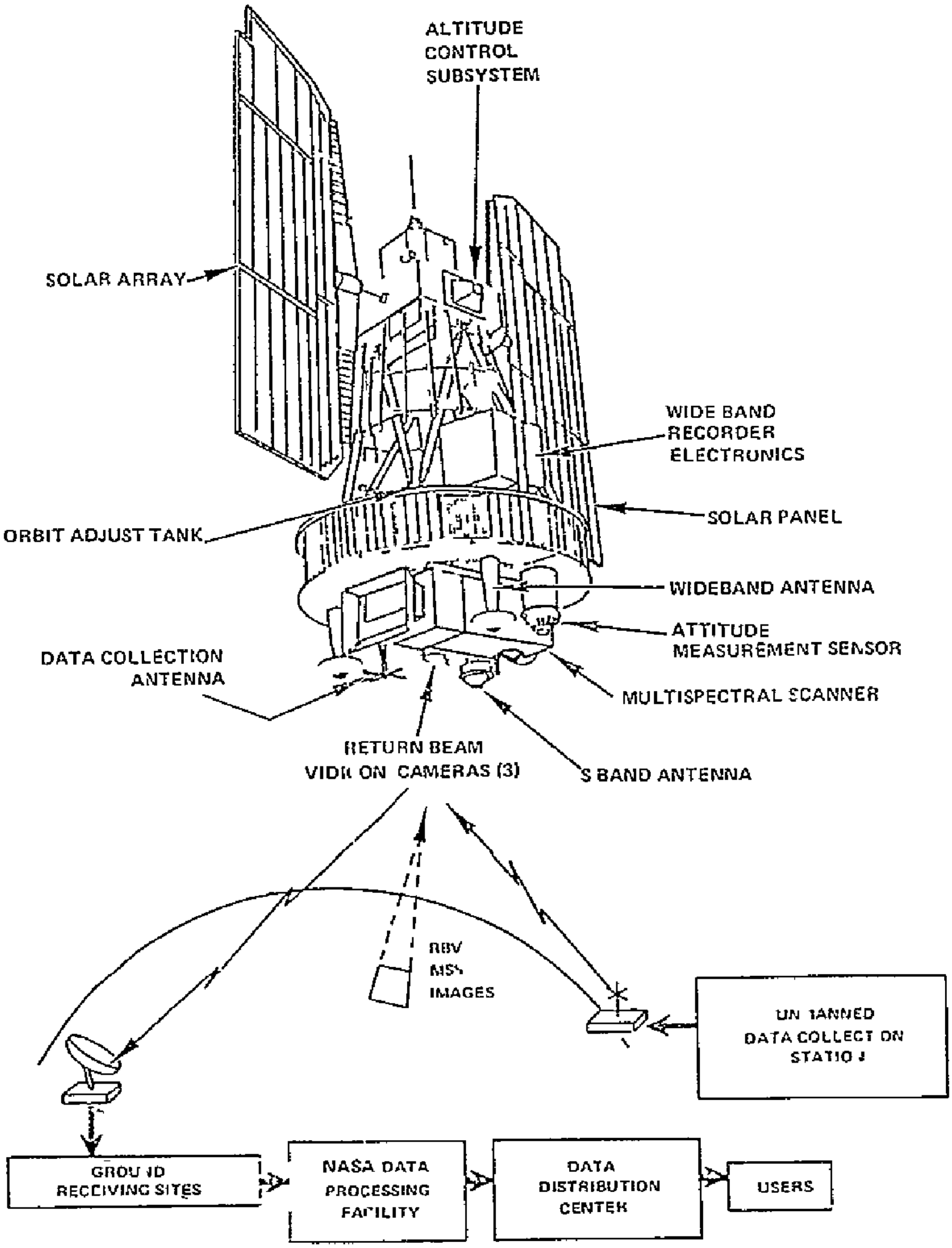

Figure 1-1 NASA Landsat Satellite and Ground Data Processing System

2 0 Remote Sensing of Agricultural Crops

2 1 Introduction

As the world population continues to grow at an alarming rate, the ability to cultivate and manage food resources to feed this expanding population is being questioned A report published by the United States Department of Agriculture (USDA) documents that the vast majority of countries must rely on grain imports to satisfy their food requirements Since the conclusion of World War II, the number of importing countries throughout the world has increased and, as the 1975-76 crop export figure dramatically shows, greater than 95% of all grains exported came from just four countries the United States, Canada, Australia, and New Zealand (ref 1) According to the International Food Policy Research Institute, if the grain production trends of the past 15 years continues, those developing countries with market economies will have food-grain deficits of about 100 million tons a year by 1986 If the trend of the last seven years continues, then food-grain deficits could reach close to 2[illegible] million tons a year (ref 2)

These figures stress the need for efficient and timel world food production management This management is required not only to insure that enough food is produced to feed the world's population, but also so that developing nations may effectively manage their resources in order to become self-sufficient

One of the tools which is being developed and used by food managers in combating this problem is remote sensing Users of remote sensing technology have learned that they can observe large areas quickly and accurately from imagery products taken from aircraft and satellite platforms Based on these observations, users ranging in level from the individual farmer to state and national governments can assess the type, condition, and extent of their crops With this information, production and yield estimates can be derived

2 2 Agricultural Applications of Remote Sensing

Remote Sensing for agricultural purposes has been used as early as the 1930's in the United States The sensor most employed has been the aerial camera. Agricultural information that can be extracted from various types of aerial photographs includes the measurement of crop acreage, identification of specific crops or types of farming, assessment of crop vigor, evaluation of soil characteristics from terrain indicators, location of surface water resources, and analyses of changes in land use patterns However, since the development of the computer compatible multispectral scanner (MSS) in the mid-60's and the launching of the Earth Resources Technology Satellite (now known as Landsat) in 1972, increased attention is being focused on the potential that MSS technology has to offer

While MSS remote sensing is still a developing technology, and many improvements in its capabilities are foreseen, it has demonstrated that it has reached an operational stage Numerous studies have shown the utility and cost effectiveness of airborne and satellite MSS when applied to agriculture For instance, from 1973 to 1975, the Mexican Water Plan (MWP) with assistance from the United Nations and the World Bank, used Landsat imagery to map 242 million hectares for present and potential land use in Mexico (Ref. 3) By comparing the maps of present and potential land use at a scale of 1 1,000,000, the MWP was able to assess areas with high, medium, and low agriculture and pasture productivity as well as areas that contained water erosion hazards Using manual interpretation techniques, the present land use study was performed at a rate of 8 million hectares per month and at a cost of 0 1 cents/hectare The potential land use study progressed at a rate of 4 million hectares per month and its cost was 0 33 cents/hectare

MacLeod in 1974 used Landsat imagery to locate water reserves in the Sahel region of West Africa, an area that has had severe drought conditions for several years By examination of the MSS imagery, he located the channels of extensive, ancient drainage systems which contain large, annually renewed reserves of near-surface water This previously untapped water source can be used by humans and livestock as well as for irrigation needs

Completed in late 1973, the Food and Agriculture Organization, Government of Sudan, and LARS (Laboratory for Agricultural Remote Sensing Purdue University) scientists conducted a demonstration project in Sudan using Landsat imagery to inventory land, vegetation and water resources (ref 4). Utilizing computer-aided analysis of Landsat data, maps were produced at a scale of 1 20,000 which delineated important soil differences, vegetation complexes, surface drainage patterns, erosion hazards, and present land use.

As these studies demonstrate, a great advantage of remote sensing for agriculture purposes is the ability to observe large areas in high resolution on a near real-time basis This ability is receiving increased attention by those who are connected with the status of the world's food resources The ability to detect, monitor, and predict the effects of drought, disease infestation, and other calamities on agriculture is needed by the country's planners in order to insure adequate food supplies for its people

With the successful demonstration of Landsat's capabilities, efforts are being made to establish a global crop production forecasting system Two major advances toward this global system are discussed below The first is the Crop Inventory Technology Assessment for Remote Sensing (CITARS) project which was completed in 1975 Although the development of a global crop inventory system was not one of its stated objectives, this project was the first to quantitatively address the technical problems of crop mapping with Landsat data over large areas The second project discussed is the Large Area Crop Inventory Experiment (LACIE) Initiated in 1974, this ongoing program is designed to develop, test, and demonstrate the ability to map wheat and project accurate production and yield estimates in the United States and seven foreign countries

2 3 The Crop Inventory Technology Assessment for Remote Sensing Project

The CITARS (Crop Inventory Technology Assessment for Remote Sensing) project, conducted between 1973 and 1975, was the first major attempt to use Landsat MSS data over large areas for the remote identification of major agricultural crops Investigators from the Johnson Space Center (NASA), ERIM (Environmental Research Institute of Michigan), LARS, and the U S Department of Agriculture (USDA) assessed Landsat imagery in an attempt to address such questions as how corn and soybean identification performance varied with time during a growing season how crop identification performance varied among different geographic locations having different soils, weather, management practices, crop distributions, and field sizes if statistical measures acquired from one time or location could be used to identify crops at other locations or times if the use of radiometric preprocessing extended the use of training statistics or increased nonlocal crop identification performance and if the use of multitemporal data increased crop identification performances (ref 5)

Based on data collected from six test sites, each 8 X 32 km, located in Indiana and Illinois, the CITARS investigators found that crop identification accuracy for corn and soybeans varied throughout the growing season, with maximum accuracy occurring in late August (approximately 80% accurac) The investigators, however, also noted the difficulty they had in ident- -- crops based on nonlocal data On the average, classification accurac decreased 23 percent when compared to classifications based on local data The investigators also found that the use of preprocessing techniques to minimize atmospheric differences between Landsat scenes improved accuracies but not in a consistent manner However, the use of multitemporal data was found to significantly increase classification accuracies when compared to the best single date classification performance The performance went from 8- accuracy for the single date data to 89% for the multidate data

2 4 The Large Area Crop Inventory Experiment

Because the Landsat rogram offers great potential as a tool for crop inventorying and monitoring on a global scale and because an urgent need exists for efficient management of the world's food resources, a second large scale agricultural program utilizing satellite MSS was initiated in 1974 Known as LACIE (Large Area Crop Inventory Experiment), this multiyear (1974-1978) program is a cooperative effort involving NASA -- , and USDA (ref 6) Although it shares the same general objective as CITARS that is, to develop, test, and provide an economically important application of remote sensing from space, it differs greatly in its specific objectives Unlike CITARS, LACIE is concerned only with wheat Wheat was chosen because of the considerable experience obtained from past remote sensing investigations and because of its importance as a world food resource Wheat is the most abundant cereal crop in the world both in terms of production and area.

extent. By concentrating their efforts and resources on a single important crop, the LACIE investigators hope to simplify the problems which arise in the development of multicrop recognition techniques Once a successful demonstration for wheat has been achieved, then the focus could be shifted to solving the problems which exist for multicrop application

In addition to identifying wheat fields, LACIE is designed to produce periodic yield determinations and production estimates on a regional and national level In order to achieve accurate yield and production estimates, LACIE has been designed to incorporate meteorological data (primarily monthly temperature and precipitation averages) obtained from an established ground network

The experiment is structured into three phases Phase I, which was completed in April, 1976, was devoted to completing the overall experiment design, implimenting a quisi-operational system which would estimate wheat acreage in selected areas in the United States, and develop and test yield models Phase II, scheduled to be completed in the summer of 1977, is designed to incorporate yield and production estimate models developed in Phase I, update the system based on Phase I results, and apply the system to larger and more diverse geographic areas In the third phase, which will be completed in June 1978, the system will be applied to important wheat producing regions of the world (ref 7)

During each phase the LACIE system is to be extensively evaluated for its accuracy and cost-effectiveness The accuracy criterion to be used is the 90/90 criterion This indicates that a 90% accuracy level for 90% of the time must be achieved in productions estimates at harvest time at a country level In addition, the LACIE investigators have imposed the restriction that the accuracy, timeliness, and cost-effectiveness of this information must improve upon the accuracy, timeliness, and cost-effectiveness of information already obtainable by the USDA from areas outside the United States and Canada

Although Phase II is not completed, the interim results are promising The LACIE yield results for areas tested within the United States appear to be following closely to the USDA Statistical Reporting Service (SRS) estimates (ref 7) When the LACIE system was applied and evaluated for the first time over a foreign wheat producing region, the yield estimates were lower than those expected for a normal year However, due to current weather conditions for this region, the trend of this reduction was in line with expected results Complete, detailed evaluations of Phase II are expected to be released by August, 1977

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3 0 Remote Sensing of Rangeland and Forestland

3 1 Introduction

Over the past few decades, the demand for more efficient utilization of uncultivated land has dramatically increased At one time, the bountiful range and forest lands were thought of as infinite resources However, with the extractive industries improving their methods and increasing their yields, careful government management is now required

The range and forest land data requirements necessary to efficiently manage vast forage and timber areas are more complex and involved than ever before In order to use modern modeling techniques, the rangeland and forestland managers require voluminous amounts of data and in a level of precision acceptable to successfully perform multiple decision making processes To be effective in long range planning schemes, the data must be provided in a timely manner

Remote sensing techniques have demonstrated the ability to assist in satisfying these data requirements At present, the aerial photographic survey is the primary operational system in use in most parts of the world However, in areas with plentiful rainfall and cloud cover, side-looking radar has shown to be an cost-effective alternative. The use of satellite platform sensors appears to be promising but have yet to achieve the accuracy required to facilitate good management decisions

3 2 Rangeland Management

Rangeland covers approximately 55% of the land area within the United States and more than 40% of the Earth's total land mass Historically, this land has played an important role as forage area for livestock and wildlife As our awareness increases, we also find that rangeland is important as watershed areas, recreational areas, and sites of potential agricultural and industrial development This land requires constant monitoring by resource managers in order to assess its present condition and project its future status and value For instance, within a rangeland there are various grazing regions which differ in geographic and climatic regime As a result, these grazing regions vary in plant composition, timing and rate of plant development, plant density, productivity, and season for optimum grazing When the additional variability due to weather is realized, one can understand how vast differences in condition and production of forage within a rangeland can occur and why constant inventory and monitoring practices are required

Information on rangeland forage production is vital to the economies of many parts of the world In the United States and abroad state and national agencies monthly report on range-feed capacity, feed prospects, moisture conditions, and livestock conditions This information is then used by local farmers and ranchers, livestock associations, feeding lot operators, and agri-businesses which produce livestock feed During 1974, in the United States alone, the livestock industry was valued at close to 41 billion dollars ($ U S) (ref 1)

The carrying capacity of rangeland, which is the foundation of the livestock industry, often may be increased two- or threefold by more intensive management programs Because of the vast expanses typically associated with rangeland, remote sensing has appealed to rangeland managers due to the ability to provide economical, accurate, and up-to-date inventories of the plant communities and continuing appraisals of range conditions Since the late 1950's, rangeland managers have increasingly relied on black and white, color, and color infrared aerial photographs to inventory and monitor range conditions With the launching of Landsat, however, an appetite for space imagery has been developed by resource managers and its utilization is being stressed in range research programs Space imagery offers advantages over extensive ground and aerial surveys in that its imagery is inexpensive, repetitive, synoptic, and obtainable in near real-time

Numerous recent studies have demonstrated the potential of Landsat in rangeland management programs Carnegge and DeGloria (1974), DeGloria et al (1975), and Reeves and Faulkener (1975) have shown that it is possible to inventory certain rangeland plants and to monitor germination dates, effects of moisture stress, the length of the green feed period for an area, and locate range areas which are affected by favorable and unfavorable climatic events

Seevers et al (1975), Wiegand et al (1973), and Rouse et al (1973) have attempted to associate vegetative biomass to Landsat radiance data Although the initial results are not conclusive, there does appear to be a general correlation between biomass and radiance The complicating factor in this approach is that the rangeland vegetation varies in density, type, and cover within a resolution cell (pixel) In addition, there are shadowing and obscuring effects due to a plant's canopy which prevents the vegetation below the canopy to be accounted for

Deshler (1974) has demonstrated the ability to map the extent of fire burns in the grasslands and savannahs of Africa with Landsat imagery By using multidate imagery of an area extending from central Nigeria east to the Ethiopian highlands, Deshler was able to trace the seasonal progression of burn from north to south He concluded that with the use of Landat imagery, the extent of burn damage can be accurately and efficiently mapped and accounted for

Despite these advances toward the utilization of Landsat imagery for rangeland applications, aerial photography remains the only fully operational remote sensing system in general use by rangeland managers As the development of space platform remote sensing progresses and its application potential is verified, one can expect its utilization by rangeland managers to increase

3 3 Forestland Management

Forests represent a valuable cash crop to the economy of many countries In addition, forests and forestlands are productive areas which provide forage, shelter and water for wildlife and hold recreational and esthetic value for human populations Because of its value, the need for careful supervision has long been recognized and is employed in varying degrees in all countries It is the role of the forest land manager to determine the appropriate uses of this land in view of the multiple and competitive needs

In order to make sound and fair decisions on forestland utilization the forestland manager must have timely and accurate information on the extent, density, type, and quality of trees on the land Remote sensing plays an important role in providing this information To date, the instrument which has received the most usage is the aerial camera The aerial photographic survey is an operational system which has demonstrated that it saves time and money and permits coverage of large, and often inaccessible, areas Using conventional aerial photographic techniques, a forestland manager can quickly obtain information on 1) location and distribution of forest stands 2) tree height measurements , 3) tree quality, 4) tree growth rate, 5) tree crown diameter, 6) stand volume per acre, and 7) site quality This type of remote sensing has been used by forestland managers in the United States and abroad since the late 1950's

With the launching of Landsat in 1972, research programs have attempted to develop the potential of satellite remote sensing in forestland management. Forest-type mapping from Landsat imagery has been accomplished in different parts of the world under various surface, weather, and seasonal conditions Requirements of the 1974 UNESCO classification system have been met in the United States, Philippine Islands, New Guinea, and East Africa (ref 8) For instance, a total of 14 classifications of timber type and condition were achieved at sample sites in the San Houston National Forest in Texas (Ref 11) Various types are discernable, depending on location, but most commonly the basic types of conifers and hardwoods can be identified

Landsat investigators have attempted to use satellite remote sensing techniques in order to derive forest volume inventory information Such information is used to determine the value of land for timber production It can also be used to determine the harvesting dates and rates which can be influenced by the amount of timber available to the logging industry In addition, it can be used to evaluate the effects of various management practices such as precommercial thinning To date, attempts to derive volume estimations of timbered land from Landsat data have had moderate success The standard error for studies in California and Oregon (ref 8) ranged from 8 to 16 percent It is believed that the introduction of the thematic mapper in the 1980's, with its increased resolution, will increase the accuracy of volume estimates from satellite data

Insect-caused defoliation has been observed from Landsat data Hall (Ref 8) found that Landsat data can discriminate sufficiently between normal and very abnormal conditions in a fairly homogeneous forest Using visual interpretation techniques of enhanced color composites enlarged to 1 80,000, Hall was able to detect areas of heavy defoliation and light, medium and heavy mortality with a reasonably high degree of reliability

Although Landsat cannot monitor forest fires due to the time required to process and relay the data, Landsat imagery can be used to locate and map areas of fire damage (Ref 9) In this manner, burn areas can be accurately mapped and its land value reassessed

As a result of the inroads these investigators have made in applying Landsat imagery to forestland management, NASA, in a report issued in September 1976, states that during the early 1980's an operational satellite system for forestland management should be completed (ref 8)

A third type of sensor which is being used by forest managers is airborne radar Originally developed as an all weather military reconnasissance sensor, side-looking radar is now demonstrating its ability to obtain information on natural resources

Along with the ability to penetrate cloud cover and provide imagery for areas where a camera or MSS system might be useless, radar has other advantages As an active sensor, emitting pulses of radiation which illuminate a scene, its imagery is independent of sunlight and thus can be used either during the day or at night Also, the imagery scale is constant and independent of aircraft altitude

Because of these features, radar is being used as the primary sensor in many countries that are located near the normally cloud covered and humid equatorial belt Venezuela and Brazil are two such countries which have utilized this sensor in mapping vast areas of previously unmapped tropical and mountain forestland Surveys conducted by Litton Industries' Aero Service Corporation working with Goodyear Aerospace have mapped over 5 million square kilometers in these two countries alone (Miller, 1972) It is felt that such information obtained over previously unmapped areas can assist in timber inventories and be used in subsequent lumber operations

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4 0 Remote Sensing of Coastal Food Resources

4 1 Introduction

The wetlands, estuaries, reefs, and upwelling regions along many of the world's coasts compare favorably in terms of gross primary productivity with the most intensely cultivated agricultural lands (Refs 1 and 2) Table 4 1-1 convincingly illustrates this fact However in most countries, the coastal zone is not being fully utilized as a source of food for an ever increasing world population Over the history of man's expansion, the true value of coastal resources has not been understood and wetlands in particular have been viewed as wastelands that must be filled-in or otherwise "improved" for the betterment of mankind Difficult access to wetlands and estuarine food resources has also prevented the assessment of their areal extent and productivity

With the launch of LANDSAT and Skylab, relatively high resolution spacecraft data became available for mapping and inventorying on a global scale tidal marshes, their plant species, and condition, upwelling regions which attract large fish populations, and other coastal water properties which relate to the presence of finfish, crustacea and shellfish of significant economic value

4 2 Wetlands Mapping

Coastal wetlands represent an important food resource for several reasons The food web of numerous estuaries and coastal waters is based on the high primary productivity of coastal marshes which constitute centers of solar energy fixation and an important link in the mineral cycles The

Table 4 1-1 Estimated Gross Primary Production (annual basis) of the Biosphere and Its Distribution Among Major Ecosystems

Ecosystem	Area 10^6 km²	Gross Primary Productivity kcal/m²/yr	Total Gross Production 10^{18} kcal/yr
MARINE			
open ocean	326.0	1000	32.6
coastal zones	34.0	2000	6.8
upwelling zones	0.4	6000	0.2
estuaries and reefs	2.0	20,000	4.0
Subtotal	362.4	—	43.6
TERRESTRIAL			
deserts and tundras	40.0	200	0.8
grasslands and pastures	42.0	2500	10.5
dry forests	9.4	2500	2.4
boreal coniferous forests	10.0	3000	3.0
cultivated land with little or no energy subsidy	10.0	3000	3.0
moist temperate forests	4.9	8000	3.9
fuel subsidized (mechanized) agriculture	4.0	12,000	4.8
wet tropical and subtropical (broadleaved evergreen) forests	14.7	20,000	29.0
Subtotal	135.0	—	57.4
Total for biosphere (round figures) (not including ice caps)	500.0	2000	100.0

[illegible]

fixed carbon and minerals enter the water primarily as detritus where a complex food web makes them accessible to commercially important fish and benthic communities.

Seed-bearing plants growing in saline soils or in areas where saline water is available for irrigation are also being studied as food for man or domesticated animals in the future. Millions of acres of land might be turned into food-producing areas and the loss of irrigated land to farming due to salinization might be reversed. In one experiment 235 selections from 65 halophyte species, largely from tide marshes of the U.S.A., Bolivia, India and Africa were found to germinate and grow in the laboratory, growth chambers, and in the field. A limited number appeared promising for growth in highly saline water and are being studied in detail (Ref. 3). Among others, <u>Spartina alterniflora</u>, <u>Distichlis spicata</u>, and <u>Spartina patens</u>, were found to merit consideration because of salt tolerance. Furthermore, <u>Spartina alterniflora</u> provides the principal base for the food web in the world's major marshes and can be mapped from aircraft and satellites.

Operational wetland mapping programs designed to meet rigorous cartographic standards typically employ photo-interpretation of low-altitude color or color-infrared aerial photographs supplemented by ground surveys. At least eight east coast states in the U.S.A. have mapped their wetlands to define wetlands boundaries and to inventory major marsh plant species at scales ranging from 1:2[illegible] to 1:24,000 (Refs. 4, 5, and 6). Aircraft have also been used in various ecological studies, including species composition of wetland vegetation, wetland productivity, wildlife habitat, diversity, impact of man-made structures on wetlands and mosquito breeding habitat (Refs. 7, 8, 9).

More recently, the potential of Skylab imagery and LANDSAT multispectral scanner (MSS) digital data for mapping and inventorying tidal wetlands has been demonstrated (Refs 10, 11, 12 and 13) In one investigation, digital analysis of LANDSAT imagery was used in an attempt to inventory the significant ecological communities of Delaware's coastal zone (Ref 11) According to Table 2, economical analysis showed that classification accuracy for most of the ten vegetation and land-use discrimination categories was quite good The classification accuracy of the key marsh plants ranged from 85% to 97 5% Classification accuracies derived by comparison with existing maps were above 80% for most categories Blowups of portions of the thematic maps digitally derived from ERTS data showed very good correlation with known sites Cal-comp plots of thematic data at scales up to 1 24,000 showed excellent cartographic precision when superimposed on existing maps The spatial resolution of the LANDSAT MSS CCT's averaged about 70 meters, representing a nominal resolution cell of about 0 49 hectares (1 1 acres) Visual photointerpretation of LANDSAT transparencies resulted in poorer resolution and lower classification accuracy

In comparison, Skylab's S190A Multispectral Photographic Facility had a resolution of 30 meters and it's S190B Earth Terrain Camera about 15 meters (Ref 12), providing valuable information for detailed wetland mapping With regard to classification, five wetland plant species were identified, and drainage patterns were mapped in more detail (Ref 10) One significant advantage of the LANDSAT system is the repetitive coverage, permitting observations of plants over their entire growing cycle, including the estimation of plant physical and morphological characteristics (Ref 10)

3 Monitoring Coastal Upwelling

Upwelling is a process of vertical water motion in the sea whereby subsurface water moves toward the surface Upwelled water can introduce large quantities of nutrients (phosphates, nitrates, etc) to the euphotic or light zone, thus, upwelling is conducive to high organic production Knoweldge of the location and prevailing conditions of upwelling areas constitutes important information for fishing fleets For example, especially extensive fishing areas and kelp beds are found in upwelling areas off the African and North and South American continents In addition, considerable bird populations, whose guano is of economic importance, occur off Peru Again, near the Antarctic Convergence, particularly in the Atlantic, the abundance of nutrients supports an unusually large standing crop of diatoms and flagellates which, in turn, ultimately support krill, the main food of whales, seals and other species

Upwelling may take place anywhere, but it is more common along the western coasts of continents Upwelling may be caused by wind displacing surface water away from the coast or by currents impinging on each other or on land masses The most pronounced coastal upwellings are found off the western United States, Peru, Morocco, South Africa, and Western Australia (Ref 14)

The ability to identify upwelling areas from aircraft and satellites lies in the fact that deep water having properties different from those of the surface water is brought up to, or near, the sea surface The most distinguishing feature of the upwelled water is that it is colder and denser than the adjacent surface water and may contain chlorophyll and other nutrients at concentrations exceeding background levels

When nutrients and cold water are brought into the sunlit layers, photosynthesis initiates a biological chain reaction which gives rise to accumulation of chlorophyll and other biochromes In highly productive areas, the freshly upwelled water is initially cold and clear but gradually warms up and turns greenish with increased surface age The fade-out of thermal contrast and the buildup of color contrast are supplementary processes (Ref 15)

Remote sensing systems that simultaneously measure sea surface temperature and chlorophyll coloration have provided valuable new information as to the distribution in space and time of the biological activity in upwelling areas (Ref 16) Particularly successful have been surface temperature observations from the NOAA series satellites (NOAA-1 and NOAA-2) which have been mapping the temperatures of vast coastal regions with accuracies within several degrees Kelvin Under relatively cloud-free conditions, the Very High Resolution Radiometer (VHRR) aboard NOAA-2, which has a spatial resolution of 1 km at nadir, gathers data in both the visible and infrared channels The visible channel (0 6-0 7 um) measures the reflected solar radiation from the earth, while the infrared channel operates both day and night to measure the radiation emitted from the earth's surface in the 10 5-12 5 um wavelength region The orbiting motion of the satellite (near-polar and syn-synchronous at an altitude of 1460 km), together with the day-night operation of the VHRR scanner, provides thorough coverage of North America and the adjacent ocean areas out to 1000 km or more from shore twice daily at approximately 0900 and 2100 hours local time The direct readout capability of this instrument, when the satellite is within the range of the NOAA command and data acquisition ground stations at Wallops Island, Virginia, Fairbanks, Alaska, and San Francisco, California, enables immediate use of the data The information content of the gray-scale images is extracted to produce charts which display several significant ocean surface thermal features Major water masses, fronts, upwelling areas, currents, and eddies can be identified and located (Refs. 17, 18)

Detection and monitoring of photosynthetic productivity in upwelling areas has been tried with aircraft, Landsat and Skylab, with some success in locating chlorophyll-rich upwelling areas (Refs 19, 20) Attempts to quantify chlorophyll concentrations in aquatic suspension have met with mixed results Inaccuracy is partly due to the inability to discriminate between chlorophyll and inorganic sediment However, measurements of marine photosynthetic organisms show a "hingepoint" at approximately 0 52 um, below which chlorophyll in suspension reflects strongly and above which absorption is dominant Sediment, on the other hand, acts as a broad-band backscatterer Thus, the use of two bands, separated at approximately 0 52 um, may allow discrimination of chlorophyll from inorganic sediment In summary, one can say that aircraft and satellite remote sensors can rapidly locate nutrient-rich upwelling areas for fishing fleets, but cannot reliably quantify the chlorophyll concentration or photosynthetic productivity of the water

Location of Coastal Fish Schools

Spotter pilots flying light aircraft are regularly used to guide twin purse seine boats and other fishing vessels to catch large schools of fish such as menhaden (Brevoortia patronus) The pilots direct the boats to a particular fish school by radio and notify the boat captains when to encircle a school with a purse seine An actual school of fish cannot be readily observed from satellite altitudes, due to resolution, atmospheric transmission and surface reflection problems However, satellites and aircraft can detect secondary indicators of highly productive coastal waters, such as chlorophyll-a, sea-surface temperature and turbidity (Ref 18) The rationale based on the assumption that fish distribution is governed by certain oceanographic parameters detectable from satellites has been substantiated by Kemmerer (Refs 21, 22) Oceanographic conditions reflected in ground truth measurements of surface temperature, chlorophyll-a, salinity, water color (Forel-Ule), and turbidity (Secchi disc transparency) from the two study areas were compared to determine which ones correlated with fishery data collected from fishing vessels at sites of menhaden capture The assumption was that if menhaden were caught in the same kind of water with respect to one or more of the parameters, then the parameters showing consistency probably were affecting fish distribution

Forel-Ule water color, turbidity, and chlorophyll-a concentrations were similar at locations of menhaden capture in both study areas salinity and temperature were not As the first three parameters can be identified in LANDSAT MSS imagery, a spectral pattern recognition technique was used to determine if water containing menhaden could be recognized from space Locations of menhaden schools were translated into the LANDSAT coordinate reference system so that areas with and without menhaden could be identified Radiance values from each of the four spectral channels were extracted from the data for these areas so that a computer algorithm could be developed Digital LANDSAT MSS data were then classified into high and low probability fishing areas with the algorithm

Menhaden school locations used to develop the classification algorithm were limited to those identified ± 2 hours of satellite coverage Twenty-five of the 29 school locations satisfying this temporal limitation fell within or immediately adjacent to the high probability fishing areas, and 16 out of 19 other schools located outside the allocated time period fell within or next to these areas A correlation analysis applied to menhaden and MSS spectral data provided correlation coefficients of 0 65, 0 75, 0 67, and 0 61 for bands 4, 5, 6, and 7, respectively, all significant at the 99% confidence level (Ref 22)

In one mission, computer classification of LANDSAT MSS data into high probability fishing areas was completed and disseminated to the fishing fleet 21 hours after satellite reception The fleet reported that menhaden were concentrated in these areas and the test was successful This report was verified by plotting locations of menhaden captures and observations on the prediction chart Most locations fell into or adjacent to the high probability areas (Ref 22)

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5 0 Programs in Developing Countries

Introduction

Having established that remote sensing techniques can effectively monitor, map and inventory important agricultural, wildlife and coastal food resources, we will attempt to summarize past and present programs in developing countries and point out some future plans and possibilities. To attain an effective capability to use space remote sensing data, developing nations depend on technical and financial support from such countries as the U S A, France, Canada, West Germany, and the U S S R. The list of international organizations which have been most active in promoting interest and cooperation in applications of remote sensing includes the United Nations, the World Bank, and the Inter-American Development Bank. Requests from the developing countries also come directly to United States agencies, such as the Agency for International Development (AID) or the National Aeronautics and Space Administration (NASA), for assistance in equipment procurement, in remote sensing training programs such as digital analysis of satellite data, in establishing centers for remote sensing research and application, and in project planning and execution applying remote sensing techniques

United Nations Programs

To make remote sensing technology available to the developing countries the United Nations Space Applications Programme was established in 1970 and has, in the past seven years, sponsored seminars in various parts of the world, arranged expert missions and disseminated information on developments in this field. Within the UN system, the major source of funds for development projects is the United Nations Development Programme or UNDP

The UNDP, however, does not have technical expertise in this field, and the management of these projects, once approved for funding by the UNDP, is carried out by the appropriate specialized agency The developing country involved usually contributes an amount comparable to that provided by the UNDP and the total amount involved can range from a few thousand to a few million dollars and the project can take from a few months to several years The FAO and the Centre for Natural Resources, Energy and Transport of the Secretariat are the agencies most involved in remote sensing, with the FAO concerned with agriculture, forestry and fisheries and the CNRET concerned with cartography, geology and hydrology Of the UNDP projects for which FAO is executing agency, 60 to 70 have some remote sensing component, while CNRET is responsible for a somewhat smaller number (Ref 1)

One of the most interesting of these projects is the Bolivian Landsat program, which has been assisted by $150,000 from the UNDP matched by an approximately equal amount from the Bolivian government This program is an example of what a developing country can accomplish with a minimum of funds, equipment, or specialized training The project consists of about 12 people trained in the user disciplines and seconded by various user agencies to the project The equipment consists primarily of a small photo lab and light tables with inexpensive magnifying equipment and the data consists of a few hundred Landsat images covering the 64 scenes over Bolivia From 9 x 9 color transparencies and 1 250,000 black and white prints, 1 250,000 base maps and thematic overlays are produced for a number of disciplines including geology, geomorphology, hydrology, forestry, and land use The significance of this project is clear when one considers that only about one fourth of the country has ever been covered by air photos, and that the only maps that exist of most of the country are 1 1,000,000 aeronautical charts For most of the disciplines, no thematic maps have existed for any part of the country In addition to the general mapping effort, the group undertook special projects such as the routing of a planned gas pipeline through eastern Bolivia It is estimated that the route chosen on the basis of analysis of Landsat data will save several million dollars in construction costs over the route previously chosen on the basis of inadequate data from other sources The group is acquiring an airborne multi-spectral camera to be mounted in a small government aircraft and is planning to establish a small computer processing capability for more detailed study of specific areas when required

A major FAO administred UNDP project is the Investigation of the Okavango Delta in Botswana as a Primary Water Resource, funded with $600,000 of UNDP funds and $1,000,000 of Botswana Government funds and continuing from 1973 to 1977 The Okavango, the only perennially flowing river in Botswana, and whose swampy delta covers 16,000 square kilometers, is potentially a great source of water for a country whose agricultural and industrial development is limited by lack of water Before any significant diversion of water takes place, however, a thorough analysis over several years on the extent and variation of seasonal flooding, of flow patterns, of seasonal and yearly changes in vegetation patterns will have to be made And when water is diverted the resulting changes will have to be closely monitored to avoid or reduce any harmful effects Since very little data exists for the area, Landsat provides an ideal tool for collecting data to be combined with measurements from hydrologic platforms and other ground sources

In another study, at the request of the Food and Agriculture Organization and the Government of Sudan, scientists of the Laboratory for Application of Remote Sensing (LARS) of Purdue University analyzed Landsat-1 data over the El Fula region in Kodofan Province, southwest of Khartoum The objective of the study was to assess the utility of computer-aided analysis of Landsat data in preparing an inventory of the land, vegetation, and water resources of Sudan's tropical savanna Results indicate that these techniques can provide very quickly and efficiently at scales as large as 1 20,000 maps delineating important soil differences, vegetation complexes, surface drainage patterns, erosion hazards, and present land use Since for most of the country few surveys are available for the land, vegetation, water and mineral resources at scales greater than 1 1,000,000 or 1 400,000, Landsat data holds great promise for the Sudan, the largest country in Africa The northern third of its two and a half million square kilometers is desert Much of the remainder is semi-arid and, without careful planning and management, is of marginal use for agriculture

Two of the United Nations regional groupings have also taken action toward providing a remote sensing capability in their regions The Economic Commission for Africa is establishing a remote sensing center for Africa and the Economic and Social Commission for Asia and the Pacific is conducting a study for a remote sensing satellite ground facility

5 3 World Bank Activities

The World Bank has been involved in remote sensing activities in over a dozen developing countries Its Agriculture and Rural Development Department is at present coordinating land cover mapping activities in Burma, India, Bangladesh and Zaire At one time or another it has provided remote sensing training and expertise to such countries as the Phillippines, Indonesia, Malaysia, Thailand, Pakistan, Nepal, SriLanka, Papua, West Samoa, Salvador, Honduras, the Dominican Republic, Peru and others (Refs 2 and 3)

A typical example is provided by the land cover mapping being conducted in Burma The Bendix Aerospace Division has been subcontracted to use its Multispectral Data Analysis System (MDAS) to produce land cover maps from Landsat digital tapes at scales from 1 100,000 to 1 1,000,000 having the two dozen categories shown in Table 5 3-1 Note that rice was not only discriminated from other crops and natural plants, but that four different rice crops or types were identified Since for many parts of Burma there existed no recent, large scales maps, the Landsat maps will significantly enhance that country's ability to plan its land-use and improve its food supply

Table 5 3-1

Burma Land Cover Mapping Categories

WATER

Unclassified
Cloud Shadow
Deep Lake
Ocean
Shallow Lakes
Rivers
Shallow, Turbid Water & Coastal Current
Swamps, Marshland

SMALL GRAINS

Wetlands/Flooded Fields
Pulses/Upland Rice/Dry Framing
(Secondary Crop) Single Crop Rice
(Tertiary Crop) Mixed Crops plus Rice
(Major Group) Double Rice Crop

OTHER CROPS

Barren Land/Scrub Vegetation
Fallow Land/Unknown Vegetation
Grassland
Riverine Shrubs/Peeds/Sugarcane
Palms/Horticulture

FOREST

Highland Mixed Forest (Diptocarps)
Lowland Coastal Forest (Mangrove)
Hill and Ridge Shadows
Major Distinct Species (i e Rubber or Conifer)
Unknown Forest/Bushland
Secondary Distinct Species or Anomoly (i e Teak or Brushland)

OTHER

Sand/Salt Flats
Mudflats/Silt Deposits
Urban/Industrial

5 4 Inter-American Development Bank Programs

The Inter-American Development Bank uses remote sensing technology as a tool in identifying potential areas for project development, analyzing certain phases of current projects and evaluating projects already completed in Central and South America This activity is carried out by an interdepartmental work group created in 1975 under the coordination of the Bank's Project Analysis Department, including seminars to demonstrate the applicability of remote sensing technology in development projects

Several member countries of the Bank (Bolivia, Brazil, Chile, Colombia Ecuador, Guatemala, Mexico, Peru and others) have been making uses of remote sensing from satellites in a great number of projects (Ref 4)

One illustrative example can be derived from the work of Carlos Brockmann in Bolivia Brockmann stated that in making the existing soil maps of Bolivia, a British contract team worked eight years to produce a very generalized soil map published at a scale of 1 2,500,000 at a cost of $400,000 This cost undoubtedly included field sampling and analysis Brockmann believes that using Landsat data he can make a more detailed soil map of the country at a scale of 1 1,000,000 in two years at a cost of about $20,000, sampling costs not included He is initiating the effort at this time and hopes to have it completed in 1976 Potential benefits in savings of time could, therefore, be estimated to be 4 1 and in dollars approximately 20 1 Even with a significant increase in cost of satellite data in the future, the potential benefits may still be substantial

Another example is a case study involving the analysis by computers of Landsat data in a 5,000 km^2 area in northwestern Costa Rica The analysis demonstrated the applications of remote sensing from satellites and the role of earth resources inventories as an important source of information It emphasized the value to policy makers in making managerial decisions based on such data about the state of depletion of the natural resources The results of the project indicate that remote sensing can be an effective tool in identifying crop, forest, and other vegetative covers, saline and other soil conditions, erosion problems, and drainage patterns. It also is useful in delineating other meaningful ground features in a tropical environment where the ecological conditions are generally far more complex than in a temperate zone An economic analysis of the project suggests that benefits may be derived through reduced labor requirements and development costs (Ref 5)

Research is being conducted by soil scientists at the Ministry of Agriculture in Chile to classify through computerized models the various soil groups, types and families, of the country The long-range objective of this research work is to create a data bank including Landsat data, whereby the multiple parameters necessary to estimate production levels of various crops will be systematically classified and used as a tool to generate more efficient inputs in future agricultural development projects

In another study conducted by I N P E of Sao Paulo, Landsat imagery is being used to map the natural vegetation units of central-eastern Brazil Plant morphology, physiology, and geomorphological characteristics are considered to identify each habitat These habitats have been verified by prominent botanist and plant ecologists Distinct boundaries were found between Atlantic, mixed and seasonal forests (spiny and sclerophyllus), Brazilian savannah (cerrado, campo limpo) and grasses (campo) The results are presented in the form of a vegetation map which shows the location of vegetation types in terms understandable to the users government planning authorities, public services agencies, investment and special research institute (Ref 6)

5 5 A I D Remote Sensing Activities

According to Conitz (Ref 7) the Landsat experiments have provided a source of data which is not only vital to the development planning process, but which would otherwise be unavilable to most developing countries

Well before the launch of the first Earth Resources Technology Satellite the Agency for International Development (AID) recognized the potential value of satellite data for use in resource exploration, assessment and management, land use mapping and planning, and environmental monitoring in developing countries AID's interest was first translated in action through the sponsorship of the Smithsonian Symposium on "Potential Applications of Remote Sensing to Economic Development in Developing Countries" in 1970 This was followed by the development of an AID Remote Sensing Project which provided funding through FY 1976 and covered such activities as the development of an International Training Course in Remote Sensing at the EROS Data Center in Sioux Falls, South Dakota, an activity which has continued successfully under USGS sponsorship, regional training workshops in Panama, the Philippines, Mali and Kenya, low-cost multispectral aircraft surveys in Indonesia, a major benefit assessment study conducted by the Environmental Research Institute of Michigan entitled "An Economic Evaluation of the Utility of ERTS Data for Developing Countries", special studies in geology and range management in Afghanistan and the Sahel respectively, a study of the applicability of satellite data to disaster warning and relief, and grants for stimulating utilization and improving local capabilities to Pakistan, Bangladesh, Thailand, Chile, Bolivia, Philippines Sri Lanka, and Lesotho A second project was developed by TA/OST in 1972 with funds provided by PHA, for an experimental project on the application of Landsat data in demographic studies This project, which is now underway in Bolivia and Kenya, is testing the use of satellite generated data for population estimates in countries where adequate demographic data are lacking Thus AID is helping more than a dozen developing countries to apply Landsat imagery to the solution of food resource related problems, including agricultural crop and land-use surveys; soil erosion, coastal sedimentation, flood and drainage control, water resource evaluation, etc

In FY 1977, AID's Technical Assistance Bureau will continue to make grants available to encourage utilization and to investigate new applications which are unique to, or particularly beneficial for, the developing countries Institutional development has been recognized as one of the most important steps in furthering the utilization of remote sensing technology in developing countries AID will address this need through the provision of a Regional User Assistance Facilty for East Africa in cooperation with the Economic Commission for Africa

Members of the Technical Assistance Bureau are also cooperating with the Regional Bureaus in the design of agriculture, range, and human settlement projects which utilize the benefits of Landsat technology in their data collection phases Examples of these projects are the Masai Range Project in Tanzania, the Mali Resource Inventory, the Sub-tropical Land Development Loan in Bolivia and the proposed AID/IBRD/FAO project for the planning and development of areas freed from onchocerciasis in West Africa The Regional Bureaus also recognize the need for training and institutional development in remote sensing Since 1971, USOM in Thailand has supported a training project with analytical equipment and the provision of a full-time remote sensing specialist In FY 1977 the Africa Bureau will establish a regional remote sensing training center in West Africa

5 6 NASA Scientific Investigations and Data Processing

Scientific investigations from more than 50 countries and five international organizations have been selected for inclusion in NASA's Landsat-1 EREP (Skylab) and Landsat follow-on investigation programs (see Table 5 6-1) The type of investigation is selected by NASA on the basis of its merit in helping to break new ground for practical Landsat applications Government agencies in the respective countries finance such research programs NASA provides the satellite data, technical support and training

In a typical NASA supported investigation, the American University applied Landsat imagery analysis to a study of drought conditions, rehabilitation problems and development potentials in the Sahelian Zone of West Africa (Ref 8) First, the possibilities of reversing the process of desertification in the Sahel through simple range management techniques were demonstrated in the course of analyses and interpretation of the imagery of western Niger Second, a regional assessment of ecological zones for agricultural and livestock production potential based on analysis of Landsat imagery was accomplished with the provision of subsequent rehabilitation and development recommendations to Sahelian governments Third, a new and ominous development (the regional movement of sands and dusts in unprecedented intensity, duration, and frequency) was observed and related, through field and image analysis, to deterioration of Sahelian plant communities and soil surfaces Taken together, these analyses show many opportunities for rehabilitation and development of the Sahelian region, but in addition, there is every indication that the region is deteriorating rapidly into a "dust bowl" condition

NASA collects and processes the satellite data for most investigations The data collected by the satellites is transmitted to one of the three ground receiving stations in the United States, at Fairbanks, Alaska, at Goldstone California, and at Goddard Space Flight Center, Greenbelt, Maryland

The data, after being collected, is processed and converted into information by NASA Then it becomes available to the users community (government agencies, foreign countries, industries, individuals) through distribution centers such as EROS Data Center, near Sioux Falls, South Dakota This center provides to the public at reasonable cost Landsat-1 and 2 data as either a computer compatible tape or photographic image Beside the ground receiving stations in the United States, an operational station is located at Diuba, in the State of Mato Grosso in Brazil, built to maximize Landsat coverage in this South American country Canada has one in Prince Albert and is preparing a second station Chile has recently signed an agreement to give complete coverage of the Maritimes with NASA to acquire and operate a ground station that will receive satellite data NASA's satellite tracking station in Colina near Santiago could be upgraded for that purpose Venezuela has expressed interest in having a receiving station The eventual installation of these two receiving stations in Venezuela and Chile respectively would give complete Landsat coverage of Central and South America Similar regional data receiving facilities have been set up in Italy and are being installed in Egypt, Zaire and Iran All of these stations are, at the moment, national stations, funded, owned and operated by the country involved Each receiving station, however, will cover an area 3,000 km in radius and the agreements with NASA under which the stations have been established stipulate that the station will respond to any requests for data within that area

5 7 National Science Foundation Programs

The National Science Foundation has several projects which relate to remote sensing However since the intent of this study was to review programs outside NSF, a discussion of these projects is beyond the scope of this report

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6 0 Summary and Conclusions

With financial and technical support from the United Nations, the World Bank the Inter-American Bank, AID, and NASA, developing countries shown in Table 6-1 are using Landsat or other spacecraft imagery in studies related to food resources and other associated areas The pertinent applications include agricultural crop surveys, with an ultimate goal of predicting yield, search for new fertile land in coastal and other areas, range management to reverse intrusion of desert sand and soil erosion, assessment of water resources, including irrigation, drainage and flood control, land use management to improve productivity, and various related problem areas The most typical study is perhaps one where Landsat digital tapes are analyzed by computer systems such as the Bendix MDAS, G E 's Image-100, or ERIM's MIDAS to produce a land cover map having as many as three dozen categories, shown in Table 6-2 The selection of categories and classification scheme is usually optimized for each particular geographic region and application While in a few instances the categorization was not detailed enough to meet all user requirements, in most studies discrimination was sufficient to map properties of interest in order to conduct detailed studies of crop production, forest inventories, coastal mapping, and urban-industrial evaluations

The accuracy and reliability of the land cover maps depends heavily on the spectral signatures of the categories, contrast and illumination, atmospheric conditions and availability of ground truth In areas where sufficient ground truth was available and atmopsheric scatter was not excessive, classification accuracies in excess of 80% have been obtained for most vegetation categories, with many categories having accuracies over 90% Compared with existing map accuracies in many developing countries, these results are quite acceptable for first-generation satellite products

The cost of mapping land cover from Landsat as compared to aircraft or ground surveys was found to be from twice to about 80 times in favor of the satellite approach Generally, the larger the area to be mapped and the more repetitive the coverage requirement, the bigger the cost advantage in favor of satellites These evaluations, however, do not include the cost of developing, testing, launching the satellite itself and the capital cost of ground facilities to receive the data and process it

Discussions with foreign investigators to review projects in developing countries seem to point to the following shortcomings which should be eliminated or alleviated in the future

a) Landsat and other spacecraft data is still not available to man users in developing countries This is particular true of university scientists and local administrators and planners who are not part of the federal establishment, particularly the proper government group ar o: these individuals still do not know that data exists and how to get it

b) Many of the early satellite images sent to investigators were poor quality 70mm transparencies or 9 inch prints High qualit maps from Landsat digital imagery have been produced only during the last two years Having seen only the early film products, some investigators gave up too soon on Landsat

c) Landsat's 70-100 meter resolution is insufficient to resolve land use in densely populated areas, inventory certain coastal resources or conduct detailed studies of crop production In the early 1980's Landsat-D is supposed to carry the Thematic Mapper into orbit having a resolution of 30 meters and at least six spectral bands However, for highly detailed investigations aircraft mapping missions may still have to be conducted

d) Relatively few developing countries are using satellite data to map their coastal resources and monitor their coastal environment The productivity of wetlands, estuaries and coastal waters may offer relief to coastal countries with food shortages To use and protect this resource, wetlands should be mapped and water properties monitored, particularly those which are related to finfish or shellfish abundance

e) Space technology is a capital intensive product of industrialized countries, while developing countries are labor intensive and often cannot economically utilize such advanced technology Thus in some countries it may be more cost-effective to employ a large number of native photo-interpreters to draw maps directly from aerial photographs than to acquire and operate a sophisticated digital analysis system like MDAS or Image-100 As a result many developing countries will continue to rely on satellite data analysis from agencies or countries having such facilities

Table 6-1 List of Less Developed Countries Using Landsat Data for Food-Resources Related Studies

AFRICA

Botswana
Central African Republic
Egypt
Ethiopia
Gabon
Guinea Republic
Kenya
Lesotho
Libya Arab Republic
Mali
Nigeria
Sudan
Swaziland
Upper Volta
Zaire

OTHERS

Papua
West Samoa

ASIA

Bangladesh
Burma
India
Indonesia
Iran
Malaysia
Pakistan
Philippines
Sri Lanka
Thailand

CENTRAL AND SOUTH AMERICA

Bolivia
Brazil
Chile
Colombia
Costa Rica
Ecuador
Guatemala
Honduras
Mexico
Panama
Peru
Salvador

Table 6-2 Typical Cover Map Classification Categories Extracted by the Bendix MDAS from Landsat Digital Tapes

URBAN OR BUILT-UP LAND

High density developed
Rural-low density developed
Tended grass

AGRICULTURAL LAND

Corn
Oats
Barley
Small grains
Hayland native
Hayland tame
Plowed fields

RANGELAND

Savannah
Shrubland
Brushland
High brush
Grass meadow
Open range
Grazed
Prairie native
Dry grass pasture

BARREN LAND

Sand
Gravel pits
Sand beaches
Bare soil types
Saline soil
Reef flat
Algal rim

FOREST LAND

DECIDUOUS

Hardwoods
Red alder
Willow
Alder
Willow-poplar
Cottonwood
Aspen
Birch
Rainforest
Cypress
Citrus

EVERGREEN

Conifers
Upland conifer
Lowland conifer
Spruce
Sitka spruce
Black spruce
Pine
Cedar
Hemlock
Mangrove

MIXED

Spruce-hardwood

OTHER

Forest burn
Native stands
Slash

WATER

Deep clear water
Shallow clear water
Turbid water
Turbid salt water
Saline water
Algal (eutrophic)
Tannin water
Acid dump

WETLANDS

Bog
Alkali bog
Wet sedge
Muskeg
Fresh water marsh

TUNDRA

Wet tundra
Moist tundra
Dry tundra
Heath tundra
Alpine tundra
Tundra burn
Tussocks
Meadow

PERRENNIAL SNOW OR ICE

Snow
Glacier ice
Lake ice

MISCELLANEOUS

Smoke Plumes

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