X-900-75-250
PREPRINT

NASA TM X- 71010

THE IMPACT OF EARTH RESOURCES EXPLORATION FROM SPACE

(NASA-TM-X-71010) THE IMPACT OF EARTH RESOURCES EXPLORATION FROM SPACE (NASA) 13 p HC $3.50 CSCL 08G
N76-11545
Unclas
G3/43 02397

WILLIAM NORDBERG

SEPTEMBER 1975

GSFC
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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CONTENTS

	Page
INTRODUCTION	1
THE LANDSAT SYSTEM	2
POTENTIAL IMPACTS	3
A. Management of Food, Water, and Fiber Resources	3
B. Exploration and Management of Mineral and Energy Resources	5
C. Protection of our Life Sustaining Environment	6
D. Protection of Life and Property	8
E. Improvements in Shipping and Navigation	9
CONCLUSIONS	10

THE IMPACT OF EARTH RESOURCES EXPLORATION FROM SPACE

INTRODUCTION

In contrast to the use of satellites for weather forecasting and for intercontinental communications, which have been available for more than 15 years, surveys of earth resources with satellites have begun only a few years ago. The impact of earth resources surveys from space on society is therefore still much more a matter of speculation than a matter of record. Nevertheless, during three years of successful operation of the LANDSAT system, we have gained enough experience to assess the potential impact of global surveys with satellites of: crops, forests, grasslands, and soils on agricultural predictions; of snow cover and watershed morphology on water resources management; of land use, water and air quality on environmental protection; and of land forms and tectonic structure on mineral exploration.

It appears paradoxical that one would want to go to outer space, to satellites orbiting many hundreds of kilometers above the Earth, to learn something useful about our immediate environment. However, the ever increasing demands that are posed by the increasing population on the resources and environmental conditions of this planet, are making it mandatory to devise methods for the global assessment of the present as well as future state of our food, fiber, water, mineral, and energy resources. Such assessments will be necessary to manage the extraction, distribution, conservation, and renewal of these resources. Yet, it is evident that it would be prohibitively expensive to make such assessments frequently and over large areas of the world with conventional monitoring methods.

On the other hand, satellites can observe almost the entire globe within a relatively short time period (12 hours to 18 days, depending on the desired spatial resolution); also, satellite observations recur frequently and regularly for periods of many years at very low incremental cost (the LANDSAT 1 system is still functioning after 3 years of operation); and satellite observations are made everywhere by the same instruments under the same controlled conditions, so that versatile, thematic maps can be readily produced.

Satellites are, therefore, the only economical and practical tool from which we may expect to obtain the kind and amount of information necessary for global management of earth resources and for protection of our life sustaining environment.

THE LANDSAT SYSTEM

The one satellite system that has been used widely for the purpose of surveying earth resources and of observing environmental impacts, though only experimentally, is the LANDSAT system of the USA. Two LANDSATs are now in such orbits that polychromatic images in four spectral bands of reflected solar radiation can be taken along 185km wide strips, anywhere in the world, every nine days. But, LANDSAT 1, which was 3 years old in July, 1975, yields data only within broadcast range of a receiving station; it cannot store pictures on its tape recorders anymore. Therefore, observations every nine days using both LANDSATs, are possible only where such receiving stations exist. This is the case for North America, via three US and one Canadian station; and over South America, via a Brazilian station; it will be the case soon over Europe and North Africa, via the station that is just now being completed over Italy; and over southwest Asia, southeast Europe and northeast Africa via a station that is being procured by Iran. A station proposed to be located in Zaire, would cover most of the remainder of Africa. Interest in such receiving stations has also been expressed by a variety of additional countries, so that the thematic mapping which can be accomplished every nine days by the two LANDSATs, is expected to cover increasingly large areas of the world. Other areas, which are not within range of such receiving stations, must depend on the data stored on the tape recorders that still function on LANDSAT 2. Such coverage occurs, of course, much less frequently. Namely, one to several times per year, depending on interest expressed by people in these areas.

The third LANDSAT, LANDSAT C, is expected to be launched in 1977. In addition to images in four bands of reflected light, it will make images of surface temperatures at a somewhat lesser spatial resolution, namely at about 200 meters. Adding this temperature mapping capability to the LANDSAT system, will improve significantly our capability of classifying crops, vegetation and soils. Also for 1977 and in addition to LANDSAT C, a Heat Capacity Mapping Mission (HCMM) is planned to map surface temperatures from a satellite that will sweep the Earth at hours of maximum and minimum heating. It is expected that soil moisture patterns, and soil or rock compositions can be distinguished better with such a satellite than with LANDSATs which do not scan the Earth at times that are optimum for this purpose.

Finally, we may expect that by 1980 earth resources surveys will be improved with the development of a new thematic mapper. This instrument would perform measurements with greater radiometric accuracy, at six spectral bands, more appropriately placed, and with greater spatial resolutions than the present LANDSATs. However, a satellite mission to fly this thematic mapper has not yet been approved in the United States.

Observations resulting from the LANDSATs have been analyzed for a great variety of purposes by many hundreds of individual investigators in more than 40 countries. These investigations had been formally negotiated with NASA and many of their results have been published. Also, many governmental organizations, especially in the USA, Canada, and Brazil have applied LANDSAT observations as aids to their operations, such as sea and lake ice surveys, preparations of environmental impact statements, water runoff predictions, flood potential assessments and updating of navigational charts, as well as of geological and general purpose maps, especially in sparsely populated or rapidly changing areas. In addition, several tens of thousands of individuals and organizations from all over the world have purchased LANDSAT data for their private purposes from one of the public data centers which the US has established. All this has resulted in an excellent basis for assessing the potential impacts of earth resources surveys from space.

POTENTIAL IMPACTS

Information extracted experimentally from two LANDSATs, several NIMBUS, and the SKYLAB space flight missions has been used to demonstrate that a number of major problems which beset mankind today could be addressed by surveys with satellite systems. These problems are:

(A) Management of food, water, and fiber resources;
(B) Exploration and management of energy and mineral resources;
(C) Protection of our life sustaining environment;
(D) Protection of life and property;
(E) Improvements in shipping and nevigation.

(A) Management of Food, Water, and Fiber Resources

One of the world's major concerns today is the production and distribution of food crops. World population projections indicate a need for a three-fold increase in world food supplies to be distributed by the year 2000. World grain reserves have shrunk from 26% of annual consumption in 1959 to 7% in 1974. North America has become the only major grain exporting region in the world.

The management of the production and distribution of food could be aided immediately by a global census and prediction of crop yield and by a survey of rangeland conditions in major cattle feeding areas of the world. Such a census would be updated at frequent intervals. LANDSAT observations have demonstrated that, given appropriate sampling from surface based observations, most major crops can be identified in sequential satellite images and that acreage measurements for these crops can be made with an accuracy of better than 90%. Thus, a satellite based, global crop survey should be feasible now. Similar findings have also been obtained from LANDSAT observations of rangeland conditions. The feeding capacity of major grazing areas could also be estimated from satellite observations, if properly augmented with ground based information. These estimates could be used for the proper distribution and control of livestock, particularly in grazing areas where marginal conditions occur frequently, such as in the American West.

While results from past LANDSAT flights have proven the feasibility of making crop and forage inventories with satellites, they have not yet resulted in any large scale determinations of agricultural yield. Investigations are now in process to make such yield determinations, but they require a combination of observations from various satellite systems, including weather satellites. Such a yield prediction system would combine the crop identifications and acreage mensurations that are already being made with LANDSAT, with: (1) analyses of soil types which can also be obtained from LANDSATs; (2) information on cloudiness, insolation, and rainfall which would be derived from existing meteorological satellites; and (3) with soil moisture information that could be derived from passive microwave measurements such as are now being performed with NIMBUS or from radar observations that are expected to be available from early flights of the SPACELAB.

Information resulting from such satellite-based crop and forage inventories and from yield predictions would result in both improvements in the planning for global distribution of grain crops and improvements in crop and rangeland productivity. The latter would be achieved by improved decisions on planting, watering, fertilization, pest control, harvesting, storage, and on cattle feeding. The former would be achieved through proper allocation of transportation requirements, earlier warning of crop failures, lesser fluctuations in markets, more rapid fulfillment of requirements and effective planning and monitoring of trade agreements. Economic benefits from these plus from a stabilizing effect on the commodity market have been estimated to range from about $10 million per year to several hundreds of millions per year.

Another satellite based observation capability which should have a major impact on the management of food, as well as energy resources, is the survey and prediction of availability of water. The world's demand for water has increased markedly, as population has increased and nations have increasingly industrialized.

In many areas of the world, such as the western United States, the annual water runoff from snow melt is being used to fill these demands. Sequential snow cover observations from LANDSAT have supplied information on the rate of melting and on the volume of water released subsequently. In ungauged, inaccessible and remote watersheds, LANDSAT snowcover data which have been related to seasonal runoff are the only means to provide early estimates of water supply. Even in areas where snowpack is monitored by conventional networks, satellite snowcover data have been used to correct runoff forecasts. These corrections often amount to 25% of total predicted runoff.

Since water runoff is managed by controlling the flow from a series of reservoirs with flood prevention as a governing criterion, better estimates of runoff accuracies will avoid the dumping of water based on erroneous runoff predictions, more accurate runoff predictions therefore will result in more water being available for irrigation, power generation, and industrial use. The value of this improved efficiency in water utilization has been estimated to be between 20 and 50 million dollars per year, in the USA alone.

LANDSAT observations have also been effective in recognizing, locating, and mapping the broadest classes of forest land and timber. Deciduous, evergreen, and mixed forest communities have been identified. Total acreages of various types of forests have been measured and changes, such as produced by cutting or new seeding, have been readily detected, under certain conditions, timber volume, age of forests, and presence of disease has been determined. But, such satellite surveys must be supplemented by on-site and aircraft measurements in judiciously selected areas to delineate changes and patterns on scales that are not detectable by satellites and to satisfy the needs of local forest management. Such an integrated monitoring system will have appreciable impact on regional logging, thinning, reforesting, and pest prevention operations, in addition to national economic planning and conservation actions. Estimates of annual economic benefits from a combined satellite/aircraft/ground sampling system for the USA range from $1 to $3 million for a national forestry inventory to $27 million for a system that could be applied to regional forest management decisions.

(B) Exploration and Management of Mineral and Energy Resources

The world's consumption of important minerals has increased more rapidly than the population. Known reserves of many critical minerals range only up to 25 years and no new significant and proven major deposits have been found since 1950 for many of these materials. Energy consumption has increased even more dramatically and estimates of fossil fuel lifetimes to support this growth, range from decades up to 100 years. Exploration for minerals and petroleum can be aided by satellite observing systems which are capable of mapping synoptically the geomorphology and general geological environment of very large areas. Such mapping can also facilitate the siting of power generating plants thus minimizing the cost of environmental protection and resulting in low cost for energy.

Analyses of geological lineaments observed by LANDSAT have demonstrated that tectonic features such as faults or fractures can be identified and mapped, and that these features may be indicative of unexplored mineral deposits. Landforms such as salt domes have been identified and their relationship to petroleum deposits has been established. Color tone differentiations observed by LANDSAT have permitted the delineation of rock types, vegetation or soil differences, each again leading to possible conclusions regarding mineral deposits; some of these color tones have been related to oxidation or other chemical reactions on the surface which may imply mineralization or petroleum deposits. A study of LANDSAT images of northern Alaska has revealed an interesting alignment of lakes over distances of several hundreds of kilometers which has led to speculations about the extension of petroleum exploration in northern Alaska.

The major impact of satellite observing systems on the mineral and energy resources problem is a reduction in the time it takes to complete the exploration cycle, lowering exploration costs by reducing the amount of more expensive geophysical, geochemical, and seismic surveys; and reducing the costs of analyzing the potential environmental impact of operations related to mining and energy generation.

(C) Protection of our Life Sustaining Environment

General population growth accompanied by extensive economic and industrial growth has resulted in significant pressures upon our finite land, water, and air resources. As far as land resources are concerned, large areas will be consumed by urban sprawl, and some have estimated that by the year 2000 the "urban impact zone" will include a third of the area of the USA. The siting of nuclear power plants, coastal zone development, mineral extraction from near surface, and the need for the preservation of wildlife, wildland, and agricultural land all call for complex land management decisions. These decisions will depend on vast amounts of timely information that can be provided economically only by satellites. For example, land use planning has been severely hampered by the lack of suitable maps showing the types of land use over large regions and their changes with time. Such maps are needed on scales ranging from 1:25,000 to 1:500,000 and are outdated or unavailable even for many parts of the USA, because of the prohibitive costs of making frequent surveys with conventional methods. The situation for the rest of the world is even less satisfactory. Vast areas of Africa, Asia, and South America are poorly, and often incorrectly, mapped. Over the last 20 years, a project sponsored by UNESCO has completed a series of land use maps at scales of 1:5,000,000 to 1:20,000,000. But, these maps are insufficient in detail to assist developers and managers in many of their decisions. Images produced with the LANDSAT system have resulted in the capability to map land use, practically anywhere in the world, at least once a year on a scale as large as 1:250,000. A detailed land use map of a three-state area of Massachusetts, Connecticut, and Rhode Island, in the USA, was prepared from LANDSAT images and eleven separate land use categories were identified and mapped. The time it took to compile the information for this particular survey amounted to 2 to 3 months, which is one-tenth of the time it would have taken with conventional methods, such as aerial surveys. The cost of making such a survey by conventional methods would have been about one order of magnitude greater than that of making the survey with satellite data.

Environmental impact assessment and improved reclamation planning has also been demonstrated with data obtained from LANDSAT. For example, destruction of vegetation by fumes and timber cutting due to copper mining operations around a 90 square kilometer area in Tennessee, USA, was observed in a 1:250,000 scale reproduction of a LANDSAT image. Various degrees of vegetation denudation could be clearly mapped. LANDSAT images have also revealed the denuding of vegetation in Ontario, Canada, where prevailing winds carrying sulfur dioxide fumes from a local sintering plant have caused similar damage. In western Maryland and in Ohio, USA, the extent of coal strip mining and the progress of reclamation is being monitored. Acreage figures are being compiled for seven land use classes, ranging from stripped earth to fully reclaimed land. This monitoring technique provides more timely, accurate, and complete data than are available from conventional surveys on reclamation of the mined areas. Satellite observations, therefore, can be used to delineate and measure the degree of vegetation damage from industrial operations in a most economical, rapid and objective manner.

In developed and industrialized nations, there are numerous national and local laws, regulations, and land use practices which could not be enforced without the type of land resources information that is provided by satellites. Estimates of economic benefits in the USA range from $10 to $115 million per year based on varying assumptions, but not taking into account any improvement in the "quality of life." However, the need for satellite land use surveys is not confined to industrialized nations. Developing countries have as much or greater needs for surveys of soil characteristics, water availability, and vegetation cover to plan for orderly developments and management of their land resources.

Similar considerations hold for the need to improve and conserve water quality and to provide timely, effective, and economical information to enforce such conservation. The Federal Water Quality Act of 1972 was established in the USA to regulate the discharge of effluents into the bodies of water of that country. Other laws and regulations govern ocean dumping to protect the offshore marine environment and the coastal zones. Surveys from space provide the broad view that is required for regional water quality management and enforcement of national or international regulations. Satellite techniques have been and are being developed so that they may be of value to those charged with the enforcement of water quality controls. As yet, only few of the most important water quality parameters may be monitored from space; namely, surface temperature, algeal blooms, turbidity and sediment distribution, and possibly large-scale petroleum spills. Techniques are now being developed for the remote sensing of more specific quantities relating to water quality and for mapping these quantities with greater spatial resolution than was possible with LANDSAT.

Satellite monitoring of air pollution is as desirable as is monitoring of land use and water quality. However, there are not yet any systematic surveys of air quality with satellites that could aid in the enforcement of air quality regulations. The transient nature of air pollution requires frequent observations of which the LANDSATs are not capable. Nevertheless, LANDSATs have detected significant aspects of this environmental problem. A highly polluted, stagnant air mass extending over an area of about 200 x 100 km was observed over an exclusively rural area of the eastern United States during August, 1973. This is an area in which no industrial or other pollution sources are located. Yet, the satellite has shown that such pollution had drifted in from the highly industrialized areas some 500 km to the northwest. Similarly, smoke plumes emitted from steel mills in the state of Indiana, USA, have been traced in LANDSAT images 200 km across Lake Michigan, as they formed condensation nuclei over the Lake and caused heavy snowfalls on the other shore in the state of Michigan. Experiments to demonstrate primarily the feasibility of monitoring air pollution from space on a more systematic basis will be conducted with NIMBUS-G in 1978.

(D) Protection of Life and Property

Aside from the property and lives that can be saved through the use of satellites in achieving more accurate forecasts of severe weather, there is a potential impact of space based observations of geological and tectonic features on the prediction of earthquakes, volcanic eruptions, and on the planning of construction and reclamation projects.

Preliminary experiments conducted with high precision laser tracking of satellites and radio-interferometric tracking of quasars have resulted in indications that such techniques might be used to measure directly tectonic motions which are of the order of several centimeters per year. Such measurements could provide advance warnings of earthquakes much earlier than is now possible with conventional techniques. However, it will take at least the next 5-10 years to refine our ability of making such high precision distance measurements between and within tectonic plates.

On the other hand, mapping of regional lineaments observed in LANDSAT images has already resulted in delineating seismic hazards not otherwise recognized. Investigators have discovered evidence of recent movement along faults in an area of California that had long been considered to be inactive. A mosaic of LANDSAT images of central Alaska has clearly revealed the presence of new sets of lineaments that correlate well with the distribution of shallow-focus earthquake epicenters in that region. At least one volcanic eruption has been observed by LANDSAT and the amount of debris discharged into the atmosphere could be estimated from the size of the plume which could be measured precisely in the image. However, LANDSAT observations occur much too infrequently to be useful for the detection, leave along prediction of volcanic eruptions. Such operations are depending on the LANDSAT data collection system which relays seismic and other geophysical information from remote, automatic, and in-situ sensors.

LANDSAT images have been used to delineate geological hazards to civil construction projects and to facilitate the planning of such projects. For example, an active leg of the Denali Fault was found to lie close to a proposed bridge site over the Yukon River, and the proposed path of the Alaskan oil pipeline. Sequential LANDSAT images of the great Kavir area in Iran were used to delineate seasonally wet, rough, and unstable ground. This analysis resulted in the planning for a new road alignment that would considerably shorten the present route between northern and central Iran.

LANDSAT 1 images have also proven to be effective in identifying surging glaciers and monitoring the areal extent of their change. Surging glaciers can advance very rapidly over large land areas and can cause devastating flooding by blocking and then suddenly releasing large quantities of meltwaters.

(E) Improvements in Shipping and Navigation

The growing requirements for oceanic bulk transportation and the increasing size of fleets as well as of individual ships (e.g., supertankers) accentuate the need for monitoring and predicting those factors which affect the efficiency and safety of sea transportation; namely, sea state, sea and lake ice distribution, ocean currents, and hazards to navigation. The cost of a world-wide system utilizing buoys or ships to measure these parameters on a fine enough grid scale would be prohibitive. Some of these parameters have already been observed by remote sensing from satellites, sea and lake ice has been surveyed by LANDSATs and the results have been applied to aid geophysical and geological exploration in the Canadian Arctic and Great Lakes shipping in North America. Bathymetry has been performed on LANDSAT images and shoals, reefs, and sedimentation patterns have been mapped to update navigational maps, particularly in coastal zones. In fact, LANDSAT observations are now being used in the USA to update all navigational charts including those for air navigation. Although ocean currents have been recognized and mapped with both temperature observations from meteorological satellites and with LANDSAT images, satellites have not yet produced the type of current measurements that would be useful to shipping forecasts. A similar situation holds for satellite observations of sea state, the feasibility of which has been demonstrated in many aircraft flights and by SKYLAB. But, in contrast to sea ice surveys and observations of navigational hazards, sea state and ocean current measurements from satellites are not expected to have any major impact on maritime operations before the early 1980's. Eventually, improvements of ship routing based on such satellite surveys is estimated to result in benefits of $30-50 million per year to US trade. Benefits to Canadian Arctic operations and offshore oil production would potentially increase this amount by a factor of four. Additional benefits would accrue from iceberg reconnaissance and the optimization of ship routing from the Alaskan North Slope Oilfields. Such surveys will also have a substantial impact on increasing coastal activities; such as, the construction of superports and on the prediction of the potential environmental hazards of very large supertankers.

CONCLUSIONS

Observations of phenomena and processes occurring on the Earth from satellite systems such as LANDSAT and NIMBUS have demonstrated the potential impact of such observations on a number of major human concerns. These concerns include the management of our food, water, and fiber resources; the exploration and management of mineral and energy resources; the protection of our life sustaining environment; the protection of life and property; and improvements in shipping and navigation. Satellite systems which are now under development such as LANDSAT-C, SEASAT, NIMBUS-G, and Heat Capacity Mapping will have the potential of impacting those concerns even further and more specifically. However, these impacts will remain potential rather than real as long as there is not an effective transfer of information from those who make the observations to those who are in need and in a position to apply this information to the solution of these problems. I consider the achievement of such information transfer as a major challenge to the space program of the next decade.