STATEMENT OF DR. ARCHIBALD PARK, EARTH SATELLITE CORP..

l)r. PARK. Thank you, Mr. chairman.

I appreciate the opportunity to appear here, Mr. Chairman.

Chairman HUMPHREY. Would you tell us a little bit about the Earth Satellite Corp.; it is private ?

l)r. PARK. Yes. It is a private consulting firm. The bulk of our business is related to remote sensing and the application of it to resource management. our clients run the gamut from agribusiness both in this country and abroad to State and local governments here in this country as well as foreign governments in a consulting capacity.

I have been given a rather enviable task of being able to sit back and look at the research that has been conducted. And a friend of mine posed the philosophical question extremely well.

He said we should look at the research from time to time to see if we have already gone by the answer. In this case, I think there is sufficient evidence in the program of the experiments that have been done to date to point out that certain results that bear very much on operational go or no-go policy have in fact come to light.

M-y paper is quite long and covers the technology in some detail based on a system design. That is, an information system design that covers all aspects of data acquisition, data processing, data analysis, the various models that are in use today and of course, the decision-making process.

The staff asked me to comment on the technical and technological opportunities and constraints that exist today in the research and development programs and the opportunities for the future for the employment of such a system for global agricultural information.

The acquisition covers the three satellite systems that have been mentioned and I don't think it is of any use to speak further on them.

The document covers Landsats, Metsats and Datasats. It also covers collateral observations and measurements both by national governments and by international organizations as well as agribusiness.

It treats the Landsat satellite, I think, with the emphasis that it deserves since it is a key to this system. In my opinion. the system really cannot exist in a way that "is both unbiased and independent without such satellites. And I will have some recommendations at the end of my presentation that deal with what might go on from here.

There are various categories of data from Landsat. The following observables are all essential to an agricultural information system:

GROUP 1

1. Agriculture versus nonagriculture.
2. Cereals versus other crops.
3. Wheat versus other cereals.

GROUP 2

1. Soils association maps.
2. Soils reconnaissance maps.
3. Soils survey maps.

GROUP *3*

1. Vegetation density.
2. Vegetation vigor.
3. Vegetation stress.

The groups are in order of technical difficulty.

My position with respect to the operational decision is based on the premise that we already know how to make maps of agriculture versus nonagriculture on a global basis. That is not a R. & D. activity;

Chairman HUMPHREY. You mean agricultural and nonagricultural lands?

Dr. PARK. Yes, sir; I do.

As Mr. Mathews pointed out, this is going to improve with newer sensors on future satellites. That is, the precision will improve.

It can detect soil color. It can detect plant stress. It cannot tell you " what that stress is caused by, but conventionally it is caused by moisture or insects or disease or a combination of those.

It can measure biomass, that is the mass of the vegetation and, of course, it can say something qualitatively about plant vigor.

In addition to these observable, it is necessary to consider the interpretation of these data by skilled agricultural professionals in the appropriate scientific discipline. The following are the outputs of the Landsat and Landsat combined sources of data:

1. Ecological partitioning of the agricultural land of the world.
2. Surface soil mapping.
3. Crop inventory and monitoring.
4. Agricultural land use change detection.
5. Global agricultural data base compilation and update.

The inputs that I see Landsat making to the global system deal only with crop inventory and monitoring only in the later years. To start with we need very badly to partition the world ecologically. If we are going to sample the world statistically. we have to develop those data on the basis of the productivity potential of the land. Landsat by virtue of its existing capability can contribute to these right away.

I have a schedule on how long it would take us if we made a decision this spring to produce such data which will in fact support an operational LACIE concept.

One of the most important attributes of a satellite is the fact that, it can detect change and agricultural land use change is a very, very important thing.

I know that you felt as keenly as anyone present at the World Food Conference about the importance of the agricultural lands of the . world. I was distressed by the fact that not one word in the technical documentation dealt with the issue of agricultural land use change. The fact that thousands of acres of good agricultural lands are going out of production everyday.

Chairman HUMPHREY. For what reason?

Dr. PARK. Principally because of road construction and urban expansion. But anywhere that one can grow crops, it is often the cheapest land on which to build buildings and roads and that's an unfortunate thing.

Finally, I would argue that there is no data base, no conceivable data base as good as Landsat itself for the global agricultural information system. For its revision, and its verification, the Landsat pictures themselves are the ideal base for the system.

In meteorology, Dr. White has mentioned the importance of that discipline to crop yield, plant growth models and I will not deal with the specifics.

The models are fairly well in hand and it is appropriate to state that we should start now. As the research develops better and better precision, it will certainly be employed. But we have enough proof of concept that we should decide to go ahead now.

Chairman HUMPHREY. That's the Metsat contribution you *are* talking about there ?

Dr. PARE. That's right; the meteorological satellite.

Chairman HUMPHREY. Is there a phase-in of the traditional type of information by the computerization of this data?

Dr. PARK. Yes, sir, and in the case of the crop yield, plant growth models, what has been done is to quantify these observational data in numerical form and fit them into numerical models. The level of sophistication of that technology is quite surprising.

I will only use one of the models in the presentation because it perhaps is the most interesting of all the models. It is the land use management model and represents one more reason for my position that we can in fact make a decision to proceed.

Land use information is derived in this concept from a multidisciplinary team of scientists who use Landsat data to derive an analytical product on land use. And, of course, in the case of agriculture it is a product that either deals with agricultural capability which is the capability of the land to sustain certain types of agriculture or land use suitability which does take into account the political factors that present the scientists with given alternatives with respect to the use of the land and so must be accounted for in the analytical tasks.

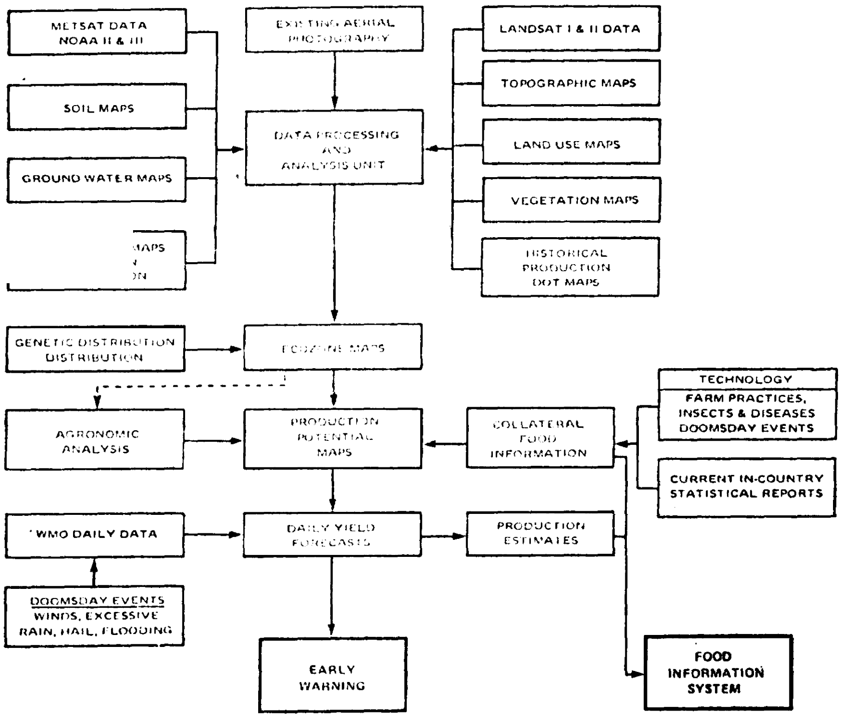
The land use analysis to date, that we, as a corporation have found to be salable in foreign countries is, of course, that which deals with intensive agricultural development, or the improvement of the range of that country, or the actual alternatives that they must consider in the deve!opment of transportation systems.

I mentioned before that land use historically was not an issue in roads. I feel it should have been. One can build a road anywhere. It is no longer necessary to use agricultural land to build roads, since engineering technology is no longer a limiting factor.

When I talk about the rational use of land I do it because the principal interest of these countries and hopefully of our own is the protection of agricultural lands.

This is a chart from the body of my report and I will spend only a moment or two on it.

AGRICULTURAL INFORMATION SYSTEM
FUNCTIONAL ORGANIZATION



I have diagramed how products and information would flow into a system that would produce these products in the order in which I suggested they were able to be produced by Landsat now.

We would use Metsats, existing air photos, and Landsat data combined with all the collateral information as you said yourself, the conventional information that we can get our hands on to produce Ecozone maps. Ecozone is a word which is apolitical in the sense that there are lots of other terms around. If you use them you mean a system that was developed by a certain country.

Landscape mapping is a Soviet term. Land system mapping is an Australian term. And so Ecozone means all of those things so it is equally clear to the Soviets and our own people that we are partitioning the world in terms of its biological productivity.

Now, given an Ecozone map, which is rather a scientific document and given genetic distribution data, an experimental agronomist using a practical approach to the analyses of these data can produce production potential maps of the world.

The real question is: How long does it take to do that if you started now ? And where are we in the R. & D. program so that that product would meet with the current research program in NASA and Agriculture.

Using World Meteorological Organization data daily, and satellite data from the Metsats daily we can produce daily yield forecasts. These are the numerical equations previously referenced in terms of the World Food Conference we are addressing the early warning part of that charge that was given to FAO.

Now, I have-I said that I would propose a timetable of events and here it is. If the decision is made to implement such a program this year, there are a variety of milestones. The soil maps of the world are complete. They are not published by any means, but they are complete. FAO is continuing this work in terms of soils limitations to agriculture.

Chairman HUMPHREY. When you say "soil maps," do you mean just the topography, or are you talking about chemical analysis also?

Dr. PARK. I am talking partially about chemical analysis, but more accuracy the graphic description of soils and a legend system that has been completed for the world. They are fairly small in scale but nonetheless they do exist.

And if you take Landsat data and interpret these soils as they must be interpreted for the models, in my estimation it will be 2 years from this spring before one is finished with the interpretive process for wheat for the world.

If you add to that, rice. it will take another year. And if you add to that, corn, still another year to complete the interpretations of the soils data as required by the models now in use to produce plant growth in yield numbers.

Chairman HUMPHREY. Then the information you obtain would be on productivity, for example ?

Dr. PARK. Yes. sir.

Chairman HUMPHREY. Do you get data on the possibility of disease ?

Dr. PARK. Not yet. That's several years away. But the stress caused by soil moisture is a part of it.

If you started this spring to ask, for example, the Department of Agriculture to develop crop calendars, it would take them a year to do wheat alone.

This calendar of the biological events descriptive of the growth of wheat in my opinion would take at least a year.

Chairman HUMPHREY. There are also critical periods in production. Information on a lack of moisture at one time of the year is more critical than at another time of the year.

Dr. PARK. That's correct.

In the plant growth ancl yield models we literally grow the plant daily and that's specifically why the yield data is a daily event. And as I say. if you want to continue with this work for just the three principal crops, it is not something that can be done just out. of hand and in a hurry.

Chairman HUMPHREY. This is what you are saying is now possible with the current technology?

Dr. PARK. Yes. sir: I am. If you decide to proceed with the Ecozome mapping of the world and you make the maps of just wheat-producing areas of the world to start with, that's a 2-year job. And a further year for rice and one more for corn to do that.

Chairman HUMPHREY. These are all very complicated terms. When you speak of the Ecozone maps, what does that specifically represent?

Dr. PARK. That is the culmination of an interdisciplinary analysis of the land which deals with the drainage, surface materials of the Earth, the geology of the Earth, the soils, and the vegetation. Transportation and cultural features mayor may not be a part of that map but it gives you the information about the natural land system,

These Ecozone maps which are *a* result of this complex; analysis, go together with additional information to produce production potential maps of the world.

Now, production of what? That's the question. As we have said the first effort would be to produce maps for the potential, for wheat growth. To do this would take 2 years for wheat, 3 years for wheat and rice, or 4 years for all three.

As for the plant growth models, in my opinion, wheat can be improved, but I believe the models are adequate.

The models for corn are the most advanced but we decided not to start with corn. The fact is that corn is not as important as wheat is in food trade, nor in the food-for-peace program. Wheat is the most important crop in international trade. And even though the models are not as well developed as they are for corn, we all agreed to start with wheat first.

In the Landsat schedule we know that C is scheduled for the fall of 1977 and D is not an approved program. Everyone has mentioned the fact that their programs are hinged on the approval of future missions and that's a key issue for the committee, in my opinion.

Finally, I believe that Earth observation satellites are the only dependable, unbiased source of data, and that Landsat imagery is the only consistent base of data. And one that I don't think can be stressed too hard; and that is that the proposed system benefits by but is not dependent on international cooperation.

That's another key issue; the system as described is one that can be conducted with or without international cooperation. It will generate statistics of acceptable accuracy in either case.

Legislation can certainly strengthen USDA or one could create an independent entity with this single responsibility. Legislation, I believe, should recognize that orbiting resource satellites are the core of the system.

Am-1 finally, legislation should recognize that no present agency of the Government has all of the necessary multidisciplinary skill mix. I would point out that the Department of Agriculture could bring to bear the proper skills but no individual agency of the Department presently has the proper staff.

Thank you very much.

Chairman HUMPHREY. Thank you very much.

[The following paper was requested from Dr. Park by OTA:]

A GLOBAL AGRICULTURAL INFORMATION SYSTEM

This report prepared for the Office of Technology Assessment deals with the application of advanced technology in the fields of remote sensing of the terrestrial biosphere and the atmosphere to provide inputs to a dynamic analytical system which produces quantitative estimates on the current status of agricultural production of selected crops on a global basis.

The report will provide a narrative description of the system including an overview of the design concept. For each element of the system an assessment of the current state-of-the-art will be made. The contribution that each element makes to the system will be covered in sufficient detail to provide both understanding at the system level and to illustrate the tremendous value many of the individual components have in the management of agricultural resources. A brief description of the status of appropriate research and development will follow. Finally, a review of the gaps and/or deficiencies will complete the technical discussion. A section will then follow which will deal with the institutional issues. These will include both national and international problems and suggested solutions where appropriate.

INTRODUCTION

The agricultural objective of the United States and other countries is the alleviation of the world food problem. The major increase in the world's food supply must come from increased production of farm crops. Historically, this has largely been accomplished by bringing additional land under cultivation. More recently increased food production has been met by increasing the yields on the land already under cultivation *in* both the developed and the developing countries.

A major essential for any agricultural management system is the availability of information on agricultural conditions in a timely fashion, Opportunities for increasing and sustaining the productivity of the land and facilitating product flow in agriculture are identified by the availability of accurate, comprehensive, and timely information on productivity, and on the current and potential use of the land. The lack of such information can be a major obstacle to the further economic development of developing countries and a subsequent obstacle to the formulation of important policies in more fully developed regions.

If one considers the broad base of data required to undertake any major review of the agricultural potential of a large country, to say nothing of a continental land mass, it becomes apparent that "on the ground" observations create manpower and logistical problems of overwhelming proportions.

Current earth observing satellites have demonstrated that with the proper technical. scientific, and institutional support, they can be employed in an operational system designed to provide a continuous overview of agricultural production and agricultural land use on a global basis with the inherent capability to forecast production in advance of harvest.

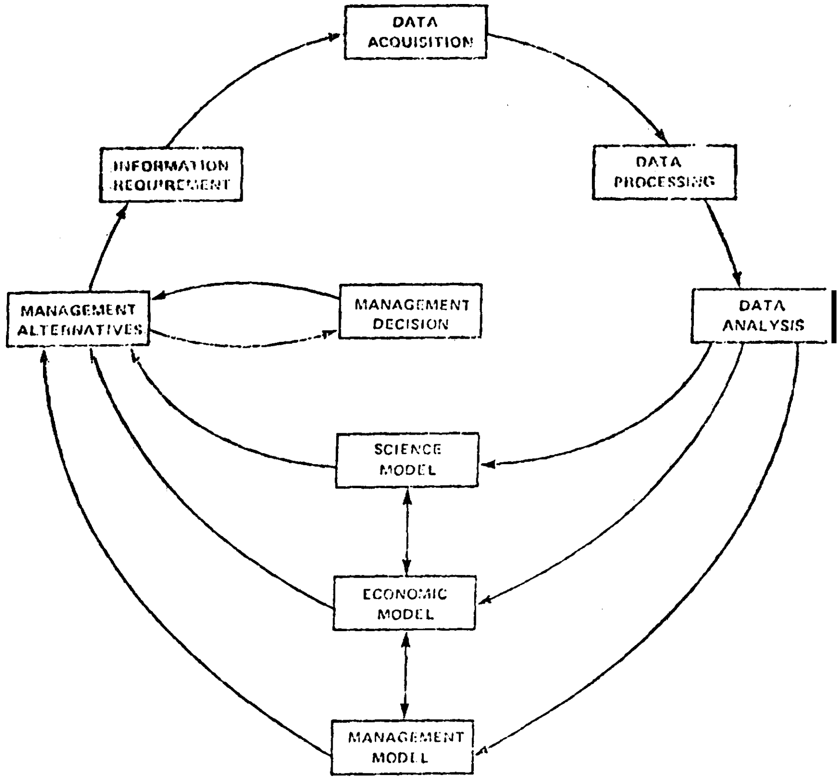


FIGURE 1

1.0 The Technology

Figure 1 is a block diagram of an information system concept which was developed by the writer several years ago and which was designed specifically for use with remote sensing. It is a closed loop model and is centrally oriented in that information flows to the management decision block and requirements for information flow from that block.

In many organizations both in and out of the government sector data is collected simply because it can be acquired. In the development of remote sensing devices there was an intensive effort to focus the research on meeting the requirements of management decision makers in the natural resource fields. This was done because of the high visibility and cost of the acquisition systems, namely satellites and aircraft.

In the DATA PROCESSING block both conventional photo products and more sophisticated and quantitative digital products are prepared and delivered to the analytical group.

In the DATA ANALYSIS block there is a variety of methods available and many of them are suitable for implementation in an operational system. They include conventional photointerpretation with simple light tables, machine assisted interpretation, and finally a fully automated approach using a variety of current computers. The direct recognition of natural resource features based on their shape alone is the exception rather than the rule. In this field the key to the analysis of the feature is frequently color, although the literature more often refers to its “multispectral signature”. In addition the interpretation team is invariably made up of natural resource scientists rather than a team of trained technical level personnel. It is the professional background of the team that makes the interpretation of the data possible.

The MODELS are parallel blocks, but the vertical line between them is meant to imply that there is an interaction between the science, the economic, and the management models. The most popular concept of modeling is that one can reduce all parameters to numerical form for processing in computers. Many natural resource models are numerical in form; many others are not. The term “model” in this document includes both the numerical form and the iterative form where there is a prescribed sequence to the ordering of the data so that cause and effect patterns are produced and conclusions are drawn from the analysis of these patterns. It is in this way that such difficult abstractions as behavior can be modeled. In the section dealing with models, an iterative model on the spread of disease will be shown,

As the figure illustrates, all three of the modeling Mocks may be required to produce information for the MANAGEMENT ALTERNATIVES block. This is as far as the natural resource scientist, in the context of this approach, goes in the production of information for management decisions. In this concept these alternatives ***are*** given to the managers who represent a different entity than the remote sensing resource scientist; and it is appropriate to consider for the purposes of this paper that those decisions are Congressional management decisions. The decision process can result in a course of actions, but that is beyond the scope of this document. However, that process can result in a requirement for additional data for that or future decisions by the management group.

The DATA REQUIREMENTS block constitutes the feed-back loop of the information system, and starts the process over again with the acquisition of data to satisfy that requirement.

If there is a unifying theme to the system concept, it is expressed in the phrase “the convergence of evidence.” These words describe both the method and the philosophy of the approach. In merely stating the goal of the technology-to provide a current assessment of the production of selected crops on a global basis--it is necessary to realize that one is trying to monitor, and in some cases predict, the behavior and the interaction between two of our most dynamic environments, the atmosphere and the biosphere. Many scientists consider both ***to be*** intractable; the atmosphere because of its enormity, and the rates at which its processes occur, the biosphere because of its complexity and the interdependence between living and non-living components. The convergence-of-evidence approach is not, however, an admission that the science is inexact. Rather, it is the recognition that it is both complex and dynamic, and that the sources of input data vary in their precision and their reliability. The concept implies that there are several input data sources, as indeed there are, and each is expressed in the following subsections.

1.1 Data Acquisition

In a system where one is going to acquire data on a global basis it is necessary at the outset to consider the issue of national sovereignty and the sensitivity of many countries concerning access to data about their natural resources. The attitude of the majority of countries, including the United States, is that anyone may conduct an inventory, sometimes after the issue of a permit (Australia). The national will is imposed in the exploitation phase. Other countries have very strict laws prohibiting even the inventory (Brazil), while others are principally concerned with their border areas (India). In any case, the use of aircraft for the purpose of an agricultural information system seems for the present to be unacceptable, and because this is so, a concept has been developed which does not use aircraft, even in the United States.

There are two major sources of information, (a) satellites, and (b) collateral data. These satellites include (1) LANDSATS, (2) METSATS, (3) DATASATS. The collateral sources include (1) national governments (Ministries of Agriculture): (2) international bodies (Food and ***Agriculture Organization, and*** World Meteorological Organization of the United Nations) ; and (3) Agribusiness.

1.1.1 LAND8AT Data

Research conducted to date by a number of investigators has established the utility of these data in agricultural information systems. There are various categories of data from LANDSAT.

a. The LANDSAT data is the only source of data.
b. The LANDSAT imagery is the primary source of data.
c. The LANDSAT imagery is supporting data to other satellites and other data sources.

The following list of observable are all essential to an agricultural information system, and each group is structured in order of technical difficulty. Each observable is followed by one of the letters (a), (b), or (c), as indicated above, to denote the category of LANDSAT data.

GROUP I

1. Agriculture vs. non-agriculture: (a).
2. Cereals vs. other crops: (b).
3. Wheat vs. other cereals: (c).

GROUP l-s

1. Soils association maps: (a).
2. Soils reconnaissance maps: (b).
3. Soils survey maps: (c).

GROUP III

1. Vegetation density—biomass—leaf area index: (a).
2. Vegetation vigor: (a), (c), *.
3. Vegetation stress: (a), (c), *.

In addition to these observable, it is necessary to consider the interpretation of these data by skilled agricultural professionals in the appropriate scientific discipline. The following are the outputs of the LANDSAT and LANDSAT-combined sources of data.

1. Ecological Partitioninfl.-Each partition, or geobotanical landscape unit, represents a synthesis of certain key items of knowledge about the area. These variables include the regional distribution of landforms, geology, meteorology and climate, hydrology, and to some extent human activity. The interaction of these phenomena produce a base to which specific living resources such as vegetation and animal life respond, and upon which natural and deposition, work.

The purpose of the analysis is to partition the region or country into meaningful ecological units—meaningful in the sense that for a particular crop or group of crops, for example cereals, the ecological units thus defined will permit samples of yield data taken randomly from the unit to be truly representative of the entire area of the unit. The stratification will greatly improve both the reliability and cost-effectiveness of all kinds of statistics related to productivity, land use, and natural resources. It also becomes a spatial data base. for the systematic organization of available information about both the natural resources and the dependent society, and it represents a basis for organizing and presenting plans for agricultural programs which are founded on the concept that opportunities and constraints to resource development are usually similar in like ecological regions.

Finally, it provides an improved basis for the development of a total resource policy for setting priorities and scheduling program implementation because it gives decision makers at all levels, both administrative and operational, a perspective of the country or region that simplifies what would otherwise be an overwhelming body of complex detail about the resource and the area.

2. Soils Association *Mapping.* —Aside from the basic essential nutrient value of soils, their most significant role in plant growth equations is the way in which they handle water relative to the root systems of plants and the evaporation demands of the atmosphere. For the purposes of the models, particle-size classes are one of the important groupings. Salinity is also considered, as it is an obvious factor in plant/water relationships. LANDSAT data is valuable in the soils task for two reasons: first, the analysis of the LANDSAT data is an agriculture vs. non-agriculture map. That map is used to determine the soils that are important to agriculture. Most soils maps have no companion overlay which indicates to the analyst that he is looking at farmland.

One can infer that certain types of soil are arable, but from the point of view of partitioning and the production of statistical strata the LANDSAT image pro-

*LANDSAT data is most often used to verify the conditions of vegetation vigor and stress, since the state of the vegetation is calculated daily in plant growth models, and the satellite data is used each 9 days or each 18 days, or even less frequently, to confirm that these vegetation condition do in fact exist. On the other hand, the (a) on both vigor and stress indicates that those two conditions can be detected directly on the LANDSAT imagery.

vides the precise boundaries of the arable land and information about surface soil color patterns which are able to be keyed into the existing soil surveys where they are available; and second, inferences can be drawn relative to the important aspects of the soil in the plant growth models, directly from the LANDSAT data where soil surveys are absent.

3. ***Crop Inventory and*** Monitoring.-The repetitive coverage of the satellite permits one to create, in a temporal sense, an inventory of the crops and an assessment of crop conditions throughout the growing season. The reason that it is necessary to conduct a temporal inventory in agriculture is that at certain times in the growing season it is very difficult to separate the species one from another. This is true for remote sensing systems both aircraft and spacecraft and for some crops (cereals) even true for surface observations. Then, at a specific time during the growing season one crop will become very easy to identify, versus all the others; a separate time a second crop, and at still a separate time, a third crop, and so on, so that it requires the repetitive nature of the satellite to build up a catalog of inventory data. It is expected that, even with the improvement in both spatial and spectral resolution afforded by future satellite systems, this particular approach to inventory would be the one that will always have to be followed.

4. ***Agriculture Land Use Change Detection.—The*** ability of LANDSAT to monitor land use change, especially in agriculture, is an exceedingly important tool. As new lands are opened up and as changes occur from dry land farming to irrigation farming, and as different crop types are introduced into the areas, the repetitive coverage of the satellites permits one to assess change, to introduce that change into the data base, and to correct the statistics essentially in real time.

5. ***Global Agricultural Data Base Compilation and Update.—There*** is no single or multiple source of data on agriculture that is comparable in any respect to the LANDSAT image itself; and if it takes five or more years to compile the LANDSAT data base of global agriculture, the task is well worth the effort. The analysis of that data is quite simple from the point of view of the data base, that is, agriculture versus non-agriculture, and the monitoring of the changes of those boundaries. The data is in digital form; it is also in pictorial form. It is able to be stored in computers. Because each picture element is in fact an X, Y coordinate in latitude and longitude, it is easy to update the data base, picture element by picture element if that is necessary. Critics of the LANDSAT program have historically criticized the spatial resolution capability of the satellite system, stating that the 80mm Ground Resolved Distance is far too coarse for meaningful studies. Without debating that issue in this paper, the point should be made that for use as an agricultural data base on a global basis, 80 meters resolution represents far too much data. Proposals have been made to let the complexity of the land itself determine the spatial character of the data base cell. In actual practice, most of these data bases in computer form have a 1 kilometer to 10 kilometer cell size, and when maps are made from this computer base, it is difficult indeed to tell at a glance that you are looking at data in digital form—which is to say that the map is made up of a series of very tiny squares.

If LANDSAT is used to create this data base, and if this data base is to be in a computer for its ready retrieval and storage capability, a decision will have to be made on how and where LANDSAT data will be aggregated to provide a realistic computer matrix cell size.

1.1.2 Present LANDSAT Deficiencies

In a discussion of deficiencies of the LANDSAT system, it is noted that these deficiencies do not prohibit the use of the satellite in the accomplishment of the task described. However, improvements can be made, and undoubtedly will be made, and for that reason they are enumerated.

1. ***Spatial*** resolution.—The present Ground Resolved Distance (GRD) or Instantaneous Field of View (IFOV) is 80 meters. It is convenient to think of the resolution cell as a square patch on the surface of the earth 80 meters long and 80 meters wide. It happens that this is very close to an acre. Because the cell size is that large, it is difficult and in some cases impossible, to see small fields. Some of the important crop growing areas of the world are long, narrow mountain valleys, and it is not possible to say with confidence that one can differentiate anything other than riparian vegetation versus other classes. In some cases even that is difficult. An improvement in the spatial resolution of the satellite would permit a more accurate delineation of fields of small size and more accurate measurement of fields of all sizes. The present measurement cap-

ability of the satellite is a statistical relationship wherein an array of 3 pixels by 3 pixels is accepted as the smallest field that can be measured. This takes into account the probability that a pixel can fall on the edge of a field and thus be made up of partly that field and partly the adjacent field. Thus for area measurement the data are acceptable only when field sizes are that large (approximately 10 acres) (4 hectares) or larger.

2. ***Spectral resolution.***-LANDSAT operates in four bands, the green, red, and two bands in the infrared portions of the spectrum. They are broad bands, being 100 micrometers wide. The multispectral scanner (MSS) was designed to the state-of-the-art, and because the satellite is operating at the altitude and at the speed at which it does, it is essential that these bands be 100 micrometers broad. That permits the detectors in the instrument to record enough energy, i.e., count enough photons to measure the colors reasonably accurately. On the other hand, this broad band color discriminant makes it difficult to separate some plant species from one another. Research conducted over the past decade in aircraft indicates that if these bands are on the order of 50 micrometers wide as opposed to 100, it would be much easier to discriminate the plants, one from another.

3, ***Temporal resolution.-The*** design of LANDSAT permits it to cover the earth in 18 days. The swath width of the image is 185 kilometers, and if one divides the equator into 185-kilometer pieces, one finds that it takes, 18 days to cover the world at the equator. This is a compromise, and resulted from a decision which was made during the design phase. The trade-off involved the question of whether or not to go for global coverage including the equator, or give up complete coverage in order to give more frequent coverage of just the United States. The decision was made to go for a global system.

The success of the satellite in collecting data at the equator and 10 degrees north and south of the equator, where cloud cover has been sufficiently severe to have caused aircraft data collection missions to have failed has in the opinion of the writer justified that decision made in the early days of the program. A large percent of agricultural production grows in that 20-degree equatorial belt around the world. On the other hand, cloud cover statistics suggest that there is a 50% probability that any given area can be covered by clouds, during the growing season: thus the 18-day coverage of the satellite causes gaps in the data resulting in some areas being covered barely adequately during the growing season (two or three times), and others with data that is altogether unsuitable for analysis for agricultural purposes (less than twice). At the present time there are two LANDSAT satellites in orbit; LANDSAT 2 was launched so that coverage is every nine days. The experience to date in the United States where there has been a regular collection of data on that nine-day interval, indicates that this may be the ideal data collection cycle.

4. Format.-Approximately 10% of LANDSAT data is able to be processed as computer-compatible digital tapes. For the analysis of vegetation there is a requirement for the highest possible radiometric accuracy that is available from the satellite data. This means that in the analysis of agricultural data it is necessary to use the data in digital form. The decision made by NASA which resulted in such a small capability has not proven to be supportive of agricultural applications, and recommendations have been made to NASA to increase this capability considerably.

5. ***Throughput.--The*** present minimum time from the acquisition of data in the United States. of the United States, to the delivery of that data to an investigator is about three weeks. The same minimum time, where the data is to be purchased from the EROS Data Center in Sioux Falls rather than be shipped to the investigator by NASA, is on the order of two months. If you ask for the data to be delivered as a computer-compatible digital tape rather than a set of multispectral photographs, that time period can be as long as four months. The maximum allowable time for the analysis of vegetation, and especially in the experimental phase where field investigations will result from observations made in the data, is 48 hours. The desirable time from acquisition to delivery to the analyst is 24 hours. The throughput is perhaps the most serious deficiency in the present LANDSAT program, and denies to the serious investigator the ability to conduct an experiment in anything like real time. It is in every case an after-the-fact analysis of the data. This has had a serious impact on the experiment program in NASA, and has resulted in a lack of serious agricultural investigations except in a very few cases.

6. l)epcndability. Although dependability is both a technical and administrative matter, the technological deficiencies in-dependability deal almost exclusively with the failure of the tape recorders on LANDSAT 1 and 2. This technology has had a history of failure in the NASA program, and one solution that NASA is currently studying is the use of data relay satellites to dispense with the use of tape recorders in future satellites. This is certainly the only sure solution to this technological problem.

The administrative dependability for the issue results from the fact that there is presently no approved operational program, and this too has a bad impact on agricultural investigators since the start-up time and the cost associated with a serious study of the application of the computer-compatible tapes to the analysis of agricultural data is considerable. The result is that even in the U.S. Department of Agriculture there has been a minimal interest *in* the program and a minimum investment on the part of the Department in this technology. The current effort among NASA, NOAA, and USDA in what is referred to as the Large Area Crop Inventory Experiment (L.ACIE) is the first intensive investigation by USDA into the value of this satellite for major agricultural programs.

1.1.3 ***Current LANDSAT Research and Dcvelopment***

In NASA there are two supporting R&D programs in the LANDSAT area. The first is the Supporting Research and Technology program (SIR&T), and the second is the Advanced Applications Flight Experiment program (AAFE). In these programs there is an orderly progression of development from the theoretical or conceptual stage, through laboratory studies, to a field program of measurements, and finally to a test flight program in aircraft at a variety of altitudes, prior to the decision that feasibility has been established and a space flight program is requested for that technology whether it be a sensor or another element of the satellite hardware.

Research and development is proceeding on a number of fronts that are appropriate to future LANDSAT vehicles.

1. Better ***Spatiul*** Resolution.—There is a Multispectral Scanner development program which has as its goal the production of an instrument for space that will have a 40-meter instantaneous field of view (IFOV). It is possible that this research will lead to an instrument that will have even better resolution than that; the number "30 meters" has been cited in the literature.

2. Better ***Spectral*** Resolution.—The advance in solid state detectors for aircraft and satellite implementation leads to the capability of providing a band width for each spectral band of 60 micrometers, so that in this particular respect it is reaching what should be considered to be an operational goal.

3. ***More Spectral Information.***—The multispectral scanner research referred to in 1 and 2 is in addition looking at the possibility of having one or two additional channels of data added to the LANDSAT C capability. LANDSAT C, or the third satellite in the LANDSAT series, will have a five-channel multispectral scanner as opposed to the four-channel scanner on LANDSAT 1 and 2. In LANDSAT C, the thermal infrared band is to be added which' will provide additional information important to agriculture and will include a night time capability for the satellite. The one or two additional channels to be added in the future will be in the reflective infrared; and when added the instrument will cover all of the infrared spectrum available to a satellite platform in which all the infrared channels are in all the atmospheric windows. This seven channel device will be close to meeting the requirements of the operational system in the visible and infrared portions of the E.M spectrum.

4. ***Better Temporal Resolution.***—It has been stated before that there are two vehicles in orbit now providing nine-day coverage. That is very likely to be the operational requirement. There is evidence of course that additional coverage would be desirable, but if that is to be the case, then it would not be -achieved by adding another polar orbiter, but rather to going to a geosynchronous orbit with a Synchronous Earth Observation Satellite (SEOS)."

If the design characteristics of SEOS do not change, it would provide the capability of viewing any place in the United States on a nearly continuous basis with the same spatial resolution as presently available in LANDSAT I and II.

5. Format.-NASA is upgrading its digital processing capability currently and has plans to go to a full digital processing capability for LANDSAT C. If

all of the other organizational and technical issues were solved, the planned launch date of LANDSAT C could be selected as a good goal for the orderly beginning of a global agricultural information system.

6. ***Throughput.-The*** current NASA/U.S. Department of Interior plans include upgrading the capability of both NASA Goddard and the EROS Data Center to provide LANDSAT telemetry from Fairbanks and Goldstone via communications satellite to Goddard. This is in fact a more cost effective solution to the central collection of conterminous United States coverage from the LANDSAT satellite rather than using the mails to send the tapes. The communications satellite interface between NASA and the Department of Interior is a link between Goddard and Sioux Falls.

The EROS Data Center does plan to reformat the satellite telemetry to any user specification. This includes the packing density on the tape, the organization of the data on the tape so that it is compatible with the current analytical software in most computers and at the same time lends itself to the production of imagery directly from the tape.

1.1.4. Research and Development Deficiencies

The principal deficiency in the research and development program is one of goals. The major thrust in the current program is the LACIE effort. The LACIE effort, however, depends on the success of a very difficult technology task, that is the identification and measurement of wheat. In my opinion, a tremendous benefit is technologically possible in the implementation of an agricultural information system without requiring the technology to solve the species identification problems at the outset. It is clearly possible to provide, as has been indicated, a global agricultural data base in pictorial form, and then to proceed with a research program, namely the identification and measurement of the important food crops. The implementation decision should not be based on achieving that particular goal before going operational. There is much that can be done in terms of monitoring the vigor of vegetation, and much that can be done in terms of partitioning the crops into plant communities without having to determine the species composition within the community. The Department of Agriculture and the Food and Agricultural Organization of the United Nations has for years worked with statistical probability and accepted the errors associated with it. In my opinion, the contribution that LANDSAT data can make to the existing statistical methods is sufficiently important and cost effective to justify its employment immediately.

1.2 METSATS

The evaluation of this technology differs from the previous section on LANDSAT in that the satellites that have been used thus far in the agricultural research program have been the operational satellites. They are the NOAA 3 and 4 satellites of the Department of Commerce and the DAPP satellites of the Department of Defense. Both systems provide visible and thermal infrared pictures every twelve hours, thus providing data day and night. However, the DAPP satellite system has two vehicles in orbit thus giving the data each six hours. The analysis of the photography is used in the agricultural research program for precipitation mapping as an input to the agrometeorological models that deal with plant growth and yield. The precipitation analysis is based on the identification of cloud type and cloud brightness and the cloud field analysis is used to draw a map of the spatial distribution of rain. In some cases where ground observing stations are not available to the analyst, he must in addition to drawing a rainfall map, add to that map the amount of precipitation that he estimates is falling from that cloud system, The meteorological data which are applicable to crop forecasting are:

1. Precipitation,
2. Maximum and minimum temperatures,
3. Wind,
4. Relative humidity,
5. Cloud cover.

These data are used to develop transformations that relate to plant growth and yield, these parameter are:

1. net radiation,
2. potential evapotranspiration (ETP),
3. precipitation,
4. degree days,
5. day length.

Evapotranspiration (ETP) and precipitation are used together with soil and vegetation data to calculate soil moisture. The soil moisture data can be used to assess moisture stress in the plant. Degree days assist in determining the phonological age of the plant. The two together (moisture stress and age) permit the assessment of the significance of the moisture stress in terms of yield.

Net radiation (RNET) is the net energy gained by the ground through the processes of insulation find terrestrial radiation losses to space. RNET is a measure of how energy is available for photosynthesis for heating the ground and most importantly, for evaporation. RNET shows a pronounced annual cycle with the highest values in the summer when the days are longest and the sun is highest above the horizon, and lowest values in the winter when the sun is lowest. Cloudiness also has an effect on RNET since it depletes both the incoming solar radiation and the outgoing terrestrial radiation. In addition, there are in the calculations coefficients which account for atmospheric transmission, latitude, longitude and time of day. An important parameter is cloud type which affects that portion of the long wave radiation that is lost to space. Frequently the climatological records do not contain the information necessary to determine the effects of clouds not only on the long wave terrestrial radiation, but also the incoming solar radiation. A method has been developed which uses satellite cloud information and is considered a major innovation in the models.

The form of the precipitation equation is:

$$P_{sat}=k_0+k_1Cb+k_2Cc+k_3Ns+k_4St+k_5B1+k_6B2$$

where ***P., t is*** the satellite rainfall estimate; Cb, Cc, Ns, St are the percentages of cumulonimbus, cumuluscongestus, nimbostratus, and stratus cloud types measured from the visible satellite images; B1 and B2 are percentages of brightest and bright cloud cover occurrences in the infrared images, k. , . . . k6, are regression constants. For the agromet cells that do not have surface meteorological observing station precipitation reports, the final estimate of precipitation is calculated by a combination of the satellite estimate P_{sat} and the ground estimate Pg. The ground estimate is obtained from the precipitation measured at the surface synoptic station assigned to that cell. The "cell" refers to our data base which is a map of the crop producing areas of the world divided into 50 or 25 or 12.5 nautical miles squares, depending on the precision desired in the production statistics.

1,2.1 Metsat ***Deficiencies***

In considering deficiencies in the Metsat data, it is important to note that we are dealing with operational systems designed to acquire operational data to meet the needs of the organizational entities that are responsible for their design and their employment. So to he critical of the deficiencies of that system when used for an entirely different purpose from which it was designed is somewhat unfair. Nonetheless, the use of the data for agricultural information purposes would be better served if there was a storage and retrieval system which would store and from which could be retrieved full resolution data and similarly if the data was in digital form, that would he preferable.

The problem is not that the data is not currently available in digital form and at full resolution in terms of its use in day to day modeling. .411 of that is possible providing an approved interface is established between NOAA, NESS in Suitland and the user. However, an important element in the preparation of the' agricultural information data is the historical analysis of climate and the value that can be derived in terms of establishing agricultural production trends in the context of climatological trends. It is exceedingly difficult to perform a rigorous analysis of the climatology of an area ***on*** the basis of the records, if any, that are kept currently by many national governments. .4 much more useful study can be made by using the satellite data in conjunction with whatever national data is available.

1.2.2 Metsat Research and Developement

In the field of the development of new meteorological satellites. the ***advent*** of global synchronous meteorological satellites similar to the United States Geosynchronous Orbiting Evironmental Satellite (GOES) will provide synoptic data over the whole world of agriculture with the possibility of monitoring cloud cover from pictures sent each 20 minutes, 24 *hours* a day from such satellites. The analysis of the contribution of the synchronous satellite to the crop production models is currently under study. The polar orbiting satellites, DAPP, and the NOAA 8 and 4 vehicles have provided the information that has been principally used in the work that has been done to date. The next generation of operational weather satellites, the TIROS series, will provide both better spatial resolution but equally important, the data will be fully digital and calibrated so that the utility to precipitation mapping and radiation mapping will be enhanced.

In the field of instrument development there is in the NIMBUS program a microwave sensor development program. This affords direct information on precipitation from clouds, however for the present these analyses are only successful over the oceans and not over the land. Some success has been noted where the topographic influence on the microwave return is minimal. On gently rolling plains the data are more interpretable than where the topography is rough. The most important single microwave measurement that can be made which will contribute to an agricultural information system is that of soil moisture.

There is, in the supporting research and technology program in NASA, a vigorous effort underway at this time to develop a microwave system that will provide direct soil moisture measurements at a variety of depths. At this point and time, it seems feasible to expect that we will be able to make soil moisture measurements to depths of about 5 centimeters. Additional research will be necessary to go below this depth but 5 cms is a very important achievement. The current soil moisture models do project soil moisture estimates to various depths which in theory match the root zones of plants at various ages. On the other hand, the rooting systems of plants are not well known in all types of soils and under all kinds of conditions at various ages. If the research is successful in producing an instrument which can measure soil moisture accurately and directly to a depth of 5 centimeters, we will have a measurement that is more accurate than much of the data in the rest of the model and would certainly support the crop growth and yield models in an early operational agricultural information system.

1.3 DATASATS

This particular technology although not really an R&D activity on the part of the Federal Government does have elements in it that have significance to an operational agricultural information system and which essentially have not been tested. There are three principal systems involved that can be grouped under the term DATASATS. The most common, in terms of awareness by the general public, are the COMSAT/INTELSAT Communication Satellites which are in use and have been in use for a number of years. A more current and important from the point of the view of United States agriculture system is the DOMSAT series which provide the United States with a domestic communication system with sufficiently wide bandwidth to transmit television pictures in color. The principal use, aside from watching international events such as the Olympics on a nearly worldwide basis, for the INTELSAT/COMSAT type of communication system, has been in international telephone traffic largely replacing the transatlantic cables. The status of communication satellites is that the administration has determined that they are operational and NASA is no longer conducting research and development on these particular systems. There, is, however, a development activity which will produce a communication system that is important for the future of the information system we are discussing. This is a wideband satellite to satellite telemetry system. For example, LANDSAT imagery acquired over Europe could be transmitted directly via communication satellites of this type to any receiving station in the United States that was equipped to handle that particular communication link.

The most significant point in discussing the data relay satellite is that a country, for example Germany, could build a ground receiving station for LANDSAT. The satellite could be transmitting pictures to the station of the entire area under the range of that ground receiving station (approximately a 3000 km radius) and at the same time be transmitting that very same data back to the United States or to an international station which might be given the responsibility and authority for the operation of the global agricultural information system. It does away with the single most perplexing technological problem in current satellites, that being the tape recorders with their attendant failures. It should be noted that applying the same scenario to the INTELSAT network, that German ground receiving station could receive the satellite telemetry from a LANDSAT satellite and via a colocated INTELSAT station retransmit that data anywhere in the world that has an INTELSAT receiving station. This scenario however requires cooperation on the part of all ground receiving stations in the world so that the global data is available to either the United States or to an international body that will conduct the agricultural information system.

Almost unknown to the general public is the capability of the earth observing satellites such as LANDSAT and METSATS including GOES to provide a telemetry channel for the transmission of data. This particular capability is not conventional in the sense that people use it for a voice grade lines, rather ground base instruments such as stream gauges, rain gauges, thermometers, thermistors, micrometeorological stations including anemometers and barometers, wet bulb thermometers, etc., have been instrumented in a way that permits the data to be recorded in electrical form, digitized and multiplexed and then sent from that particular platform location to LANDSAT or GOES and then from the vehicle, which merely acts as a repeater, the data is retransmitted back to a central location in the United States. The Suitland facility of NOAA is the receiver of the GOES data and in the case of LANDSAT the Goddard station is the receiver. Currently other stations in the world including some of the unified S-band NasCom stations are able to read out the LANDSAT system which is referred to as the Data Collection System (DCS). The bandwidth is relatively modest, about the same order as the housekeeping telemetry. The information that is transmitted over this net is exceedingly important from the point of view of its compatibility with a potential operational agricultural system. It is possible for example to equip all of the synoptic weather stations of the world with the kind of telemetry that is now available to the LANDSAT satellites, which incidentally is itself compatible with the telemetry systems on GOES. A single platform can either transmit to LANDSAT or to GOES. It is possible to take all these measurements from everywhere in the agricultural world using LA4NDSAT and retransmit these data to a sufficient number of ground stations so that global acquisition of surface meteorological data is possible. It is a rather unwieldy system at present, simply because so many ground stations are involved and so much repeating of the data would have to occur to assemble it in one place. In the near future when the European, Japanese and Russian versions of the GOES satellite are placed into their respective orbits, we will have a global capability with just four satellites and four centers. However, it will still be necessary to retransmit this data to a central location for processing,

One conceivable organizational entity which might evolve is that regional agricultural data processing centers would be located in association with the U. S., European, Japanese and Soviet satellites. It is not necessary that the station be located in any one of those sponsoring nations but merely within line of sight of the satellite. In the case of geosynchronous satellite this is a very large footprint indeed.

In summary then, there has been a good deal of work particularly in the LANDSAT experiments on the transmission of data that is important in support of agricultural information system models. None of these data have been transmitted in anything like an operational mode, but the experiments have been successful. In conjunction with that is the current availability of INTELSAT facilities which have an extensive worldwide capability. In addition a global geosynchronous capability will exist sometime between now and 1980. This will afford a complete capability for the global acquisition and transmission of data that is supportive and important to the agricultural information system.

In my opinion, no additional technological development is required. The most important single event will occur when data relay satellites are launched and placed in orbit so that the imaging satellites can dispense with tape recorders. It will be possible to go from the surface to satellites to satellite to a single location on the ground where a global agricultural information system can operate.

1.4 Surface Observations and Measurements

There are a number of collateral data sources that are important to the operation of a system which is interested in agricultural production on a realtime basis. These are somewhat non-numerical in nature in that they deal with the collection of data from current agricultural research reports, the publication of agricultural statistics by national governments, the summation and publication of similar statistics by international organizations like the Food and Agriculture Organization of the United Nations and finally the contributions that can come in from agribusiness if they choose to cooperate in the operation of such a system.

'The problem that has been cited by both the Department of Agriculture and by FAO is that with the exception of a very, very small number of countries, the data are either inaccurate or incomplete or not received in time. At least two out of the three problem areas are associated with almost all of the countries in the world. Timeliness is an issue everywhere and in fact timeliness is one of the strong motivating factors behind the current LACIE research and development program of the NASA/NOAA/USDA team. We need more timely data and we need it almost on a continuum throughout the growing season in order to have the information necessary to make policy decisions. International statistical organizations are really victims of national governments in that all they can really do is publish whatever is provided for them by the national governments.

If no information is provided by any particular national government, very rudimentary estimates are made by professionals on the staff of that organization. Agribusiness finds the current accuracy and availability of statistical data on agriculture so wanting that they have had to create a staff of employ- in the important countries where they do business; there to provide them with their own estimates of production so that they can manage their own transportation, warehousing, sales, etc. In the past three years, our dealings with the Soviet Union have forced us to look at the accuracy, timeliness and completeness of Agricultural statistics with the same degree of urgency and need that has always been the case in the industrial side of agriculture.

2.0 *Data Processing*

Data processing is set out separately because of the impact that this particular technology has, not only on cost and schedule, but also because of its impact on the user, It covers that part of the technology that deals with manipulation of the satellite data in preparation for delivery of a product to the user whether that be a government agency like the Department of Agriculture or an individual experiment investigator. The two principal products out of the processing line are pictures and computer compatible tapes. The scheme that has been developed by NASA for preparing the data, that is converting the satellite telemetry from a high density digital telemetry tape to a picture or to a computer compatible tape. involves a number of steps. In the case of the picture, the digital data goes through a computer where it is corrected for geometry distortions, referred to as system corrections, in which the effect of the rotation of the earth under the satellite is corrected. There is an additional correction possible using the attitude sensor on the satellite. The attitude of the satellite relative to true vertical is calculated and those corrections can also be made in the scene. In addition to geometry there Is a radiometric correction made. This is necessitated by the fact that the detectors in the sensor do degrade with time. One or more can fail, thus it is necessary to check the calibration frequently and make the radiometric corrections as required.

The computer compatible tape on the other hand is neither geometrically nor radiometrically corrected. The data is merely reformatted from high density digital tape (20,000 bits per inch) to computer compatible tape (conventionally 800 bits per inch.) It is the responsibility of the investigator to make the geometric and radiometric corrections necessary in the tape.

2.1 Deficiencies

The principal complaint on the part of the users of LANDSAT-1 data was the selected scale of the imagery. The high density digital tape was used to drive an instrument called an electron beam recorder which wrote an image line by line at a scale of approximately 1:3,000,000. That particular scale is so small that essentially none of the users of the data had experience at working at that scale. The ground data processing facility also produced an image at a scale of 1 :1,000,000 which was derived from a photographic enlargement of the original 70 mm scene written on 230 mm (9 inch) format, This product was acceptable for a few applications, principally studies that involved regional geology or studies that involved the mosaicking of a large number of LANDSAT frames. Where very large regional geologic structures were the subject of investigation, then the scale of 1:1,000,000 and the mosaicking of that format proved to be a very appropriate tool. However in almost no other case was the 1 :1,000,000 scale useful, The original 70 mm material was merely treated as a file copy for use in the photographic laboratory and either NASA produced the imagery at 1:1,000.000 or the user did with his own enlarger. However, where the user required larger scales, including scales of 1:250,000 or greater, the investigators that were most successful were those who made the 1:250,000 scale enlargements from the NASA product which reached them at a scale of 1:1,000,000. This is a simple 4X enlargement and does not require an expensive ($5,000) enlarger lens. The 4X enlargement was made from nine inch film which is standard aerial photographic format. There were fortunately many users that were able to bring this rather simple technology to bear on the problem of processing the data into a format useful for analysis.

The other problem in the pictures proved to be that of contrast. The photographic rendition in every case contained 100% of the grey scale information that was available on the satellite telemetry tape. On the other hand, that information was frequently biased at one end of the grey scale spectrum or the other and the material sent to the field was practically unusable. A good example is to consider the reflectance that one would expect to get from the desert during mid-summer where sun angle is highest. The return is very, very bright. This produces a very, very dark negative and indeed the "dark negatives" from the NASA ground data handling system created a very difficult problem for many investigators during the first summer of the data gathering mission of LANDSAT-1.

In the case of the computer compatible tapes, the principal deficiency is that of format. Prior to a recent decision by NASA to change the format, a LANDSAT *scene* covering an area *on* the surface of 185 X 185 kilometers was sent *on* four tapes. The format was a 25 mile strip of band 1, 25 mile strip of band 2, a 25 mile strip of band 3, and a 25 mile strip of band 4 each on a separate tape. The 25 mile strips put together made a 100 nautical miles which is the equivalent of 185 kilometers. That kind of format is useful for a certain analytical procedure and perhaps those people who are interested in a small portion of the scene who defend the decision to go with 25 mile strips, but Murphy's law would almost guarantee that the area of interest would be on the extreme edge of two tapes rather than being in the center of one 25 mile swath. Tape density was principally 800 bits per inch whereas 1600 bits per inch is a more cost effective format. The current decision of NASA will change to 1600 bits per inch. The decision also affects format and the combination of changing to 1600 bits per inch and changing the format will permit NASA to record ***all of a*** LANDSAT scene on ***one*** computer compatible tape.

2.2 *Rcscarch and Development*

There are some important R&D tasks underway that have exceedingly useful implications for the subject of an operational agricultural system. In the first **place,** from the point of view of pictures, NASA is planning to go from the electron beam recorder to the laser beam recorder. That will mean that the recording device can have the capability of accepting data from the next generation of multispectral scanners. These have 30 to 40 meter spatial resolution and seven channels of data as opposed to LANDSAT with 80 **meter** resolution with just four channels. In addition the device can be implemented to record in color as opposed to black and white which is all that is presently available.

However, the most important attribute of the Laser Beam Recorder is that it has been implemented to write on the large format, that is the 1:1,000,000 scale format. In analysis done of the information content of LANDSAT 1 indicates that if the original image is written at a scale of 1:1,000,000, and if further enlargement is done photographically with reasonably high quality photographic leases, with careful processing of the data, that all of the resolution of LANDSAT will be equally available to the photographic interpreter as is now only available to the analyst who uses computers to aid him in the presentation of the data. This means that the principal Complaint of the users, that being the very small scale of the image, will be solved in the very near future. In the digital field, the research and development is equally encouraging. NASA is acquiring a facility which will employ the very latest hardware and software as sort of a model for the users and available to the users for the interpretation of data. Although this facility is in fact an analytical facility, there will be an opportunity to employ the best and latest software and hardware in the processing stage as well as the analytic stage. Both NASA and the users can take advantage of the facility.

2..? Issues

The principal issue facing the community of LANDSAT users between now and the time when an operational decision will be made is the one of the definition of the role of the satellite. Is it proper to perform quasi-operational or even operational tasks with a so-called experimental vehicle? For many of us, the experiment phase of the program was finished when NASA demonstrated that LANDSAT 1 worked successfully in orbit. The satellite provided color-infrared imagery of the earth. The supporting research and technology program had for the previous five years demonstrated the value of color-infrared imagery of the earth, and the experiments performed during that phase concerned themselves principally with operational activities of the Federal Government in the three departments that were the principal interface with NASA, the Department of the Interior, the Department of Agriculture, and the Department of Commerce. Thus the issue of format and through-put is a very real issue and always has been. It may on the one hand be correct to avoid spending the money necessary to achieve what amounts to an operational interface between NASA and the users during an "experimental" program. The impact of that decision, however, was very negative on a whole body of investigators whose application, by the very nature of it, required a very fast turnaround time between acquisition and delivery of data in an immediately useable form.

A second question is related to how far NASA should go in providing rather sophisticated processing of the data for the group of users that are the general interface in this program. For example, any data that is going to be delivered to users in pictorial form can go through a number of preprocessing steps. Each of these has an impact on the quality of the data, and each of them is characterized by the fact that the more sophisticated the processing step the less sophisticated the user needs to be in the analysis phase. It is very nearly axiomatic that there is an inverse relationship between the skill of the user and the degree of complexity required on the part of NASA in the processing stage.

A few examples can illustrate the problem. In addition to the geometry correction for the earth's rotation which is called a deskew algorithm, and the system correction of the radiometry, the image could very well be squared so that it approaches a map-like quality before that data is delivered to the user. He then can fit this image to a map of some specified scale without having to go through any further steps.

Secondly, there is the issue of black negatives discussed previously. The images can be equalized so that there is a balance between the two ends of the gray scale spectrum and instead of having a black negative the investigator gets a negative with very high contrast. In cases where the gray scale content of the scene is less than the dynamic range of the film, the scene can be stretched so that even very subtle shades of gray are discernible to the photographic interpreter.

Third, certain image enhancement algorithms can be performed on the data. One such algorithm enhances edges and is very useful from the point of view of the agricultural scientist because linear features, such as field boundaries, roads, etc., are enhanced, and this increases the interpretability of the data considerably.

Fourth, it is possible to enlarge the data in the computer so that the delivered image can be played on an image recorder having been enlarged digitally. There is no photographic step between the acquisition of the data on high-density digital telemetry tape, and delivery to the user of a scene as large as 1:100,000. The resulting picture made from such a tape is extremely useable to any investigator, since there is no loss in image quality when the processing is done in the computer.

If desirable and necessary, a team could be made up of agriculturalists, hydrologists, geologists, soil scientists, and the like, each of whom would specify from among the library of programs what the final format should be for each scene that is going to be analyzed by one of his fellow disciplinarians. A processing recipe book could be prepared for pictorial presentations of the LANDSAT data for each of the resource areas.

Finally is the issue of budgets. Perhaps the most serious issue with respect to responsibilities and where those responsibilities cease, is related to the budget. If for example the Department of Interior budget is the source of let's say analytical hardware for the program and that budget is cut, then the entire earth resources survey program suffers. and not just the Department of Interior program. Similarly, if the Department of Agriculture budget is cut. it affects not just the Department of Agriculture, but practically all vegetation-related studies. NASA has been fortunate in that the designation of the program as "experimental" has had the advantage of permitting NASA a very wide flexibility in terms of devoting resources to the further development of applications which might on the face of it be purely the province of the Department of

Agriculture, or purely the province of the Department of the Interior. For a number of years now there has been a mechanism for the previous review and submission of 'a joint budget. The Administration formed a committee which coordinated the entire R&D program; they follow the conduct of the research and development; they approve program content and they approve budgets. The Office of Management and Budget has cooperated to the extent that the agency examiners have worked together on the program as an entity. The General Accounting Office has in fact stated that the Earth Resources Survey Program was a model of how an inter-agency research and development program should be conducted, The principal problem related to the project has resided in the fate of those budgets in the Congress. It is not the purpose of this paper to discuss the legislative history of this program, but it is possible for the Office of Technology Assessment to review the inter-agency documentation including the budget material since the inception of the inter-agency committee responsible for the program, and then to compare that with the fate of the budget, department by department, over the past several years. The impact of these budgetary problems has been diffcult and it is in fact a credit to the program managers that the program enjoys the maturity that it does today.

3.0 *Data Analysis*

This section can be thought of as **being** in three parts. First there are the analytical methods, using only man. These are classical photointerpretation techniques, somewhat modified because of the synoptic view of the data. The conventional aerial photograph is usually acquired at a contact scale of 1:200,000, although there are lots of newer materials at scales of 1:100,000 and smaller from high altitude aircraft. The scale of the original LANDSAT material provided by NASA is as stated before, 1:3 million, and much of it provided at a scale of 1:1 million. ***One*** of the most important findings of the extensive experiments that were done with LANDSAT concerning the productivity of the photointerpreters to get a job done is that for agricultural analysis. It was not unusual to find that the interpretation was able to be done 20 times faster on the LANDSAT imagery. This is not due to any other intrinsic value of LANDSAT beyond the fact that it provides a single image on which to work as opposed to the hundreds of images which would be required to make up a scene as large as the LANDSAT scenes strictly from aerial photography at almost any acquisition scale. For example, at a contact scale of 1:20,000, it takes more than 6,500 conventional air photos to make a single LANDSAT scene.

The second analysis method is completely automatic. There are a number of computers that have had LANDSAT analysis performed on them. Among them are IBM, UNIVAC, CDC, HONEYWELL, Digital Equipment Company, Hewlett-Packard, XEROX, and finally one of the largest computers the United States government has ever built, ILLIAC--IV. This machine is in the custody of NASA, and is at the Ames Research Center in Mountain View, California where it is shared with the Lawrence Radiation Laboratory as a national facility. Some rather interesting capability studies have been done concerning the ability of ILLIAC-IV to provide the operational support for an operational LANDSAT system. Because ILLIAC-IV has a storage capacity of 1 trillion bits, it is possible to store the United States in multispectral form, at full resolution, in the machine, and to perform analytical tasks on the country as a whole. Thus a national data base would be able to be updated, used, analyzed, measured, etc. in essentially real time.

The third and last method is the combination of the first two: a man/machine mode, The concept behind this technique is that one should really let man do what man does best, and let the machines do what they do best. After some 10 years of working this problem, it is possible now to state what those parameters are. Man recognizes shape and integrates a scene, coming to a spatial conclusion about that scene almost infinitely faster than a computer. On the other hand, man is a very ***poor*** judge of color. Man% eyes are logarithmic sensors, which means that it takes a 10% change in reflectance before man notices that color has changed. Consider the accuracy of the radiometer that is on the very first LANDSAT vehicle. The sensitivity of the multispectral scanner is 3%. Expressed another way, the MSS is 3 times better 'than man's eyes and with the potential to grow much more sensitive than that. The machine does the color analysis, and separates things on the basis of color, man does the spatial analysis and separates things on the basis of shape.

In terms of available equipment some of the universities have participated in the development of this man/machine interface concept. A principal university charged with this responsibility from the point, of view of hardware development was the University of Michigan, specifically the Environmental Research Institute of Michigan, formerly Willow Run Laboratories of the University, of Michigan. There has been industry support; the Bendix Corporation and the, General Electric Corporation have produced off-the-shelf analytical man/machine hardware devices. These are starting to be used. There have been sales, in this country for sales in Europe, and they are extremely useful machines, most. of them built on. the same principle, slightly different in terms of complexity and what each machine can do. Nonetheless, both are candidates for any operational decision for the analysis of LANDSAT data in an agricultural information system.

3.1 Data Analysis Deficiencies

The deficiencies in data analysis stem largely from the small' support that has been able to be afforded in the program. LANDSAT is a digital data gathering machine. It follows that most of the serious investigations should have been at least man/machine-oriented, or even totally machine-oriented. However, a review of the some 300 experiments on LANDSAT indicates that relatively few were supported by proper digital equipment. The supporting research and technology program, however, has created a few university centers of excellence. Purdue University and the University of Michigan are two of those, and most of the work that has been done in the digital data analysis has been done by those two organizations, The work that has been done gives us confidence that given the proper technical approach to the problem it is feasible to set up a system which employs both men and machines to perform an agricultural task on a global basis.

3.2 *Research and Development*

The principal R&D in the field of data analysis today is in the further exploitation of the man/machine concept and as a refinement, a serious look at the issue of analog versus digital analytical techniques. Some investigators feel that the state of research and development in the digital computer field is so dynamic that it is not wise to spend a great deal of money on analog techniques in the Earth Resources Survey field. In principle, the analog device is exceedingly fast, but it is fairly inflexible, and it is somewhat destructive of data. This is exemplified by the fact that playing an analog tape over and over again does indeed destroy some of the voltage records on that tape; whereas the repetitive playing of a digital tape does not destroy the numbers, although there is an error rate associated with all digital tapes and tape recorders. On the other hand, there is the issue of a tremendous data volume generated by a multispectral instrument ***in*** space, especially ***on*** the global scale, and a desire on almost everyone's part to perform the analytical function as fast as possible. Aside from the magnitude of the data, there is the realization that the satellite is going to repeat its orbit in 18 days and that is a very short time indeed, to complete the analysis of that data. This is further complicated by the fact that if there are two satellites then we have twice as much work to do. Therefore, there is a serious look at what is known as a hybrid device where certain tasks are done in analog fashion and certain done in digital fashion. The other school of thought holds that digital devices are becoming so fast and so cheap that one should not invest in hardwired analog devices.

The Italian ground station for LANDSAT has two programmable digital microprocessors which can reformat the satellite telemetry in real time and can present the data in a format that permits the ground station to either go to a photographic line for reproduction or go right into their analytical line for analysis. It is not necessary there to create computer-compatible tapes although the station is designed to do that for other users. This digital device, the programmable microprocessor, is sufficiently fast that the high-density digital tape is subjected to a series of complicated arithmetic steps in real time.

These devices permitted the Zaire ground station design to employ a two-shift mode of operation wherein the first shift uses the system to produce photography and computer-compatible tapes for the customers within the footprint of that ground station, and the second shift uses the identical equipment to produce analytical type products including the analysis of data in digital form, and the production of analyzed photographs in which objects in the scene can be color coded. This concept is most cost-effective for a country like Zaire or any similar regional ground station.

These new concepts are solely the result of this new very fast, very flexible, programmable digital device.

3.3 *Issues*

The principal issue in data analysis is organizational, and this is related to cost. It is possible, for example, to design a central data processing facility; if you will, another Sioux Falls EROS Data Center, this one, however, being de. signed specifically for the analysis of agricultural data. It is equally possible to design a central processing station with regional analytical centers. These analytical centers can be of two types. One type could be where the orientation is geographic, and the center would be located in the geographic area for which it was responsible. The second orientation could be subject matter, wherein all of the crops would be clone at one regional center, all of the range and forestry studies done at another center, and all of the maps made in still a third center. It is true that cost savings can be accrued by centralization, especially with systems like LANDSAT and METSAT. One has to determine whether or not the input to a regional analysis center is in fact repetitious for the data processing center or whether each is different in nature. Put another way, do the specialized thematic analyses require the very same data regardless of their task? If they do then that argues well for centralized data processing ***and*** analysis centers where you have one machine doing processing and feeding a number of stations wherein the special studies are conducted.

The analysis work done to date tends to further support the centralized facility. The activity at Purdue University is typical of the success of putting together a complex, multi-disciplinary group of people who came from a variety of backgrounds; from mathematics, statistics, physics, computer sciences, agronomy, soils, forestry, range, meteorology, hydrology, etc.

These scientists came together under one roof. The organizational entity was not merely a paper chart, but a real physical plant where they were separated from their otherwise parent institutions and where they learned ***over a period*** of time to work together. The synergism that resulted from that decision was real and mensurable. The programs achieved in a very short time by the Laboratory for the Application of Remote Sensing at Purdue was sufficiently important that NASA recognized Purdue as a center of excellence in the field of digital data processing.

If the Congress undertakes, or if the Congress directs the Department of Agriculture to undertake, this global food information system, I recommend strongly that a centralized data processing and analysis facility be created for the staff that will operate it. The author undertook to do an analysis of a similar situation for the Food and Agricultural Organization of the United Nations. It was recommended that the data processing and analysis group become a self-contained, separate entity in FAO. In an operational unit, such as the one designed, that cuts across organization lines, it is useful and certainly desirable for the unit to have autonomy for at least two reasons: First, the contributing parent organizations can and will make demands on the time of their personnel assigned to such a job; and secondly, the value of some of the by-products, such as the ecozone maps, may create a demand for that product which will interfere with the larger task which is the creation of an agricultural information system. A functional organization chart of the data processing and analysis unit is included as Figure 2.

AGRICULTURAL INFORMATION SYSTEM
FUNCTIONAL ORGANIZATION

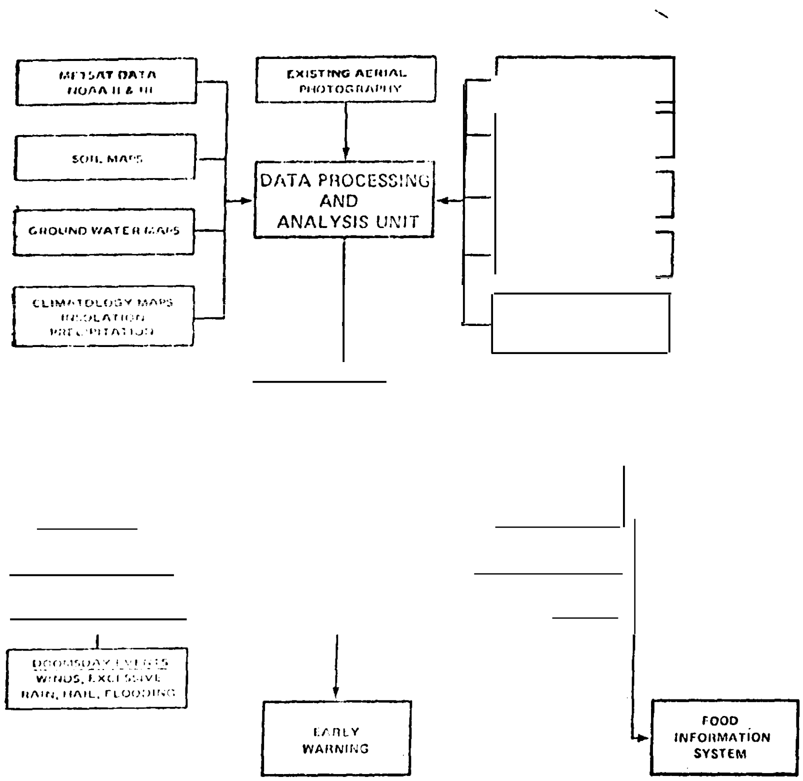


FIGURE 2

4.0 Models

There are three types of models currently employed in the development phases of the earth resources survey program that are applicable to agricultural information. These are 1) science models, 2) management models, and 3) economic models. It is correct to consider that 1 and 2 together constitute the basis of an economic model, except that the science and management models need not have the economic multipliers. For the purpose of this paper, two science models related to agriculture and one management model related to agriculture will be used.

4.1 Crop Production

The classical approach to the statistical reporting of crop production involves the design of a sampling system which considers the total population of the crop or crops involved, and draws statistically valid samples on a geographic basis with a frequency that is appropriate to the phenology of these crops. In countries where the agricultural statistical services are considered to be well conceived and operated, the selection of the location of the sample areas is done on a random basis within an ecologically defined "crop reporting district," as is the case in the United States. However, the classical statistical approach does not make any use of agro-meteorological data except as the sample data manifests the plant environment into actions expressed as changes in estimates of yield from one sample period to the next. The basic limitation of this statistical approach is in the inherent impossibility of timely predictions, particularly early in the growing season.

The sample only provides estimates that reflect what has occurred in the plant from planting to sample time. If the plant moisture and heat conditions remain optimum until harvest, good estimates are possible. It is important to point out that the "excellent" accuracies attributed to currently accepted methods are all based on sample data collected during the period just prior to harvest. In the case of the agro-meteorological approach, the primary advantage is timeliness. The diagnosis of the plant environment interaction provides daily estimates of yield changes. The application of reasonable skills in short-range forecasts (seasonal or yearly) permit the projection of the evaluated data on daily yield changes to the end of the growing season. One's confidence in the projection grows each day, and one can project that confidence with the same rational expectancy without mounting the vast manpower that would be required for daily ground sampling. The agro-meteorological approach to crop forecasting has been used in limited regions of the world for many years. In recent years the Canadians have applied agro-meteorological approaches to wheat forecasting with excellent results. These results reflect the fact that given accurate meteorological data and plant stress, wheat is well enough understood physiologically to permit yield predictions for large areas in spite of the within-field and field-to-field yield variability that is inherent in ground sampling. A block diagram of the production ***model is*** Figure 3. The model is based on the simple equation Yield X Hectares= Production. The yield modifiers, including water, soils, thermal units, and photoperiod, are all numerical inputs from the LANDSAT and METSAT data in combination with data from the World Meteorological Organization synoptic weather stations.

Hectares are modified by water and physiography, both derivable from LANDSAT data. All of the other modifiers, both to Yield and to Hectares at this point in time, are derived from the judgment of professionals in the various fields. Principally, these inputs are used to weight production, and are provided by the expert opinion of scientists which must determine, in their best professional judgment, the influence of plant pests and genetics as modified by agricultural practices, and the amount of agricultural technology that is in use and its effect, and finally the policy of the national government and the impact of that policy on production.

CROP PRODUCTION MODEL

FIGURE 3

Some technological innovations can have results on both sides of the equation. Irrigation is a good case in point. New land brought into production because of irrigation adds to the Hectares side of the equation, whereas there is expected increase in Yield when irrigation is applied to presently cultivated land. When all agricultural land is brought under irrigation, any new dry farmland is usually located on the poorer soils remaining, particularly in those countries where good agricultural land is scarce. It is recognized that basic data on this subject is extremely poor in nearly every country where it ***is*** obvious that irrigation is important. It is another instance best where it is fairly easy to make parametric statements about technology whereas it is frequently difficult to get accurate cause and effect statistics.

4.2 Plant Pests

There are several aspects of the approach to plant pests (insects and disease) control and eradication that lend themselves to the use of modern remote sensing and surface observation and measurement. While it is not possible to inventory the pests themselves, i.e., insects, bacteria, viruses, fungi; .it is possible to inventory the host plants using remote sensing, and in addition, it is t're-quently possible to detect the effect of the pest on the plant using this new technology. Similarly, while it is not possible to remotely detect the emergence of an insect or the onset of the spread of disease, for example a spore shower, it is possible to monitor the environment and in particular those factors that control these phenomena; temperature, moisture, number of daylight hours, etc. Algorithms . have been developed which can merge these alphanumeric environmental parameters, with satellite information, with a spatial precision equal to the resolution of the imagery itself. This permits surface point measurements from in situ sensors, for example, hygrometers, thermistors, etc., to be generalized over very large areas of the image. The conventional approach to the generalization of a point measurement between collecting stations, for example soil moisture, is to treat it as a continuum between stations, or as a gradient between stations depending on whether the values at the stations are the same or different. Neither is necessarily correct. The acquisition of full resolution meteorological satellite digital tapes permits one to map rainfall distribution accurately using the surface meteorological station reports as control. Even in the absence of ground stations, qualitative maps can be made.

In addition to image processing and image correlation algorithms, software has been developed to combine plant growth (phenology) models with predictive climatological, equations into an agro-climatology model, admirably suited to plant insect and, disease modeling and forecasting. Modeling implies numerical equations expressing the reaction of the vegetation to energy as either direct (solar) or converted (nutrient). It is. necessary to consider the total plant environment. Plant growth models are reasonably well advanced and for some species have progressed to the point where simulation algorithms are very accurate, reacting precisely to a variety of environmental pressures both supportive and subtractive towards plant growth and the yield of harvestable material.

Figure 4 represents the structural diagram of the plant pest model and is a classical epidemiological model used for disease processes in plants and animals

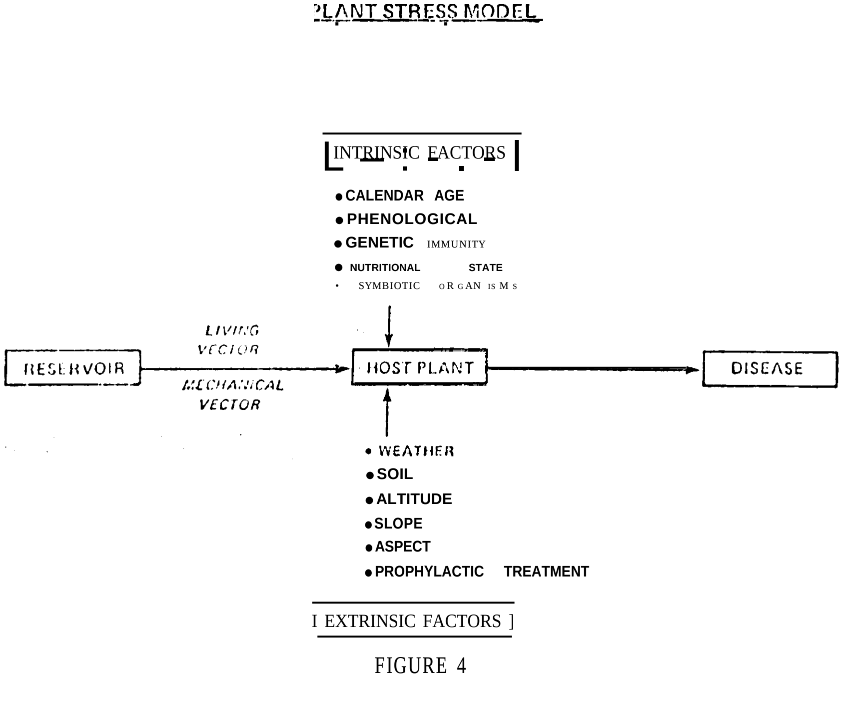


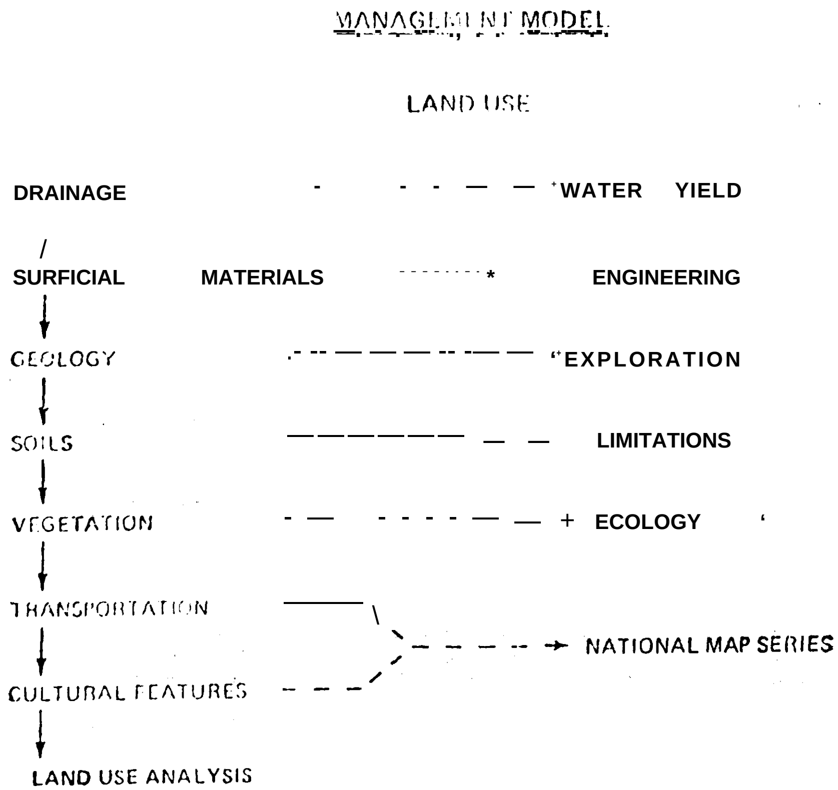
FIGURE 4

as well as man, Note that. there are two groups of factors acting on the host plant; those called Intrinsic factors which are internal to the plant and over which there is relatively little or no control, and those that are Extrinsic, or external to the plant, which are somewhat more variable and in some cases controllable. All of these factors can act in a positive or negative way to either assist the plant in throwing off the attack of the invading organism or acting in a negative sense in creating an environment which is very favorable for the success of the disease organism.

4.3 *Management Model*

LAND USE

The land use model falls into the category of models which are *more* descriptive and narrative than they are numerical. Figure 5 shows the orderly conduct of an analysis function by a multidisciplinary team of earth resource scientists to



for:

1 INTENSIVE AGRICULTURAL DEVELOPMENT

2 RANGE IMPROVEMENT

3. TRANSPORTATION SYSTEM DEVELOPMENT

4. INDUSTRIAL DEVELOPMENT

5 URBANIZED AREA DEVELOPMENT

FigURE 5

create any one or all of the five products that can come from this kind of a land use analysis. As indicated in the diagram the first task performed is an analysis by a hydrologist of the drainage, in the form of an overlay to a LANDSAT image. The overlay is then passed to a geologist who uses this analysis to produce two independent overlays; first the surficial materials, and second the geology overlay. These three products then go to the soil scientist who now has a benefit of the drainage patterns which show him the transport media for the soils, and the geologic materials which assist him in the analysis of the parent material of the soils. These two documents assist him in the preparation of soils maps. All four of those documents now go to the vegetation analyst. It is at this point in the analysis that there is a good deal of interplay between the four scientists who have participated thus far, and the vegetation analyst interacting with the soil scientist can improve the soil survey. Similarly, the vegetation analyst interacting with the geologist can improve the geological overlay. The inverse is also true, that the geologist, hydrologist, and soil scientist participating with the vegetation analysts can improve the vegetation overlay.

The transportation and cultural features overlays can for the most part proceed independently from the first five tasks. Although if the job at hand is the design of a transportation net or the design of the location of a new town or a new urban area then the engineers who would be doing the transportation overlay and cultural features overlay ***in*** fact need the inputs from the other four scientists. If, however, it is a case of straightforward production of a national map series then the job can be done independently.

The team, when finally finished with their independent tasks and with their joint tasks come together, usually under the leadership of a geographer, and perform a land use analysis. This analysis is specifically focused. It may be an intensive agriculture development task or the job at hand may be to improve the range, or to develop a new transportation system, or an urbanized area, or an industrial site selection.

In the Mock diagram note that there are arrows at right angles to each of the integrated tasks which are arrayed vertically. This is meant to imply that there is independent value for each of these overlays.

1. The drainage map combined with topography can be used to create a water yield map.

2. Surficial materials maps showing sands and gravels by themselves are useful engineering data.

3. The geology map is a useful document for a mineral and petroleum exploration.

4. The soils map, although it has a variety of possible uses, has principally been used in agriculture to indicate the limitations to agriculture development.

5. In actual practice most ecology maps are in fact vegetation maps. They may be either natural or man-made ecosystems; nonetheless the principal use for vegetation maps beyond agricultural inventory and development is in the field of ecology.

6. The national maps, and in fact most maps available to the average car driver, contain information on transportation and cultural features.

The reason that this iterative approach is considered a management model is that in practice the use of this type of analysis has been principally a management decision tool to assist in the prioritizing of development schemes.

4.4 Economic Models

This paper does not deal specifically with economic models. There have been a number of cost-benefit studies performed relative to the use of remote sensing and principally LANDSAT data in the natural resource field. One of the more valid criticisms of these efforts has been that cost-benefit studies were undertaken before all the answers were in. This is a perfectly legitimate criticism, and in fact it is quite correct to say that we are still learning what can be done with LANDSAT data. A review of the section on METSATs will show that there are applications cited for METSATs which are not at all what the satellite was designed to do.

5.0 Management Alternatives

This block is really the end of the function that has been served by the data processing and analysis group. They have taken the data from the satellite and from the field and have processed it and analyzed it; they have run it through numerical models of a variety of types, and the final product is a series of alternative decisions. It is not the purpose of the staff to make those decisions. That is left to another group, and as is seen in Figure 1, they are the central figure of the block diagram around which the whole system revolves. They take these management alternatives and make a decision. In the field of natural resources the decisions are usually associated with the exploitation of the resource or its conservation. From that decision process can also flow a request for additional information. That takes us through the information requirement block, which is referred to as the management feedback loop starting the data acquisition system working, and the entire process repeats itself.

Conceptually this is the final point in the design of an information system. There is a very large body of technology available. There is much more to learn, but it is not correct to presume that the decision to go ahead is necessarily dependent on the results of the current efforts, especially in the LACIE program. There have been enough positive results that are sufficiently important for an operational system to be designed around the established capability of the LANDSATs and METSATs and the learning process could go on. There is no reason to delay the decision simply because there is more to learn. There will always be more to learn, and that process will be enhanced by the fact that there is an operational base to the program.

6.0 ***Institutional Questions***

There is a very real concern on the part of many countries about the legal and institutional issues raised by a food information system. Even if national sovereignty were not an issue, the protection of the data would still need to be considered because of the opportunity for unscrupulous speculation in the market place. There are at least two precedents which are instructive concerning the handling of natural resource data. There are really five issues involved:

1. Giving the owner (the country) the first opportunity to benefit from the data.
2. Giving everyone in the market place an equal opportunity for fair trade.
3. Providing for the security of the raw data.
4. Providing for the security of national aggregated data.
5. Providing the information necessary for the food information system to function effectively.

The precedent for (1) is found in a method employed by the U.S. Geological Survey in conducting geophysical surveys of very large areas. In this case the owner of the land is provided his copy of the data, derived from his property prior to the publication of the results. A similar convention for the food information system can easily be employed. The precedent for (2) Is found in the present system for handling agricultural statistics by the Statistical Reporting Service of the U.S. Department of Agriculture. The results are released to the public information media at a prescribed time and in a prescribed format in order that no one in the market place has an advantage over anyone else.

A similar global system can be set up on a north-south hemispherical basis, crop-by-crop, for the species selected for inclusion in the system. The best security approach to issues 3 and 4 is to assign the responsibility to an acceptable body and to permit it to establish criteria and procedures to be approved by the countries concerned. Finally, in order to meet the stipulation of ***issue* 5**, the responsible authority would regularly report regional aggregations of these data which would serve to implement the intent of the early warning part of the system and would semi-annually report on a north-south hemispherical basis the data which would implement the food information system as a whole.

It may be undesirable to handle the situation of the secure facility by the usual method of employee security clearance and by the physical security of the plant concerned. There are, however, ways of handling the data so as to protect it. It would be advisable ***in*** any case to take ***measures*** to provide for the security of the data base. Since it would be in computer form, it would be necessary to protect it from inadvertent modification and/or erasure. It is an additional step to provide for complete inaccessibility of the data base via security algorithms. Thus, changes, updates, etc. become procedures which assure major importance requiring the assistance and supervision of a security officer.

These issues may at first appear to be somewhat melodramatic. But they are very real issues which may be the key to cooperation on the part of many countries. Those who remember the first world food conference will recall that the issue of national sovereignty proved to be the principal cause of its failure.

The recent World Food Conference recommended that Food and Agricultural Organization and World Meteorological Organizations take the necessary steps to implement first a global early warning system wherein there would be advance

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warning of serious adverse agricultural conditions in countries, and would provide sufficient warning that the necessary steps can be taken through the Food Aid Program to provide assistance. Secondly, that FAO improve its existing food information system. The World Food Conference even went so far as to recommend certain technological steps to achieve these ends, particularly some of the steps that have been recommended in this paper dealing with crop modeling and agrometeorology.

It is appropriate that the Office of Technology Assessment consider the charge given to FAO and WMO in the light of the realization that much of the technology that could be brought to bear on this problem exists only in the United States; that is, the technological wherewithal is here. There is sufficient scientific talent and sufficient support staff in WMO and FAO in their international offices to provide the manpower required. But the hardware and much of the software exists only here, and certainly the state of learning on the part of these very well-qualified agricultural and meteorological scientists with respect to the remote sensing satellite portion of the technology is not comparable to what is available here in the United States with U.S. scientists.

There is a precedent in part. The World Oceanographic Library is organizationally located in NOAA. It is only partially a precedent because the library itself has no holdings. That is to say, the actual data is resident in many different locations all over the world, and the library is merely a reference center which collates and keeps track of and publishes listings of all of this data. The difference here would be that in addition to an international facility being located in the United States, it would be a functional facility which would have holdings. It would keep raw data, and there are therefore a whole variety of new sensitivities which have to be considered, Finally, however, it should be pointed out that in debates in the United Nations concerning this program it has been stated that if the institutional problems are solved, the national sovereignty issues are very likely to abate.

The principal fear that many of these countries have is that there will be exploitation of their natural resources by multi-national corporations or extranational organizations who have more information about the resources of the country than the country has of itself. The fact that this may have always been true is a non sequitur. The presence of the LANDSAT satellite photography and the policy that NASA has adopted relative to the open skies and free acquisition of LANDSAT photography everywhere in the world has raised the issue afresh. If *some* method could be evolved wherein these countries would feel that they are getting as much information about their country as anyone else can get, and that they are getting it in the same time frame, then the issue of national sovereignty would become small indeed since the opportunity to exert their national will more logically comes during the licensing and exploration phase rather than in the satellite inventory phase.

In addition to the institutional questions which are related to the international acceptance of the program, there are those which concern the missions and roles of agencies both national and international. Perhaps the most important deficiency in the system is the current state of surface meteorological observing stations. They are for the m@ part designed to serve the needs of civilian aviation. It is difficult in many cases to use the information because of the location of the station. In all cases it is necessary to do a careful analysis of the terrain around the station before attempting to extrapolate the measurements made at that point to the general area. This task is part of the ecozone mapping function. The . interesting part of this problem is that while it is fairly easy to use an observing station designed for agriculture to meet the needs of civilian aviation, the reverse is not necessarily true. WMO has recognized this problem and has assured FAO that in the future they will recommend to their member governments that the needs of agriculture be given prime consideration.

The fact that WMO can only recommend, is in itself a problem. The WMO is not an action agency and does not design and build observing stations. Agricultural weather forecasting requires many more stations than are presently in the Synoptic Network. It addition, if the existing climatic stations are going to contribute to agriculture they will have to report at the very minimum each 10 days instead of each 30 days as they do now. Here again, WMO can only recommend.

United States agencies are for the most part properly structured, staffed and funded to participate in the system. Agrometeorology is perhaps the most neglected of the contributing sciences. This deficiency is in part related to the lack **of a** clearly expressed need at the State and local level, as well as the Federal level, but also in part because our educational system produces less than 100 agrometeorologists fit the Ph. D. level per year. It is interesting to note that the USSR produces 500 such scientists each year. Before one dismisses this as an irrelevant observation, consider the fact that the USSR has consistently entered the world marketplace, buying wheat well in advance of their own harvest.

The importance of the program to the developing world, to national governments in the developed world; to the United States Government, in its concern over its national agricultural programs as well as its foreign aid programs in agriculture~ are best illustrated by a final review of benefits of the program. These benefits flow from the successful implementation of a capability to forecast the production of the important food crops. The expected order in which this could occur would be Wheat in year 2; Corn (Maize) in year 3; Soybeans in year 3: Rice in year 4; other major crops in the ensuing years as the physiological models are developed. This information is vital to the following management problems:

1. Import/Export policy.
2. Allocation policy for: Seed, Fertilizer, Pesticides, Fuel, Storage, Transportation, and Port Facilities.
3. Rational land use policies for: Intensive agricultural development. Protective agricultural zoning, Regional development, Industrial site selection, and Urban expansion.

No other source of data so widely serves the management decisionmaking process necessary for the wise conservation and use of our renewable and nonrenewable resources.

SUMMARY

A very brief review has been made of the current state of technology that could be applied to the creation of a Global Agricultural Information System. Because of the complexity of such a System, only the highlights have been documented.

It is the opinion of the writer that such a system is feasible, that both the requisite hardware and software exist, and that the creation of such an operational system would provide the most appropriate base for the orderly development of foreseeable technological improvement. The creed of such an undertaking might be “It is no handicap to good research to have a purpose in mind.”

[The following questions were submitted by Senator Humphrey to Dr. Park and his answers thereto:]

Question 1. What is the relationship of the Earth Satellite Corporation to NASA and to other Government agencies?

Answer 1. Earth Satellite Corporation is a private consulting firm that has performed a number of studies for NASA in the role “of a principal investigator in the LANDSAT program. In addition, the corporation has performed a major cost benefit study under contract to the Department of Interior concerning the costs and benefits related to the LANDSAT program. All of these procurements were competitive and Earth Satellite Corporation enjoys no special relationship with either NASA or other Government agencies.

Question 2. You recommend that a LANDSAT program be made operational. How would an operational program differ from a continuation of the current experimental programs ?

Answer 2. The LANDSAT program poses a special problem for the Government. There is no single operating agency of the Government that has a clear mandate to become the operational agency. There are equally important applications of this particular satellite sstem to be found in the Department of Interior, the Department of Ariculture, the Department of Commerce, and the Corp of Engineers. The term operational, from the point of view of the user agencies, is defined as a commitment on the part of the Government to provide a continuum of data from the LANDSAT family of satellites. If the current experimental program, which is the responsibility of NASA. is supported by that commitment on the part of the Government, it is not only likely that this would satisfy the rest of the operational agencies, it may in fact be the preferred mode of operation. The program is characterized by extremely close interagency coordination which NASA has sponsored. NASA has implemented engineering studies which emphasized the in]] 1:1 of engineering alternatives on the several applications that are the responsibility of the user agency.

The experiment program is sufficiently clearly defined in advance of the flight of any particular satellite that the operational agencies are able to use the data in their regular program. The documentation provided by the writer for the OTA Board discusses the difficulties that have arisen in the field of data processing and data analysis that have occurred in the conduct of the program to date. In my opinion, the only important function that really should be changed in terms of the existing program is a commitment by the user agencies to provide an analytical operational capability that is presently missing *in* some agencies of the Government.

Question 3. What major U.S. Government management programs would be served by an operational LANDSAT program?

Answer 3. LANDSAT data, properly interpreted, can provide information important for decisions made in the management of our water resources, forest and range resources, our agricultural crop resources, our mineral and petroleum resources and in part, our marine resources. Perhaps the most important application for LANDSAT is its utility in the rational use of our land resources. It is correct to say that our concern for the environment can be directly traced in all respects, whether we are talking **about** air pollution, water pollution, or land pollution, to our use of the land. The capability of LANDSAT to first of all inventory this land use and secondly to monitor it over time represents perhaps the single most important use *of* the data.

Question 4. What types of information from LANDSAT would they use?

Answer 4. The type of information varies with the application. For example, in the case of water, the data are directly interpretable from imagery since the multispectral nature of the imaging system provides a very sharp interface between water and other surface features, thus permitting direct measurements to be made. In the case of mineral and petroleum resources, the interpreters conventionally look for linear features in the data. It has been found that the satellite platform affords a vantage point actually unattainable in any other fashion from which to see structures on the surface that are not just tens of miles long but in fact hundreds of miles long. From these linear features the geologists have made interpretation which has proven to be important to the extractive industries. In other cases, the linears that are noted are circular rather than straight or broken. Generically the data yields information on structures. In the case of agriculture, forestry, and range, the LANDSAT data is used directly since one of the principal scene components is the vegetation itself. The document provided by the writer to the OTA Board discusses the vegetation resource in some detail, and notes that for this purpose the digital data is requisite because of the importance of being able to discriminate between the various species of vegetation on the surface. In the case of the marine resource, the nature of the information is related to conditions in the nursery habitat of the ocean fauna. The satellite has demonstrated its ability to monitor estuarian circulation patterns and to map vegetation in the shore area. In the case of land use, there is a discussion of the nature of' the multidisciplinary analysis that is necessary to extract this data from. LANDSAT and it does indeed require the compex staffing pattern as described in the OTA report.

Question 5. Would it be possible to make better estimates of the crop production in other parts of the world without a cooperative agreement of the countries involved ?

Answer 5. Unequivocally, yes. The estimates could be even better with cooperation but the lack of such agreement does not prohibit better estimates than are currently available for many countries of the world.

Question 6. In your report to FAO, what specific information on crop production did you promise in the first year of operation ?

Answer 6. Specifically, we promised to provide the capability to monitor soil moisture in the monsoon area of India, and the Sahelian ***zone*** in Africa. While. those two areas of the world were stated, it was implied that we would be able to monitor this parameter on a global basis during the first year.

Question 7. Which countries have indicated their willingness to cooperate in the global agricultural information project ?

Answer 7. I do not have the answer to this question. I am informed by FAO that thus far 45 countries had signed the agreement which was a product of the. World Food Conference.

Question 8. In your opinion, how could U.S. Government be of greater assistance to FAO in the establishment of a more effective early warning system?

Answer 8. The U.S. Government has the resources in terms of hardware. software and scientific staff to actually do the early warning system for the FAO. If" this function could be a part of the U.S. Government obligation to the United Nations in my opinion it would be one of the very best investments we could make. in helping to alleviate the world food problem.