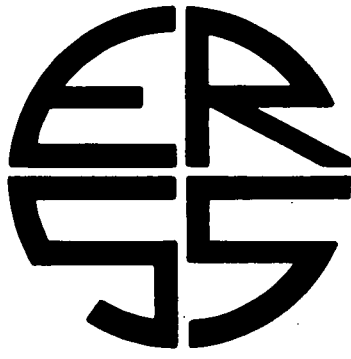


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NASA Earth Resources Survey Symposium

HOUSTON, TEXAS
JUNE 1975

FIRST COMPREHENSIVE SYMPOSIUM
ON THE PRACTICAL APPLICATION
OF EARTH RESOURCES SURVEY DATA

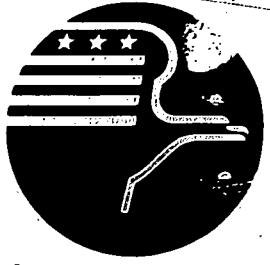
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VOLUME III

SUMMARY REPORTS



National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER

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NASA  Earth Resources Survey Symposium

VOLUME III
SUMMARY REPORTS

PREFACE

The first comprehensive symposium on the practical application of Earth resources survey data was sponsored by the NASA Headquarters Office of Applications from June 9 to 12, 1975, in Houston, Texas. The Lyndon B. Johnson Space Center acted as host.

This symposium combined the utilization and results of data from NASA programs involving Landsat, the Skylab Earth resources experiment package, and aircraft, as well as from other data acquisition programs.

The primary emphasis was on the practical applications of Earth resources survey technology of interest to a large number of potential users. Also featured were scientific and technological exploration and research investigations with potential promising applications.

The opening day plenary session was devoted to papers of general interest and an overview. The following 2½ days were devoted to concurrent discipline-oriented technical sessions and to three special sessions covering State and Local Users, Coastal Zone Management, and User Services. These special sessions were structured to provide governmental and private organizations with a comprehensive picture of various applications in the management and implementation of remote-sensing data use in their own programs. The concluding day was a summary with selected state, international, and technical session papers, summaries of significant results from special and technical sessions, and an overview of Federal agency and international activities and planning.

Volumes I-A, I-B, I-C, and I-D contain the technical papers presented during the concurrent sessions. Volume II contains the opening day plenary session, special sessions, and the concluding day summary sessions. Volume III contains a summary of each session by the chairman and session personnel and provides an overview of the significant applications that have been developed from the use of remote-sensing data. Volume III also includes the conclusions and needs identified during the individual sessions and workshops.

All contributors were given an opportunity to review their transcripts and reports; however, some final editing was necessary, primarily to achieve a uniform format and eliminate repetition. Illustrations have been selected to most effectively clarify and expand upon the written presentations and to avoid duplication. Editing guidelines also included preservation of each author's terminology and individual style, considered by the coordinator to be an integral part of the reports. Care was taken to retain the meaning and emphasis; however, where any inadvertent alteration may have occurred, the coordinator assumes full responsibility.

Opinions and recommendations expressed in these reports are those of the session members and do not necessarily reflect the official position of NASA.

Olav Smistad
Symposium Coordinator

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NASA  Earth Resources Survey Symposium

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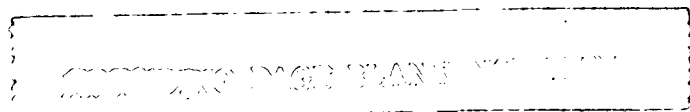
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I. Agriculture

Richard Baldwin^a

INTRODUCTION

The United States has always been able to meet its demands for food, fiber, and timber. There was always more land to cultivate; fertilizers and other agricultural chemicals have increased the food producing capacity of land already under cultivation; hybrids and new plant strains grow faster, produce more, or are hardier; and cheap energy has replaced horsepower to operate mechanized farm equipment, which has replaced much manpower.

For the future, one important new tool is remote sensing. It has potential applications in four areas: crop reporting, range management, forest management, and soils surveys.

APPLICATIONS

Users and potential users include persons who are oriented to applications research, those who are implementing remotely sensed data into their operations, and government or managerial people who require various levels of information for their decisionmaking. Several levels of information that can be extracted from remotely sensed data and a number of applications for the information have been identified. Much of this information can be acquired at a relatively low cost per acre.

Crop Reporting

Several papers reported the ability to identify crops and to inventory acreages, as well as to spot areas of plant damage (by weather, insects, or disease), using processing techniques on Landsat data.

In one test area composed of small grains (95 percent wheat), sod, and fallow land, remote-sensing techniques identified the small grains with 98 to 99 percent

accuracy, sod with 96 to 97 percent accuracy, and fallow land with 91 percent accuracy. This success encourages a broader use of Landsat data (when combined with information on soils, weather, and previous crop yields) to supplement nationwide or perhaps even worldwide estimates of crop production. A need exists for such information on a worldwide basis to improve the orderly marketing of feed and grain supplies and to provide early warning signals for distress so that corrective action can be taken in various parts of the world.

For that purpose, a large area crop inventory experiment (LACIE) has been undertaken jointly by the U.S. Department of Agriculture (USDA), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration. The LACIE effort is concentrated on the application of remote-sensing technology to locate, identify, and measure wheat acreage. (Wheat was chosen as the experimental crop because of its importance in human nutrition and international trade.) The experiment will combine crop area measurements obtained from Landsat data and meteorological information from NOAA satellites and ground stations, designed to relate weather to yield assessment and, ultimately, to production forecasts. The USDA will study incorporation of the experimentally derived production estimates into its crop reports. If the activity is successful and the results prove useful, the application will be extended geographically and, ultimately, to other crops.

In another potential worldwide application, Landsat data have been used in field trials for mapping natural vegetation at a scale of 1:1 000 000. The United Nations Educational, Scientific, and Cultural Organization has established a uniform classification system that can be used more or less directly with Landsat-generated maps because of the small scale. The theory is that natural vegetation is the best clue to the cultivated crops an area will optimally support.

^aCargill, Incorporated, Minneapolis, Minnesota.

Range Management

Techniques for estimating and predicting the available forage for range animal consumption were demonstrated in several major rangeland areas. The sandhills region in Nebraska is a unique area for using Landsat data in estimating vegetative biomass for managing this 20 000 square statute miles (52 000 square kilometers) of rangeland. The uniform soils of this area minimize the variances in radiance caused by soils variability. Correlation coefficients of 0.9 for radiances to biomass were achieved using band 5 of the multispectral scanner and automatic data processing methods. The ability to monitor annual grasslands was demonstrated in the intermountain region of California. By use of Landsat data, the investigator was able to correlate plant growth stages and forage production with climatic and other environmental factors. Image characteristics and spectral reflectance data were then related to forage production, range condition, range site, and changing growth conditions.

Landsat data appear to be adequate to determine, with a high degree of confidence, the available forage in selected rangelands. This information could be of great value to range management agencies (such as the Bureau of Land Management, the Forest Service, or regional groups) in determining how many animal units can be put on a specific piece of rangeland and when to take them off. For this use, the data are needed promptly (within 5 to 10 days after collection) and frequently (at 9-day intervals). An operational system needs to be devised and implemented to test this demonstrated technology for cost effectiveness and feasibility for full-scale ongoing operations.

Forest Management

Forest lands, both public and privately owned, also cover large areas, and efficient management is essential to capture their greatest productive capacity. Speakers discussing forest-related applications demonstrated various ways of converting data from Landsat and high-altitude sensors to useful information.

One speaker showed how the data were used to update maps of clear-cut forest areas, to map cutting rates, and to better manage forest areas. A representative of a large paper and timber company described how, on a limited budget, his company was developing simple techniques to help determine the location, type, quantity, and quality of available timber supplies. Another speaker demonstrated how Landsat data can be

used to classify timber with as high as 95 percent accuracy for types of trees and as high as 80 percent accuracy in defining the conditions of the forest stand.

Landsat data were converted to information depicting the available fuel for sustaining fires in the Santa Monica Mountains in southern California. Here, 1.25 million acres were mapped for a cost of less than 3 cents per acre. This information was used as input to an operational model, which aids in reducing and controlling forest fires and in preserving the forest.

The results of a study of gypsy moth infestation demonstrated that Landsat data can be used to discriminate between defoliated and healthy vegetation in Pennsylvania and that digital processing methods can be used to map the extent and degree of defoliation.

Soils Surveys

Soils mapping, from a broad synoptic view down to the soil association level, was demonstrated in the papers presented. Soils mapping was used to help satisfy state tax legislation in South Dakota. Soils association maps keyed to productive capacities and land values were developed for the state. Cost for producing such low-intensity surveys was approximately 2 cents per hectare.

At the Purdue University Laboratory for Applications of Remote Sensing, digital data were analyzed to identify a specific soil association that had not been detected in previous soil surveys. This soil association was a continuity of a narrow, meandering strip of prairie soil in an area of predominantly timber soils. It is believed to be a buried valley of the glacial age.

These examples demonstrate that first-echelon soil mapping can be done from satellite data at a very low cost per unit area. Of course, supporting classes of soils must be mapped in the conventional manner.

Skylab data were used to delineate possible avenues of travel of citrus pests between Mexico and the United States. Also identified through Skylab S190B data were various crops and frost damage.

A speaker described how his company used remotely sensed data to manage various crops, especially cotton, in an effort to get an early determination of plant stress, disease, weed or insect infestation, and faulty irrigation. With such information on a timely basis, corrective action can be taken soon enough to actually improve the yields. It was stressed that such applications, to be useful, must be cost effective and very timely.

CONCLUSIONS

The workshop participants generally agreed that the technology exists to extract useful information, but several problems must be overcome before an operational system can be implemented. First, one must remember that remotely sensed data do not provide a total information base but are complementary to existing systems. One of the biggest tasks ahead is to design the optimum information mix for each user need. Second, the data should be supplied to a user in a format and quantity for his particular needs and parameters, rather than being supplied in bulk and excessive to his needs. Furthermore, costs to the user must be realistic.

The timeliness of data is probably the most critical problem inhibiting the implementation of an operational

system. Those dynamic applications requiring data within 9 days of acquisition cannot be functional at this time. By contrast, applications requiring data seasonally or annually can be implemented immediately.

It appears that organizations which acquire and supply data must work in conjunction with those who extract information and those who use it to identify the best information, format, analysis system, and time frame for each potential application.

Interest is high in generating useful information from remote-sensing data for all four areas of agriculture. The technology does exist and it can be a valuable tool in producing and distributing food, fiber, and timber to a growing population.

II. Coastal Zone Management

E. Lee Tilton, III^a

INTRODUCTION

This NASA Earth Resources Survey Symposium marks a major milestone in the application of remote-sensing technology. For the first time in a major symposium, the area of coastal zone management has been recognized and emphasized as a significant applications area. The intent of the symposium session was to give the audience an indication of the real problems of coastal zone management from the viewpoint of Federal and state organizations responsible for the legislation, enforcement, and management of coastal zone activities. This purpose was accomplished by having a panel of Federal and state representatives concerned with coastal zone affairs discuss their problems relating to information required for decisions.

Another intent of the session was to present examples of remote-sensing technology as applied to coastal zone management problems. This purpose was accomplished by a series of presentations describing demonstrations being performed by a variety of agencies in a variety of geographical areas requiring different information needs. The summary for each of the coastal zone management session presentations is included in Volume II of these proceedings. These discussions and presentations will be summarized here.

COASTAL ZONE CHARACTERISTICS AND INFORMATION NEEDS

Because of the obvious influence, both present and future, of the Federal Coastal Zone Management Program on the definition of survey and information needs in U.S. coastal zones, the program was a central theme in the panel discussions and will be used here as a focus for this summary. The framework of the program is provided by the Coastal Zone Management Act of 1972, which is administered by the Office of Coastal

Environment, National Oceanic and Atmospheric Administration, Department of Commerce. As a result of comments on the act received from the states, the act was modified and guidelines were published in the Federal Register on November 29, 1973. The following quotation is from the Federal Register.

"The act recognizes that the coastal zone is rich in a variety of natural, commercial, recreational, industrial, and esthetic resources of immediate and potential value to the present and future well-being of the nation. Present state and institutional arrangements for planning and regulating land and water uses in the coastal zone are often inadequate to deal with the competing demands and the urgent need to protect natural systems in the ecologically fragile area. Section 305 of the act authorizes annual grants to any coastal state for the purpose of assisting the state in the development of a management program for the land and water resources of its coastal zone (development grant). Once a coastal state has developed a management program, it is submitted to the Secretary of Commerce for approval and, if approved, is then eligible, under Section 306, to receive annual grants for administering its management program (administrative grants)."

The act essentially places the responsibility for managing U.S. coastal zones with the individual states and provides them with the opportunity to tailor their program to individual needs. As will be seen, their needs vary widely with population, location, and coastal configuration. As defined by the act and Section 920.49 of the guidelines, final definition of coastal zone boundaries must be made by the states before June 30, 1977. Most of the states currently are formulating their programs. Thirty states, as well as Puerto Rico, the Virgin Islands, Guam, and American Samoa, are included in the definition of coastal states. The characteristics of the 30 states are summarized in table II-1.

Information for state area and population was taken from reference II-1, which was based on the 1970

^aNASA Earth Resources Laboratory, Bay St. Louis, Mississippi.

TABLE II.- COASTAL STATE STATISTICS

State	Area, sq. stat. mi.	Total counties	Coastal counties/ percent of total	Coastal zone counties/ percent of total	Total population	Coastal county population/ percent of total	Coastal zone county population/ percent of total	No. of major coastal bays or estuaries	No. of major coastal rivers	Coastal water body	General coastline length, stat. mi.	Tidal shoreline length, stat. mi.	Ratio ^a
Maine	33 215	16	8/50.0	--	993 663	464 883/46.8	--	3	4	Atlantic Ocean	228	3 478	15.3
New Hampshire	9 304	10	2/20.0	--	737 681	209 382/28.4	--	0	1	Atlantic Ocean	13	131	10.1
Massachusetts	8 257	14	9/64.3	--	5 689 170	4 260 448/74.9	--	7	2	Atlantic Ocean	192	1 519	7.9
Rhode Island	1 214	5	5/100	--	947 723	947 723/100	--	3	0	Atlantic Ocean	40	384	9.6
Connecticut	5 009	8	4/50.0	--	3 032 217	1 883 434/62.1	--	2	3	Atlantic Ocean	--	618	--
New York	49 576	62	18/29.0	--	18 190 740	12 740 484/70.0	--	5	1	Atlantic Ocean	127	1 850	14.6
								2	1	L. Ontario	294	331	1.1
								0	0	L. Erie	77	77	1.0
New Jersey	7 836	21	13/61.9	--	7 168 164	4 995 116/69.7	--	6	5	Atlantic Ocean	130	1 792	13.8
Delaware	2 057	3	3/100	--	548 104	548 104/100	--	1	1	Atlantic Ocean	28	381	13.6
Maryland	10 577	23	15/65.2	--	3 922 399	2 050 276/52.3	--	7	6	Atlantic Ocean	31	3 190	102.9
Virginia	40 817	96	28/29.2	--	4 648 494	1 621 879/34.9	--	1	4	Atlantic Ocean	112	3 315	29.6
N. Carolina	52 586	100	20/20.0	--	5 082 059	509 457/10.0	--	6	4	Atlantic Ocean	301	3 375	11.2
S. Carolina	31 055	46	7/15.2	--	2 590 516	497 984/19.2	--	6	7	Atlantic Ocean	187	2 876	15.4
Georgia	58 876	159	6/3.8	--	4 589 575	281 155/6.1	--	8	6	Atlantic Ocean	100	2 344	23.4
Florida	58 560	67	36/53.7	38/56.7	6 789 443	5 401 711/76.6	5 470 194/80.6	2	1	Atlantic Ocean	580	3 331	5.7
								17	13	Gulf of Mexico	770	5 095	6.6
Alabama	51 609	67	2/2.9	--	3 444 165	376 690/10.9	--	3	2	Gulf of Mexico	53	607	11.5
Mississippi	47 716	82	3/3.7	--	2 216 912	239 944/10.8	--	3	2	Gulf of Mexico	44	359	8.2
Louisiana	48 523	64	14/21.9	26/40.6	3 643 180	1 505 337/41.3	2 315 441/63.6	18	7	Gulf of Mexico	397	7 721	19.4
Texas	267 338	254	17/6.7	--	11 196 730	2 944 719/26.3	--	14	13	Gulf of Mexico	367	3 359	9.2
California	158 693	58	19/32.8	--	19 953 134	15 008 518/75.2	--	5	7	Pacific Ocean	840	3 427	4.1
Oregon	96 981	36	7/19.4	--	2 091 385	428 927/20.5	--	4	7	Pacific Ocean	296	1 410	4.8
Washington	68 192	39	15/38.5	--	3 409 169	2 322 010/68.1	--	12	11	Pacific Ocean	157	3 026	19.3
Alaska	586 412	24	21/87.5	--	302 173	176 357/78.0	--	10	6	Pacific Ocean	5 580	31 383	5.6
								5	15	Arctic Ocean	1 060	2 521	2.4
Pennsylvania	45 333	67	4/6.0	--	11 793 909	1 904 056/16.1	--	0	1	L. Erie	51	51	1.0
										Delaware R.	50	50	1.0
Ohio	41 222	88	8/9.1	--	10 652 017	2 931 941/27.5	--	2	2	L. Erie	246	312	1.3
Michigan	58 216	83	43/51.8	--	8 875 083	4 915 571/55.4	--	3	3	L. Huron	622	934	1.5
								5	6	L. Michigan	862	1 058	1.2
								3	0	L. Superior	583	917	1.6
								1	1	L. Erie	80	143	1.8
Indiana	36 291	92	3/3.3	--	5 193 669	738 709/14.2	--	0	0	L. Michigan	45	45	1.0
Wisconsin	56 154	72	15/20.8	--	4 417 933	1 914 709/43.3	--	2	0	L. Superior	150	325	2.2
										L. Michigan	425	495	1.2
Illinois	56 400	102	2/2.0	--	11 113 976	5 876 167/52.9	--	0	1	L. Michigan	63	63	1.0
Minnesota	84 068	87	3/3.5	--	3 805 069	237 467/6.2	--	0	0	L. Superior	180	189	1.1
Hawaii	6 450	5	5/100	--	769 913	769 913/100	--	7	0	Pacific Ocean	750	1 052	1.4
Total 30 states	2 078 537	1850	355/19.2	--	167 808 365	78 703 071/46.9	--	173	143	--	16 111	93 534	--
Total U.S.	3 615 122	--	--	--	^b 203 184 772	--	--	--	--	--	--	--	--

^aTidal shoreline length divided by general coastline length.

^b1970 census.

census. The only exception was the population of election districts of Alaska; this value was taken from reference II-2, based on the 1960 census. County information was taken from references II-3 to II-5 as well as from a 1972 U.S. Geological Survey map (scale 1:2 500 000). Note that a distinction is made between a coastal county and a coastal zone county because the coastal zone will generally cover more than just the coastal counties under the comprehensive definition given for coastal zone in the act. Separate examples are given in table II-1 for Florida and Louisiana where a preliminary definition has been proposed by each state. The difference can be significant, as in the case of Louisiana, the southern or coastal area of which is almost entirely marsh and extends several counties (parishes) inland (fig. II-1).

An estimate of the number of major coastal bays and rivers for each state was made from references II-6 and II-7. The criterion for selection of a river was that it should be longer than 30 statute miles and wider than

0.5 statute mile at some point in its course. Bays and estuaries were counted if they were larger than 25 square statute miles in area.

The information for general coastline and tidal shoreline was taken from references II-8 and II-9. Work done by Robert Hagen in 1948 (under the direction of P. H. Judd) and updated by G. E. Roper and E. F. Kulp, Jr., in 1952 entitled "Shoreline of the Great Lakes and Connecting Rivers" was also consulted. The following definitions for these two terms are taken from reference II-8. "General coastline figures are lengths of general outline of the seacoast. Measurements were made with a unit measure of 30 minutes of latitude on charts as near the scale of 1:1 200 000 as possible. Coastline of sounds and bays is included to a point where they narrow to width of unit measure, and the distance across at such point is included. ... Tidal shoreline figures were measured in 1939-40 with a recording instrument on the largest scale charts and maps then available. Shoreline of outer coast, offshore islands, sounds, bays, rivers, and

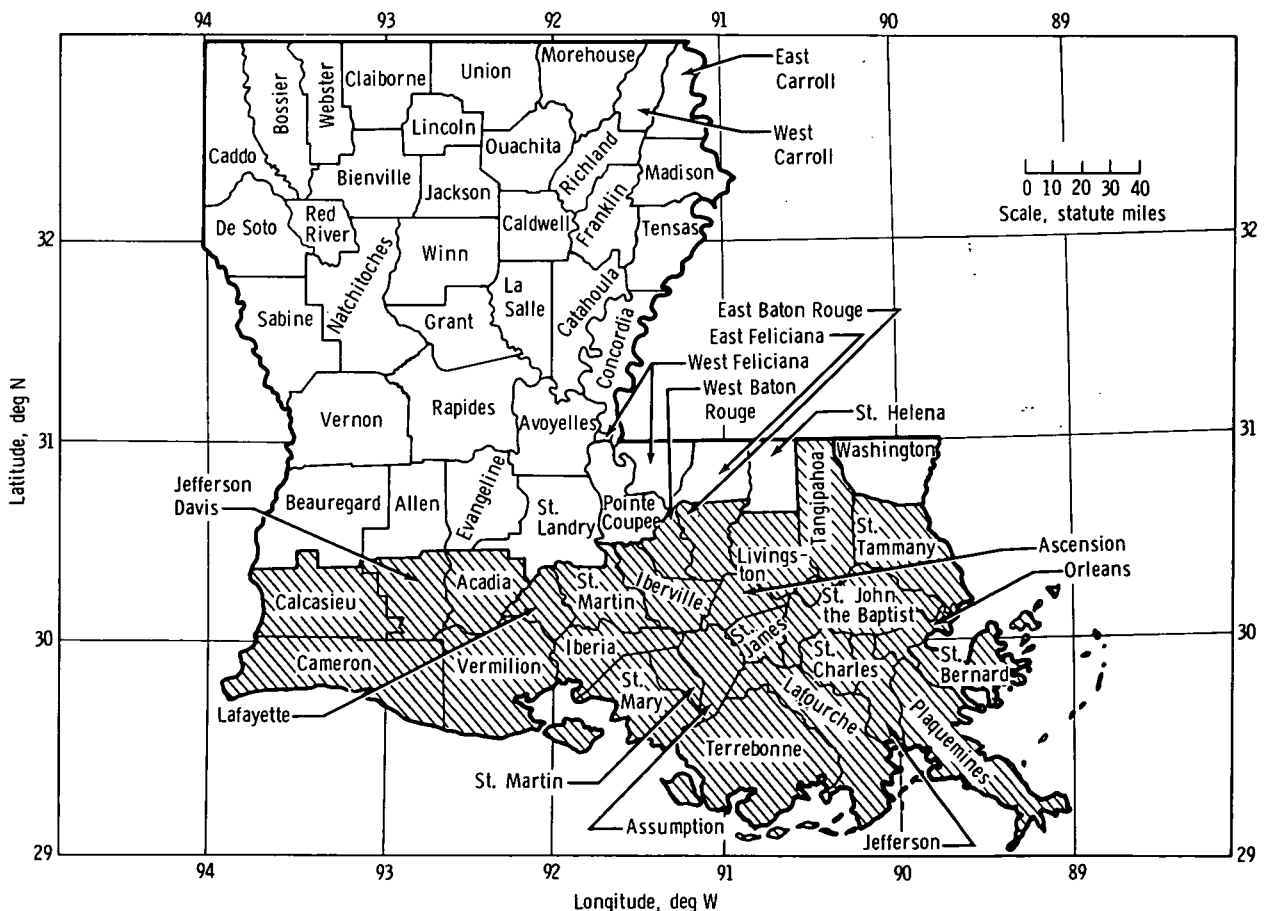


Figure II-1.— Map of Louisiana coastal zone parishes (shaded area).

creeks is included to the head of tidewater or to a point where tidal waters narrow to a width of 100 feet." Although the definitions of these two parameters are reasonably straightforward, their accurate and standardized measurement has been difficult to obtain.

In general, 82.6 percent of the U.S. population resides in coastal states, 38.7 percent of the U.S. population resides in the 355 coastal counties, and in 14 of the 30 coastal states, more than half the state population resides in the coastal counties. Within these coastal counties are 173 major bays or estuaries and 143 major rivers emptying into coastal waters. Based on past measurements, the general coastline of the United States totals approximately 16 111 statute miles with a tidal shoreline of 93 534 statute miles. Note that the ratio of tidal shoreline to general coastline is one measure of coastal zone complexity and is also an indirect measure of the marine productivity of a coastline. Thirteen of the 30 states have ratios greater than 10.

Most of the states either have, or are in the process of passing, local or state legislation governing activities in the coastal zones. A very large variation exists in the types of agencies responsible for preparation and enforcement of coastal legislation. In addition, most current legislation is very limited both in its coverage of coastal activity and in its definition of the coastal zone. For example, much of the state legislation covers only that area below the watermark of ordinary high tide, whereas the 1972 act calls for a much more comprehensive definition. Coastal zone areas being considered in Florida range as far as 25 statute miles inland and in Louisiana as far as 50 and 60 statute miles inland. These larger coastal zone areas generally encompass productive coastal waters and marshes as well as those areas of dense human population which interact with and affect coastal waters. Present activity in the states is concerned with the identification and classification of land and water uses to determine where coastal zone and land use boundaries will be drawn.

On the seaward side, the act defines the territorial waters of each state as part of the coastal zone. The territorial limit is generally 3 nautical miles from the coast. However, two states, Florida and Texas, presently claim 9 nautical miles as their limit, and there is a general desire among the coastal states to increase the territorial limit. In fact, it is likely that U.S. territorial waters will soon extend 200 nautical miles from shore. To gage the area of interest, one could choose the following general definition: the coastal zone is a strip having a width of 50 nautical miles, of which 10 nautical miles is seaward from the general coastline and 40 nautical miles is inland from the general coastline. This

definition is not wide enough in some states and is too wide in others, but, using it and the general coastline length from table II-I, the coastal zone is estimated to consist of approximately 15 percent of the total area of the United States or approximately 600 000 square statute miles. Therefore, the coastal zone is very large and complicated and consists of approximately 80 percent land or wetlands. It is reasonable to assume, then, that extensive use would be made of surface classification techniques. As will be seen later, a key element in the use of these techniques is the correct interpretation of vegetation changes through the use of remote-sensing data.

Before the technical aspects of the applications of remote sensing in the coastal zone are discussed, it should be noted that the panel discussions revealed other aspects that should be considered. The general adoption of remote sensing for coastal zone management by organizations responsible for coastal zone management is affected by a number of nontechnical factors. For example, capabilities of remote-sensing techniques may have been oversold in the past, partly because of the glamour associated with this new vantage point in the sky. Nevertheless, this oversell is responsible for a number of groups being leery of this new technology and the problem does indicate a definite need for better communications between the technologists and the users. In fact, this whole general area of better communications between those developing the technology and those requiring the technology is significant and requires increased attention. Neither the technologist nor the user will benefit unless the user is educated in the advantages and limitations of the technology and unless the technologist is educated in the problems and needs of the user. Achievement of this understanding will require maintenance of a dialog between the two from very early stages of the technique development throughout demonstration of the technique application to specific problems. It is not adequate to merely publish a report and expect that the technology will be used.

The panel discussions also revealed that the mere existence and availability of good technology do not assure its use, even if the user is aware of its existence and availability. The reasons for this hesitancy are often political and depend on the specific application. For example, budgetary limitations, public opinion, and other pressing affairs of state are all important factors when an organization, such as a state, is considering the expenditure of public funds on new technology.

Another area requiring significant attention throughout the transfer process is the cost of the

technology to the user, not just in the sense of tax dollars for development but in the sense of everyday operational expenses for application of the techniques. Again, this area must be treated from the very beginning of technique development because only this awareness throughout the development will yield cost-effective hardware, software, procedures, and information products on a timely basis. Consideration of all the preceding factors is essential to the successful transfer of this new technology to the user community and must be an integral part of the transfer mechanism.

APPLICATION OF REMOTE SENSING TO COASTAL ZONE SURVEY

It would be useful here to briefly discuss the general application of remote-sensing technology to coastal zone survey and monitoring before some specific examples are shown.

Remote sensing is defined as the acquisition of electromagnetic spectral data with instruments on aircraft or satellites for the purpose of deriving information about the character and condition of the land, wetlands, water surfaces, and intervening atmosphere of the Earth. Significant advances have been made in recent years in the demonstrated usefulness of such data. Techniques are available for land use classification, vegetation classification, water surface temperature measurement, and salinity measurement; other techniques are being developed for measurement of water color, sea state or wave climate, and shoreline extent and erosion. (See "Marine Resources," vol. I-C.) Not all these techniques are adaptable for satellite use (as opposed to aircraft), but additional advances in capability are occurring almost monthly. Currently, airborne and satellite multispectral scanners having channels in the visible, near-infrared, and thermal-infrared parts of the spectrum are the most useful instruments for monitoring changes in land use, vegetation, shoreline, surface water temperature, and water color. Other candidates are active microwave systems for sea state and other scanner channels in the middle- and far-infrared bands for atmospheric sounding of parameters needed to correct the surface measurements.

These instruments can provide data that, with suitable processing and interpretation, can result in accurate, relatively inexpensive, and timely information in many areas of interest related to coastal zone management. Unfortunately, the direct translation of coastal problems into information needs and, in

particular, information that can be supplied through remote-sensing techniques is not straightforward. Many state and local agencies are not yet prepared to define their needs in terms of measurements that might be made from an aircraft or a spacecraft, partly because of a lack of familiarity with remote-sensing capabilities and partly because of the inherent difficulty in defining the information requirements for coastal zone management.

Problems in the coastal zone may generally be divided into the three geographic categories of land, wetlands, and water. In each category, the primary concern is the management of resource use. The use may generally be classified as (1) developing (exploiting or changing) the resource, (2) conserving (renewing or controlling) the resource, or (3) preserving (protecting or leaving unchanged) the resource. The resources may be categorized as historic, cultural, esthetic, ecological, or economic. In all cases, the gathering of information through monitoring is required for effective management. The problems and information requirements for land, wetlands, and water are described briefly in the following discussion.

Land problems in the coastal zone primarily stem from high population densities and competing interests for use of the limited coastal lands. Thus, the problem is to determine the best possible use of the land considering its limited availability, its attractiveness because of special-purpose uses unique to the coastal zone (esthetic and recreational advantages, accessibility to water transportation, etc.), and its vulnerability to natural disasters, and considering the ultimate effect on the ecological balance of the coastal zone. Because of the high population densities on the coastlines of the United States, one of the major problem areas is the planning of residential and industrial complexes for maximum use of the limited coastal land resources while still protecting the environment.

It is estimated that monitoring and complete classification of coastal zone land use should occur at least every 3 years with a classification update each year being desirable to support land use planning. The type of information desired is that indicated in reference II-10, although no specific format for the information is required or dictated by the Coastal Zone Management Act. Reference II-10 contains the following major (Level I) classifications for land use: urban and built-up land, agricultural land, rangeland, forest land, water, nonforested wetland, barren land, tundra, and permanent snowfields and icefields. This type of classification scheme generally includes wetlands and water and, with some modifications at a detailed level, could be used to classify coastal lands.

The wetlands are usually transitional zones between land and water in coastal areas. In some states, the wetlands are very small parts of the coastal zone; in others, such as Louisiana, they are dominating geographical factors (ref. II-4). The wetlands are sensitive ecological regimes that contribute heavily to coastal marine productivity and that are affected by such problems as salinity intrusion, deterioration, and erosion, all of which are influenced to a large degree by man's activities such as dredging, leveeing, and extracting mineral resources. Characterization and change detection in the wetlands can be determined largely through correlations with vegetation. Both monitoring of the vegetation types and extent and measuring land and water area and shoreline length provide desirable types of information for effective coastal zone management. Changes in vegetation can be used as an aid in the analysis of changes in ecological factors. In addition, some of the erosion and deterioration processes are occurring with such rapidity that semiannual surveys of the coastal wetlands would be very useful and, in some cases necessary, for interpretation of changes.

Coastal waters represent a very dynamic environment resulting primarily from the introduction of river waters and watershed runoff and from the effects of tidal action and wind-driven circulation. In some coastal areas, storms also are important and frequent contributors to the shaping of coastal geometries. The dynamics of coastal waters may be divided into two parts: the daily or even hourly changes caused by tides and winds, and the longer term changes characterized, for example, by seasonal levels of temperature, turbidity, and salinity, by river flows, by prevailing currents, and by shoreline erosion.

Like the physical processes taking place, the chemical processes of the coastal waters are also quite dynamic and are more directly influenced by man's activity because of industrial and agricultural effluents as well as waste products from residential areas. These chemical influences affect the biological productivity of coastal waters in various ways and also affect the quality of the water for man's use. Information required for management of coastal zone resources includes that derived from the monitoring of water quality parameters and the measurement of circulation, temperature, turbidity, and salinity for the purpose of water quality standards enforcement, from the evaluation of sites for location of development activities, and from the detection of natural changes in the physical environment.

With regard to the remote sensing of land, wetland, and water parameters, a person is generally concerned

about the selection of the proper spectral, spatial, and temporal coverage for the parameter in question. For example, with regard to spectral coverage, if one is interested in the measurement of water surface temperature, the remote-sensing instrument used must be sensitive to radiation in the thermal-infrared part of the spectrum. If one is interested in the characteristics and classification of vegetation types in the marsh, he must acquire data in the visible and near-infrared parts of the spectrum. For spatial coverage, one is usually interested in the highest vantage point possible (i.e., satellite) so that synoptic coverage can be obtained over large areas. However, as one goes to higher altitudes, the ability to discern small objects (the resolution) decreases. For example, from satellite altitudes, one can easily classify the extent of forest land; however, if one is interested in the extent of water hyacinths in small navigable waterways, he must use aircraft remote-sensing systems with higher resolution. For temporal coverage, at least two factors are involved. If a highly dynamic area, such as coastal waters and current patterns, is involved, coverage must be obtained at very short intervals, perhaps within hours or even minutes, to determine the measurements of interest. In the case of land covers, such as forests, the activity, or changes, are much less dynamic and need not be covered at such short intervals. Another factor to be considered in temporal coverage is the ability to discriminate between parameters of interest. For example, it is easier to discriminate pine trees from hardwoods in the winter when the hardwoods have dropped their leaves than it is in the summer when the pine trees and hardwoods are all green. A third, indirect temporal factor is the interference of weather. That is, measurements must be made when the remote sensors are capable of detecting the selected parameters. For example, satellite measurements of the surface of the Earth in the visible portion of the spectrum require cloud-free conditions because the visible radiation will not pass through the clouds. However, measurements in certain parts of the microwave region of the spectrum can be made through the clouds and essentially constitute an all-weather measurement. All these factors must be considered when determining what data and information can be usefully gathered using remote-sensing techniques.

Generally, it may be said that a number of useful remote-sensing techniques exist for application to coastal zone management problems. For example, techniques are available for using remote-sensing data, such as those obtained from Landsat, to obtain surface classifications such as the acreage and boundaries of forest, urban, agricultural, forested wetland, nonforested

wetland, and water categories. Accuracies are generally consistent with, or exceed, those obtained using conventional techniques. The most significant advantages of remote sensing, however, are the timeliness and the reduced cost with which these measurements may be obtained using automatic classification techniques. Surface classification updates may be obtained on a seasonal or an annual basis when weather conditions are suitable. It is possible to obtain accurate measurements of boundary lengths, such as shoreline, and to obtain accurate measurements of water parameters, such as surface temperature and salinity. Surface salinity measurement techniques require further technology advancements; such measurements are possible only from low-altitude aircraft currently. In cold regions, such as the Great Lakes, it is possible to determine the extent and the thickness of ice to provide information for better navigation using aircraft remotely sensed data relayed by means of communications satellites. Soon, techniques being developed should enable capabilities such as the measurement of surface winds on the oceans, more accurate measurements of the shape of the Earth, the delineation of salinity regimes in the marshes, better measurement of environmental conditions relating to the assessment of living marine resources, and better interpretation of coastal zone water processes such as circulation and organic and inorganic constituents.

As an example of the use of remote-sensing data in the coastal zone, a 10-category land use and vegetation map of the Delaware Bay coastal zone was presented. The primary objective of this effort was to inventory coastal wetlands according to major plant species types and the spatial relationship of other major natural and manmade cover types. This information was prepared using a semiautomated analysis system, Landsat multispectral scanner data, and a variety of hardware and software components to allow flexibility in input data display and output.

Surface classifications of major ecological zones of southern Louisiana have been prepared using Landsat-1 digital data and automated surface classification techniques. Both a photomap and the surface classifications were transformed by computer from the Landsat coordinate system (scan lines and element number) into the universal transverse Mercator geographic reference system (northings and eastings). The New Orleans District of the U.S. Corps of Engineers is evaluating the usefulness of the environmental maps in developing plans for the region. Indications are that the cost of preparing these maps is many times less than those of present methods.

In areas of the world for which little information exists, such as Alaska, these types of surface classification techniques can be used extensively to classify surface features and to determine acreage of these features in the early planning and development stages of the coastal zone. Because the information is digital, such parameters as acreage and shoreline length can be quickly and accurately determined. For example, figures II-2 and II-3 are computer displays of Mobile Bay at two different tidal stages. The Geological Survey of the State of Alabama is using this information to determine changes in water acreage and shoreline length at the different tidal stages. Another example of the application of this particular technique is shown in figure II-4, in which Landsat data have been used to show changes in land acreage and shoreline length from the Mississippi River Crowfoot Delta during a period of 11 months.

Remote-sensing techniques also are under development and in use for a variety of problems associated with the monitoring and management of coastal waters. For example, the primary ocean current trends in the California coastal area as developed from a series of both aircraft and satellite images are shown in figure II-5. The high-altitude-aircraft and satellite imagery produces extremely complete and near-synoptic

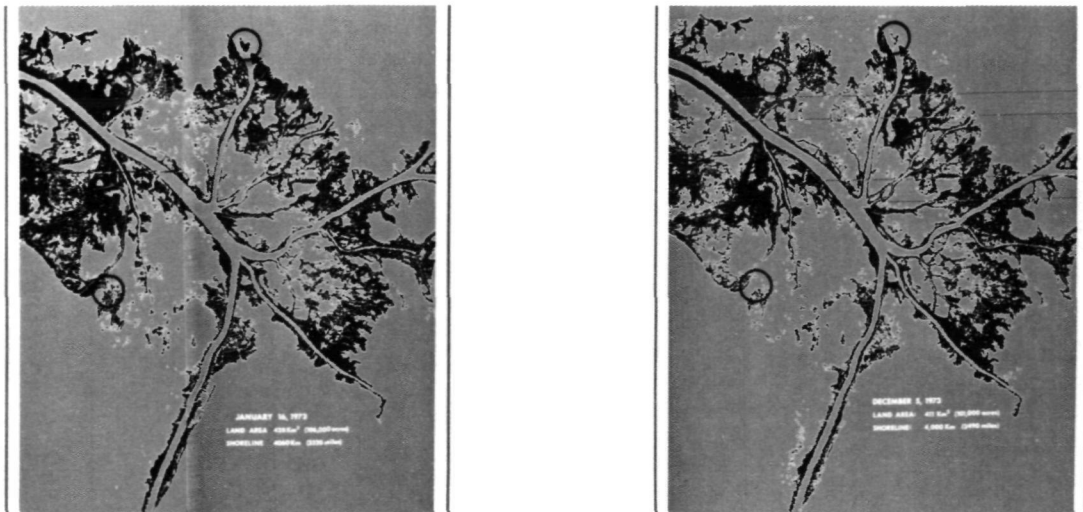


Figure II-2.— Computer display of Alabama shoreline (1172 kilometers long) on December 28, 1972.



Figure II-3.— Computer display of the same area shown in figure II-2 a year later (December 5, 1973). Note that the shoreline length has decreased (to 879 kilometers).

views of the ocean surface and reveals large-scale phenomena and relationships that often cannot be seen from low altitude or from a surface perspective. Thousands of individual image frames were analyzed by the San Francisco District of the U.S. Corps of Engineers to extract the bits of current vector directions that have been assembled into generalized seasonal current charts. Another example is presented in figure II-6, in which aircraft thermal-infrared imagery reveals the distribution of oil on the surface of the Mississippi River after a major oilspill. Such information is being used by the Environmental Protection Agency for enforcement and regulation purposes. A final example is shown in figure II-7 of the use of remote sensing in a coastal zone. Shown here is an example of an ice chart which, through the efforts of NASA, the U.S. Coast Guard, and the National Weather Service, was prepared and transmitted to Great Lakes vessels in near-real time during the 1974-75 winter navigation season. The data are acquired by an all-weather microwave system on an aircraft. More than 150 similar charts were generated during the season for various key shipping areas in the Great Lakes and used by shippers to find the path of least resistance through the icefields to eliminate costly delays.



(a) January 16, 1973: land area, 428 square kilometers (106 000 acres); shoreline length, 4060 kilometers (2520 statute miles). (b) December 5, 1973: land area, 411 square kilometers (101 000 acres); shoreline length, 4000 kilometers (2490 statute miles).

Figure II-4.— Landsat multispectral scanner data processed by the water search and shoreline analysis programs. A decrease in land area of 17 square kilometers and a decrease in shoreline length of 60 kilometers at the mouth of the Mississippi River is indicated for a period of less than 1 year.



Figure II-5.— Map of ocean current trends in a coastal area developed from aircraft and satellite imagery.

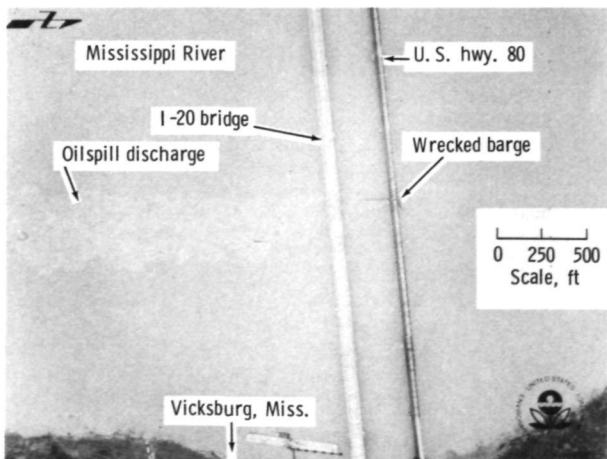


Figure II-6.— Oilspill detected by aerial thermal-infrared imagery west of Vicksburg, Mississippi, on March 6, 1975.

New applications are being found and demonstrated almost daily for remote sensing in the coastal zones. Many complex and critical information needs today can be met, or supplemented, in a timely and cost-effective manner from data acquired by aircraft and satellites and suitably processed and formatted to meet a variety of monitoring and management functions.

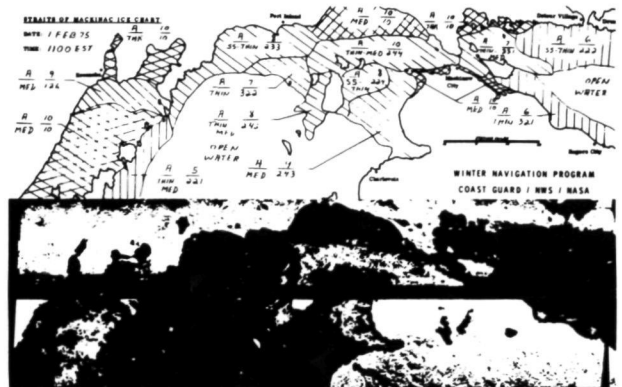


Figure II-7.— Ice chart transmitted by facsimile network to ship captains in the Great Lakes. The side-looking airborne radar image is at the bottom. The hand-drawn map at the top was prepared quickly by an analyst to aid the data user.

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III. Environment

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A succinct summary of the papers presented in the environment session is that, while the papers did not break any new ground in remote-sensing technology, they demonstrated a growing awareness and application of the technology in the field. This status is heartening. The fundamental need is recognition of the value, the efficiency, and the cost-saving advantages of the remote-sensing tools in solving environmental problems. With more recognition and with more users applying even the most fundamental techniques, technological advances will result.

The term "environment" as used in this symposium is too generic. Most of the papers in all the sessions had environmental aspects. With the advent of "land use" as a local, state, and Federal regulatory concern, however, the term environment is tending to be restricted to local, state, and Federal environmental quality *enforcement* considerations. Effective enforcement of environmental regulations requires comprehensive data bases and efficient monitoring. Both needs are potentially well served, and in some instances exclusively served, by remote-sensing techniques.

Those attending the symposium who were concerned with that more specific consideration of "environment" did well to choose from among the total offering of papers. It is recommended that selection of reports and papers for reading should be based on individual titles and not restricted to the environment session alone. For example, several papers dealing with river water quality were presented under the session heading "Water Resources."

This summary attempts to capture some of the key points of the papers presented and their broad significance, and to project their future application, problems, and payoffs. The discussion is based on the four general headings used for the symposium presentations.

WILDLIFE HABITAT AND LIFE SCIENCES

The urbanization of society increasingly encroaches on remaining wildlife habitats. To simply designate areas as preserves for such wildlife is not sufficient (E-1, vol. I-A). Wildlife species depend not only on sufficient space but on specific combinations of soil, water, vegetation, and other elements providing the necessary ecology.

The investigators produced 2 classification analyses in Travis County, Texas, of land and water cover, 10 resulting classes of which will be turned into base maps drawn from Landsat and other imagery. These maps will be used by biologists to begin the job of delineating species management units and by wildlife managers to apply management treatment necessary to produce sustained yields of wildlife resources. Such mapping of terrain suitable for wildlife species offers great potential for preserving and conserving biota, including those considered to be actually or potentially endangered by the continued encroachments of man.

The opposite situation, particularly that in which insect infestations are harmful to man, was considered in two papers. Although these papers dealt with eradication of the screwworm (E-2, vol. I-A) and the saltmarsh mosquito (E-3, vol. I-A), the applications of remote sensing to such work are broad enough to apply to most, if not all, infestation controls.

The screwworm, an agricultural pest, breeds principally in Mexico and affects North American livestock across the border. It can be eliminated by distributing sterile flies in the breeding grounds from aircraft. The governments of Mexico and the United States work jointly on this project.

Once the ecology of a screwworm, or other species, is understood, a mathematical model of its population dynamics can be built. Through remote sensing, its breeding grounds can be identified and monitored.

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Because screwworm infestations are largely determined by weather conditions, the National Oceanic and Atmospheric Administration ITOS satellites help delineate areas of screwworm activity at any given time. Satellite data can indicate not only where but when to combat insect infestations.

The paper on saltmarsh mosquitoes deals specifically with identifying the breeding grounds of this creator of nuisance and health problems throughout the U.S. coastal areas. It became clear in this presentation that the ecological relationships of the mosquito to particular vegetation and to flooding and exposure to saltwater in the marsh areas are being understood through remote-sensing outputs. Once these relationships are known, programs of control and abatement can be intelligently applied. Experience suggests that without such data, attempts at eradication are likely to destroy or harm other biota essential to the marshland environment.

The final paper in this section dealt with predicting human health levels using remote-sensing data (E-4, vol. I-A). Identifying incidence of mortality and of tuberculosis, hepatitis, and other human diseases in urban areas by aerial low-level color photography can seem preposterous. The potential, however, becomes clear when one recognizes the relationships of health levels to poverty and population density. The selection of block groupings having common characteristics in an urban community and the determination of the various health factors present by means of a ground census provide the basis for expanding that survey from the air to cover the entire urban area. Aerial photography reveals not only the density of population per urban block but such health-influencing factors as the amount of foliage and lawn and the presence of paved streets, gutters, and litter.

Very good correlations between ground census data and aerial data were reported. There appears to be much more work to come on this project to verify relationships of disease and mortality through both ground and aerial census data, but the hope for new advancements in the control and reduction of disease in urban environments is renewed by this effort.

STRIP MINING

Papers on the use of remote sensing for identification and control of strip mining summarized the state of the art in this area. One group applied Skylab and aircraft imagery as well as Landsat imagery to define strip-mine problems (E-6, vol. I-A). The focus here included

reclamation assessment; that is, the extent of seedling and grass growth and survival. Extendable digital techniques for large area coverage were used in a study (E-7, vol. I-A) demonstrating the feasibility of strip-mine monitoring to within 5 acres (2 hectares) with an average accuracy of classification greater than 93 percent.

To identify strip-mine locations, size, and environmental impact is fundamental. Multispectral analysis of satellite digital data is a useful monitoring technique in validating mining reports, in locating abandoned or unvegetated mines, and in assessing reclamation costs and requirements. Use of this technique also enables the identification and location of acid spoil and acid mine drainage sources and of siltation sources and routes, the monitoring of underground mine fires and of burning refuse piles, and the classification of materials in mine refuse dumps. Thermal imagery data, not available from Landsat-1 and Landsat-2, would be a valuable supplement to delineate ground-water outflow, ponding on strip-mine benches, storm runoff, surface water flow, and acid mine drainage.

Common to all such operations are the remoteness and the lack of ready accessibility on land to monitoring and enforcement efforts for ensuring proper and adequate reclamation of land areas and prevention of water quality degradation. Some of the illustrations presented with the papers (notably E-6, vol. I-A) clearly indicated how quickly, easily, and economically the required operational and restoration controls can be monitored.

WATER QUALITY

The water quality section focused on turbidity, eutrophication, and pollution discharges in lakes. One paper (E-9, vol. I-A) demonstrated quantitative measurement of suspended solids by use of Landsat multispectral scanner reflectance levels. Investigators found a 67-percent confidence level in accuracies of 12 p/m over a 0- to 80-p/m range and 35 p/m over a 0- to 900-p/m range. Correlation involved relating 16 separate Landsat passes with 170 water samples from 3 Kansas reservoirs during a period of 13 months.

Turbidity in lakes and streams minimizes the multiple-use functions of those water bodies. At known levels of turbidity, fish cannot spawn and cannot feed themselves. Fishermen catch little or nothing; swimmers avoid the water; and boaters and visitors to the shoreline find the lake or stream unattractive. Public and private commercial and recreational interests count resulting losses in dollars. Thus, monitoring and control of lake and stream turbidity is essential.

In one use of remote sensing in this area, Landsat data have helped determine valid reservoir sampling stations (E-10, vol. I-A). Landsat data help monitor reservoir areas not accessible by land or water and provide Secchi depth measurements in those inaccessible areas. The value of Landsat data in accurately monitoring land use changes and in predicting population shifts in reservoir (and natural lake) areas was also reported. This application is potentially significant in determining lake eutrophication (E-11, vol. I-A).

Eutrophication is a normally slow aging process in which a lake becomes so rich in nutritive compounds that algae and other microscopic plant life become superabundant and ultimately choke the lake and cause it to dry up. The process is accelerated by human activities in the vicinity of the lake, in fact, by the mere presence of humans. Using the Landsat multispectral scanner, investigators have located lakes and classified them in terms of the magnitude of nutrient growth and type on a eutrophic-oligotrophic scale.

In similar work (E-12, vol. I-A), a computer classification has been developed of the trophic status of the more than 3000 inland lakes of Wisconsin larger than 20 acres. Furthermore, researchers have been able to distinguish the difference between silt, tannin, and algae lakes from the Landsat imagery. Typically, costs were of great concern and available funds quite limited. "Overall," say the authors, "about \$4000 of computer time and \$6000 for operator salaries were required to obtain data for the 3000 lakes."

One paper (E-13, vol. I-A) reported not only on lake classification by biological condition of the water but on detection and quantification of sewage effluents outside Copenhagen, Denmark, in the Oresund. Lakes can be classified, using the Landsat multispectral scanner, by measuring the density of registered gray tones produced on bands 4 and 5. Good correlations with Secchi disk transparency readings were found. The result is a measure of lake transparencies and, indirectly, a relative measure of water turbidity and of algae and plankton content. Band 5 also appears to be useful in identifying water pollution. Landsat imagery showed surfacing of escaping sewage well off the shores of Copenhagen, the direction of its flow, and the extent of dispersion. Such conditions presumably would remain undetected without these remote-sensing techniques.

WETLANDS AND GENERAL ENVIRONMENT

The final section, on wetlands and general environment, featured the more dynamic papers in terms

of findings and potential applications. One paper (E-14, vol. I-A) compared the usefulness of Landsat-1 and Skylab data in coastal wetland mapping. Color photography from low-altitude aircraft, although high in accuracy, was found to be expensive, time consuming, and limited in scope of coverage. Landsat and Skylab data did not have these disadvantages. Using Landsat data, the team was able to distinguish between three classes of coastal wetland; Skylab data permitted a more detailed system consisting of five classes. Landsat data could not be used to delineate freshwater marshes; Skylab data could. In addition, drainage patterns could be mapped in more detail using Skylab data.

This report was particularly impressive in identifying the large amount of monitoring information available through remote sensing by satellite. Landsat data can be used to identify and monitor damming and river flow diversion, dredge and fill operations, lagooning for waterside homes, and highway construction. Skylab data have been used to identify dredging, spoil disposal, and mosquito ditching operations, all of which materially degrade wetlands. Similarly, a paper on the Green Swamp in central Florida (E-15, vol. I-A) showed how Skylab data were used to produce automatic mapping of a nine-category and three-category land-water cover map used in interpreting hydrologic conditions.

The goal of one investigator was to specify a practical procedure for the uniform mapping and monitoring of natural ecosystems and environmental complexes using the full range of satellite remote-sensing techniques (E-16, vol. I-A). He provides a comprehensive outline of his methodology, his findings, and the resulting procedure, which he considers operational.

Although most of the papers demonstrated how information necessary for decisionmaking could be collected through remote-sensing techniques, none more graphically pointed to ultimate decisions made as a result of remote sensing than a paper presented on applications in Kansas (E-17, vol. I-A). Among other things, these applications of remote sensing have led to the completion of an interstate highway and the cancellation of construction plans for a large reservoir, as well as to zoning changes around a smaller reservoir. This paper also discussed applications leading to expansion of irrigation programs in Kansas, and the incorporation of remote-sensing techniques into data acquisition methods used in Kansas City. Such urban applications include housing censuses, environmental impact measurements, and civil defense-disaster relief plans.

The paper concludes with the importance of such remote-sensing techniques as an added data source to state and local government officials. "As with the

introduction of any new technology," the authors say, "a measure of resistance is encountered in convincing officials to adopt remote sensing. Rapidly rising costs of alternative data collection systems, however, are stimulating many officials to examine the technology...."

Remote-sensing applications in the inventory and analysis of environmental problems were also considered (E-18, vol. I-A). Under the Federal Water Pollution Control Act, point sources of water pollution have been subjected to compliance control and have required permits for the last few years. Point sources are, in effect, specific, identifiable, single points of effluent discharge. The Federal act further requires subjecting nonpoint sources, such as runoff from animal feedlots, to controls. Nonpoint sources are much more difficult to identify and inventory. The Environmental Protection Agency (EPA), with NASA high-altitude aircraft support, is using remote sensing to develop such inventories. The EPA is also identifying stresses on ecosystems resulting from manmade changes to the environment.

THE VIEW AHEAD

The development of data bases, the collection of data, and the monitoring in the environmental field ultimately depend on budget allocations, which, apart from a few exceptions in the private sector, are inevitably tied to political decisions. Traditionally, such research, basic or applied, has had little political "sell" for elected officials; support for such programs has offered little with which to make favorable impressions on a political constituency presumed to want results rather than exotic collections of data that, they are told, can lead to desired results. Therefore, in budget-trimming exercises on environmental programs, the first cuts are usually made on items labeled research, data collection, or monitoring.

Strong signs that this situation is changing are evident. As environmental statutes, rules, and regulations increasingly limit individual, commercial, industrial, and governmental options — particularly in construction and production — environmental requirements are being challenged by such statements as "Prove the need for these requirements" and "Justify these controls." Too often, the answer is that although environmental problems have been identified, the lack of specific background data on the one hand prevents enforcement specifically geared to the need, and the lack of adequate monitoring on the other hand prevents effective and equitable enforcement.

Another major sign of change is the increasing disenchantment with essentially negative results produced by environmental control programs. The public is constantly being told what it cannot do in a specific locale; it is not told where proposed activities are environmentally acceptable. In the present economic climate, few communities will continue to tolerate environmental bans of proposed industrial developments unless suitable alternative sites can be offered.

Another impetus is the demand for better and faster response to large-scale crises: floods, development booms, energy shortages, unemployment, and other economic shortfalls. The demands for data become immediate, and the data must be in a form quickly usable and identifiable. Existing satellite and aircraft remote-sensing techniques offer help for these increasingly recognized needs, but remote sensing must be sold to guardians of the public purse in terms of results, of accuracy, of time savings, and of cost in comparison with existing ground collection efforts and efficiency.

An undercurrent of the symposium was the question of who should be providing what services. In the environmental field, the problem can be simply described: A Federal law requires that nonpoint water pollution sources be identified and controlled and assigns the EPA to the task. The EPA, in turn, seeks to get the states and local and regional governmental agencies to implement the law. Would it not be more sensible for EPA, itself, to provide the base data and to monitor, using standardized remote-sensing techniques and reporting, rather than to fund individual nonpoint source projects that operate with inevitably incomplete ground data exclusively? The question is one of efficient and effective use of national resources. Although it is clearly evident that many remote-sensing applications are of local and regional concern and should be so funded, delegating nationwide concerns to the smaller governmental entities for implementation when nationwide solutions exist calls for reconsideration.

The final paper of the environment session (E-18, vol. I-A) raised the question of using remotely sensed data in court. Use of such data in courts certainly will become common practice soon. Environmental laws, both Federal and state, have provided the public with a complete array of legal tools to challenge both permissive and restrictive environmental actions. The burden of proof in contested case hearings and suits is essentially on the governmental regulatory bodies. Remote sensing opens the door to an entirely new body of evidence in such cases. Remote-sensing data and data interpreters can expect to be called to court in a variety

of environmental cases, particularly those involving alleged violations of National Pollution Discharge Emission System permits.

The symposium revealed an almost infinite amount of data potential for application to recognized environmental problems. State and Federal leadership is needed to solve this problem of selectivity and of setting priorities in data acquisition and use.

Finally, there are large numbers of people, mostly government employees, in environmental and related fields whose work now and for the past many years has been to gather data on the ground. Remote sensing appears as a threat: a satellite photograph doing in moments what might represent years of work for them. Yet the symposium clearly established the continuing

need for such "ground truthing" work, especially to meet the verification needs of this still-new technology.

The simple fact remains that we have a tremendous need for information, which, if and when obtained, will prove to be too much to handle by conventional means. After all, the need is not for the data but for the information product. The requirement is to convert data from many sources to information products. Here, of course, the ultimate users must be involved, working with NASA and others to prepare outputs standardized for wider dissemination of information. Today, such standardized outputs might, for example, be maps showing lines of constant sediment concentrations. In the future, they may well be "environmental indices" essential to the coordinated effort toward mankind's need to preserve and protect the planet.

IV. Geology

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INTRODUCTION

The geology session at this symposium differed from those at the three Landsat symposia in two major features.

1. Significant papers from private industry reporting applications of remote sensing to oil and gas exploration were presented. These new applications were funded by industry rather than by government contracts. This voluntary release of corporate results effectively demonstrates the practical value of remote-sensing technology. The committee recommends that this trend be encouraged and enlarged at future symposia.

2. Digitally processed Landsat images were successfully employed in several geologic interpretations. We believe this application represents a significant technologic turning point. Private discussions indicate a growing interest in digital image processing among the geologic user community.

The papers covered a wide geographic range, as shown on the index map (fig. IV-1). They also covered a wide technical and application range. At least one paper was presented on each of the following topics.

1. Oil and gas exploration, by use of radar and multisensor studies as well as by use of Landsat imagery or Landsat digital data
2. Mineral exploration, by mapping from Landsat and Skylab imagery and by Landsat digital processing
3. Geothermal energy studies with Skylab imagery
4. Environmental and engineering geology, by use of radar or Landsat and Skylab imagery
5. Regional mapping and interpretation
6. Digital and spectral methods

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OIL AND GAS EXPLORATION

Oil and gas companies have long been the major industrial users of remote-sensing imagery, but until 1975, little of their work had been revealed. In Volume II, Sabins points out that the pressure of exploration work, rather than company security, prevents many petroleum geologists from presenting their work.

Radar Applications

At a gas field in which production was from a "tight" sandstone reservoir (with the most productive gas wells located where the sandstone is naturally fractured), Owens and Ryan reported that radar imagery was the most effective method for locating surface fracture and fault zones. The 15 wells drilled on the basis of this information proved to be twice as productive as the average field wells.

Another successful radar application involved regional and local studies in Indonesia (G-1, vol. I-B). In the low relief part of the basin, a major arch and a drainage anomaly were mapped; both should merit detailed investigation. Two different types of folds were mapped in the foothills region. Long, narrow, sinuous folds probably do not persist at depth, but terminate at thrust faults. The radar imagery distinguished a second and more favorable fold type exemplified by the giant Dusseldorf anticline; these are relatively gentle folds that should persist at depth. In this rugged jungle area with poor weather for aerial photography, radar imagery provided a clear view of the terrain. Potential exploration targets were defined so that expensive field and seismic work could be concentrated on the most promising areas. Any oil discoveries in this area would probably be credited to geophysics despite the key role played by remote sensing.



Figure IV-1.- Geographic distribution of papers presented in geology panel.

Landsat Applications

A major oil company found an area worthy of drilling on the basis of Landsat imagery. In another instance, a different oil company acquired an exploration area based largely on Landsat interpretation (G-2, vol. I-B). The investigator compared the Landsat results with his earlier interpretation of conventional aerial photographs. The lineaments defined on Landsat imagery were clearer, more continuous, and more extensive than those on the aerial photographs. The Landsat lineament pattern appeared to define a sedimentary basin, which was confirmed by subsequent geophysical work. A surprising amount of lithologic and geomorphic information was also obtained from the imagery.

Exploration Potential

Four papers demonstrated a variety of oil exploration uses of remote-sensing imagery. Some nonindustry people have questioned the value of remote sensing in general and of Landsat in particular because "it has not found any oilfields." As Sabins indicates in Volume II of the proceedings, no single technique can reveal oilfields;

Landsat imagery has only been available for a short time, and the greatest use is for reconnaissance studies to indicate anomalies for detailed field and geophysical investigations. The economic value of Landsat for exploration should not be judged by "how many oilfields it has found" but rather by the fact that industry purchases large volumes of data and assigns valuable manpower to its interpretation.

MINERAL EXPLORATION

Analysis of Landsat multispectral scanner (MSS) images has resulted in development of two techniques having considerable potential for augmenting conventional mineral exploration methods: (1) delineation of landforms, especially linear and generally circular features, that may be the morphologic expression of important crustal features, and (2) detection of hydrothermal alteration zones, which represent the surface expression of potential ore deposits. Although these approaches to mineral exploration had been discussed previously, their potential has been reinforced by the results of this symposium.

Conventional Imagery for Landform Studies

The value of satellite images and photographs for detecting large-scale linear and circular features has been recognized for more than a decade, but adequate evaluation of these features has been complicated by several factors, including their horizontal and apparent vertical extents, the subjectivity of the basic data, and the complexity of their surface expression and origin. Consequently, the usefulness of this approach to mineral exploration has been the subject of debate. However, field evaluation has shown that some of these linear features are zones of crustal weakness; many others undoubtedly have similar origins. In general, circular features are less enigmatic than linear features; most circular features are intrusive or volcanic. Some very large circular to elliptical features are of undetermined origin, and these may be especially critical to the distribution of ore deposits.

Before this symposium, most mineral exploration papers inferred the relationships of known ore deposits to linear and circular features. In other words, the results were general rather than specific. At this symposium, two papers described the occurrence of ore deposits along the traces of specific lineaments. More importantly, one of these studies identified a mineral prospect that warrants further evaluation. Through evaluation of lineaments mapped on MSS images of eastern Nevada (G-28, vol. I-B), 17 favorable targets were selected for mineral exploration. Field studies of 11 of these areas suggest that 7 have favorable structural and alteration features, and semiquantitative spectrographic analysis of selected limonitic samples showed anomalously high arsenic, molybdenum, copper, lead, zinc, and silver content. Although these faults are shown locally on available geologic maps, their regional extent was defined in the Landsat lineament studies.

The second paper (G-21, vol. I-B) described detailed field studies in Pennsylvania of a series of widely spaced northwest-trending lineaments found in Landsat imagery. This terrain and the surface expressions of the lineaments contrast sharply with those in Nevada. Statistical analysis of field data shows that brecciated rocks are concentrated in the lineament zones. In many places along the lineaments, limonitic staining is present. Mineralization is not widespread in this region, but lead and zinc deposits appear to be localized along some of these apparent fracture zones. Although considerably more work is needed to define the origin of these features, early speculations indicate that they are vertical, crustal fracture zones, which are at least as old as the late Paleozoic era.

Geophysical data as well as geological evidence are being used more widely to determine the geologic significance of lineaments. Pascucci correlated aeromagnetic and gravity data with Landsat data showing lineaments to define promising target areas. This combined geophysical and Landsat analysis is important in exploring for ore deposits concealed beneath the alluvium that covers approximately 50 percent of the area.

Although Skylab photographs are being used less extensively than MSS images in mineral exploration, a circular feature in California visible on Skylab imagery was described (G-7, vol. I-B). It has the topographic, structural, vegetation, and color anomalies that are typical of some mineralized zones, especially copper porphyry deposits. The topographic expression is seen best in Skylab S190A and S190B color photographs obtained when light snow cover was present, but the feature is detectable in other Skylab photographs and in MSS images.

Digitally Processed Imagery for Detecting Hydrothermal Alteration

Detection of hydrothermal alteration zones in MSS images depends on slight spectral reflectance differences between altered and unaltered rocks. Although these differences are apparent in visible and near-infrared (0.4 to 2.5 micrometers) reflectance spectra, they are subdued by the positions and the widths of MSS bands. Despite these and other limitations, several workers have shown that alteration zones can be mapped in MSS images. Because of the subtleness of these spectral differences, however, digital processing of a computer-compatible tape (CCT) has been necessary for detecting most alteration zones. In general, conventional MSS color-infrared composite images and Skylab color photographs have not proved useful for this particular application.

Two papers described different approaches to detecting and mapping hydrothermal alteration zones using Landsat CCT data. Approximately 80 percent of the anomalously colored outcrop areas in a color-ratio composite proved to be related to hydrothermal alteration, Rowan, Ashley, and Goetz indicated. Subtle color differences among the altered areas appear to be due to slight mineralogical variations.

Outcrops of pink hematitic tuff and limonitic shale and siltstone were erroneously identified as altered rocks because of reflectance similarities in the MSS spectral

response ranges. At wavelengths near 2.2 micrometers, there are reflectance differences that should distinguish the tuff from altered rock. The ferruginous shale and siltstone, however, have a reflectance spectrum nearly identical with that of the altered rock, and the possibility of discriminating these rocks is slight.

In a two-stage study (G-26, vol. I-B), a known hydrothermally altered, sulfide-bearing copper porphyry deposit was used as a reference area for identifying other altered areas. The first stage of the study was based on evaluation of very high quality Landsat color-infrared composites. Seven candidate targets were identified and checked in the field. No significant alteration was found in any of these areas, confirming previous experiences of other workers using color-infrared composites for this purpose.

Machine processing of the digital radiance values was used in the second phase of analysis to develop a classification scheme. A classification map was prepared, and 30 targets were selected as being spectrally similar to the reference area. Nineteen of these areas were visited in the field. Of these, five are altered quartz-feldspar porphyry and contain 5 to 10 percent pyrite, an indication that these areas may be porphyry copper deposits. The Pakistan government is now conducting a detailed evaluation of these areas.

Although these two approaches to mapping alteration zones have significant differences, they are complementary rather than competitive. In most cases, the most effective approach will probably be a carefully tailored combination of enhanced-image interpretation for compiling alteration maps of large areas and of digital classification for detailed analysis of specific altered areas.

Research Needs

Although the feasibility of these techniques for mineral exploration has been demonstrated, more research is needed to bring them to the operational stage. The most critical need in both cases is development of models that take into account the large number of variables encountered in different geologic and environmental settings. Studies are underway for refining and expanding existing spectral reflectance models for commonly occurring rock types, especially alteration products. Because of the subtlety of the spectral reflectance differences among rocks and the relative importance of other factors, quantitative models will ultimately be required for reliable application of this technique on an operational basis.

Models are also essential for analyzing linear and circular features, but quantification is difficult at this stage because of limited understanding of the origin of these features. However, as specific types of features are identified, models should be developed to describe their distinguishing geologic and geophysical characteristics.

ENVIRONMENT AND ENGINEERING GEOLOGY

High-resolution aerial photography has been used for years for engineering geologic applications, such as establishing sites for large construction projects. More recently, such photography has been useful in preparing environmental geology maps. Additionally, other types of remote sensing, such as side-looking airborne radar imagery and satellite imagery, have been used increasingly in these two areas.

Environmental Geology

Aerial photography at various scales was used to construct a series of environmental geology maps and physical property maps for the State of Texas (G-27, vol. I-B). These maps show surface features such as rock and soil cover, drainage, slope stability, location and properties of building materials, and roadway routing. They are currently being used by state agencies in Texas.

Engineering Geology and Identification of Geologic Hazards

Use of Landsat-1 imagery has been recommended in helping plan new highway routes (G-12, vol. I-B). The imagery was used successfully to map a northern Arkansas lineament complex which correlates well with landslide-prone areas along major highway routes in the area.

In a similar application (G-14, vol. I-B), Landsat-1 data were used to map lineaments and to identify possible faults in areas being considered as sites for nuclear powerplants. Substantial savings to clients were cited because sites identified as containing faults were not included in expensive ground surveys.

An investigator (G-11, vol. I-B) used side-looking airborne radar data acquired through the NASA Earth Resources Aircraft Program to identify probable flood scour features near the area where the trans-Alaskan pipeline is to cross the Yukon River. The features are

located at elevations on the banks higher than floodwaters are known to reach and raise a question as to the statistical frequency of occurrence of floods that might be expected to cause such features and thus cause a problem for the pipeline.

Nearly simultaneous rupturing of water mains in two Pennsylvania towns is believed to be related to activity along two lineaments and a fault identified on Skylab and Landsat imagery (G-21, vol. I-B).

Findings from studies of faults (G-13, vol. I-B) on Landsat and Skylab imagery could be important in identifying areas prone to future earthquakes. Investigators using Landsat, Skylab, and aircraft imagery identified several faults near the NASA Lyndon B. Johnson Space Center that appear to have been activated by the withdrawal of underground water and are believed to be related to subsequent subsidence in the area (G-15, vol. I-B).

These results relate the importance of remote sensing in identifying geologic hazards and in providing information to environmental and engineering geologists. They also indicate that, although high-resolution photography remains the primary method for acquiring remotely sensed information for these purposes, increasingly smaller scale orbital imagery can provide useful information in a cost-effective manner.

MAPPING AND INTERPRETATION

Lithologic Identification

Earlier reports on the use of satellite images revealed a general inability to identify and distinguish most rock types. Spectral response curves for many common rocks do not contain enough characteristic narrow wavelength "peaks and troughs" (as, for example, does X-ray analysis) to permit ready discrimination of different rock types. The properties recorded by cameras or scanners in the visible to near-infrared wavelengths are essentially colors and brightnesses, or spectral reflectances, which simply do not show enough correlation with mineral composition and textures to allow accurate recognition of most major rock types. Thus, light-colored sandstones, limestones, tuffs, and even granites would produce similar tones in photographic images. Adequate recognition of rock types is largely confined to those having distinctive or unique albedos or colors (e.g., basalts) or to those occurring in characteristic terrains or settings (e.g., some granitic intrusives).

Several papers described the problems of making useful rock identifications by conventional photogeologic techniques. Certain alluvial and eolian deposits, regionally homogeneous sediments, basalts, and coarse-textured crystalline massifs have been identified in vegetation-deficient, arid terrain (G-22, vol. I-B). Investigators concluded, however, that this limited selection was insufficient for effective geologic mapping. In another study, it was noted that red outcrops are not necessarily related to weathered sulfide-bearing rocks, but could be volcanic or sedimentary rocks (G-10, vol. I-B).

The greatest recent advances in rock identification have been in the computer processing of Landsat MSS digital data. Work by Rowan, Ashley, and Goetz using the VICAR program developed at the NASA Jet Propulsion Laboratory to make contrast-stretched and band-ratioed color composites is leading the way. Multiple and hybrid ratio and contrast-stretched images from VICAR processing were used to enhance a broad color anomaly related to higher iron content in Tertiary continental sediments (G-5, vol. I-B). This anomaly was significantly affected by variations in topography, by local exposure of a red sandstone, and by changes in vegetation types and densities. On the digitally processed images, this iron-related anomaly could be clearly distinguished from one caused by deep red siltstones of Triassic age. At least one variant of the VICAR program is also in use.

Stratigraphic Boundaries

One essential aim in geologic mapping is the accurate location of accepted stratigraphic boundaries. The limitations of rock identification and the low resolution of space imagery together imply that the production of such maps would be difficult at a level of specificity required to mark the boundaries accurately. However, both Landsat and Skylab images have been used to improve or edit many small-scale maps for such types of boundary relationships as the contacts of igneous intrusives, basalt flows, dikes, and some thick sedimentary sequences.

Boundaries of a granitic intrusive on a color-ratio composite image were compared with those on a published map and the conclusion was made that the intrusive is larger than had been mapped (G-22, vol. I-B). More precise boundaries can now be drawn. Other investigators (G-7, vol. I-B) used Skylab S190B photographs to better outline the boundaries of a poorly mapped circular feature having a well-defined

topographic expression. The Triassic Chugwater red beds were found to have a distinctive color in color-ratio composite images (G-5, vol. I-B); this color distribution does not coincide with the Chugwater outcrop shown on aerial photographs or on the state geologic map. Field studies show this discrepancy is caused by spectrally similar red colluvial soils extending beyond the Chugwater outcrop limits.

Geomorphic Features

No systematic study of landforms was given at this symposium. However, various investigators illustrated the continuing use of remote-sensing imagery in recognizing, describing, and analyzing geomorphic features. For example, workers using Landsat images have been able to map coalescing alluvial fans (G-2, vol. I-B) and to acquire information on other alluvial landforms (for example, G-9, vol. I-B). Erosional changes along the Atlantic coast were monitored by Landsat. A 3-mile-long island, not shown on maps made 25 years ago and presumably newly formed, was "discovered" in band 7 images. From Landsat images, Pickering mapped more than 1000 Georgia lakes with geometric and geographic characteristics that suggest they belong to the swarm of Carolina Bays farther north. The alignment trends and occurrence of slight rims on the south sides (as seen from the ground and from aerial photographs) suggest a meteorite impact origin. Skylab images assisted (G-16, vol. I-B) in recognition of paleo-riverbed channels in the Italian Po River plains.

Structural Relations

In the three Landsat symposia and at many professional meetings since the launch of the two Landsat and the Skylab spacecraft, most geologic papers described detection of linear features from space. Those features not caused by man were generally identified with structural faults, fractures, and lineations. The geology sessions in this Earth resources symposium were marked by a notable reduction in linears as the primary feature observable from space. Much less was said about the simple recognition and charting of linears. Instead, more emphasis was placed on linears as geologic structures, on criteria for their identification, on problems in objective selection of "genuine" lineations, and on regional implications of the numerous newly discovered extensive linear features.

Investigators described the effects of operator subjectivity and of machine processing in identifying linears on Landsat scenes (G-19, vol. I-B). Using an Australian study as a model, each of four geologists at the NASA Goddard Space Flight Center (GSFC) mapped linears from the same scene in western Oklahoma. A wide disparity in selecting the same linears resulted: all four operators found only 4 of 785 linears in common; three chose 37 in common; two selected the same 140; and the remaining 604 linears were identified by one or another of the individuals. The total number and the average length selected by an individual also varied extensively, but broadly similar orientation trends were observed by all four in common. The linears picked by GSFC operators agreed with only 30 percent of those drawn by an oil company in its study of the same area. This company has reported only 35 percent coincidence of linears mapped from Landsat images with those seen on Skylab images. These examples of variability (largely related to subjectivity in selection) indicate that a set of recognition criteria are needed to minimize "false alarms" and misclassifications. Some automated procedure may be needed to remove operator subjectivity from the selection process. An analog system using an enhanced television display of a Landsat transparency achieves some measure of objectivity. In another approach, a digital enhancement program is used to provide an image display that minimizes directional effects.

Criteria were defined for field recognition of 16 long linears that extend across central Pennsylvania (G-21, vol. I-B). These criteria include (1) breccia zones, (2) fractured and slickensided rocks, (3) gossans and other types of iron and/or manganese staining, (4) sulfide mineralization, (5) stratigraphic offsets, and (6) anomalous water flows from springs and seeps.

Aeromagnetic and gravity contours from maps were converted into trend lines. The coincidence of these geophysical trend lines with linears appearing on Landsat imagery was then checked by statistical tests. A high positive correlation was determined; furthermore, 60 percent of the mineral deposits in the study area are associated with linear and trend line coincidences.

Elston and Dipaolo found three major orthogonal directions of lineament pairs on Landsat, Skylab, and RB-57 images of Arizona. The most abundant and prominent lineaments are identical with the trends of major Precambrian faults and transect terrain underlain by Paleozoic and Tertiary strata. This indicates that the lineaments reflect basement structures that were periodically reactivated.

WORKSHOP

Various papers illustrated the advantage of space imagery for locating circular features and curvilinear trends. The several origins proposed suggest that significantly different types of circular features occur. Investigators (G-10, vol. I-B) noted arcuate fracture systems that seemingly relate to intrusive structures. Others (G-17, vol. I-B) found new curvilinear traces that probably outline volcanic centers. Some of these features are caused by active tectonism; others may be caused by subsidence following withdrawal of ground water or petroleum.

Following the Earth resources symposium, an interesting map was shown by Dr. A. Jackson, principal investigator of Landsat imagery for Lesotho (an enclave within South Africa). From 4 images, more than 13 000 linears that correspond to short dolerite dikes intruded into basalt flows were mapped. Where stereographic overlap and sidelap strips were examined, the number of linears nearly doubled. This observation offers strong justification for including stereographic capability in future satellites, particularly those dedicated to geologic applications.

SUMMARY

In 1975, the Kansas and Texas symposia demonstrated the increase in applications of remote-sensor imagery by industry. Not only Landsat and Skylab imagery but that resulting from older methods such as radar and thermal-infrared imagery and aerial photography are being applied practically. Industrial users should increase the publication of their results to help justify continuation of the U.S. remote-sensing programs.

Another trend in 1975 was toward applications beyond conventional geologic mapping. These applications include recognition of landslide hazards, identification of active earthquake faults, and siting of nuclear powerplants.

A pronounced trend toward geologic application of digital processing of Landsat data, especially for mineral exploration, was evident. Both ratio imaging and multispectral classification were successfully demonstrated in test areas that were probably ideal. In moving from the experimental Landsat program to application satellites, particular attention should be given to the optimum spatial and spectral resolution and to the spectral range. This emphasis is necessary to achieve successful applications in areas that are less than ideal.

After the formal papers were presented, 125 workshop participants discussed problems and future requirements for applying remote-sensing technology to geology.

Linears

The often controversial subject of linears and lineaments received much attention. Numerous faults on geologic maps are not identified on Landsat and other remote-sensor imagery. Conversely, many linears on the imagery do not correlate with mapped faults. On the positive side, a number of new faults have been discovered on Landsat imagery, even in regions that have been thoroughly mapped. Several excellent individual investigations of Landsat-identified linears have been reported, but a systematic evaluation of linears expressed on different scales and types of imagery in different geologic terrains is clearly needed. Computer-assisted statistical methods should aid the objective analysis of linear studies. The following needs exist.

1. Objective methods for recognizing and classifying linears
2. Definition of optimum imagery properties (scale, resolution, and spectral bandwidth) for linear recognition
3. Systematic evaluation of geologic significance of linears

Digital Image Processing

The U.S. Geological Survey, NASA facilities, universities, and commercial organizations are developing and applying computer technology for digital image processing. The processing is predominantly applied to Landsat images which are available in computer-compatible tape format. Noise removal, banding correction, haze removal, geometric correction, and contrast enhancement provide optimum images for the interpreter. Color composites of ratio images and multispectral classification are more advanced techniques. The expense and limited availability of the image processing systems have restricted the application of these techniques to geologic problems. Development of relatively inexpensive interactive processing systems should be accelerated.

Spectral and Spatial Resolution

Color-ratio composites and spectral classification techniques are potentially powerful exploration methods for recognizing surface alteration associated with ore deposits. The low spatial resolution of Landsat relative to the heterogeneity of geologic terrains is a handicap to this application. The Landsat spectral bands are not optimum nor do they extend far enough into the near-infrared region for maximum definition of rock, mineral, and alteration signatures. We urgently need a spectral signature library of these targets (measured in the field, not the laboratory) for two reasons: (1) to analyze existing multispectral imagery and (2) to define optimum spectral regions for future sensor systems.

Radar Imagery

Radar imagery for geologic applications is presently confined to the K- and X-band regions (1- to 3-centimeter wavelengths) and has been very useful for structural studies in heavily vegetated terrain and areas of persistent cloud cover. The L-band region (25 centimeters) may also have significant geologic application. Before satellite deployment, more aircraft L-band imagery is needed for evaluation.

Relationship of NASA and Geologic User Community

In response to constructive suggestions from the workshop, a representative of the NASA Office of Applications stated that NASA policy is to consider carefully research suggestions from the earth-science community that include clear, reasoned geologic requirements supported by feasibility studies and experiments. NASA planners note, however, that geologic opinion is divided on several subjects affecting applications, such as linears; this leaves NASA planners confused as to the needs of the geologists.

This apparent division among geologic users of remote-sensing imagery results from the diversity of geologic problems. Geologists use remote-sensor imagery for mapping lineaments ranging in scale from continent-wide down to less than a mile. Petroleum geologists map entire sedimentary basins searching for potential oil structures measured in miles; mining geologists examine specific mineral belts for areas of rock alteration only a few acres in extent. Regional mappers are content with scanner images analogous to color-infrared photographs; those using digital processing need narrow spectral bands and data that extend farther into the infrared region where significant spectral signature differences occur. Geology is the most technically diversified user discipline, and no single combination of scale, spatial resolution, and spectral range and resolution will meet all of these requirements.

Recommendations

The following recommendations were made.

1. A definitive investigation of linears and lineaments that includes imagery expression correlated with surface and subsurface data should be designed and conducted.
2. In the field of digital image processing, development of relatively inexpensive interactive systems is required to make the technology more widely available.
3. Collection of a library of field reflectance spectra of geologic targets should be accelerated. These spectra are needed to design future imaging systems and to interpret existing multispectral data.
4. A definitive experiment on spatial resolution requirements for different geologic applications is also needed to define future imaging systems.
5. Longer wavelength radar imagery (L-band) should be acquired and made available to the geologic user community for evaluation and application. This is essential training for the forthcoming satellite radar imaging systems.

V. Information Systems and Services User Services

David Landgrebe^a

The other sessions in this symposium were associated with the user community through a so-called user discipline (e.g., agriculture, geology, land use). The information systems and services session and the user services session were also related to the user community but in a different fashion; its association was more directly with the technology itself.

Prepared papers were presented in both sessions; an "interactive session," in which members of the audience could interact directly with a panel of experts, was held in the user services session. Papers presented can be categorized topically as follows.

1. Data availability and distribution
2. Descriptions of complete processing systems
3. Developments regarding subsystems
4. Applications related to the technology
5. Research for future technology
6. Education and training opportunities and materials

Modern remote-sensing technology has been under intensive development by NASA for about the last decade. Now, two important questions, which were amplified during this symposium, must be considered. Is there really a technology ready for the user? If so, to what extent has this technology already begun to permeate the user community?

Of the papers presented, fully one-third were descriptions of complete, ready to use data processing systems that are offered by various organizations. Figures V-1 and V-2 are examples of those discussed. These and similar systems provide concrete evidence that hardware specially designed for remote-sensing technology and for the user community is now available off the shelf, which was not true at previous symposia. These systems represent recognition by private enterprise of the existence of a user community and a market and of the actual and potential use of such

technology. This trend is a major indicator of the answer to the question about readiness of remote-sensing technology.

A second observation can be noted from the applications papers presented during this session. For example, a speaker (I-6, vol. I-B) from the U.S. Forest Service described a straightforward and routine application of remote-sensing technology using Landsat data as a part of the agency's daily efforts. There have been many spectacular events in this field in the past; however, there are now evidences that remote-sensing techniques are being used in many more routine kinds of applications. These nonspectacular applications are important because they indicate a maturing of the technology.

Further conclusions about remote-sensing technology and its relationship to the user community may be drawn from information about data availability and from descriptions of data uses. There were two presentations on data availability (I-21, vol. I-B, and U-2, vol. II). Some statistics regarding requests to the Earth Resources Observation Systems (EROS) Data Center were given that lead to some perceptions about trends in data use.

The number of requests received at the EROS Data Center for remote-sensing data is shown in table V-I by fiscal year (FY). Notice the very large increase in requests for Landsat imagery, 94 percent, from fiscal year 1973 to 1974, and another increase in fiscal year 1975.

In his remarks during the opening session of the symposium, William Stoney emphasized the very rapid adaptation of the user community to digital data. The expanded use of Landsat computer-compatible tape (CCT) units shown in table V-I clearly illustrates this fact.

^aLaboratory for Applications of Remote Sensing,
West Lafayette, Indiana.

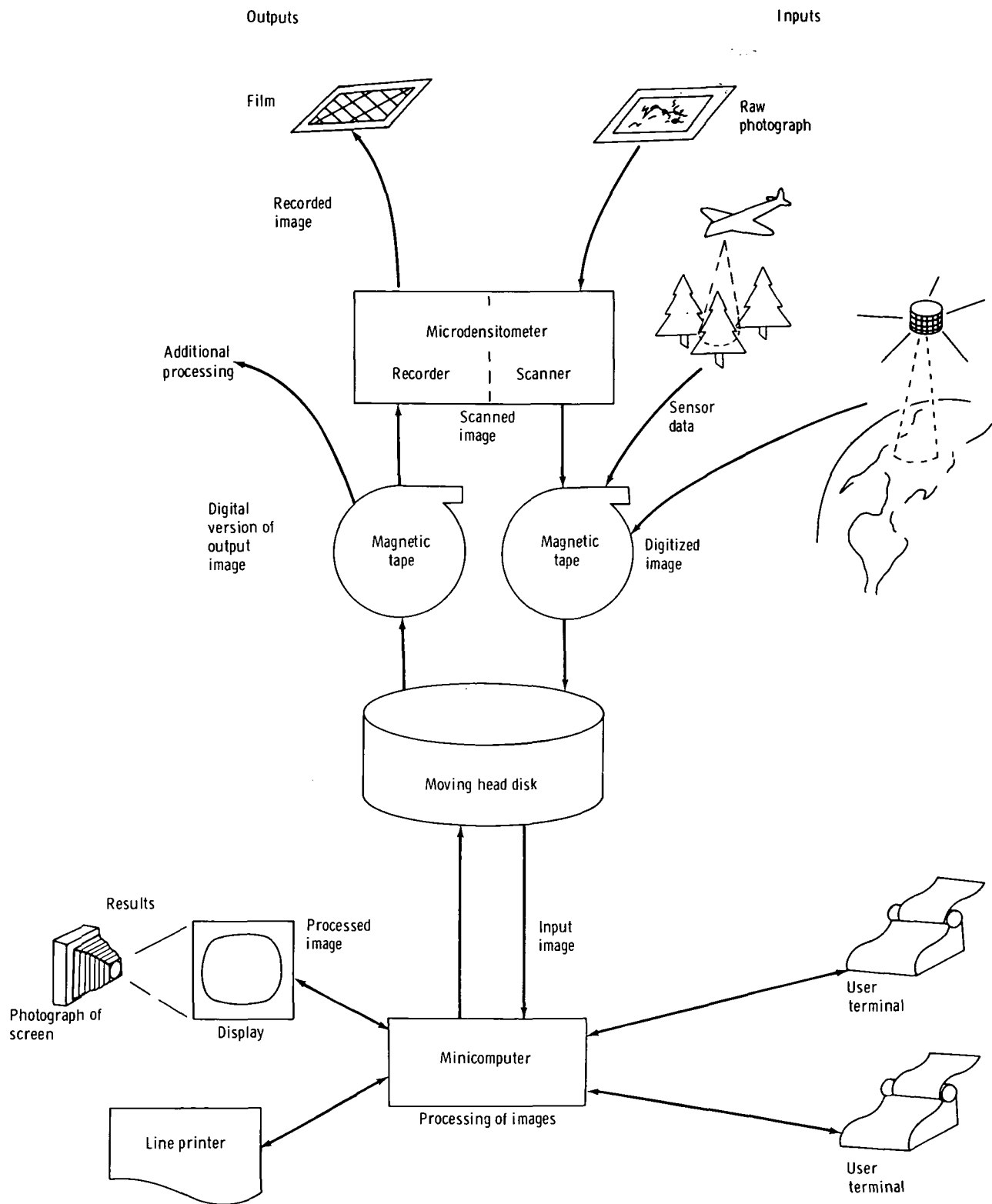


Figure V-1.— Input/output resources and capabilities of the interactive digital image manipulation system.



Figure V-2.— The PDP 1145 minicomputer used in the screwworm eradication data system and elsewhere.

Because Landsat data are relatively new, one might suspect that many of the data requests represent curiosity rather than actual use. Although curiosity is undoubtedly a factor, the table also shows a significant increase in requests for aircraft data as well. Aircraft data are not new; this data source has existed for many years.

A customer profile for the EROS Data Center is shown in table V-II. Notice that the largest customer, both in number of requests and in money spent, was private industry. Industry accounts for at least one-third of the total data requested. It seems logical that private industry should occupy this position. With regard to a new technology, industry is the most mobile of the various sectors; it has more local control over its resources and therefore can move more rapidly when a new and viable technology becomes available. It usually takes longer for the governmental sector to secure the necessary approvals and appropriations to take advantage of such technology.

During the period April 1974 to March 1975, the same as that covered in table V-II, the EROS Data Center received orders for 413 000 frames of all types of data, including 167 000 frames of Landsat imagery. These figures certainly indicate more than a casual interest in this type of data by the user community.

The EROS Data Center has also classified the major uses of its products into the following general areas.

1. Mineral and fossil fuel exploration and related geologic base mapping
2. Applications research
3. Cartographic and related mapping applications
4. Water resources management and inventory
5. Timber and forest product inventories and land use mapping
6. General land use stratification
7. Agricultural land use stratification
8. Wildland inventory and monitoring
9. Miscellaneous (uncategorized)

TABLE V-I.- EROS DATA CENTER DATA DEMAND

(a) Quantity

Data type	FY 1973 no. of frames	FY 1974		FY 1975	
		No. of frames	Increase, percent	No. of frames	Increase, percent
Landsat imagery	81 071	157 178	94	185 000	18
Landsat CCT's	10	228	2200	820	260
Skylab and Apollo data	--	17 201	--	33 000	92
Aircraft data	83 942	109 490	30	193 000	76
Totals	165 023	284 097	72	411 820	45

(b) Cost

Data type	FY 1973 cost	FY 1974		FY 1975	
		Cost	Increase, percent	Cost	Increase, percent
Landsat imagery	\$ 228 042	\$ 528 514	132	\$ 792 000	50
Landsat CCT's	1 600	36 480	2200	164 000	349
Skylab and Apollo data	--	34 421	--	124 000	250
Aircraft data	114 676	237 332	64	520 000	119
Totals	\$ 374 318	\$ 836 747	124	\$ 1 600 000	91

It is important to emphasize the potential impact of remote-sensing technology in the preceding areas on major contemporary problems, such as the availability of energy sources and of food supplies and the utilization of land resources.

During the last several years, remote-sensing technology has been somewhat troubled by its own success. Demand for data rose more rapidly than anticipated; as a result, delays in obtaining data became excessive. This problem is being corrected, at least for data in image form, and it seems reasonable to assume that faster availability of digital magnetic tape data will also result soon. The importance of solving this problem of delay is very great.

A third perspective from which one can sense this movement to technology utilization should be noted. If a technology is to be broadly used, educational and training opportunities must be available. Through this symposium, much information about remote-sensing

training programs and training materials has been assembled. One author (U-3, vol. II) found 10 books and 5 scientific journals devoted exclusively to remote sensing. He further noted at least 4 regularly scheduled symposia on the subject and 11 regularly occurring short courses presented by different organizations, including one now offering a 1-week short course each month.

The opportunities and materials offered for training in remote sensing must be regarded as unusual because of the diversity of educational materials available. They range from the usual books, ad hoc short courses, and the like to prepackaged minicourses, television and audio-tutorial tapes, and even include a computer remote terminal system. One of the most unusual programs was produced by the University of Nebraska and consists of materials for use in secondary schools. High school administrators have shown a great deal of interest, and a description of the program also stimulated much interest at the symposium session.

TABLE V-II.- EROS DATA CENTER

CUSTOMER PROFILES^a

User	By item, percentage	By dollar value, percentage
All data		
Private industry	34	30
Foreign	12	12
Federal Government	27	24
Academic	14	16
Individuals	7	11
State and local government	1	1
Unknown	5	6
Landsat data only		
Private industry	24	24
Foreign	24	20
Federal Government	15	15
Academic	14	15
Individuals	10	13
State and local government	1	1
Unknown	12	12

^aApril 1974 to March 1975.

In summary, during the information systems and services and user services sessions, and during the other sessions as well, ample and convincing evidence was given that remote-sensing technology has moved and is moving into the user community. Therefore, it seems important, while continuing to encourage this movement, to begin in earnest the development of a

second stage of remote-sensing technology. We are only at the beginning; the potential for further development is great. If the benefits beginning to accrue from past technology development are true indicators, the importance of bringing this potential to reality over the years to come is indeed great.

VI. Land Use State and Local Users

Charles M. Parrish, III^a

The state and local and land use sessions discussed in this summary involved a cross section of the expanding community of government managers who are now using remotely sensed information to make programmatic decisions. In this summary, the specific applications discussed in individual presentations are not itemized; these are available in Volumes I and II of the proceedings. Instead, problems and potential solutions that can be inferred from the presentations and resulting discussion are addressed.

The objective of the state and local interactive session was to compare approaches to remote-sensing applications for state and local resource management problems. With the possible exception of some international papers, this objective applied equally to the land use session; however, the land use session differed because of less time for discussion and consisted primarily of several presentations emphasizing techniques.

Mr. Charles Mathews has personally requested emphasis on problems that NASA should be addressing. In responding to that request, I have included other Federal agencies and, wherever possible, have suggested directions for future program development.

Many papers throughout the symposium related to state and local applications. Those included in the two sessions summarized herein were selected to provide material for stimulating interaction and thereby for emphasizing as many of the generic issues as possible. Hopefully, the audience of state and local managers furthered their appreciation of the status and direction of remote sensing as a useful tool for problem solving.

Many current applications of remotely sensed data to management problems exist, and some have been used for years. However, the papers presented dealt with some of the more complex approaches, simply because people believed discussion of such approaches was

appropriate. Among the general categories of major applications discussed were wildlife habitat determination; crop production estimation; impounded water surveying; urban development monitoring; corridor location (transportation, communication, energy); flood area definition (fig. VI-1); urban planning; agricultural potential determination; surface water runoff estimation; water quality determination; strip-mine rehabilitation monitoring; coastal zone baseline information surveying; significant natural resource area definition; and forest management planning.

Interest in the use of satellite-acquired data was greatest among users concerned with large areas. In general, the strongest interest was shown by users from the larger states, which often encompass large tracts of relatively inaccessible land.

The use of imagery still is more common than the use of digital data. However, interest in the use of digital data and of computer implementation information-extraction techniques is increasing rapidly.

In general, aerial photography is widely used as a source of information, but it provides only a part of all information desirable for decisionmaking. Even though much remotely sensed data is being acquired, uncoordinated acquisition by various projects at various levels and scales sometimes precludes the use of these data for comprehensive statewide inventory. Yet there is considerable interest in the initiation of statewide information systems.

The most striking characteristic of the international presentations was that most projects use the satellite-acquired data in an operational context because these are often the only data available. However, in some cases, satellite data coverage is still less than adequate.

For the urban orientation, there were not enough participants to obtain a representative cross section of

^aGeorgia Department of Natural Resources, Atlanta, Georgia.

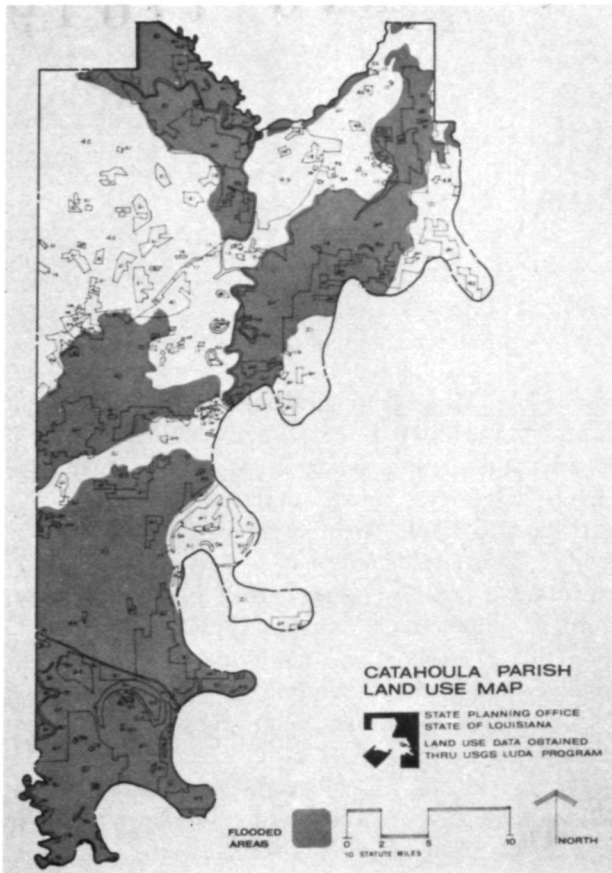


Figure VI-1.— An example of satellite data used to map flooded areas in a county. The dark areas, interpreted from Landsat imagery, were overlaid on an existing land use map.

urban users who apply remotely sensed data. The statements and conclusions made in this section are based on what was heard.

Urban planning has been identified as a major area of application of remotely sensed data. As in past years, low-altitude aircraft photography currently is the predominant source of remote-sensing data used in the planning process. However, many planning groups still use conventional ground data-gathering methods. Much of the photography collected is in the range of scales from 1:2000 to 1:24 000 and provides adequate detailed information (Levels III and IV) for most urban planning functions.

During the past 5 years, some urban planners have had access to NASA high-altitude aircraft photography at scales from 1:100 000 to 1:125 000. Most evaluations of these data indicate that the detail is insufficient and

that the scale is too small for many planning purposes, particularly those dealing with urban cores and adjacent areas; however, the data do have potential in planning for those areas near and beyond the urban fringe (fig. VI-2). Although Landsat data cannot provide the detailed information and mapping required for most urban planning purposes, the imagery is potentially useful in applications of digital processing techniques to monitor suburban expansion and to provide change detection throughout the urban/suburban area.

As planning becomes large scale (beyond the urban fringe), it may be wise to compare the advantages of obtaining a land cover inventory from a satellite source such as Landsat to obtaining it by the traditional technique of aerial photointerpretation or field survey. The advantages are measured not only in dollars saved, but, more important, in time saved. (Three examples of this consideration were given within the session.)

The author drew a few general conclusions from the proceedings. First, a tremendous gap exists between the technical development and the managerial application of remotely sensed information. However, a number of people were surprised at the extent to which remote sensing is being actively applied by state and local government agencies. There is apparently a rather rapid expansion in its use across the country. Some recommendations are made in the following paragraphs.

1. The NASA and other Federal agencies, as well as state agencies, are becoming more conscious of the user and his needs. Although this progress is healthy, educational programs should receive an even higher priority. Formal education programs, developed and sponsored by Federal agencies and made available to state and local governments, are extremely important.

2. Documented procedures directing the user from the first step to the final product are essential. Without a formal approach, a new technique will appear excessively risky to most users. All successful applications research should culminate in a formal procedure.

3. Symposia, conferences, and briefings are necessary to make the manager aware of the state of the art, but these meetings must have direct followup assistance in technology transfer. The concept of cooperative remote-sensing centers was discussed, but no consensus on their function was apparent.

4. Research projects as funded, together with their primary objectives, should emphasize the involvement of students who one day will be in operational programs trying to resolve resource management problems.

5. The simple technique should not be neglected. Often, a sophisticated approach is used when a proven

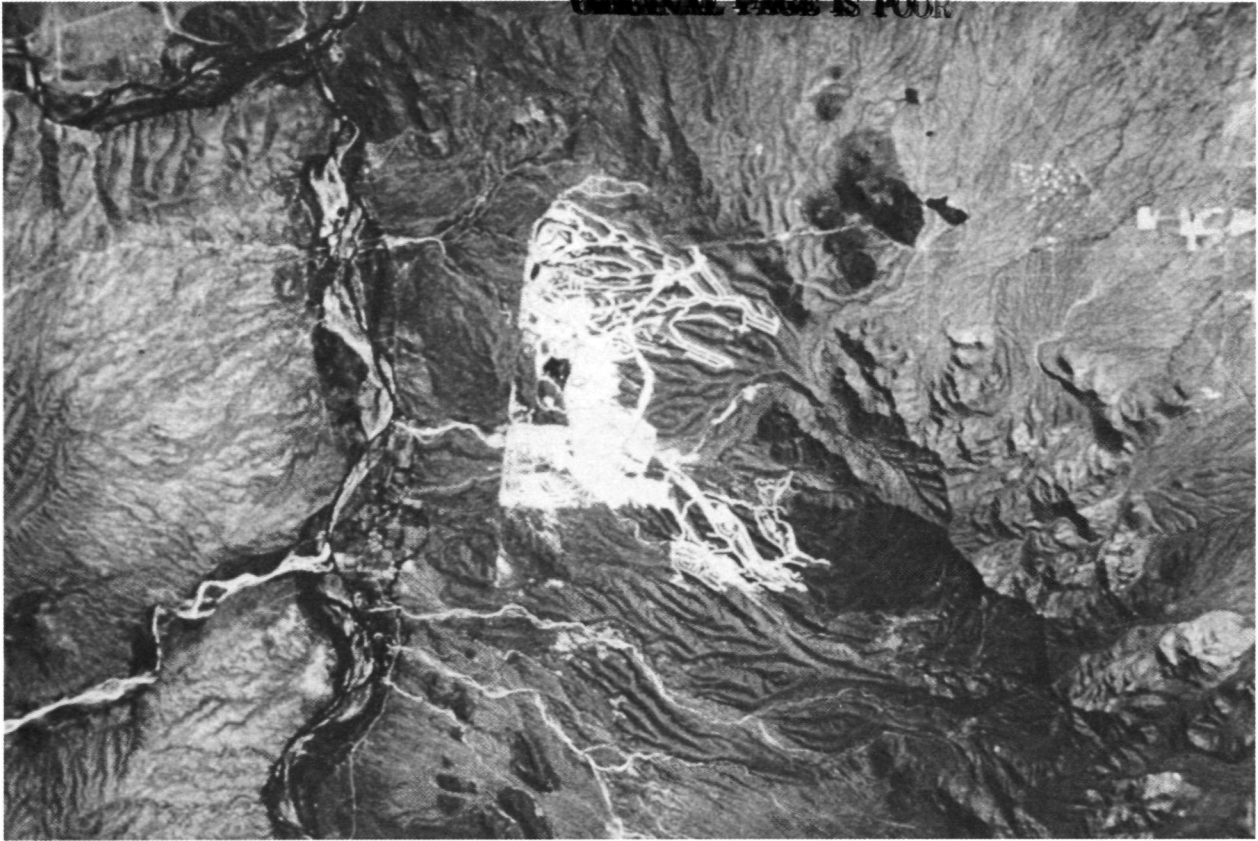


Figure VI-2.— Trends and residential growth in outlying subdivisions are visible in this small-scale photograph.

simpler method may be equally effective. More complex approaches should be applied only as they are proved and as management problems require their application.

6. As much for education as for improving solutions, the intended user should participate in the design of data acquisition and handling systems. If the user works on system development and understands system operation, he will be able to use the system better.

Second, the user must be confident that the operational system will have guaranteed continuity of service. Many are using Landsat data routinely now, but because the system is not classified as operational, any large commitments to training, technology, and equipment would be very risky. If one concentrates on the established capabilities of Landsat and evaluates those in relation to specific problems, he will recognize that Landsat should be an operational system.

Third, the fact that no single system will ever be a panacea must be recognized. A collection of tools specific to the particular problems dealt with by managers is needed. Such combinations as spacecraft and

aircraft, digital and optical will be necessary for a long time.

Fourth, data must be made available to users at a high resolution, with a quick turnaround, at a low cost, and in a rectified form. There was much interest in greater resolution and more rapid data delivery, but it was recognized that a tradeoff exists between the two, with cost the ultimate limiting factor. Rectified data referenced to the ground and to a nominal scene with sufficient accuracy and available in volume from the EROS Data Center would greatly increase the usefulness and affordability of the information. Rectification is the main requirement to geographically reference information extracted from remotely sensed data to other physical and socioeconomic information.

It must be remembered that in any remote-sensing technique the data need only have accuracy or precision to the degree required by its application. Such information often becomes acceptable when it is of a quality equal to or better than information assembled by existing operational ground surveys.

Fifth, cooperative programs should be developed. If states share the cost, the data probably will be worth collecting. The states will also have more involvement in the manner of collection and the type of format chosen.

Sixth, more personal communication is needed among data users and between data suppliers and users. A consensus approach to management should be developed. During the state and local session, there was only minimal attendance and involvement from local governments. State governments were better represented. However, most of the time, the person who actually makes the final decisions is probably in local government.

Seventh, users must be encouraged to help develop future programs. To this end, a structured effort by the

Federal government is needed. This conference has gone a long way, and other efforts have been made in recent months and years. These efforts must be continued. Of course, participants in the session did recognize that state and local governments, the ultimate users, share the responsibility of defining their own needs and expressing them to the Federal government and thereby aiding in the development of programs. Although the sessions identified many of the basic problems that need to be resolved in developing future programs, nothing should prevent users from going ahead and applying the data that now exist to management needs. Existing data can go far toward solving problems today. At the same time, users should work together in a structured, focused, and intensive manner to define the needs of future programs.

VII. Marine Resources

John W. Sherman, III^a

The papers presented in the marine session may be broadly grouped into several classes: microwave region instruments compared to infrared and visible region sensors; satellite techniques compared to aircraft techniques; open ocean applications compared to coastal region applications; and basic research and understanding of ocean phenomena compared to research techniques that offer immediate applications. The fact that no papers were based on operational applications to the marine environment was not surprising since the instrumentation was designed for terrestrial applications and/or marine research. Nevertheless, the ensemble of papers has clear and direct impact on the Nimbus-G and Seasat-A research platforms planned by NASA for observational capability in 1978.

In this summary, overall implications of the marine session papers will be presented. First, the Landsat series of satellites has a greater role in coastal applications beyond that of serving as a surveillance tool and for general circulation observations (M-5, vol. I-C). The need for establishing a standard technique for measuring the linear distance of coastlines was illustrated (M-13, vol. I-C). Variations of two to one were found in the measured value depending on the agency making the measurement; automatic techniques using Landsat offer a systematic means of making this measurement on a time scale sufficient to show changes in the linear definition of the coastline.

Continuing with Landsat applications, a comparison of the information derived from the Skylab S190 and S192 experiments suggests that water penetration in tropical waters to depths of approximately 20 meters can be achieved (M-10, vol. I-C). This finding suggests that an operational Landsat system could have improved application to shallow water areas by including more of the blue-green portion of the visible spectrum. Further, it was illustrated (M-9, vol. I-C) that a rapid turnaround time of Landsat data, using onsite analysis of

high-data-rate Landsat images at the NASA Goddard Space Flight Center coupled with low-data-rate facsimile transmissions by way of Applications Technology Satellite 3, can support oceanic applications in field survey data collection using in situ techniques. The implications of this possibility are important from needs expressed (M-8, vol. I-C) in relation to game fish and the work of the National Marine Fisheries Service in establishing relationships between water clarity and the locations of specific schools of fish. Near-real-time information potentially could support fishing vessel operations keyed to the 18-day Landsat repeat cycle or could extend the applications of the Nimbus-G coastal zone color scanner (CZCS) to immediate field utility and to circulation activities (M-5, vol. I-C).

The CZCS system was described (M-6, vol. I-C) in conjunction with performance of measurements using a breadboard scanner flown on an NASA U-2. Numerous implications are found concerning the measurement of ocean color. Also, such sensitive parameters as atmospheric and Sun-angle effects, which have been previously described as theoretical, are now being measured empirically and will soon be measured quantitatively. The use of the blue region has been demonstrated together with requirements for reducing atmospheric effects. This CZCS system will provide data on a more routine basis and will extend some suggested applications (M-7 and M-11, vol. I-C).

The oceanic use of active and passive microwave sensors from space was demonstrated in the Skylab S193 experiment. The altimeter portion and results from Experiment S193 were described (M-1, vol. I-C). This altimeter has been fundamental in the development of the third Geodynamics Experimental Ocean Satellite, launched in April 1975, and will be used for both instrument and experiment design for Seasat-A. This S193 experiment was one of the most successful Skylab oceanic experiments with the measurement of many large geoidal features to a resolution of ± 1 meter.

^aNational Oceanic and Atmospheric Administration/National Environmental Satellite Service, Washington, D.C.

Two prime oceanographic variables for which reliable data are needed to improve safety at sea (surface roughness and wind) were discussed in papers M-2 and M-3 (vol. I-C). Both papers have direct bearing on the research and demonstration experiments planned for Seasat-A. Of particular note in paper M-2 is the possible parameterization of the wind field in terms of the wave spectrum by means of a nondimensional determination of the total energy. This approach may significantly reduce the computer time required by forecasting models. The usefulness of 1.4-gigahertz radiometers for measuring surface salinity in brackish water having salinity greater than 5 to 10‰ was demonstrated (M-12, vol. I-C). Spatial resolution limitations prevent development of this technique for satellite applications in the near future, but it could be implemented on an operational basis from aircraft.

The importance of monitoring the interface between the land and the sea was exemplified (M-14, vol. I-C). The marshland, vital to many forms of marine life, is being subjected increasingly to pressure from population expansion. The ability to monitor and observe changes in vegetation and vegetation health becomes increasingly important. Multispectral techniques for monitoring salinity-level effects on vegetation using aircraft scanners were described in this paper. Although the areas involved in some regions are large, relatively narrow bands of salinity-dependent vegetation may exist. Therefore,

existing satellite resolutions may not be sufficient to classify all marshlands. It appears this technique could also be implemented on an operational basis from airborne platforms. It is noted that the 1.4-gigahertz-radiometer salinity measurement forms an excellent complementary tool for tracking brackish water characteristics near and within wetland areas free of immediate vegetation.

In summary, the papers included in the marine session were both timely and appropriate. Ten papers dealt primarily with coastal activity, an area that will receive increasing attention during the next decade as a result of both national and international needs. National needs are most strongly identified through the Outer Continental Shelf program involving the development of offshore facilities and international needs through the attention being given to extending jurisdictions from 12 to 200 nautical miles offshore. Studies of the global aspects of the ocean, reported in four papers, will lead to improved environmental forecasts both in the coastal states and in the open ocean. Safety at sea will become increasingly important as larger cargo and tanker vessels operate on the high seas and in the coastal region. Remote-sensing technology appears to be keeping pace with national and international needs; the problem is to translate and integrate the demonstrated technology into operational capability.

VIII. Water Resources

D. B. Simons^a

Remote-sensing techniques can be extremely useful for all aspects of watershed analysis. For example, they have been used for determining runoff from watersheds, for estimating flood hazards, and for performing flood zone studies. In addition, such studies are extremely valuable in connection with identification and analysis of droughts. Soil moisture, which relates to runoff from the watershed, can be mapped. Ground water can be considered, and methods of improving ground-water storage as well as of identifying ground-water reservoirs represent possible uses of remotely sensed information. The interrelationship of all these many factors helps water resource researchers to obtain common, useful answers. Studies in water resources management and development have involved most regions of the United States and several foreign countries. The results of such studies can be incorporated into models that lead to planning, decisionmaking, and ultimate development.

This summary is subdivided into broad headings, arranged in an order intended to assist the reader in obtaining a better, more meaningful overview of the contributions that have been made, the areas of research that should be pursued, and probable long-term benefits that can be realized by undertaking continued activities of these types.

GEOLOGY AND HYDROGEOLOGY

Skylab and Landsat data are excellent for the identification of major watershed features, such as large-scale rock formations, drainage networks, major faults, and vegetated areas. However, because of the vast area visible by this means, remote sensing from space platforms cannot give the detailed information that may be of interest within a watershed. Aircraft-flown sensors are needed for classification of details where much greater resolution is required. By this means, data can be gathered at a scale chosen to obtain the desired detail for studies of particular small areas or points of interest.

ANALYSIS OF WATERSHEDS

Water resources represent one of the most valuable assets of any nation. To understand, to appreciate, and to properly use water resources, one must understand the overall complexities of watersheds and river systems. Figure VIII-1 illustrates the complexity and area of a major river system. The Mississippi River watershed, like that of any size river, is both complex and dynamic. In fact, rivers are the most rapidly changing of all geomorphic forms.

One can clearly identify and study stream networks and their characteristics using data from Skylab, Landsat, and aircraft sensors (W-8, vol. I-D). All sources of data are useful, and the ultimate value of remotely sensed data depends on the problem being studied. For an overview of the watershed and for the determination of some of its major features, Skylab or Landsat data are indispensable. Conversely, for studying in detail a short reach of river, riverbanks, or a remote watershed, aircraft data become more valuable because one can concentrate on a small area and obtain sufficiently detailed data to analyze even the most minute aspects of the watershed.

As a result of recent studies of watersheds and their characteristics, techniques have been developed that enable more accurate identification of impervious parts of the watershed, whether they are impervious as a consequence of natural formations or as a consequence of man's development of the surfaces. This capability to sense the imperviousness of a surface is an advance that will improve man's ability to assess the effects of such surface areas on the magnitude of runoff, the time of concentration, the time of peaking, and so forth.

SNOW AND ICE

In considering water resources, snow cover is an integral and important part of the hydrologic scene. Either directly or indirectly, snow cover affects most of

^aColorado State University, Fort Collins, Colorado.

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the world population; snowmelt affects floods and droughts, and water for irrigation, for industrial production, for hydroelectric power development, for recreation, and for a multitude of other uses.

Using satellite imagery (W-24, vol. I-D), the extent of snowpack and its spatial variation with time can be mapped (fig. VIII-2). Furthermore, it is now possible to differentiate between snow and clouds by use of a scanner such as the Skylab S192 (because the Skylab data showed snow cover to have much lower reflectance in the near-infrared portion, 1.55 to 1.75 micrometers, of the spectrum). Previously, clouds over snow were difficult to identify. The ability to differentiate between snow and clouds is a significant breakthrough for both hydrologists and climatologists.

Multispectral comparison of satellite imagery has made possible delineation of that part of the snowpack actively undergoing snowmelt. Continued surveillance can identify the active and inactive parts of the pack as they relate to runoff of the watershed at any particular time.

PREDICTION OF RUNOFF FROM SNOWMELT

Associated with the snow cover is the prediction of runoff as a consequence of snowmelt. Large changes in snowcapped areas are often visible in successive satellite imagery over relatively short periods of time (W-23, vol. I-D).

Measurements of the satellite-derived snow cover area have been related to seasonal streamflow, and results indicate that snow cover is a potentially important index parameter for reducing error in runoff forecasts (W-26, vol. I-D). Even a small increase in the precision of predicting runoff can be an extremely important contribution because water and knowledge of its availability is so fundamental to both technology and economy. Because of the promising results regarding improved forecasts, NASA has activated a program involving six Federal and three state agencies. These groups are doing snow mapping and conducting tests related to snow area technology and use of operational systems to improve runoff estimates.

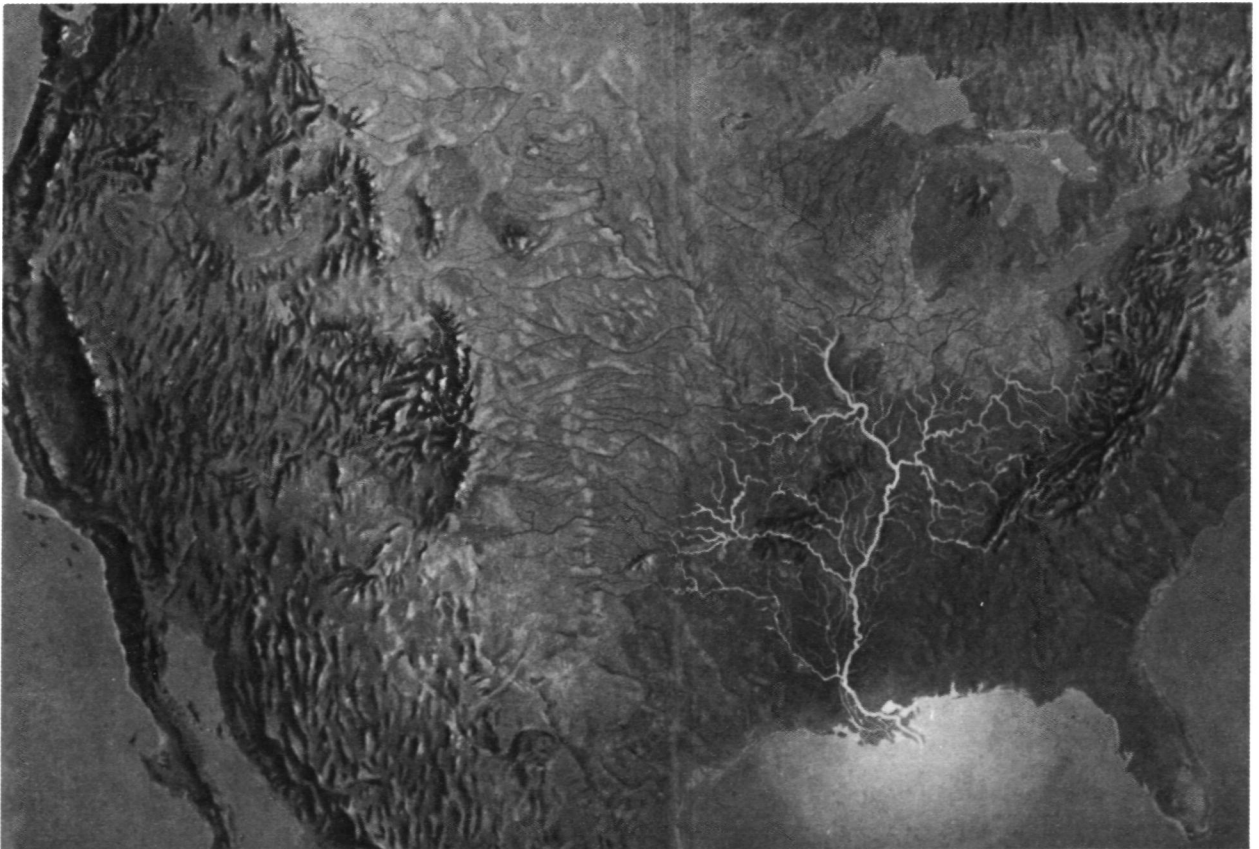
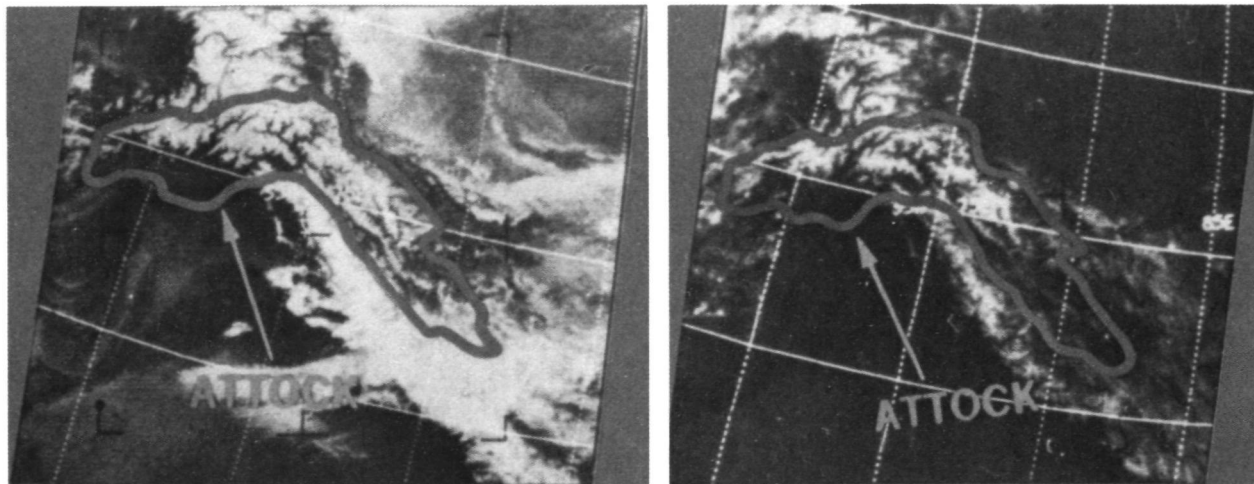


Figure VIII-1.— Extent of Mississippi River watershed.



- (a) April 4, 1969: snow-covered area, 60 percent; predicted April to June runoff, 29 590 000 acre-feet.
- (b) April 3, 1971: snow-covered area 44 percent; predicted April to June runoff, 24 990 000 acre-feet.

Figure VIII-2.— Satellite observations of the variation in snow cover at the beginning of snowmelt in the Indus River Basin. Imagery is from the Environmental Science Service Administration satellite ESSA-9.

HYDROLOGIC LAND USE CLASSIFICATIONS

Hydrologic land use classifications are important to river watershed management. Multispectral analysis of satellite and aircraft data can yield this vital information regarding the water surface, the agricultural activity and type of agriculture, urban development, residential construction, forested areas, marsh areas, and so forth in the watershed (W-13, vol. I-D). Such analysis techniques have been applied to satellite and aircraft data to provide a broad and detailed information base related to conditions in the flood-prone areas of the watershed. These data have been compared to conventional U.S. Geological Survey (USGS) flood-plain boundary maps, and unflooded regions were shown to exist within the USGS-identified flood boundaries. An important point should be made here. When remotely sensed data are used to study a watershed, an opportunity to look at the total watershed is created. Of course, the detail depends on the type of remotely sensed data available. Conversely, when flood-plain boundaries are based on field reconnaissance and field surveys, time limitations may prevent consideration of all conditions adjacent to the streams. Consequently, the occurrence of unflooded areas within flood plains may not be detected when conventional methods are used.

The cost of studying watersheds varies greatly depending on the details desired. Watershed mapping by satellite of the type mentioned could be conducted for an approximate cost of \$4.30 per square kilometer. This technique enables the mapper to obtain an excellent understanding of at least 90 percent of the watershed being studied.

Other studies (W-19 and W-22, vol. I-D) indicate that significant financial savings result from using remotely sensed data properly. In one instance, the most economical method of performing a land survey involved using U-2 aircraft imagery, although both the satellite and the U-2 data provided less expensive and more effective information than could be obtained using conventional methods. Remote sensing enables an overall view to the degree of precision dictated by resolution requirements and budget limitations. Such information helps resolve differences in survey statistics regarding areas of irrigated land, fallow land, and other land uses. More precise information of this type assists greatly in planning and developing an area.

SOIL MOISTURE

Skylab microwave data, especially from the L-band, have indicated a high correlation between radiometer

temperature and soil moisture content near the land surface (W-6, vol. I-D). Such information is extremely valuable to all groups and individuals interested in watershed utilization and development. For example, in considering runoff from watersheds, knowledge of the moisture values at any given time over the total watershed would add greatly to the precision with which storm runoff and sediment discharge from the watershed could be estimated for immediate and subsequent storms.

EVAPOTRANSPIRATION

When water availability and utilization from and on the watershed are being considered, knowledge of evapotranspiration rates is important. More specifically, it is vital to irrigated agriculture and water supply for all users. Maps estimating evapotranspiration rates from the agricultural landscape have been produced using Skylab S192 data (W-21, vol. I-D). These results were evaluated using ground measurements. Such studies can greatly benefit operational irrigation scheduling management systems.

PLAYA LAKES

The many small, shallow playa lakes in the High Plains of Texas, or similar lakes anywhere, are of great importance in the optimum use of water resources. These lakes also may affect the salinity of adjacent lands. In the High Plains of Texas (W-18, vol. I-D), nearly 70 000 irrigation wells are in operation. As a result, water is being mined from this region more rapidly than natural recharge can resupply it. Overuse of the ground water ultimately may affect the agricultural economy of the area significantly. Remote-sensing techniques are being used to obtain current statistical information on the number and areal extent of the playa lakes in this region. The State of Texas is considering these lakes as a possible source of water to help recharge the ground-water basins. If the lake water could be introduced into the ground-water reservoir, it would not only greatly enhance the local water supply but would greatly reduce evaporation losses in the region. Lakes of this type have very high evaporation losses.

Another important factor is the effect such lakes have on the salinity of adjacent lands. Salinity can be studied using satellite- and aircraft-sensed data, but salinity conditions are dynamic. Because of its transient nature, salinity varies considerably with time. After a period of

wetness, much of the saline area may be difficult to observe as a consequence of the flushing action of the rainfall. Conversely, during extended dry periods, the saline areas grow in size and are easily identified. Therefore, analyses must be performed carefully to make certain that reliable results are obtained.

SURFACE RUNOFF

Many methods are currently used to estimate surface runoff from watersheds. Runoff coefficients for an empirical equation have been related to remotely sensed data, both from Landsat multispectral and aircraft passive microwave systems (W-15, vol. I-D). This relationship is simple and effective and considerable advantages are to be gained by continuing to utilize these simple, effective concepts. However, as a consequence of improved data provided by satellites and aircraft, more complex methods of estimating surface runoff are gaining attention. The capability, through remotely sensed data, to obtain information on land use, antecedent moisture, precipitation, evapotranspiration, geology, watershed geometry, vegetative types, and so forth will lead to advanced techniques for assessing and allocating water resources.

FLOOD HAZARDS

Flooding is an international problem. From the beginning of time, man has tended to populate the river valleys because they are fertile and because rivers have provided cheap transportation. Therefore, a great need exists for knowledge of flood hazards. Information is needed on the extent of inundated areas, frequency of flooding, and possible remedial measures that could help alleviate flooding. Also, the consideration of overall environmental aspects is important.

Figure VIII-3 is a schematic of a common flooding situation. At low flows, the area inundated is relatively small. In fact, for the most part, the water is confined to the well-defined channel. However, during periods of flooding, large areas adjacent to the river channel can be subjected to various degrees of inundation. Therefore, certain basic information on the extent and the potential frequency of flooding is vital for more efficient land use. Suitable evaluation of the potential for flooding should incorporate much of the information already discussed: watershed geometry and geology, vegetative cover, soil types, soil use, antecedent moisture, snow cover, and so forth.

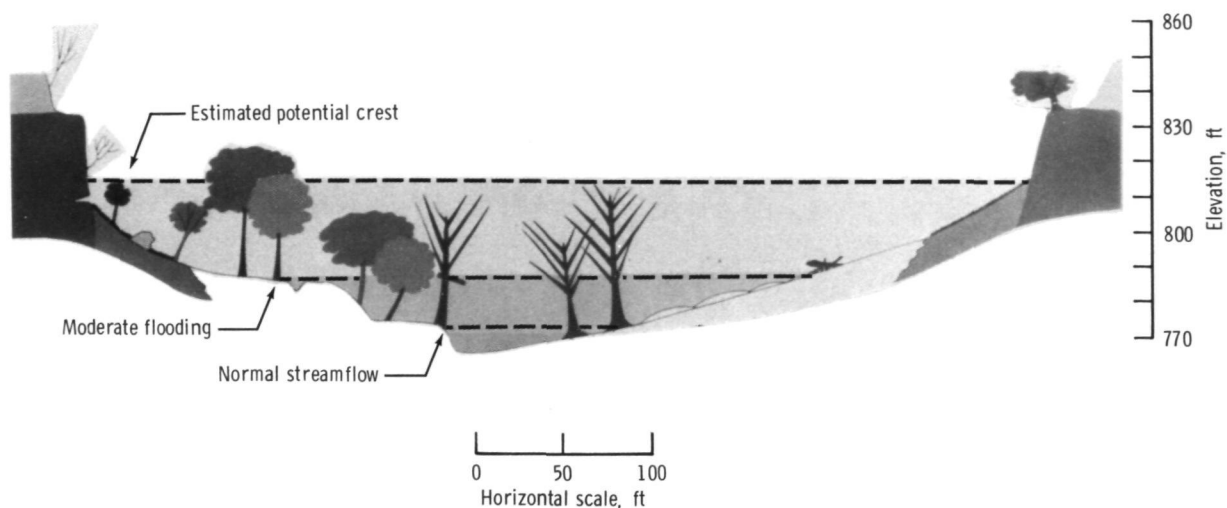


Figure VIII-3.— Schematic drawing of flood crest estimations.

WATER QUALITY SURVEYS

Remote sensing is of great value in assessing the water quality of both rivers and lakes. In one water quality study (W-12, vol. I-D), analysis of Landsat data produced eight distinct classes of water. Investigators have also found they can classify water, both in lakes and in rivers, to some extent by depth. With the advent of new water-penetrating film, more work is expected on this topic and very useful results should be produced. Studies of this type show that the identification of water quality problems related to the biomass and the sediment in a system is feasible.

Another aspect of water quality involves the inflow of contaminated streams to main stem streams. Hence, information concerning the mixing of flows from sewage treatment plants, industrial plants, and so forth with the water in a particular river is urgently needed.

One study of lateral and longitudinal mixing (W-11, vol. I-D) used thermal scanning and a two-dimensional mathematical model. The study indicated the possibility of differentiating, by using remotely sensed data, between a polluted effluent entering a stream and the better quality water in the stream. Such studies also give vital information concerning the rates and extents of mixing with respect to time and space.

Additional work is required in this area. The manner in which pollutants entering a stream, either from point or nonpoint sources, mix with the system must be

determined. A great distance is sometimes required before thorough mixing is achieved. For example, a thermal plume from a steam powerplant was tracked 15 statute miles downstream of its source in one instance. Such studies will continue to provide valuable information about the environment and thus enable better utilization of total resources.

RIVER MECHANICS

In the preceding paragraphs, the broader view as it pertains to watersheds, water resources development, and some of the factors that can be sensed on the watersheds was discussed in detail. It is possible to make detailed studies of the river scene by use of data from aircraft sensors. In one study (W-10, vol. I-D), flows coming together at different velocities downstream of an island were photographed. The different velocities result in a shear flow that generates a line of large vortexes, which extend to the bed of the stream. The increased depth below this line of vortexes can be mapped from aerial photographs. Use of these techniques to study water movement can provide extremely valuable information about the location of a navigation channel, the distribution of sediments in the cross section of a river, the lateral and longitudinal distribution of velocities through a system, and so forth.

In the broad perspective, by using remotely sensed information from satellites and aircraft, geologic controls along the rivers can be determined and major structures of interest can be identified. Also, the different types of soil making up the riverbanks and the land adjacent to the rivers can be identified; the types of vegetation can be observed and related to soil type; and the rivers can be classified according to form. Finally, because rivers are dynamic, a sequence of photographs taken periodically provides extremely valuable information on the rate of change with respect to time. Such information is important in the development of water resources systems.

CONCLUSIONS AND RECOMMENDATIONS

The general conclusions resulting from this session attest to the great value of remotely sensed data in water resources studies. The papers and discussions in the water resources session not only add to the current storehouse of knowledge but it is anticipated that they will also help establish a path of endeavor that should lead to even better results in the future.

The following predictions can be made.

1. With the further development of remote-sensing techniques, more sophisticated and accurate models of runoff, sediment yield, water quality, salinity, and so forth will be developed for utilization in the future. Many such studies have been completed at least through the preliminary phases.

2. In the future, there will be greater utilization of simultaneous satellite, high-altitude aircraft, and low-altitude aircraft sensing missions to give adequate information for more detailed studies.

3. As we proceed into the future, much more interdisciplinary effort will occur with a greater tendency for those working in geology, land use, watersheds, water quality, agriculture, and so forth to

cooperate in arriving at more meaningful and better answers to specific problems.

The following recommendations are offered.

1. The availability of data will be an important issue in the future. Some users of remotely sensed data will be increasingly interested in obtaining recent information on a near-real-time basis. Better methods of making data more readily available at an economical and timely rate must be developed.

2. Because many users of remotely sensed data do not have access to advanced and refined machine-processing equipment, such equipment should be made available to small users at a reasonable fee.

3. Work should be continued on watershed parameters.

4. Researchers should evaluate the significance of future snow and ice studies carefully.

5. More cooperation must be established between workers in remote sensing and in modeling. The work group stressed that there should be a marriage between remote sensors and modelers to get the most benefit from both fields.

6. Better working relationships must be developed between research communities and data users.

7. It is essential to stress the importance of practical communication, cooperation, education, and use of results produced from water resource studies.

8. Where a simple and effective concept exists, considerable advantages are to be gained by continuing its use.

9. In all aspects of using remotely sensed data, field verification work continues to be an important and fundamental part. Without such ground-truth information, the accuracy of the analysis of data from satellites and aircraft will be greatly reduced.

Finally, many of those participating in the water resources session are looking forward to the possibility of advanced satellites that relate specifically to problem areas such as hydrology, snow, rivers, and water quality.