Chapter 4

Public Interest in Remote Sensing

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U.S. land and meteorological remote-sensing systems have from the beginning been intended to serve the public interest, whether primarily for research, as in the case of the Landsat system, or for operational weather forecasting and severe weather warning, as in the case of the meteorological satellite (metsat) systems. As the debate over the best treatment of these two systems continues, it is essential to be clear about their respective roles in serving the public interest. This chapter illustrates the use of both kinds of remotely sensed data in the public and private sectors, and suggests certain conditions and requirements that might be imposed on a private sector offeror for the Landsat system.

PUBLIC-GOOD ASPECTS OF REMOTE SENSING FROM SPACE

As understood in economic theory,[1] a public good is a good or service for which it is impossible or undesirable for reasons of efficiency to charge customers a price or a user fee for services rendered. Public goods are therefore frequently provided by Government and paid for out of tax or other general revenues. Examples of public goods are streets and highways, national defense, parks and recreational areas, police services, general weather forecasts, and various informational services.

Although it is theoretically possible to charge for some public services such as weather informaion (in this case, say, by using coded TV signals), the cost of doing so, compared with the cost per additional viewer (the marginal cost), would be disproportionately large. * For this reason, among others, weather forecasts are provided without charge.

In addition, for weather broadcasts, it would not be prudent to charge for the most valuable aspect of the service—warnings of severe weather—since society as a whole benefits from well-informed individual citizens. The objective of having as many members of the public "consume" weather forecasts is furthered by having as low a "price" as possible—nothing. This is a second reason why weather data are provided without charge.

For most public goods, reliance on the private market to produce them would result in either no production or production at an inadequate level compared with what society as a whole might be willing to pay through taxation. Unless they are subsidized by the public, private producers are not capable of providing public goods at socially optimal levels, i.e., where price equals marginal cost, because sales revenues at prices that would assure these levels are inadequate to finance production.

For the producer, a financial problem in pricing goods at marginal cost arises whenever the marginal cost is below average cost. It becomes particularly severe when marginal cost approaches zero. However, if prices are above marginal costs—the resource cost of servicing the consumer—some potential consumers are then priced out of the market. Production will then not reach socially optimal levels. This latter problem is also most severe for the consumer when marginal costs approach zero, if price is set equal to full (average) system cost. The conflict between financial efficiency and social efficiency is inherent in the nature of public goods.

In part because of these considerations, the metsat systems, both foreign and domestic, have always been operated by the Government, and weather data have been distributed gratis to the public. Current policy dictates that general-pur-

[1]For example, Richard A. and Peggy B. Musgrave, *Public Finance in Theory and Practice*, 3d ed., ch. 3 (New York: McGraw-Hill, 1980).

*When the marginal cost—that is the cost of servicing an extra customer—is zero and a person's consumption of the service does not reduce the benefit derived by others, we have the case of a "pure public good," since there is no rational social reason to exclude anyone from consuming it, even if it were possible to do so.

pose weather data will continue to be distributed free, even if they are eventually supplied by private firms under contract to the Government. The Government has clearly chosen social efficiency as the goal in the case of meteorological satellites.

A few of the specialized services now provided by the National Oceanic and Atmospheric Administration (NOAA), on the other hand, might be provided profitably at socially desirable levels by profitmaking private firms, using the initial satellite weather data as the input. Services such as providing fruit frost warnings from the geostationary satellites or ocean surface temperature charts could fall into this category if there were sufficient interest in the private sector. A small value-added industry already uses data provided by the meteorological satellites to provide tailored weather services for a variety of customers. Thus, meteorological remote-sensing services, as presently provided, are a mixed public/private good.

It would be a mistake to conclude that just because a good has the features of a public good that it should necessarily be financed through the public budget and distributed free. The decision depends in part on whether or not Congress decides that it wants to bestow the benefit directly on those who benefit and pay for it out of tax revenues. The simplest case is when the tax payers benefit in proportion to the taxes they pay. Then making the service in question available from public revenues is relatively straightforward.

The public is unwilling to finance some public goods, however, because they are seen primarily to benefit narrow interest groups. As a consequence, some public goods are produced by the private market at nonoptimal levels. The public interest was just not great enough to result in public subsidy.

Services using data from the Landsat system could also be considered a mixed public/private good. For Landsat, however, the private-good aspects are much stronger than they are for the meteorological satellites because Landsat data have potentially high economic value. The cost of producing extra images is extremely small once the system is in place, making it undesirable from the point of view of social efficiency to recover the cost of the system by charging a price equal to the average system cost, since marginal users of images would then be charged much more than the marginal costs of servicing them. This is the public-good part of the Landsat services. As in the case of weather data, the value-added industry is a normal profitmaking industry (once it has its digital input) and thus produces private goods.

The big difference between the weather and land remote-sensing systems is that land remote-sensing customers such as oil companies, mining companies, and even municipalities in some other State are not the entities that the public prefers to subsidize. Nevertheless, the Federal Government itself is the largest user of the Landsat system—for land management, agriculture, forestry, mapping, and for foreign intelligence (ch. 5).[2] Therefore, there are significant public purposes that would in any case result in budgetary expenditures. When such a situation exists—i .e., an industry with the characteristics of a public good that also has the Government as a principal customer—Government production is a natural outcome.

At present, Landsat is also available as a partially subsidized Government-produced service to a variety of domestic and foreign users. Under this arrangement, which arose initially because of the research and development (R&D) nature of the system, Landsat has been used by State and local governments for rangeland, forest and water-resources management, by resource companies as an aid in resource definition, and by a variety of other private, profitmaking and nonprofit organizations. Some analysts predict that the market for data and for data products from space will one day expand and grow into a major industry.[3]

The issue before Congress is whether to consider land remote sensing primarily a public good or a private good. If Congress considers it primarily a private good, direct commercialization makes sense. The remote-sensing industry would join the thousands of other unsubsidized American industries producing private goods.

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[2]*See* also *Civilian Space Policy and Applications* (Washington, D. C.: U.S. Congress, Office of Technology Assessment, OTA-STI-177, June 1982), apps. B and C.

[3]Donn C. Walklet, "Remote Sensing Commercialization: Views of the Investment Community," ERIM Conference, May 9-13, 1983.

However, if Congress considers the Landsat system to be primarily a public good and decides that Government should not itself produce the good a further issue arises—how much, if any, subsidy Congress will continue to give the industry to ameliorate the efficiency problem. A related issue is how much regulation of the industry will be necessary to enable it to use other mechanisms for such amelioration.

A widely used mechanism in public utility regulation, the two-part tariff, illustrates how some of the efficiency advantages of subsidized Government provision of Landsat services can be preserved in the event that the public is unwilling to subsidize them. In this mechanism, both a system access fee and a fee that depends on usage are charged. The usage fee can be set closer to marginal cost because the upfront access charge finances part of the system cost. Departures from optimal production can be reduced in this way even if there is no subsidized provision of the service by the Government. Given the relatively large Government usage of remote sensed data, the access charges under such a scheme could possibly be assumed by the Government, not as a subsidy per se but as payment for its usage.

If the public-good aspects of land remote sensing are considered large or important to the general public, a further question arises as to whether the industry should be continued under Government ownership or under private ownership, or in some combination of Government and private ownership. Whether the industry under full private ownership and operation, even with subsidy or regulation to ameliorate the efficiency problem, would serve the public interest is an important aspect of commercialization that remains to be determined by Congress.

USERS OF REMOTE SENSING

This section enumerates the organizations, agencies and categories of private firms that are the primary users of remote-sensing data from both land and meteorological satellites. These users constitute the primary customers for a remote-sensing industry. Although the two communities of land and meteorological data users overlap one another to a certain extent, and both include domestic, foreign, and international users, in most respects they are separable.

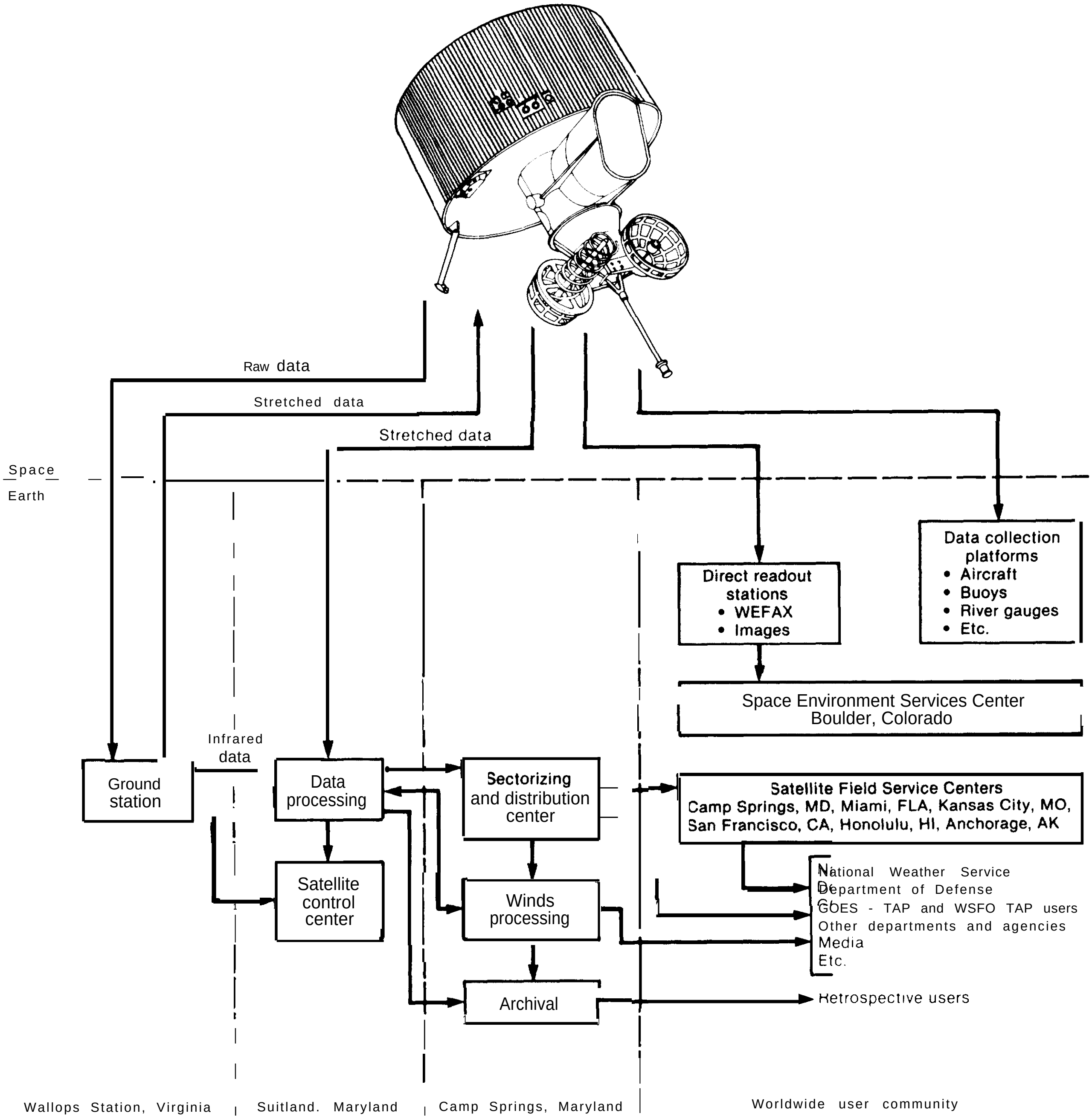
Meteorological Data

The largest domestic user of metsat data is the general public, with NOAA as supplier. The National Weather Service has a vital interest in the metsat data and its sister agency, the National Environmental Satellite and Data Information Service, operates the U.S. Weather Satellite system currently consisting of two geostationary and two polar-orbiting satellites—respectively GOES East and GOES West and NOAA-7 and -8 (figs. 2, 3). Both qualitative and quantitative data are collected, processed, and distributed via communications networks. Other users are included in table 2.

Prominent among the domestic private sector users of metsat data products are the airlines, private meteorological forecasting companies, the fishing industry, sea-ice consultants, agricultural industries, and a large number of research specialists such as climatologists, hydrologists, and oceanographers. Many of these people are engaged in pioneering studies involving water-resources management; others use the satellites' communication capabilities from terrestrial data-collection platforms to monitor various parameters such as water, soil, or plant temperatures or snow depth for practical, operational management decisions.

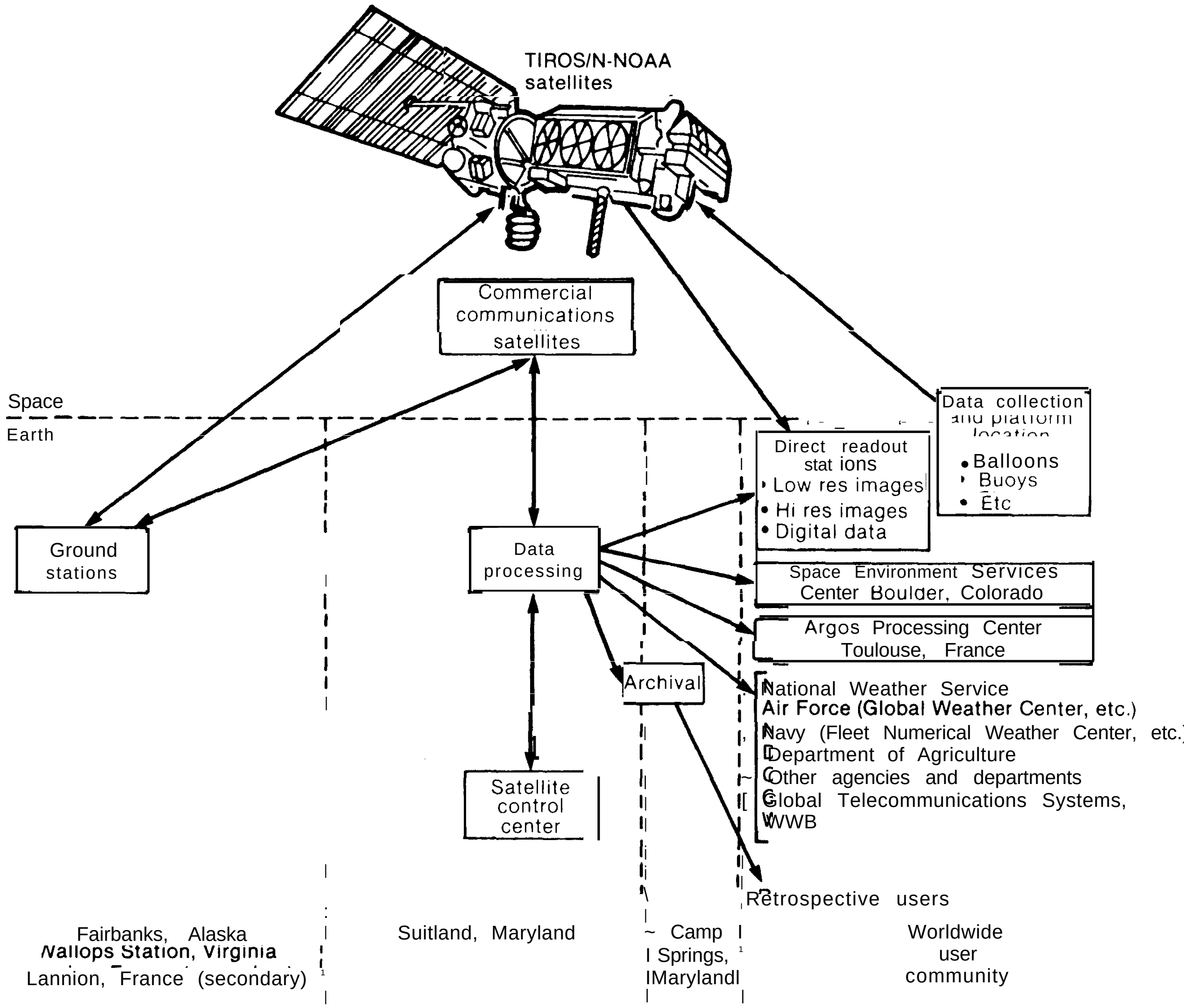
Foreign users of metsat data are many. The most popular aspect of the early metsat program was the free availability of the U.S. meteorological satellite data to all countries through the Automatic Picture Transmission program. This program engenders much good will for the United States throughout the world. Inexpensive antennas and receiving equipment enabled even the poorest of the third-world nations to have weather satellite images for better weather forecasting, The Canadians have taken particular advantage of these data to provide better forecasting and bet-

Figure 2.—Geostationary Satellite System



SOURCE National Oceanic and Atmospheric Administration

Figure 3.—Polar.Orbiting Satellite System



SOURCE National Oceanic and Atmospheric Admimstration

Table 2.—Domestic Distribution of Polar Satellite Products

- National Weather Service
- Environmental Research Laboratory
- Other NOAA offices
- Department of Agriculture
- Department of the Interior
- National Aeronautics and Space Administration
- Department of Defense (Air Force and Navy)
- Coast Guard
- Academic community
- Commercial users (e.g., farmers, fisheries, oil companies, engineering and consulting companies)
- Private individuals
- State governments

SOURCE" Office of Technology Assessment.

ter data for the more remote and inaccessible portions of their vast country. About 125 countries of the world similarly collect data using their own collection stations (see table 1 in ch. 3).

Certain scientific disciplines, such as meteorology, climatology, oceanography, and geology, transcend political boundaries because the boundary conditions they deal with are physical rather than national. Study of global phenomena requires global cooperation. The need for international cooperation in these disciplines has led to international programs (e. g., the International

Hydrological Decade) and organizations (e.g., the World Meteorological Organization).

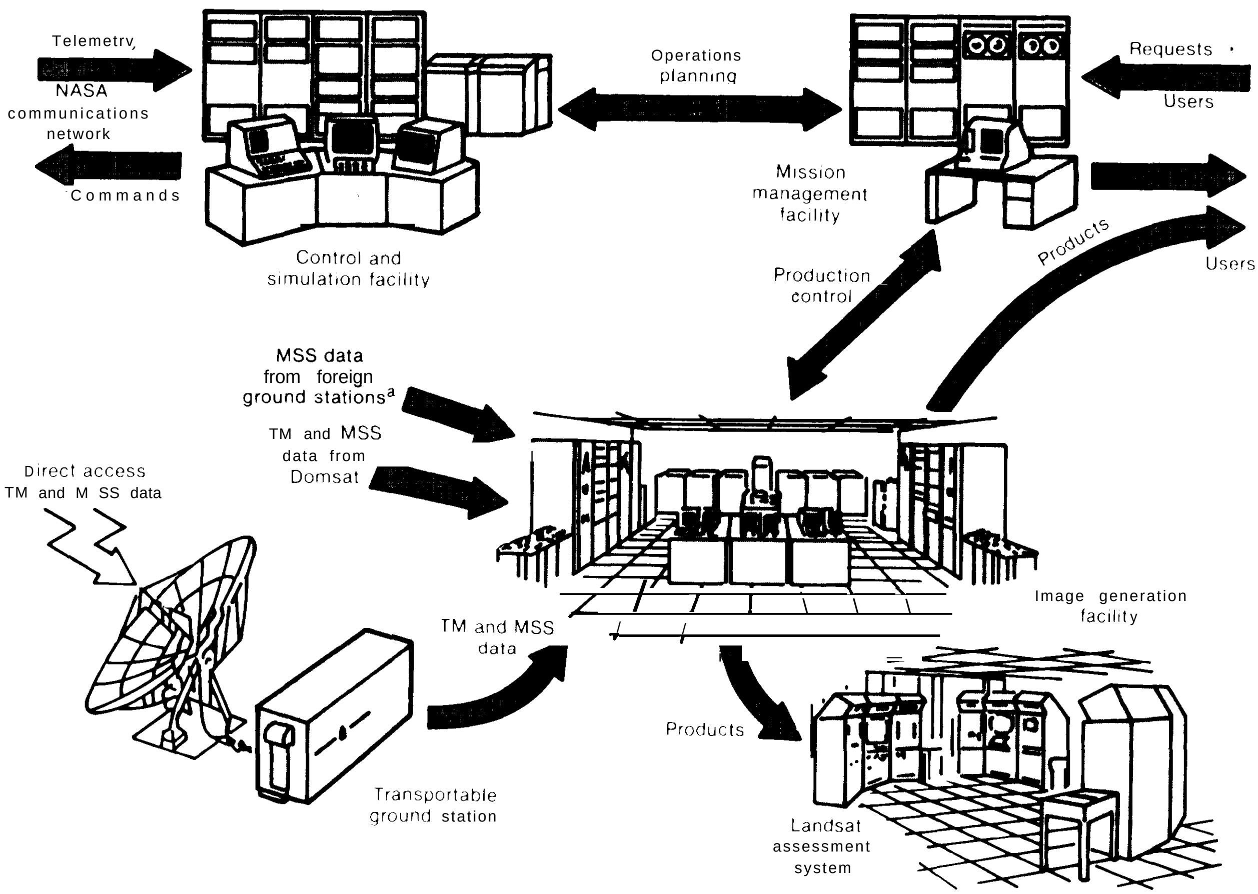
Land Resource Data

The Landsat system (fig. 4) possesses several properties that permit the development of a global data base for resource inventory and monitoring over time:

- perspective over a range of selected spatial scales;
- selected combinations of spectral bands for categorizing and identifying suface features;
- repetitive coverage over comparable viewing conditions;
- direct measurement based on one set of reflectance conditions for a wide surface area;
- signals suitable for digital storage and subsequent computer manipulation; and
- accessibility over remote and difficult terrain and across political divisions.

As with the meteorological data, the largest single user of Landsat data is the Federal Government (see table 3). Within the Government, the Department of Agriculture (USDA) and the intelligence community are the two greatest users. Both of these agencies and the other Federal agencies combine these data routinely with other information to assist their missions.

Figure 4.— Major Elements of the Landsat System



[a]Prior to TDRSS Phase-In

SOURCE National Oceanic and Atmospheric Administration

Table 3.—Domestic Distrubition of Landsat Products

- Department of Agriculture
- Department of Defense
- Department of the Interior
- National Aeronautics and Space Administration
- Intelligence community
- Coast Guard
- State planning and resource management agencies
- Regional planning agencies
- Academic community
- Commercial users (eg., foresters, mineral exploration geologists, engineering and consulting companies)
- private individuals

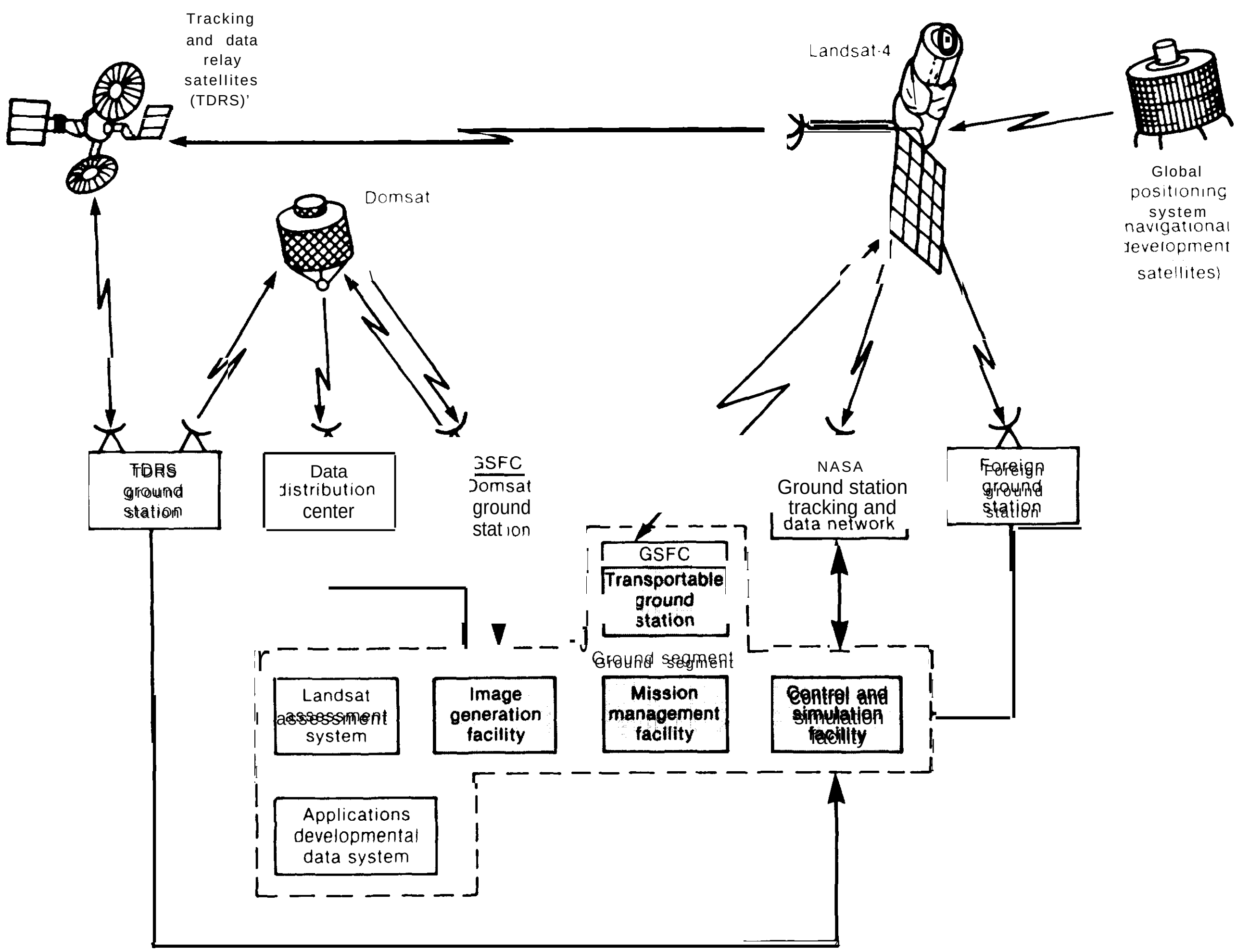
SOURCE Off Ice of Technology Assessment

The major commercial customers of Landsat data include the agriculture, forestry, mineral industries, and land-use planners, directly or indirectly through the value-added industry (discussed below). The academic community (discussed below) primarily supports the research efforts of Federal and State agencies and the private sector.

The Value-Added Industry

Transfer of the land remote-sensing program to the private sector is likely to introduce both desirable and undesirable changes in the remote-

Landsat Ground Segment



SOURCE National Oceanic and Atmospheric Adminisiration

Landsat Data Needs of Foreign and Domestic Users

- *Agriculture* (Federal, State, and private): specific sampling areas chosen according to the crop; time-dependent data related to crop calendars and the weather patterns
- *Forestry* (Federal, State, and private): specific sampling areas; twice per year at preselected dates
- Geology *and nonrenewable resources* (Federal, State, and private): wide variety of areas; seasonal data in addition to one-time sampling
- *Civil engineering and /and use* (State and private): populated areas; repeat data required over scale of months or years to determine trends of land use
- *Cartography* (Federal, State, and private): all areas; repeat data as needed to update maps
- *Coastal zone management* (Federal and State): monitoring of all coast lands at selected dates depending on local seasons
- *Pollution monitoring* (Federal and State): broad, selected areas; highly time-dependent needs both for routine monitoring and in response to emergencies

SOURCE Off Ice of Technology Assessment

sensing value-added industry. This small but expanding industry exists both as small units of large resource companies and as independent smaller companies. The business base of the independent companies has developed since the late 1960's in parallel with the Nation's space-borne remote-sensing program. Value-added operations of various types exist not only in the United States but also in free-market European countries and Japan. The availability of remotely sensed data on an unrestricted basis at an acceptable cost is essential to the continued strong growth of this industry.

Data services or products furnished by value--added firms range from improving the image by simple processing of the raw data, to the provision of information services specific to various natural resources industries. Petromining, agriculture, hydrology, land-use planning, and oceanographic companies all benefit from services provided by value-added companies. In many cases the firms supplying services and products based on remotely sensed data provide information that can significantly alter the way many industries make decisions.

Presently, over 50 commercial organizations in the United States provide analyses of remotely sensed data. They or their customers use the imagery acquired from space to evaluate specific areas of Earth's surface for hydrocarbon resource potential, estimating future crop production and water resources, and surveying land use. Several of these firms also sell hardware designed to process data remotely sensed from space.

A strong value-added industry is essential to creating a self-supporting land remote-sensing business. For example:

> Without the competitive nature of a strong value-added industry it is unlikely that the products, the services, and the multilevel derived geological information will be made available to the private sector energy and mineral explorationist with whom the U.S. Charter for finding our future nonrenewable resources lies. If so, no commercial market is likely to evolve.[4]

It is also important to recognize that profitmaking value-added firms exist in an infrastructure including other entities that provide ancillary data, onsite inspection, and a variety of related services. Important among these are the Government laboratories and management units that provide an essential research base from which the value-added companies derive some of their information-processing techniques.

'Frederick B. Henderson, "The Significance of a Strong Value-Added Industry to the Successful Commercialization of Landsat, " presented at the 21st Goddard Memorial Symposium, Mar. 24-25, 1983.

USING LANDSAT DATA FOR FORESTRY AND AGRICULTURE

Landsat data have been used in a variety of fields where low- to moderate-resolution spectral data can be integrated with other information to provide analyses important to the exploitation and management of resources. This section presents examples from two areas where these data appear to be especially helpful: forestry and agriculture. It specifically excludes discussion of petroleum and other mineral exploration because these have been discussed in considerable detail in other publications.[1] However, the petroleum and mineral exploration industry is now the largest private purchaser of Landsat data. Its relative importance for the near-term prospects of commercializing land remote sensing is high.

Forestry

In forestry, as in many other disciplines involving land management, there is a distinct need for timely, reliable information about the resource base. The "synoptic view" provided by images obtained from spacecraft altitudes is proving valuable when information over extensive geographic areas is required, as is the case in managing our Nation's forest resources. For instance, the Forest and Rangeland Renewable Resources Planning Act of 1974, in which Congress mandated the U.S. Forest Service (through the Secretary of Agriculture) to provide information on the condition and productivity of approximately 1.6 billion acres of public and private land every 10 years, emphasized the need for efficient, cost-effective systems to collect detailed data periodically over very large areas.

Numerous other examples could be cited of requirements for accurate, detailed information for a wide variety of resource-management and/or policy decisions. These range from the needs of an individual forester who works for a single forest company and makes market-related decisions about a specific block of land to those of State or Federal legislators who must make policy decisions which could affect forests and other natural resources of an entire State or of the Nation for decades to come.

In at least three respects, the characteristics of the information required for effective and efficient management of forest resources are unique. First, the forests are so extensive, both nationally and globally, that the quantity of data needed is gigantic. Second, the forests are highly complex and diverse, which results in the need for detailed information on their various components. There are different species and species mixtures, different age classes, and varying stand densities. Third, the forest grows slowly but can be harvested or adversely affected relatively quickly, which makes inventorying and characterizing the forests expensive. Yet, because of both human and natural influences (e.g., insects, disease, severe weather) on the extent and condition of forest resources, inventories of some type are mandatory. The interval between inventories might well vary, depending on the type and severity of the particular changes expected. In sum, the demands for the type and frequency of information concerning forest resources are quite different from those involving crops, water, or mineral resources.

Because of these special information requirements and economic limitations peculiar to forestry, the Landsat system is uniquely capable of obtaining the type and quantity of data needed. Only the Landsat system provides reasonably detailed data (i. e., each pixel or minimum element of Landsat data represents 1.1 acres on the ground), over the forested regions of the **entire Earth, at very modest cost (on a per-acre basis),* and at a frequency that** allows most **changes to be monitored effectively. However, if the cost of the data used for forest inventories, on either a local or worldwide basis, is too high,** such data will not and cannot be used to obtain the necessary information. Management decisions will, by necessity, continue to be made, but may be based on inadequate, outdated, resource information.

The advantages and limitations of Landsat data to foresters, and examples of the use of Landsat data are discussed in some detail in appendix F. The following paragraphs summarize its conclusions.

Three major groups involved in forest resource management have found Landsat data to be particularly effective:

[1] Alexander F. H Goetz and Lawrence C. Rowan, "Geological Remote Sensing," *Science*, vol. 211, 1981, pp. 781-790; "Satellite Remote Sensing Data An Unrealized Potential for the Earth Science Community," The Geosat Committee, Inc, 1977; 'Remote Sensing and Exploration Geology," Proceedings of the Geosat Panel Discussion, COSPAR Conference, May 21, 1982, Ottawa, Canada, Geosat Technical Report No 3.

* Current cost per computer-compatible tape covering approximately 13,225 square miles is $650.00, which is less than $0.05 per square mile, or less than 1 100 cent per acre. However, this cost figure does not include sizable data acquisition or data analysis costs. Also, because aerial photos contain much more detailed information, and can be ordered to cover smaller more discrete areas, many users are willing to pay much higher costs for aerial photography than for Landsat data.

- **Forest industries.** The St. Regis Paper Co. has found Landsat data cost-effective in increasing efficiency of forest mapping, and improving field operations. Although other forest companies have shown interest in using Landsat data, they are reluctant to invest the time, money, and personnel necessary to use a new technology in their operations when the continued availability of Landsat data is in considerable doubt. They are also fearful of continuing price increases that would decrease the cost-effectiveness of the data. In addition, in forestry, the use of land remote-sensing data has not reached the operational level that has been obtained in the geosciences. Continued research by the companies will be needed to determine just how to use the data most effectively under day-to-day operational conditions.
- **Federal and State agencies.** The Federal Bureau of Land Management (see app. F) uses Landsat data for managing forests and rangelands under its care. In addition, States such as Minnesota, Mississippi, and Pennsylvania, as well as regional groups of States, have explored the use of Landsat imagery to aid in monitoring their forest lands (see apps. D and E).
- **Foreign countries. One of the primary resource concerns** in other countries, particularly developing countries in tropical regions, is the rapid loss of forests because of clearcutting for agricultural purposes and for fuel. Landsat data are particularly cost effective (at current subsidized prices) for monitoring the rate of deforestation (see apps, A and G). They have been used for this purpose in Brazil, the Philippines, Thailand, the Dominican Republic, Nigeria, and Costa Rica. A critical factor in the future use of Landsat data, however, will be their cost as well as their timely availability. Many of these data were supplied by the Agency for International Development (AID) as part of the U.S. effort to make Landsat data available to developing countries. If AID dramatically reduces the support it gives to land remote-sensing research programs in other countries (see ch. 3), their ability to monitor the rate of deforestation will decrease accordingly.

Remote Sensing for Agriculture

Drawing on the information and analysis of appendix D, this section summarizes the use of remote sensing for agriculture. Land and meteorological remote sensing provide only some of the data important to planning agricultural production. Yet, as agricultural analysts have gained experience in applying these data, the data have increased in importance. The repeatability, synoptic view, and spectral and spatial characteristics of satellite-derived systems could make agricultural prediction and planning over wide geographical areas much more reliable than it now is.

Soon after the launch of the first Landsat satellite, USDA entered a joint research program with the National Aeronautics and Space Administration (NASA) and NOAA, called the Large Area Crop Inventory Experiment (LACIE). This program developed software to estimate grain production in the Soviet Union and Canada. LACIE experienced both successes and failures, but showed enough potential for USDA to develop a joint research program with NASA, Agriculture and Resource Inventory Surveys through Aerospace Remote Sensing (AgRISTARS). The AgRISTARS program seeks to develop satellite remote sensing for practical agricultural purposes.

Most of the agencies at USDA are able to use satellite data to support their missions. Much of this current know-how resulted from either LACIE or AgRISTARS. In the private sector, several companies have learned how to combine meteorological with Landsat data to predict future crop yields, These data are important to Government agricultural planners as well as to farmers, farm cooperatives, and merchants and traders who buy and sell farm commodities.

Although remote-sensing data satisfy a small part of the total information needs of agriculture, timely delivery of accurate, comprehensive, objective, remote-sensing data could improve most of the information areas for agriculture (table 4) if the data were inexpensive enough.

Table 4.–Information Needs of Agriculture

Information type	Remote-sensing data could improve quality
Resources:	
Physical	•
Human	
Economic ., ...	
Farmer/producer behavior	
Agronomy	•
Current crop and livestock .,	•
Market news	•
Economic predictions	•

SOURCE Off Ice of Technology Assessment

Criteria of a Good Agricultural Information System*

Satellite technology has tremendous potential to supply data with the necessary characteristics. However, this potential has yet to be realized with Landsat technology. Data from the meteorological satellites meet most of the necessary criteria, especially cost-effectiveness and timeliness, but the low spatial resolution and limited spectral characteristics of the metsat data necessarily limit their overall effectiveness for agriculture. These criteria are:

- **Accuracy.** To be used for predictive purposes, data must contain acceptably small errors. Satellite data have the potential to be both precise and accurate, but considerable research on the data is needed to determine how to reduce sampling errors. In the meantime, the data are being used to predict future crop yield.
- **Timeliness. Agricultural decisions require data that** are no more than a few days to 2 weeks old, depending on the particular decision to be supported by these data.
- Cost-effectiveness. To achieve maximum usefulness to the agricultural community, satellite data must be cost-effective compared to older, less efficient, but more familiar ways of gathering data (i. e., ground and aerial survey).
- **Expandability. An effective information system must be able to adapt** to new modes and new technologies without increasing costs excessively. Satellite technology has the potential of making objective, accurate crop yield measurements with current data for large farm plots. The thematic mapper (TM) and other proposed sensors having high spectral resolution are expected to increase the accuracy of these measurements and allow sampling of smaller fields as well.
- **Repeatability y. Surveys made at different** times should reflect changes in the target population rather than alterations in the methods for collecting data. Remote sensing from space makes possible highly repeatable data characteristics. Because the Landsat system has been a research effort until recently, data format, spectral and spatial characteristics, and orbital characteristics have changed over time. Such changes make it difficult to compare images taken at different times.

Implications of Improved Information for Agriculture

Global, timely, reliable information on major food and fiber crops is a significant element of national economic and political intelligence. Such information may affect a broad spectrum of public and private sector activities. Better information, distributed in a timely way, could lead to more equitable sharing of the profits and losses of farming activities. Of more importance, it might lead to avoidance of spot shortages or of overproduction in particular geographical areas. It could also reduce the total energy consumption devoted to agricultural production.

Because the agricultural community needs repetitive data over periods of days, weeks and months, it would be the major customer for land remote-sensing data if good data can be delivered promptly and cheaply.

Concerns of the Agricultural Community

- **Costs.** For fiscal year *1984,* USDA has allocated *$7.4* million to purchase the Landsat data it needs. However, potential private customers are likely to make little use of Landsat data until the cost per scene is reduced considerably, the data can be delivered promptly and the costs of analysis can be reduced.

*Howard W. Hjort, "World Agricultural Information System: A Critical Evaluation," contract report for OTA, September 1975.

- **Continuity. Agricultural statistics assume greater meaning** when collected and analyzed over time. Current data must be compared with those of earlier years. For the agricultural community to make more use of land remote-sensing data, data format should be standardized and the data should be available promptly and continuously, without gaps in delivery.
- **Copyright. Existing legislation charges several different Government agencies with managing our national resources. Landsat data have be**gun to play a significant role in meeting this responsibility. For these agencies to use the data effectively, they must be able to pass them freely among themselves. Copyright restrictions on data, if imposed by a private operator, could impede the free exchange of information among Government offices.
- **Data control. Although grain companies and** other agricultural firms are not now large users of Landsat data, they are interested in the technology. Some agricultural analysts fear that a policy allowing discriminatory access to data might result in predatory marketing practices. Theoretically, a firm that could pay for first access to the data would have an unfair advantage and could make windfall profits simply by postponing availability of data to the outside world. This is especially crucial in agriculture, where the value of the data is highly time-dependent.
- Technological improvements. Parts of the agricultural community are concerned that transferring the Landsat system might result in a freeze of technology at the current level of sophistication, In their view, not only improved sensors are important, but lower cost, improved image-processing.

STATE AND REGIONAL USE OF LANDSAT DATA

Because computers are now used in most States and regional organizations, Landsat data find a ready niche in their resource information systems. With considerable assistance from NASA, many States have purchased the hardware, software, and training to process Landsat data. At least 18 States have now merged Landsat data with other data in broad-based geographic information systems (table 5). Some of these systems can use Landsat data directly (app. B).

A prime example is the State of Mississippi, where Landsat data are integrated directly in a single information system—the Mississippi Automated Resource Information System (MARIS). When operating fully, MARIS will provide a catalog of natural resources and cultural data about the State, interpretive maps, and the analytical staff to analyze and interpret trends (app. B). Landsat data are being used in Mississippi to identify and study the available nuclear waste-disposal sites, ground water depletion, and the amount and type of ground cover. Landsat data have been found to be highly cost effective in meeting Mississippi's resource information needs.

Because of their synoptic coverage, Landsat data are particularly useful for regional management. In 1975, the Pacific Northwest Regional Commission, with support from NASA and the U.S. Geological Survey, started a project to investigate the applications of Landsat data to a variety of resource problems in the Pacific Northwest. The project's goal was to integrate these data with other data on the region's vegetation, soils, and terrain. The Pacific Northwest is particularly interesting ecologically because it is the site of two major, but contrasting, ecoregions—the Humid Temperate Domain of the coastal areas of Washington and Oregon, and the Dry Domain east of the Cascade Mountains.

Participants in the study concluded that the Landsat system was a cost-effective source of management data. However, a "critical mass" of individual agencies is necessary to prove the value of Landsat data on a State or regional basis. Although the cost of the necessary processing hardware and software constitutes a barrier to using Landsat data, "the most critical element is continuity of data. Without assurance of continui-

Table 5.—Summary of Operational Landsat Applications in the States

A. **Water resource management**
- Surface water inventory
- Flood control mapping and damage assessment
- Snow cover mapping
- Water resources planning and management
- Irrigation demand estimation
- Determination of runoff from cropland
- Watershed or basin studies
- Water circulation
- Lake eutrophication survey
- Irrigation/saline soil
- Geothermal potential analysis
- Ground water location
- Offshore ice studies

B. Forestry and rangeland management
- Forest inventory
- Forest productivity assessment
- Clearcut assessment
- Forest habitat assessment
- Wildlife range assessment
- Fire fuel potential
- Fire damage assessment and recovery

C. Fish and wildlife management
- Wildlife habitat inventory
- Wetlands location and analysis
- Vegetation classification
- Snow pack mapping
- Salt exposure

D. Land resources management
- Land cover inventory
- Comprehensive planning
- Corridor analysis
- Facility siting
- Flood plain delineation
- Solid waste management
- Lake shore management

E. **Environmental management**
- Water quality assessment and planning
- Environmental analysis or impact assessment
- Coastal zone management
- Surface mine inventory and monitoring
- Wetlands mapping
- Lake water quality
- Shoreline delineation
- Oil and gas lease sales
- Resource inventory
- Dredge and fill permits
- Marsh salinization

F. Agriculture
- Crop inventory
- Irrigated crop inventory
- Noxious weeds assessment
- Crop yield prediction
- Grove surveys
- Assessment of flood damage
- Disease monitoring

G. Geological mapping
- Lineament mapping
- Geological mapping
- Mineral surveys
- Powerplant siting
- Radioactive waste storage

SOURCE National Governors' Conference

ty, States (and therefore regions) cannot accept the risks of utilizing Landsat data as a primary tool."[7] Here, as in Federal use of land remote-sensing data for resource management, it was often important to share the primary data among State agencies, a practice that copyrighting them could prevent.

[7]Letter from Governor Straub of Oregon, State co-chairman of the three-State project, to NASA Administrator, 1979.

REMOTE-SENSING RESEARCH WITHIN THE UNIVERSITIES

Universities use Landsat data for research in a variety of resource and land-planning applications encompassing the entire range of remote-sensing applications. They develop techniques for specific applications and carry out research on the spatial and spectral characteristics of new, more powerful sensors. The universities work with local and State governments as well as with the Federal Government and industry. In some States, university researchers constitute the major source of remote-sensing information and support. University researchers have expressed concerns about the state of land remote-sensing policy, and about the proposed transfer of land remote sensing to the private sector. They would also like to see future research needs provided for.

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Overview of Landsat Applications in the 50 States

State	Water resources	Forestry/ rangeland	Wildlife management	Land resources management	Environmental management	Agriculture	Geologic mapping
Alabama	x	x		x	x		x
Alaska	x		x	x	x		x
Arizona	x	x	x	x	x	x	x
Arkansas				x		x	x
California	x	x	x	x	x	x	x
Colorado	x		x	x	x	x	
Connecticut							
Delaware	x				x		x
Florida	x	x	x	x	x	x	
Georgia	x	x	x	x	x	x	x
Hawaii		x		x	x		
Idaho	x	x	x	x		x	
Illinois	x	x		x	x	x	
Indiana		x	x	x	x	x	x
Iowa	x			x	x	x	x
Kansas	x		x	x		x	x
Kentucky	x	x	x	x	x	x	x
Louisiana	x	x		x	x	x	
Maine	x	x		x	x	x	
Maryland				x	x	x	x
Massachusetts					x		
Michigan				x	x		
Minnesota	x	x	x	x	x	x	x
Mississippi	x	x	x	x	x	x	
Missouri	x	x	x	x	x	x	x
Montana	x	x		x		x	
Nebraska	x	x	x	x	x	x	x
Nevada	x						
New Hampshire		x		x			
New Jersey		x		x	x		
New Mexico		x	x	x	x	x	
New York	x	x	x		x	x	x
North Carolina	x	x	x	x	x	x	
North Dakota	x		x	x	x	x	
Ohio				x	x		x
Oklahoma	x	x		x	x	x	x
Oregon	x	x	x	x	x	x	
Pennsylvania		x		x	x		x
Rhode Island							
South Carolina	x	x	x	x	x		
South Dakota	x	x	x	x	x	x	x
Tennessee			x	x	x		x
Texas	x	x	x	x	x	x	x
Utah		x	x		x		x
Vermont		x			x		
Virginia	x	x		x	x	x	x
Washington	x	x	x	x	x		
West Virginia		x			x		x
Wisconsin	x	x		x	x	x	
Wyoming	x		x	x	x	x	x

SOURCE National Governors Conference

Photo credit National Aeronautics and Space Administration

New York/New Jersey area as seen by Landsat 1

In gathering data for this section, OTA interviewed 21 people at 19 universities. Most are State universities with close ties to various State mapping and monitoring agencies that either now use Landsat data or are considering it for the future.

University Experience With NASA's Landsat Program

Because land remote sensing from space is a novel technique for obtaining information about the Earth's surface, its use requires innovative educational and training programs. With no previous community of users, exposure to the technology, training, and experience were needed to develop understanding of the potentials of Landsat data. Early in the development of the Landsat system, NASA instituted a Universities Program to demonstrate practical benefits from the use of remote-sensing technology to a broad spectrum of new users, principally in State and local governments. During the period 1972-82, NASA provided between $8 million and $10 million to universities a year as seed money for research, demonstration, and training in the uses of land remote-sensing technology.

A wide variety of State, local, and private organizations, as well as the recipient universities, matched NASA funds with direct financial support and in-kind grants. The university role assumed increased importance as NASA's satellite flight programs for remote sensing became better understood and emphasis shifted from the hardware to the resulting data and its users. A 1978 survey shows, for 20 selected universities, details about program duration, size, scope, and unique characteristics (see app. C). [a]

The interviewees generally agreed that university courses of instruction trained personnel in new applications of remote sensing. They pointed out that the close relationships established with other disciplines allowed prompt feedback to the universities, prompt assimilation of lessons, and rapid revision of instructional programs. The multidisciplinary course work and research have led to several new domestic applications of remote-sensing data. The universities have trained foreign students, conducted symposia, and assisted AID and other agencies in overseas development work. They have also assisted in introducing remote-sensing technology into the work of State and regional agencies. Their work has even resulted in the development of several small profitmaking value-added companies.

University Concerns Over Land Remote-Sensing Policy

The university remote-sensing community expresses major concerns about three general questions: 1) the future of land remote sensing in the United States, 2) the effect of current budget constraints on university research programs, and 3) the effects of future costs of Landsat data on teaching and research budgets.

"'Survey of University Programs in Remote Sensing Funded Under Grants From the NASA-University Space Applications Program," Battelle Columbus Labs, report No. BCL-OA-TFR-78-3, Mar, 31, 1978.

University researchers worry that both the operational and research aspects of the Landsat program lack direction. Uncertainty at the Federal level has led to even greater uncertainty at the local level. Industries, as well as Federal and State agencies, are reluctant to invest in their own research programs on Landsat applications until they are assured that land remote-sensing data will be continuously, promptly, and inexpensively available. This reluctance is having a significant negative effect on remote-sensing programs in universities throughout the country.

For the multidisciplinary centers of remote-sensing research (which were put together laboriously over a decade with Federal support) to continue their work, they will require assured budgets and flow of data. Decreased activity by Federal, State, and local agencies, and by private industry has caused many university programs to be drastically curtailed—staff have been reduced, researchers have redirected their efforts elsewhere. This trend is likely to continue until the overall direction of the Landsat program is defined or until the French SPOT program becomes operational. If a strong market for land remote-sensing data were to develop, some funding through private industry would likely become available, In the meantime, universities are losing the qualified, experienced, and knowledgeable people needed for remote-sensing research.

The third major concern is the cost of Landsat data. Table 6 shows past, present, and future costs of a few of the Landsat products. For teaching purposes, a professor often needs multiple copies of a single image. Even if he or she can use the same data in subsequent semesters, it soon becomes frayed, torn, and marked up. The teaching budg-

Table 6.—Costs for Some Landsat Data Products

	Cost			
Product	Until October 1981	October 1981 — October 1983	October 1983– February 1985	February 1985— ???
Multispectral scanner (MSS) computer-compatible tape (CCT)	$200	$ 650	$ 650	$ 730
Thematic mapper (TM) CTT	Not available	$2,800	$3,400	$4,400
TM CCT (quarterly)	Not available	$ 750	$ 925	$1,350
Color composite image (1:250,000 scale):				
MSS	$50	$ 175	$ 175	$ 195
TM	Not available	$ 235	$ 275	$ 290

SOURCE National Oceanic and Atmospheric Ad-ministration ets for supplies and equipment in many universities are extremely modest. As one university professor explained:

> Ordering just four color prints of a thematic mapper image would exhaust my entire teaching budget for all of my courses for an entire year! As of February 1985, a single frame of thematic mapper data in CCT format would cost more than is contained in my total teaching budgets for 4 years! It is quite clear that these prices will (and already have) caused me and many other teachers to modify the course content, decrease the availability y of "hands on" laboratory materials for the students to use, and virtually eliminate future orders for Landsat products to use in the classroom."9

This and similar examples from other universities demonstrate that the long debate over the fate of land remote sensing in the United States has negatively affected the quality of education in remote-sensing techniques as well as further decreasing the volume of products being ordered.

Issues Raised by Proposed Transfer to the Private Sector

The issues of the proposed transfer are imbedded within the general concerns of the university research community towards Federal land remote-sensing policy in general:

- **Continued, open availability of data.** This is mentioned most frequently as the major issue. As understood by university researchers, it includes a predictable and affordable price structure, perhaps with special rates for nonprofit groups, and the absence of restrictions on use of the data. In other words, OTA's respondents were opposed to copyrighting the corrected data. *
- **Research and training support. For the universities to continue their programs, they** will need assurances that Federal funding for scientific research, methods-development, and training will continue. Even if the proposed transfer to private ownership is highly successful, it will take many years for the market to build to the point that the private sector and the States can support these important university programs. In the meantime, an important resource and the pool of skilled labor will have dwindled to the point that rebuilding them will be extremely expensive and time-consuming. Teaching programs in remote sensing have declined and both professors and students are directing their efforts elsewhere.
- **Data quality.** The quality of the data over time needs to be assured to obtain the value of repetitive coverage. This is especially important for agriculture and forestry. Some respondents expressed concern that the consistency of the radiometric and geometric corrections, which are now carefully controlled by university and Government experts, may degrade under private operation. Still, it would be in the best interests of a U.S. private operator to maintain its data at a high level of quality because of competition with SPOT Image or other U.S. private companies.
- **Continuing university input.** Members of university remote-sensing programs fear that transfer to private hands will diminish the public-good aspects of land remote sensing and reduce their role in finding new and better ways to use the data.
- **Long term data trends.** Plotting potentially harmful changes on the Earth's surface requires data to be continuously available and safely stored for later retrieval. It also requires a research community with adequate resources. University researchers express concern that transfer to the private sector may mean a loss of data continuity, reduction in the quality and quantity of the archival material available, and reduction in Government support of research in this important area.

'OTA Workshop on Remote Sensing, July 26, 1983.

'Corrected data are the raw data as received from the spacecraft, corrected only for radiometric and geometric distortion. This is the way the data are now sold in standard packages from the EROS Data Center.

USING HIGH-RESOLUTION DATA

Thematic Mapper (TM)

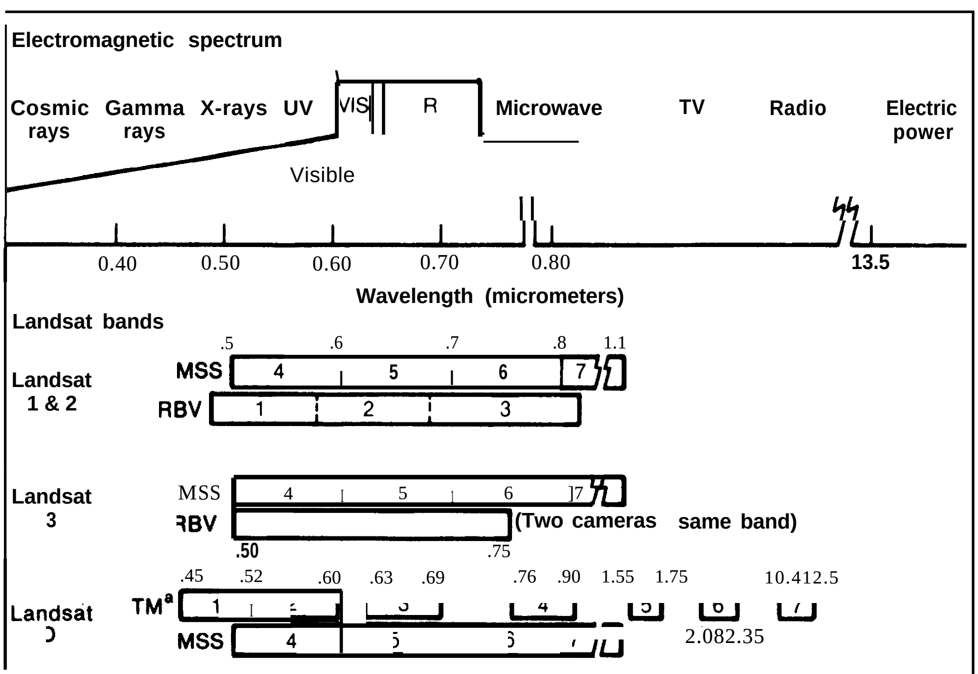
Most research and applications projects using Landsat data have used MSS data having a nominal spatial resolution on the ground of *80* meters and four spectral bands. The TM, which is operated by NASA as a research instrument, has a much improved 30-meter spatial resolution and seven spectral bands. Studies with simulated TM data sensed from aircraft, as well as with some of the early TM data from outer space, indicate that this higher spatial resolution will enable major advances in the utility of such satellite data.

For example, NASA research suggests that in suburban areas land-use classification accuracies of *89* percent are possible. In urban areas, the potential accuracy is difficult to estimate before more detailed research is done .'" Certain aspects of TM data have great promise. For tasks where spatial discrimination is important, such as mineral exploration, high resolution is the most obvious improvement over data from the MSS; other attributes of the system are equally remarkable from a technical standpoint. The TM digital data come in an eight-bit configuration which potentially will offer more information content than the six-bit configuration of the MSS data. In addition, the seventh spectral band is thermal which, when combined with the other six bands, can be expected to provide new interpretive capacity.

For agriculture, the real advantage of the TM derives from the narrowness of the spectral bands as well as their extension into the near infrared at 2.2 micrometers and thermal infrared at 11 micrometers, These attributes make the TM much more than a high-resolution MSS. Initial analyses of the TM data from U.S. agricultural areas show much sharper delineations of crops having different textures and tone. These observations suggest that TM data will be much more capable of sep-

'"Dale A. Quattrochi, "Analysis of Landsat-Y Thematic Mapper Data for the Discrimination of Urban Features, " Decision *Support Systems for Policy, and Management,* Urban and Regional Information Systems Association Annual Conference, Atlanta, Ga. , August 1983.

Landsat Bands and Electromagnetic Spectrum Comparison



[a]Thematic mapper.

SOURCE U S Geological Survey

arating corn from soybeans and, perhaps, barley from spring wheat. The improved resolution also offers significant improvements in delineating drainage in and around agricultural areas.

For forestry, the major improvements provided by TM data will probably include increased accuracy of measuring areas occupied by different types of vegetation—a highly significant improvement for forestry applications (see, however, below). The additional detail in the Landsat data should enable more accurate analysis of the data as well—small forest stands, roads, streams, and other features not discernible on MSS images are clearly seen in TM data.

For petroleum geology, the improved spatial and spectral resolution of TM data have already proved their usefulness. Nonetheless, those who specialize in locating new sources of oil or other minerals have indicated that the ability to sense Earth in stereo would be more important to their industry than the increased number of spectral bands or higher resolution.'[1]

As the case of forestry illustrates, in some situations different analysis techniques will be necessary effectively to utilize the increased spatial and spectral resolution of the TM data. A recent study[12] showed that with standard "per-pixel" classification techniques, as the spatial resolution of the pixels improves, the ability to classify forested areas with accuracy decreased significantly. Indeed, with data having 30-meter spatial resolution, overall classification performances were considerably poorer than with Landsat MSS data of much lower resolution. The use of 15-meter-resolution data resulted in a significant decrease in overall classification performance.

These results substantiated earlier studies" that found a similar decrease in classification performance with increasing spatial resolution primarily in areas of forest cover, but not in agricultural cover types. The reason is that images having higher spatial resolution allow more detailed spectral data to be obtained. Thus, in forested areas, the spectral response of one resolution element of TM data could be dominated by tree crown, whereas the adjacent resolution element could be dominated by the shadow area between tree crowns, and so forth. The coarser spatial resolution of Landsat MSS data averages such spectral differences, resulting in much less variability from one resolution element (pixel) to the next.

In agricultural areas, where the field size is larger than the 80-meters resolution of the MSS instrument, approximately the same percentage of row crop, bare soil, and shadow is being sensed and integrated into the spectral response of each resolution element, whether it be a 30- or 80-meter spatial resolution. To take full advantage of the higher spatial resolution of the TM data for forestry applications, therefore, the standard per-pixel methods of analysis must be replaced by finer methods using both the spectral and the spatial information of the data. This finding brings out three key points which apply as well to uses of TM data other than forestry:

1. Different disciplines may need to apply different analysis techniques in order to use the same type of land remote-sensing data (e.g. geologic analysis techniques often are significantly different from those used in agriculture).
2. Changes in sensor systems may cause such significant changes in the characteristics of

' Michael T Halbouty statement on Civil Remote Sensing Systems before the Subcommittee on Space Science and Applications of the House Committee on Science and Technology, and the Subcommittee on Science, Technology, and Space of the Senate Committee on Commerce Science and Transportation (97th Cong), July 22 and 23 1981 pp 213-2.32.

[12] R M Hoffer M E Dean, D K Knowlton, and R S Latty, Evaluation of SLAR and Simulated Thematic Mapper Data for Forest Cover Mapping Using Computer-Aided Analysis Techniques. LARS Technical Report 083182 Purdue University West Lafayette Ind , 1982

[13] E. P. Kan and F. P. Weber, "The Ten Ecosystem Study: Landsat ADP Mapping of Forest and Rangeland in the United tates," Proceedings of the 12th International Symposium on Remote Sensing of Environment, Ann Arbor, Mich., 1978, pp. 1809-1825; F. G. Sadowski, W. A. Malila, and R. F. Nalepka, "Applications of MSS Systems to Natural Resource Inventories," Proceedings of the National Workshop on Integrated Inventories of Renewable Natural Resources, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-55, USDA Forest Service, Fort Collins, Colo., 1978, pp. 248-256.

the data that entirely different analysis techniques must be developed and tested,

3. The sheer volume of data in a TM scene for seven spectral bands will limit their use. Research efforts should be directed to offering the ability to select a windowed array of data from anywhere in the scene; currently only a quarter subscene is available on special order from the EROS Data Center at Sioux Falls, S. Dak. Thus, if one wants to process a portion of Earth's surface located near the center of the four quarter-scenes, it is necessary to order a full scene.

So far, investigators have devoted relatively little attention to evaluating TM data other than studying the quality of the data received. Neither NASA or NOAA have conducted formal applications tests. Therefore, one can only speculate on the uses or value of TM data for forestry, agriculture, or even geologic applications.

The French SPOT System

The SPOT satellite, with its 20-meter resolution, three spectral bands, and ability to point the sensors, promises to provide coverage not available through the existing Landsat system. SPOT's pointability (i.e., the ability to obtain images at angles to the vertical) will enable repetitive coverage of transient phenomena. [14] To take one example, between April 13 and 18, 1979, the Pearl River Basin in Mississippi, rose to an unprecedented level of 43.5 ft and devastated Jackson, the State capital. Providing cloud cover did not interfere, if coverage comparable to SPOT's (e.g., pointability and resolution) could have been obtained on April *15, 16,* or 17, estimations of damage and analysis of the event could have been greatly improved. Landsat 3, which was in use during the flood, passed over shortly before the torrential rains occurred and again just as the flood waters receded (an 18-day period).

The 20-meter resolution of SPOT data may not prove to be as valuable as its paintability because higher resolution data have a point of diminishing returns. The sheer volume of data resulting from such high resolution over a large study area can quickly overload the storage and data-handling capacities of most computer systems now processing Landsat data. This problem is faced already by analysts attempting to use the TM data. The fact that SPOT will use three bands, rather than the TM's seven, will ease the problem of handling data volume at the expense of losing important spectral information. In addition, the SPOT satellite will sense a narrower swath of Earth's surface. Each scene will be proportionately smaller, making the data handling problem easier per scene. *

SPOT has flown simulated missions in the United States, and the results of these will answer

“W. G. Broome, Larry J. Warwick, and G. Weill, “SPOT Satellites: A Major New Information Source for Urban and Regional Environments, ” *Decision Support Systems for Policy and Management,* **Urban and Regional Information Systems Association** Annual Conference, Atlanta, Ga., August 1983.

● The SPOT sensor views a ground swath 60-km wide compared to a swath width of 185 km for Landsat.

The SPOT Satellite

Characteristics of the high resolution visible (HRV) instrument	Multispectral mode	Panchromatic mode
Spectral bands	0.50-0.59 µm 0.61-0.68 µm 0.79-0.89 µm	0.51-0.73 µm
Instrument field of view	4.1 3°	4.13”
Ground sampling interval (nadir viewing)	20 m x 20 m	10 m x 10 m
Number of pixels per line	3,000	6,000
Ground swath width (nadir viewing)	60 km	60 km
Pixel coding format	3 x **8** bits	6 bits DPCM[a]
Image data bit rate	25 M bits/s	25 M bits/s

[a] DPCM (digital pulse code modulator) is a mode of data compression that does not degrade the radiometric accuracy of the image data (256 grey levels)

SOURCE SPOT Image

many questions about its future application. Some State agencies and other public and private groups are interested in formatting SPOT data to use existing Landsat processing computer software. If totally new software is required, it will slow the use of SPOT data.

Comparison of SPOT and TM Data

It appears probable that the enhanced resolution of either TM or SPOT data would be of significant value for measurement, but how the seven channels of TM data will compare to the three channels of SPOT data is still a matter of conjecture. * The middle infrared portion of the spectrum (available only with TM data) should eventually prove invaluable for geologic and snow cover mapping purposes. For forestry applications, the differences between TM and SPOT data are not obvious. It would be surprising if the stereoscopic capability of SPOT data had any major advantages in forestry, unless topographic maps for the area of interest did not exist, a condition that is much more likely in developing countries than i n the industrialized ones. As mentioned above, however, it should be highly useful to the geologists, and will also improve the ability of mapmakers to generate high-resolution t(~pographic maps. The higher resolution of TM, SPOT, or future systems may eventually prove to be very useful in differentiating and categorizing different varieties and maturity of trees, which would allow better estimates of timber- volume in a forest stand. It will also allow agriculturalists to estimate crop production better in countries where the average field size is significantly less than the 80-meter resolution of MSS data.

Investigators have frequently raised questions about the advantages of various data formats or types of data from future proposed instrument systems. Such quest ions clearly indicate the need for an effective, ongoing research program to provide guidance and direct ion in developing meaningful operational systems.

For operational uses, TM data will tend to be used in a sampled mode rather than as complete coverage. This may limit the sales of TM data once the newness wears off, even in the petromining industries where the data have received high praise. At over $4,000 per frame, even the petroleum exploration geologist will tend to look at narrow areas rather than broad ones.

Advances in technology, such as high spectral and spatial resolut ion sensors, when linked with on-board data processing and improved computer processing may aleviate some of the near-term problems investigators expect to experience in using high-resolution TM or SPOT data.

*When data from the recent simulated SPOT flights are fully studied, it will be possible to compare the data from the two systems.

REMOTE-SENSING ARCHIVES

Data gathered from meteorological satellite observations are obviously useful for short-term weather predictions. Less well-known is their part in forecasting over periods of weeks, years, centuries i.e., in the long-term prediction of climate. As we learn more about the long term effects of such climatic effects as El Nino (see app. H) and increased atmospheric levels of carbon dioxide, the utility of satellite data for climate studies becomes apparent. The operational weather satellites make major contributions to the long-term global climate record kept by the National Climate Program within NOAA. It assembles these data and combines them with other satellite and terrestrial data from the Department of Defense, the Department of Energy, USDA, the National Science Foundation, and NASA to produce world climate models.

Through this program, the Government has developed the mechanism to assemble and store meteorological data to meet the research needs 01 climatologists and others who require historical data about the weather. These data are recognized as a national resource and are treated accordingly. To continue the research on weather and climate, it will be important to continue to archive satellite data. Continuity of the format of the data stored in the archive is particularly important:

> The overriding requirement is for a continuous, intercomparable data record for a span of time that is climatologically significant . . . the longer the more valuable it is in determining the likelihood of "extreme" occurrences. "[15]

For Landsat data, the EROS Data Center in Sioux Falls, S. Dak., maintains an archive containing most of the data it has received. Although the archive includes foreign scenes taken by Landsats 1, 2, and 3 when their recorders were operating, and some other foreign scenes acquired by special agreement with foreign ground stations, the vast majority of these data are domestic scenes. The EROS Data Center does not sell most foreign data, either current or historical. Normally, customers must purchase data acquired from foreign ground stations directly from the stations in question.

The expense of maintaining a complete archive of all the data ever received from the Landsat system is great; in fact, not all data are equally worth saving, and it would be helpful to purge the archive of certain scenes, such as those containing a high proportion of cloud cover and duplicate scenes. However, obtaining a complete set of cloud-free data for the entire world would be a worthy goal. Such a data set would be especially useful for mapping, land-use planning, mineral exploration, deforestation, and desertification. Because of lack of funds, this has not been done so far, although NOAA and NASA recognize the value of such an archive. One of the problems in setting up such a worldwide data set is that the various foreign ground stations use slightly different standards for data acquisition and storage: the data are not entirely comparable.

Whatever form the archive were to take, the Government would have to decide whether the limited archive maintained at the EROS Data Center would be transferred to the private sector and under what conditions. If the archive were transferred, safeguards to protect it from later deterioration or destruction should be instituted so that all interested parties would continue to have access to these data, at least, without copyright restrictions.

[15]Civllian *Space Policy and Applications, op. cit.,* p, 344.