interpret images and digital data obtained from aircraft and spacecraft sensors. Even very conservative estimates of dollar benefits suggest that these efforts could have enormous economic benefit for agricultural businesses and society.

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PART D

LAND USE, URBAN, ENVIRONMENTAL, AND CARTOGRAPHIC APPLICATIONS

LAND USE, DISASTER, AND ENVIRONMENTAL MONITORING

Effective State, regional, and national land-use planning requires the compilation of a wide range of areal data. These include data on static components of the environment (including soils, slope, geology, and hydrologic systems) and on dynamic cultural land use and related components (including transportation routes, urban and rural land use, and public infrastructure). In the interplay of these natural and cultural features, with natural features relatively static and cultural features to a greater or lesser degree dynamic, planning is accomplished. Monitoring the changes in land use is of value not only in itself but also for determining the interaction with other land uses and with the background environment. This section focuses on radar applications and land-use analysis in the monitoring of land-use change, especially the more dynamic components, and the interaction between land use and dynamic features of the environment (floods, hurricanes, etc.). Because public awareness of land planning is relatively new, a more detailed discussion of land planning in relationship to remote sensing is included in this section.

Although the relationships between land use and environmental quality are not well defined and are not conducive to orderly simple analysis (ref. 2-129), general public awareness has increased and has helped focus attention on land-use planning and management as one means of achieving a reasonable balance between economic well-being and environmental quality.

Growth in economic productivity has caused a greater demand for leisure and recreational services, which are highly dependent on environmental quality. Environmental quality is becoming more highly valued in relationship to potential increases in economic standards of living. Growth in productivity depends on increasingly powerful technologies and therefore has greatly increased the geographic and temporal extent of each person's effect on the environment. The results of these trends have been recognized, and new laws have been passed; new institutions have been created for protecting the environment. As new policies have been developed and implemented for controlling specific types of environmental effects, there has been increasing recognition that land-use patterns have a strong influence on the relationship between future economic production and environmental quality. These overall land-use patterns influence such key factors as (1) the location of environmental disruptions that arise from the extraction of resources; (2) the magnitude of wastes generated, especially from transportation activities; and (3) the costs of treatment to lessen the impact of residuals discharged into the environment.

More fundamentally, the experience of the last 5 yr has furthered the recognition that land-use patterns determine who shares which environments and with whom. As this sharing and the resulting external effects include more people over larger areas and for longer times, the potential economic, environmental, and social benefits from more centralized, comprehensive land-use planning increase. These benefits have provided the incentive for a restructuring of the Federal, State, and local land-use planning processes and techniques. The beginnings of this restructuring are evident in recent legislation, and its effects will have a strong influence on spacecraft remote-sensing systems during the next several decades. A parallel reaction by the private sector is already underway.

Recently, there has been increasing concern in the Congress about what many Americans perceive to be a national land-use crisis. Evidence of congressional concern is demonstrated by the following facts:

1. More than 120 land-use-related bills were introduced in the 91st Congress.
2. More than 200 such measures were considered in the 92d Congress.
3. By March 10, 1973, more than 50 land-use-related bills had been introduced into the 93d Congress.

Presently, Congress has temporarily tabled a Land Use Policy and Planning Assistance Act to encourage the establishment of the decisionmaking framework and to assist in the development of data collection techniques. This act may be reintroduced and passed within the next 2 yr. The desire of many officials to pass such an act indicates the belief that land-use planning is beneficial. If passed, the act will establish broad requirements for data collection, part of which may be accomplished with satellite data (including active microwave sensor data). Related trends are evident in State legislation. Three recent reports (refs. 2–130 to 2–132) summarize the changes in the land-use planning and control activities of various States and local jurisdictions.

The Rubino-Wagner report (ref. 2–130) identified five States that have already developed land-use plans—Hawaii, Alabama, Delaware, New York, and Rhode Island—and seven other States that have recently initiated innovative State legislation in the field of land use.

The Bosselman-Callies report (ref. 2–131) provides detailed descriptions of the experiences of recent land-use control legislation in Hawaii, Vermont, San Francisco, Minneapolis, St. Paul, Massachusetts, Maine, Wisconsin, and New England.

The Haskell report (ref. 2–132) views the changes in land-use planning practices from a somewhat different perspective than either of the other reports. Although the primary focus of the report is on organizational and institutional design over the entire range of environmental problems, it also includes some techniques used for various specific areas of environmental management, including land management and regulation.

These reports indicate an increasing trend toward innovation in State land-use planning activities, which will create an increasing need for data on which to base land-use planning decisions. The Haskell report states: "A first tool used by some states to strengthen their land planning effort is the generation of an adequate data base, and the development of analytical capabilities needed to make effective use of such data."

Several developments in analytical capabilities appear to enhance the potential benefits from use of satellite data in land-use planning. The first development is the use of computerized information storage and retrieval systems for handling land-related data. Several States have developed or begun such systems, including Minnesota, New York, Maryland, and Arizona. Efficient and low-cost means for handling large arrays of data through parallel processing technology can be expected to enable the satellite systems to produce large data arrays much more efficiently than at present. These methods of data handling will apply not only to future ERTS-type systems but also to digital radar image systems.

A second related development is the work on models capable of partially simulating the complex interrelationships of socioeconomic activities, land-use patterns, and the resulting effects on natural resources and environmental conditions. Such models can help land-use planners analyze land-related data to assess more accurately the tradeoffs between economic production and environmental quality and thus increase the benefits from satellite systems.

General Objectives of User Agencies and Industries

Land-use planning, monitoring, and regulation.—Traditionally, most U.S. land-use data have been for counties and various metropolitan planning agencies. Counties have rarely been of sufficient size or commanded sufficient capital to include regular land-use inventory as part of their planning function. However, counties have been the principal arena for interplay between the public and private sector when zoning and development are in conflict. Small undercapitalized planning departments have been no match for private interests, and zoning decisions frequently remain only as long as the more powerful private interests are not included. Although the balance between public and private interests—as represented by metropolitan planning agencies, councils, and private developers—has perhaps been more even than at the county level, there are numerous examples of the protagonists of "the highest and best use" in a strictly economic sense, which ignore environmental and neighborhood quality considerations.

These facts have stimulated the intense Federal and State interests in land-use inventory, monitoring, and planning. The Federal initiatives in this area focus on stimulating State-level activity. Thus, the natural interests of the State (reflecting citizen concern for a more forceful public voice) and the Federal pressures for State action have converged in making the State and, in some areas and for some problems, regional groups of States the prime focus of the current trends in land-use planning.

Constitutionally, the State governments have the authority to determine powers of local government units. Although the trends in land-use planning do not indicate State reassertion of authority for land-use control, they do show a complex reworking of intergovernmental relationships in which the State governments play a more active role in providing framework, data, information systems, overall guidelines and coordination, and many of the public facilities and services that influence land-use decisions.

Although these trends and pressures are still evolving, it is highly probable that, by the time spacecraft active microwave systems are used in land-use planning, a wider and stronger role for the State will have developed. Similarly, State-sized areas and regional groups of States concerned with common environmental problems (for example, Rocky Mountain States and Northern Plains States concerned with strip mining and oil-shale development) will have developed and strengthened.

The counties are too small in many instances to benefit from space-derived data because their problems are too detailed and require information that cannot be obtained from remote sensing, but the State is, in many ways, a prime candidate (in area, scale of problems, and information needs) for the capabilities of high- and moderate-resolution spacecraft remote sensing. The general objectives of user agencies and industry must therefore be considered in relationship to the trends to strengthen State land-use planning, which is aided both by Federal legislation and funds and by public pressure.

The principal interests of the States are converging in the development of statewide geobase information systems as part of the planning base and in the possible integration of economic modeling and forecasting through use, on a small-area basis, of the geobase data on natural and human resources. The ability to overlay and spatially examine finely disaggregated economic and census data (at the census tract level), land use, and static and dynamic environmental background data is now seen as a major area for State agency planning and development. The State Department of Planning in Maryland is already working in this area.

In a parallel manner, the interests of major corporations are converging in large-area analysis. Corporations with large or scattered real estate holdings, with land owned in sensitive areas, with requirements for utility-site and route selection and planning, and with concerns for general community development are beginning to anticipate the need in their planning departments for pre-environmental effect analyses in which geobase data on land-use change are essential. Examples are visible in planning departments of major electrical utilities in which public and private funds are used jointly to prepare land use and other data for entry into geobase information systems. The many regulatory and monitoring requirements in existing and planned Federal and State legislation will hasten the process and offer opportunities for remote sensing of (1) land use, (2) changes in land use, (3) environmental stress, and (4) illegal or undesirable actions in the private sector.

Desirable monitoring, planning, and minimization.—In addition to the previously mentioned environmental and land-use monitoring concerns, both Federal and State agencies together with private corporations and relief agencies have shown increasing interest in planning for natural disasters. This interest is expressed by concern with insurance programs, disaster relief, damage area and value assessment during and following the event, population resettlement, and related matters.

Several State and Federal agencies realize that detailed land-use information, together with data on the extent of the disaster in relationship to various land uses, is one of the most effective ways to obtain perspective on the scope and intensity of a disaster and on the conditions that will partly dictate the response.

Detailed land-use data by area will aid in the assessment of the number of lives endangered and the property value at risk. For example, in flood-plain land use, the critical method for assessment during a flood is the interaction between the extent, depth, and persistence of floodwaters and the effects by class of land use of such extents, depths, and persistences. Studies are now beginning but will be of increasing importance as State-developed information systems begin storage of land use, census, and relevant socioeconomic data by city block and census tract.

Certainly, one of the widely anticipated advantages of a statewide geobase information system is its ability to rapidly provide data in disaster situations, and refinements such as anticipatory planning for river flood and coastal area damage through storage of high-density data are expected to become commonplace.

Objectives Relative to Active Microwave Capabilities

Both of the concerns mentioned (land-use planning and disaster monitoring) are directly relevant to active microwave remote sensing. For disaster monitoring, the use of active microwave sensors is obligatory because they are the only sensors that can obtain data on demand. Therefore, active microwave sensors must be the prime sensors for a disaster-monitoring system designed to obtain data on the extent and progress of riverine floods, hurricanes, great fires, tidal waves, volcanic eruptions, earthquakes, landslides, and blizzards. Data on these events must be obtained at night, through clouds, rain, smoke, dust, fog, and smog. Only imaging radar meets these requirements.

Active microwave sensors are of at least equal rank with visible-region sensors in a general program of land-use monitoring, updating, and regulatory management. The purposes of active microwave remote-sensing systems may be summarized as follows. (Refer also to tables 2–VIII and 2–IX.)

1. The systems will provide data in areas partly obscured by clouds and, by cross-calibration with visible-region sensors, may be used for partial extrapolation at a single time.

2. By assuring systematic, orderly acquisition of data, active microwave remote sensors will enable the establishment of monitoring systems in which continuity of data acquisition is a primary factor. Such situations will occur when regulatory matters are

TABLE 2–VIII.—*Functional Requirements of Active Microwave Systems*

Requirements	Area of application	
	Input for complex watershed and crop-yield models	Irrigation scheduling
Desired incident angle, deg from vertical	0 to 40	0 to 40
Wavelength:		
Minimum, cm	1	1
Maximum, cm	100	100
Desired number of channels:		
Aircraft	4	3 to 4
Spacecraft	2	
Laboratory		5 to 10
Minimum number of channels	2	2
Polarization:		
Research mode	All combinations	All combinations
Operational mode	1 or 2	1 or 2
Swath width:		
Aircraft, km	10 to 40	10 to 20
Spacecraft, km	200 to 350	NA [a]
Spatial resolution:		
Desired, m	30	10
Maximum, m	100	30
Gray scale resolution:		
Desired, dB	20	20
Allowable, dB	10	10
Calibration accuracy:		
Type	Relative	Relative
Accuracy, dB	2	1
Ground truth:		
Operational system	Monitor key large fields with two fields (extreme wet and dry) having recording rain-gage records.	Same as application in preceding column.
Research system	Gravimeteric sampling of fields with full range of soil moisture (two sets); one set to develop prediction scheme, other set to verify penetration.	Laboratory controlled (gravimetric samples).
Need for real-time data (operational)	Daily values required for watershed models in real time; 1- to 18-day interval may satisfy crop-yield models.	Real-time values essential for operational systems, not needed for research.
Data format	CCT and images.	CCT and images.
Special techniques needed	Computer programing for rapid extraction and computation of soil-moisture output (most vital requirement for this application).	New computing developments for operational systems.
Probable ultimate platform	Spacecraft.	Aircraft.

[a] Not applicable.

TABLE 2–IX.—*Relative Probabilities of Conditions Restricting Photography in World Environments*

Environment type	Relative probability of adverse imaging condition for visible and/or IR
Wet Tropics	High probability of persistent clouds, haze, and rain.
Midlatitude west coast	Seasonally high probability of fog, clouds, and rain.
Arid Tropics	Seasonally medium probability of dust.
Arctic	High probability of long-term darkness, clouds, and snow.
Midlatitude continental areas ..	Medium probability of clouds.

involved and when progressive change is a key element in land-use analysis. This purpose may be described as the provision of key time data in which active microwave remote sensing is essential for the effective functioning of the monitoring system. Certainty of data acquisition will frequently be the deciding factor in a decision to initiate a satellite remote-sensing monitoring system. Just as a manufacturing plant at the mercy of irregular supplies of key materials incurs high costs and may be forced to operate below peak efficiency, an information system subject to sporadic arrivals of data, long time gaps, partial data at a single time, and similar problems would be forced to operate at low efficiency or, possibly, go out of business.

3. In areas of persistent cloud cover (such as parts of western Europe, wet Tropics, and Northwest United States), in areas of rain and fog, or in high latitude during winter, the active microwave systems will be the only sensors on which a rational program can be built. For such areas, the active microwave sensor is obligatory.

4. In land-use (including agricultural areas) data acquisition programs that use multistage sample designs, it is commonplace to find that these designs are not strong in the face of missing data. A purpose of active microwave sensors may be to provide key complementary information.

If imaging radar systems are provided to meet the short-term data-gathering requirements previously outlined for disaster monitoring (2 hr to 10 days) and for midterm land-use monitoring, updating, and regulatory management (11 to 100 days), the opportunity will also occur to use active microwave sensors for other, less time-dependent, but system-essential roles. These additional roles mainly involve once-a-year surveillance at a key time of the year. The long-term monitoring programs (100 days or more), though required infrequently, may nevertheless have critical time-dependent features that restrict the period of data acquisition. The usefulness of active microwave sensing will be proved by its applicability to short-term and midterm land-use monitoring. Once the decision is made to use them, many secondary opportunities in land use will occur, principally the long-term-monitoring type providing backup to visible-region sensors.

Demonstrated Remote-Sensing Observations

To compare performance to objectives for several sensors, two approaches will be used: (1) the ability of a given sensor to obtain the data needed by sensor type and resolution, independent of considerations of weather and timeliness, and (2) the ability of the sensors to obtain data rapidly (2 hr to 10 days) and under less severe time constraints (greater than 100 days). These time periods respectively relate to disasters, land use, regulatory monitoring programs, and annual (or longer) updating programs.

The ERTS–1.—The ERTS–1 has demonstrated a high-level capability to update land-use maps at levels I and II of the Anderson et al. classification system (ref. 2–133) shown in table 2–X. The usefulness of data at this level varies from State to State, depending on its size and land-use characteristics. With few exceptions, all categories were identified in one or more studies as shown in table 2–XI. The land-use classification (ref. 2–133) in level II is still highly generalized, and many States find

TABLE 2–X.—*Land-Use Classification System for Use With Remote Sensor Data* [a]

Level I	Level II
Urban and built-up land.	Residential.
	Commercial and services.
	Industrial
	Extractive.
	Transportation, communications, and utilities.
	Institutional.
	Strip and clustered settlement.
	Mixed.
	Open and other.
Agricultural land	Cropland and pasture.
	Orchards, groves, bush fruits, vineyards, and horticultural areas.
	Feeding operations.
	Other.
Rangeland	Grass.
	Savannas (palmetto prairies).
	Chaparral.
	Desert shrub.
Forest land	Deciduous.
	Evergreen (coniferous and other).
	Mixed.
Water	Streams and waterways.
	Lakes.
	Reservoirs.
	Bays and estuaries.
	Other.
Nonforested wetland.	Vegetated.
	Bare.
Barren land	Salt flats.
	Beaches.
	Sand other than beaches.
	Bare exposed rock.
	Other.
Tundra	Tundra.
Permanent snow and icefields.	Permanent snow and icefields.

[a] Classification system defined in ref. 2–133.

either that data at this level are unacceptable for State planning purposes or that the data require extensive support data.

The question of the accuracy of land-use determination using the ERTS–1 is still under review because few investigations have reported quantitative results. In some situations, accuracies at level I are 90 percent or better. Generally, accuracies drop to as low as 60 percent at level II. Accuracies are not assessable at level III.

In several studies, level III categories were distinguished, but the number varies from State to State, depending on the particular natural land use and cultural patterns of the area. No consistent nationwide or statewide level III identification system could be based on ERTS–1 data. Nevertheless, the situation is much better than was anticipated for ERTS–1 imagery because the data were expected to be useful only for level I. The ERTS–1 has performed better than anticipated, which is encouraging for future spacecraft sensing.

Additional land cover/use categories [2] (level III categories) identified in ERTS–1 studies (in addition to level II categories contained in ref. 2–133) are as follows: mobile homes, parking lots, unimproved open space (bare), improved open space (irrigated), unimproved open space (with trees), low-density residential, high-density residential, developed open space (urban), rural open land, rights-of-way in forest, rural settlements, wooded rangeland, soybeans, corn, exposed soil, winter ryegrass, and stubble. Other categories were high-density single family, low-density single family, mixed multiple and single family, agricultural (plowed), agricultural (nonplowed), extractive (mines), extractive (tailing pipes), extractive (basins), extractive (gravel pits), sanitary landfill, water (natural basin), water (excavated basin), wetlands (northern bogs), wetlands (southern perennial), wetlands (southern seasonal), low-income residential, middle-income residential, coastal strand, coastal salt marsh, coastal sage, woodland savanna, and riparian vegetarian.

Regarding the two principal areas of concern—disaster monitoring and land-use change and regulatory monitoring—ERTS–1 has performed the following:

1. A limited, but not satisfactory, role in disaster monitoring, being severely limited

[2] Unpublished data from M. T. Heinz et al.

TABLE 2–XI.—*A Sample of Experiments Delineating Land-Use Categories From ERTS–1 Data* [a]

Experiment	Total number of land cover/user categories delineated	Level of categories involved	Technique used
Wray/census cities	11	I, II, III	Automated/manual.
Simpson/New England	11	I, II, III	Manual.
Henry/Alabama	6	I	Manual.
Erb/Houston	32	I, II	Automated/manual.
Sweet/Ohio	19	I, II	Manual.
Ingles/Mississippi	13	I, II	Automated.
Sizer/Minnesota	34	I, II, III	Manual.
Thomas/Maryland	6	I	Manual.
Raji/Los Angeles County	12	I, II, III	Automated.
Houston/Wyoming	19	I, II, III	Automated/manual.
Sattinger/Michigan	9	I, II	Automated.
Colwell/California	17	I, II, III	Manual.

[a] Unpublished data from M. T. Heinz et al.

(by weather, timing, and resolution) to occasional usefulness in long-term persistent floods in less cloudy areas

2. A limited, but not fully satisfactory, role in land-use monitoring and regulatory processes, being limited by cloud cover, timing, resolution, and ambiguities in identification

The Skylab Program.—A recently completed study (ref. 2–134) concerns Skylab instrument performance in land-use mapping. The instruments studied were the S192 multispectral scanner, the S190A camera, and the S190B Earth terrain camera. Comparisons were made with land-use data in the Washington-Baltimore area and the Eastern Shore of Maryland to level IV and, in some cases, to level V. Modifications of existing classifications and a new classification developed for the study were used.

The Earth terrain camera was extraordinarily valuable; it was capable of enlargement to 1:24 000 scale (enlargements to 1:10 000 are possible), and updating of land-use classes with virtually no (or very low) ambiguity was possible. In addition, the results of mapping with S190B data compared very favorably with land-use mapping using high-altitude color IR aircraft photography (RB–57). When mapping was prepared with aircraft data, updating by using Earth-terrain-camera data for longer detection proved readily feasible, particularly for classes involving land clearing for urban development, for which the resolution was good enough that peripheral information enabling separation of plowed land from land cleared for development could be obtained. These results suggest the following applications:

1. For disaster monitoring (2 hr to 10 days), a future shuttle spacecraft could obtain excellent data in noncloudy areas, especially if resolutions better than the 2 m of S190B were obtained. Such data would be calibrated against radar imagery for use when radar is the only data available. Under all inclement or night conditions, the camera and scanners of Skylab (except thermal IR at night) would be of no use.

2. For land-use monitoring (11 to 100 days), high-resolution photography on a shuttle-type vehicle would be invaluable for updating land-use data in arid and semiarid areas where the probability of obtaining data is high. In all other environments, to insure orderly provision of data, radar imaging would at least equal the photography, and, in the more humid environments, it would be the obligatory sensor.

Active microwave results.—The principal studies with imaging radar concerning the identification of land-use classes comparable to those found in levels I and II (ref. 2–133) are those described in references 2–28, 2–102, 2–119, 2–133, and 2–135 to 2–151.

In addition, extensive but unpublished studies have been used in the assessment of current and projected capabilities of radar images in land-use mapping. The studies were performed in Brazil during Project Radar of the Amazon and in New Guinea by D. S. Simonett, who used X- and Ka-bands, respectively; in Michigan by M. L. Bryan, who used X- and L-band multiple-polarization data; and in Kansas by R. K. Moore, who used a three-frequency multiple-polarization system for crop identification studies.

Summarizing the results of this literature review and analysis of the unpublished data, the following conclusions were reached:

1. A single-frequency radar with single polarization in X- or Ka-bands and with 15-m resolution could distinguish all level I and II categories (table 2–X) virtually without ambiguity.

2. Improvement of the radar system by adding polarizations and, especially, additional frequencies in the range of 1 to 50 cm will make many categories at level III and several categories at level IV distinguishable.

3. Improvement of spatial resolution to approximately 8 m would make the multipolarization, polychromatic radar system highly competitive with color photography in shape and content evaluation and identification and would make many identification classes superior because of the wider multispectral capability.

4. Because of the wavelengths of radar (1 to 50 cm in the areas under consideration) and the spatial frequencies and geometries of natural and artificial land-use features, multifrequency, multipolarization radar is expected to have a high land-use-information content, probably as high as any multifrequency system in the visible region. The strongest indications of this assumption are in the unpublished data of M. L. Bryan and R. K. Moore.

In summary, the evidence strongly supports the view that multispectral sensing in the radar region will probably be at least as successful as that in the visible and near-IR regions with, of course, different strong and weak areas.

All the studies previously listed are empirical, and most are quantitative or semiquantitative. Thus, although issues of theory and modeling have been bypassed, the general area of measurement and quantification of identification accuracies with manual, digital, and statistical analyses has been addressed. The research completed is sufficient to provide a good quantitative base for judgment.

Functional Requirements for Active Microwave Investigations of Land Use

The main variables within functional requirements are the timing of data gathering and the return of data to the user. These variables tend to govern the data storage, transmission, and processing techniques used. If an active microwave system is designed to provide optimal data for the broadest spectrum of actual users, then the functional requirements for short-term applications will dictate the optimal microwave system for land-use analysis. The functional requirements for midterm and long-term applications comprise the greatest applications area for active microwave systems.

Short-term events (floods, earthquakes, etc.) often require data collection under cloudy, foggy, or smoky conditions. Short-term events require data within a 12- to 48-hr period. Rapid data transmission to the user is mandatory. To be of practical value, data should be made available from within a few hours (near real time) to 1 day. Data acquisition should be possible at any time of the day or night and during any time of the year. A satellite system should have the option to take data on command and perhaps to acquire very-high-resolution data of 50- by 50-km areas. Shuttle systems should have the option of modifying mission plans to allow for data acquisition within a 2-hr period.

An active microwave system used in this

application should be broadband and use the 3- to 30-cm wavelength region of the spectrum. The system should be multispectral; however, multispectral (multifrequency) radars will have to be tested in spacecraft and aircraft to determine optimal bandpass. A multiple-polarization capability is important, and HH, vertical transmit/vertical receive (VV), and cross-polarizations should be available. Instantaneous coverage on a synoptic level (100 by 100 km) will be desirable for monitoring; however, high-resolution coverage of small areas may be desirable on a command basis.

Worldwide repetitive coverage on a demand basis will encompass the largest user community. The desired resolution of 15 m is allowable if a narrow strip of very-high-resolution data can be embedded in lower resolution data. A 50-dB dynamic range in 2-dB steps would be desirable for gray-scale resolution. Design of the active microwave system should approach a −30-dB scattering coefficient. Ground truth, together with very-high-resolution color photography to calibrate active microwave interpretive procedures, should be acquired in selected areas. Data storage, transmission, analysis, and dissemination should be a key development area. Multispectral analysis techniques, both optical and manual, and computer processing must be used. Multistage data analysis and cross-comparative data analysis will be an important functional requirement.

Data reduction and analysis.—As discussed later, the spacecraft and aircraft radar data are expected to be in three principal formats that will govern the data reduction and analysis processes: black-and-white image format, color-combined images, and CCT's.

The CCT data would enable multispectral pattern analysis and digital image enhancement and should be considered in precisely the same way as multispectral scanner data for processing and analysis options. These options will include the use of time-congruenced digital images for areas of very low relief.

Color-combined and black-and-white images will be interpreted manually to provide major land-use boundaries, which may then be registered to the CCT's by using interactive terminals (graph tablet, light pen, etc.). Within these manually determined boundaries, detailed multispectral classification will be conducted by using computer classification. Within the next 10 yr, parallel processing will cause a sharp reduction in the cost per pixel classification and will result in interactive identification and mapping programs.

Display and distribution timeliness.—Data needed for disaster monitoring are required within 12 to 48 hr, preferably 12 hr. Data for land use and regulatory monitoring should be obtained within 1 week of acquisition. Data for longer term monitoring should be obtained within 2 weeks to 1 month, preferably 2 weeks.

Formats.—The data obtained from aircraft and spacecraft imaging systems will be in the form of CCT's and images prepared from the digital tapes, which include enhanced preprocessed images.

Scales and projections.—All images derived from the CCT's should be outputted on universal transverse Mercator (UTM) projection, with indexing to UTM coordinates and latitude/longitude coordinates. Scales may be variable, but a recommended group of scales would be 1:24 000, 1:50 000, and 1:100 000.

Ground truth.—Ground truth should be obtained (mainly in the form of field observations of land-use categories) during the experimental phases of the aircraft testing needed to define the limits of data interpretability. During spacecraft research and development and later operational missions, training sets should be established and updated regularly as small samples for extrapolation. Studies are needed on the proportions and types of ground truth essential for regulatory monitoring and disaster situations.

Accuracy of calibration.—Two forms of calibration are required: absolute calibration to 2 dB and relative calibration to 1 dB. Ground calibration with corner reflectors may be needed in some instances.

Unique Justification of Microwave Sensing

The unique justifications of microwave sensing are as follows:

1. Disaster monitoring (2 hr to 10 days): Radar is the only sensor capable of monitoring the progress of a disaster under inclement conditions.
2. Land-use monitoring (11 days to 100 days): Radar is the only sensor that can guarantee data acquisition and thus is essential to the effective initiation and functioning of a truly responsive monitoring system.
3. Long-term land-use update (100 days or more): Radar does not have a unique role in this area; it is secondary or supportive.

Anticipated Active Microwave Results and Accuracies Within 5 to 10 Yr

The results and accuracies shown in tables 2–XII and 2–XIII might be anticipated between 1978 and 1984, if a prompt commitment is made to construct a flexible aircraft research radar system capable of testing resolution, wavelength, polarization, bandwidth, swath width, depression-angle effects, and azimuth-angle effects on the radar return with completion before June 1977, and if a systematic testing program is initiated.

Value of disaster monitoring.—The annual loss of life resulting from disasters is large, and the annual monetary cost of such disasters is roughly estimated to be $300 million in the United States and $10 billion on a worldwide basis. The degree to which these losses could be reduced through the introduction of a quick monitoring system, which could be used to direct relief operations, recovery, land management practices, etc., is largely unknown and will require a systematic and thorough analysis. Savings of 1 percent in the United States and 2 percent on a worldwide basis for areas of poor communications would total $3 million and $200 million, respectively.

TABLE 2–XII.—*All-Weather Monitoring of Disaster Areas, Intensities, Persistencies, and Effects*

Disaster characteristics	Percent accuracy	
	5 yr	10 yr
Flood area	95	98
Flood area and time by class of land use	90	95
Fire damage (large area)	80	85
Wind damage	60	70
Earthquake damage	30	50
Blizzard effects	60	70

TABLE 2–XIII.—*All-Weather Monitoring of Land-Use Change, Regulatory Monitoring, and Updating of Land-Use Classes*

Category	Percent accuracy	
	5 yr	10 yr
Level I	95	98
Level II	92	96
Level III	60	80
Level IV (accuracy based on good identification, 90 percent of a small number of classes)	10	15

The cost of testing a disaster-monitoring system using a standby shuttle vehicle and a multifrequency radar system is estimated at less than $25 million per year, which does not include development costs of the system or systems.

Value of land-use monitoring.—To decisionmakers, the value of an integrated geobased land use information system using radar for systematically updating to level III is estimated to be $6 million annually. Throughout the world, such a system might be worth 10 times that amount. If borne exclusively by a single land-use monitoring program, the cost of operating the multifrequency system would probably exceed $20 million annually. The problem of double counting for both cost and benefits will arise when the same data serve multiple purposes.

Cost/Benefit Considerations

The complexity of cost/benefit analysis is evidenced in the studies now being conducted for the U.S. Department of the Interior. These studies indicate the types of analyses required and the difficulty of pinpointing the benefits for the United States and other parts of the world.

Conclusions and Recommendations

The principal conclusions of the panel regarding presently demonstrated feasibility is that published and unpublished studies strongly support the view that radar imagery at one or two frequencies and several polarizations can be used satisfactorily for mapping and updating land use to level II in the Anderson et al. (ref. 2–133) land-use classification system.

The present capability leads to the consideration of a full-scale multifrequency, multipolarization, digitally recorded, synthetic aperture, 8-m resolution system as a candidate for spacecraft use in disaster and land-use monitoring. The development of a polychromatic system is important because land-use data at level III (not considered in the Anderson et al. paper (ref. 2–133)), and possibly at level IV, are much more useful for State-level geobase information system functioning and for disaster monitoring, when penetration of tree cover is important and a diversity of wavelengths up to 50 cm (short of the limiting region of Faraday effects) is required.

Research is needed in the scanning of detailed land-use classes to level III and the scanning of disaster areas in a systematic testing program with a flexible polychromatic radar system. The detection of land-use change for regulatory monitoring and the interaction between disaster and detailed land-use classes constitute the basis of the experiments needed in which the following radar parameters should be systematically and repeatedly examined against these classes.

1. Wavelength: 1 to 50 cm; 4 to 5 bands.
2. Polarization: Linear, HH, VV, HV.
3. Bandwidth: One band of greater than usual bandwidth (e.g., ½ octave).
4. Resolution: Experiment with one band of very-high-resolution, narrow-swath-width imagery embedded in moderate resolution.
5. Swath width: 20 to 100 km.
6. Depression angles: 50° to 80°.
7. Azimuth angles: Multiple flight directions.
8. Stereoscopy: 60 percent sidelap.

Recommendations on data gathering for which imaging radar is the obligatory sensor.—A class of management and policy decisions exists in both public and private sectors that requires timely rapid-response data under inclement conditions of night, cloud, rain, fog, smog, dust, and smoke. Many of these decisions relate to national and especially international emergencies caused by great storms, earthquakes, fires, volcanic eruptions, blizzards, floods, tidal waves, landslides, oilspills, and related events. Only active microwave sensors can meet these needs. Timely data on the interaction between these events and land uses in time and space will be critical in defining the areas affected, the types of property damage anticipated, emergency operations, the progress of flood recession, and so forth, especially for developing countries.

The development of an emergency preparedness system including the following components is necessary.

1. Single- or dual-frequency radar spacecraft imaging system.
2. Digital onboard processing of wide bandwidth transmission to a central facility in the United States.
3. Rapid-analysis teams at the central facility.
4. Provision of alternative information to emergency headquarters and field teams by means of—
   a. Provision of hardcopy images.
   b. Multicolor-enhanced interpreted images.
   c. Commercial satellite television transmission of enhanced interpreted images.

Recommendation 1: A significant effort should be initiated by NASA to define the most effective radar system to image the diverse group of areas and emergency conditions. This effort should explore multiple resolutions, wavelengths, bandwidths, polarizations, incident angles, azimuth angles, and swath widths by theoretical analyses and aircraft data gathering.

Recommendation 2: For the purpose of defining a radar system for emergency conditions and for many other less-time-dependent uses of radar imagers, NASA should develop a flexible aircraft multiplex radar system (or systems) in which the interrelationships between system parameters and target response may be systematically examined.

The aircraft system (or systems) should have the capability to explore basic questions on target and background radar response with variations in resolution, wavelength, bandwidth, polarization, depression angle, azimuth angle, and swath width.

Recommendation 3: With the aircraft system (or systems) of recommendation 2 available, NASA should examine to at least level III in the Anderson et al. (ref. 2–133) land-use classification system the target/background interactions before, during, and following major hurricanes and similar disasters in the United States. These data will set bounds on interpretability, decisions, management options, etc., and will define the spacecraft radar designs.

Recommendation 4: Following successful research analysis and development through the previous recommendations, NASA, the European Space Research Organization, and the United Nations should take the steps necessary to establish emergency interpretation and data dissemination facilities and to explore the methods and techniques of hard-copy and television transmissions.

Recommendations on data gathering for which radar is required for effective functioning of a land-use monitoring and change detection system.—Many States are concerned with monitoring land-use changes (1) for compliance with regulations at both the State and Federal level, (2) for the normal updating needed in a geobase information system, (3) for using changing land-use data to level III as a basis for economic and forecasting models, (4) for maintenance of planning options, and (5) for anticipation and planning of new public and private sector cooperative planning of utility sites and routes, development works, population shifts, and related matters. In many cases, the original decision to establish a remote-sensing satellite-based monitoring system will be conditioned on the ability of the system to reliably and orderly supply data and information as needed to facilitate key land-use management decisions. The value of active microwave sensors in insuring that the system will function independently of weather conditions should not be deemphasized. Radar imagery will probably meet many, if not all, monitoring needs. Visible-region sensing will be adequate in some subhumid and arid areas but will benefit significantly from radar support in cloudy areas.

URBAN AND TRANSPORTATION APPLICATIONS

A series of Government-sponsored ongoing research programs concerned with the collection and use of data from urban areas is underway. Many of these programs are concerned primarily with using a set of remote sensors, including multiband photography, multispectral scanners, and SLAR mounted either in aircraft or spacecraft. Most data that have been properly collected, analyzed, and used in application programs for decisionmaking have been confined to the visible and IR portions of the electromagnetic spectrum. The microwave portion of the spectrum has been sparingly used as a viable data source for urban information.

Some uses of active microwave imaging systems, specifically SLAR, for urban data collection are discussed in this section. The usefulness of SLAR data is compared with data collected by other sensors, and the applications of these SLAR data for urban studies are identified. Therefore, this discussion is a continuation and extension of previous work by NASA (ref. 2–152) in identifying Earth resources from space, with specific emphasis on urbanized areas and active microwave sensors. The objectives of such programs are as follows:

1. To determine the capabilities of various remote sensors to record physical data, both natural and cultural, about the atmosphere, oceans, and terrain of the Earth.
2. To identify potential applications of these data in scientific and resource management fields.
3. To design information systems based on both the needs of users and the capabilities of forthcoming remote-sensing satellites.

Work on these objectives has not progressed as a unit. Usually, after completing a functional data collection system, the data collected by the system are subjected only to modest analysis. In urban studies, this type analysis is especially relevant because the problems are only partially within the immediate domain of technology. Social problems, which are not really amenable to the technologist's approach or to the scientific method (ref. 2–153), are an integral part of the problem that must be solved before stating the usefulness of active microwave sensor data.

Definition of Subject and Problem

Urban studies measure three parameters: population density, functional use, and morphology. Population density is often measured and expressed by housing density and population size and density. The rural/urban fringe is delineated by using population density. Another means for delineating the fringe is by counting street intersections per square kilometer. Normally, the sources of these data are Federal, State, and local census-gathering projects, aerial photographs, and topographic maps. However, some measurements, especially street intersections per square kilometer, could be interpreted from radar imagery.

Functional boundaries within a city are also defined primarily by census-type data and high-resolution aerial photographs. These data would be more difficult to derive from existing SLAR systems, although several studies indicate that this can be accomplished at relatively low levels of accuracy.

Defining morphological regions is difficult because the definitions vary from region to region. Generally, the information wanted is the shape and texture of features such as the central business district, the alinement of street patterns, or the pattern of commercial development. As will be documented later in this chapter, active microwave sensors can provide part of these data.

Transportation, a key to urbanism, must also be considered because, without the ability to move people and goods quickly and cheaply, urban centers would not exist. The fact that streets occupy from 10 to 20 percent of the surface in urban areas is proof of their importance.

Determination of transportation network and site usage has importance for land planning and management at all levels of government. Conventional photographic techniques are limited by (1) the requirement for repetitive coverage at large scales (1:6000) and high resolutions, (2) weather conditions, (3) daytime observation, and (4) vegetative cover. Active microwave sensors may provide accurate data, especially if they can result in the identification of moving (transient) subjects.

Land-Use Classification

In urban areas, where most of the surface is covered by artificial construction, the determination of actual land use is difficult under any circumstances. Asphalt and other petroleum derivatives are used for racetracks, roads, parking lots, driveways, and roofs. The actual use of the asphalt is determined by the original intent, age, and changing spatial context. The use may also be multipurpose, with each use being valid and possibly time dependent (e.g., a parking lot during business hours may become a recreational area at night and on weekends).

Using photographic remote sensing, which detects only the surfaces (e.g., the tops of trees, roofs, or bottoms of gravel pits), the functional uses of these surfaces or of the surfaces they obscure from view are difficult to determine.

Existing systems for classification of urban land use are separated into levels of generalization based on the amount of detail described. The level of generalization is usually dependent on the scale and target detection capabilities of the imagery. Also, the level of generalization of urban land-use data may be determined by the requirements of the user. Map users at the national scale would normally require only the highest level of generalization, whereas users at the local scale would need detailed information available at a second or third level in a land-use classification system. Table 2–XIV shows the relationship of user needs to levels of generalization in urban land-use classifications (refs. 2–133 and 2–154).

Urban land-use classification systems are similar at the first level of generalization but vary to suit conditions as more detail is added. Urban land-use maps based on radar imagery at aircraft altitudes show that imagery of urban areas can be classified adequately to produce maps that include most level II categories shown in table 2-XV. In a few instances, a refinement to a level III category has been possible (i.e., relative residential densities and relative ages of residential areas).

TABLE 2–XIV.—*Land-Use/Scale Relationships* [a]

User scale	Level of generalization	Source of information
National	I [b]	Satellite imagery and high-altitude photography.
State	I and II	Same as for "National."
Local (city or county).	III and IV [c]	Medium- and low-altitude photography.

[a] Refs. 2–133 and 2–154.
[b] Most generalized.
[c] Most detailed.

TABLE 2–XV.—*Land-Use Classification System for Use With Remote Sensor Data* [a]

Level I	Level II
01. Urban and built-up land.	01. Residential.
	02. Commercial and services.
	03. Industrial.
	04. Extractive.
	05. Transportation, communications, and utilities.
	06. Institutional.
	07. Strip and clustered settlement.
	08. Mixed.
	09. Open and other.

[a] Ref. 2–133.

Demonstrated Remote-Sensing Observations

Present methods of collecting data about urban areas and the analysis of these data are time consuming, costly, and rather inefficient. Normally, these methods involve extensive fieldwork, interviews, and similar operations (e.g., census data and origin-destination studies). To provide management and decisionmakers with current information, emphasis has been placed on the development of new systems and analysis techniques, which include exploring the potential of remotely sensed data, including SLAR. Most previous research in remote-sensing data-collection analysis and management has used photographic systems (black and white, color, color-IR, and multilens cameras). Thermal imagery and radar have received relatively minor attention (ref. 2–155).

Photography and ERTS.—Urban land-use data from aerial photographs are feasible on both a block and parcel basis; however, mapping parcels usually requires supplemental data (ref. 2–156). Block mapping can be accomplished on photographs at scales as small as 1:100 000. By using ERTS imagery, eight major land-use categories have been mapped in Rhode Island at a level to meet standards set in State land-use maps published in 1960 (ref. 2–155).

Aerial photographs are standard tools in transportation studies. Highway departments use photogrammetric and interpretive techniques for route selection, road design, and recording the various stages of construction. Mapping traffic-flow patterns, planning future parking facilities, and determining necessary road maintenance are other demonstrated applications of aerial photographs.

Current high-resolution large-scale photographs can provide accurate data on transient events by repetitive aircraft overflights. Though more cost effective than ground surveys, this approach is still expensive in terms of time and money, because (1) repetitive coverage over small areas at low altitudes is required and (2) large volumes of data must be analyzed by conventional photointerpretive methods. Current quasi-operational satellites (ERTS) do not have the resolution or repetitive frequency required for detection and identification of transient subjects.

Other urban-oriented applications of aerial photographs are as follows:

1. Planning collection routes (e.g., garbage, sewage, and buses) and zoning changes.
2. Establishing the rights-of-way for powerlines and pipelines.
3. Monitoring atmospheric pollution.
4. Determining dwelling units and estimating population.
5. Determining housing quality.

Active microwave.—Radar imagery has been used much less frequently than aerial photography. However, published reports indicate that radar imagery is a potential source of urban data. Radar has been used to map land-use patterns within urban areas (refs. 2–28, 2–148, and 2–149). An example of this application is shown in imagery of San Diego, Calif. (fig. 2–37). Industrial, commercial, and residential zones and vacant lots were delimited in all cases. Finer divisions were possible in a smaller and less complex urban area; parks, cemeteries, golf courses, and relative ages of residential regions were delineated.

The relationship between population and the radar-derived area of urban regions has been studied and tentatively established (ref. 2–151). Settlement detection was evaluated for 100 percent of the cities with a population larger than 7000, for 80 percent of the towns with populations between 800 and 7000, and for 50 percent of the villages with populations between 150 and 800 (ref. 2–146). Differentiating rural from urban areas was found to be consistently possible.

Other studies (refs. 2–148 and 2–137) have evaluated polarization schemes for detecting cultural features. Polarization is important in the delineation schemes for detecting cultural features. Polarization is important in the delineation of railroads and powerlines (fig. 2–38), the separation of parks from urban areas, the distinction between residential areas differing in age or building materials, and the detection of bridges. Bryan (ref. 2–147) recently conducted similar studies using a two-frequency, two-polarization imaging radar system. His studies concentrated on two areas in the Detroit metropolitan area: one was near the central city with heavy industries and large railroad yards, and the other was a suburb composed primarily of residential areas. The residential areas and the heavy industrial areas (fig. 2–39) on this 10-m-resolution imagery were clearly and accurately delimited. Generally, the accuracies of identification of the residential areas were approximately 75 percent correct, whereas industrial areas were discriminated with accuracies of approximately 63 percent. These accuracies may appear to be low; however, they were made solely on the basis of the existing SLAR imagery.

Anticipated Microwave Results

Because most urban changes do not occur within a 2-day timespan when cloud cover or daylight could be critical and because most urban areas are concentrated in the well-developed countries, radar imagery is in com-

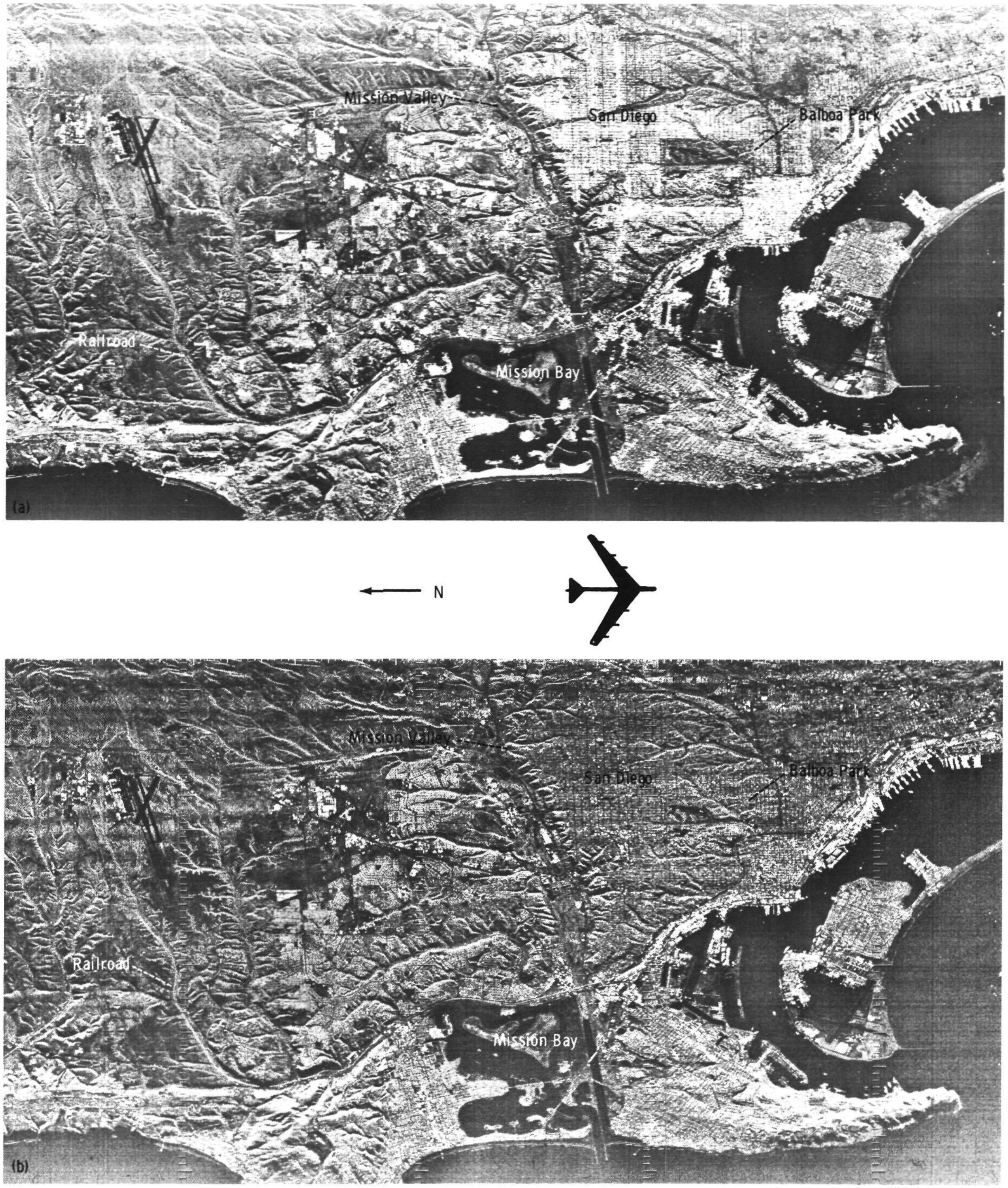

FIGURE 2–37.—Imagery of San Diego, Calif., showing separation of residential, park, and business areas by using two radar polarizations. (*a*) An HH polarization. (*b*) An HV polarization.

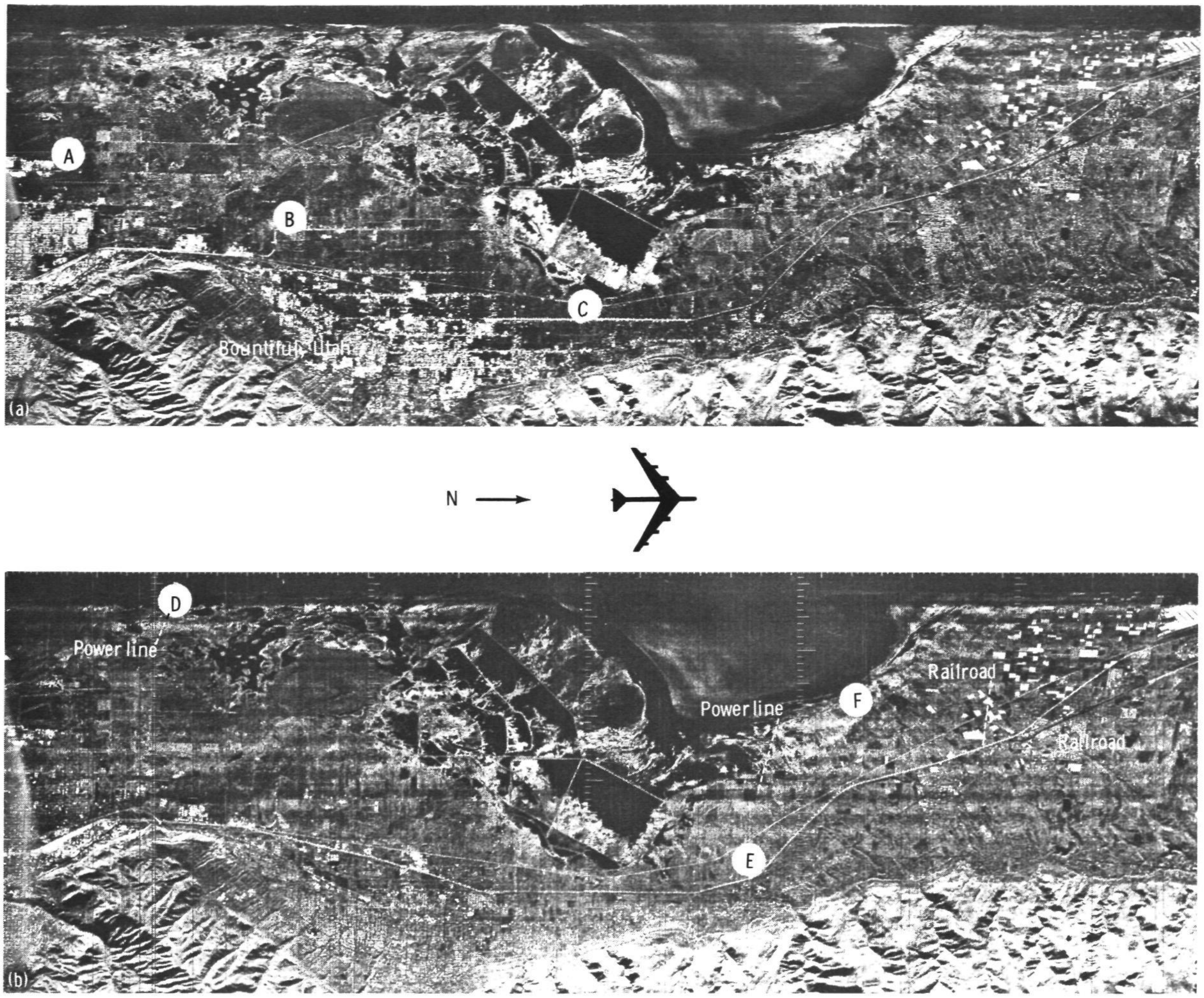

FIGURE 2–38.—Imagery showing delineation of railroads and powerlines near Bountiful, Utah, using two radar polarizations. (*a*) An HH polarization. (*b*) An HV polarization.

petition with aerial photography as a source of data. Existing active microwave systems may provide the technology necessary for frequency-of-use analysis based on identification of transient subjects. Microwave systems with resolutions of 10 m (with different polarizations and with moving-subject analysis) may possibly be used to identify the transient subjects previously outlined. Moving-target analysis using active microwave sensors has been proved feasible. Radar may also provide data on (1) short-term phenomena, such as urban flooding related to high-intensity rainfall; (2) nighttime-related activities; and (3) urban or commercial activities in the tropics and underdeveloped countries. The near-all-weather capability of active microwave sensors makes possible the collection of such short-term information without the loss of critically timed data.

Active microwave sensors aboard a spacecraft could produce imagery capable of mapping to a level of generalization suitable to users at a national and regional scale; that is, level I. Furthermore, radar imagery from a satellite should enable mapping of certain in-

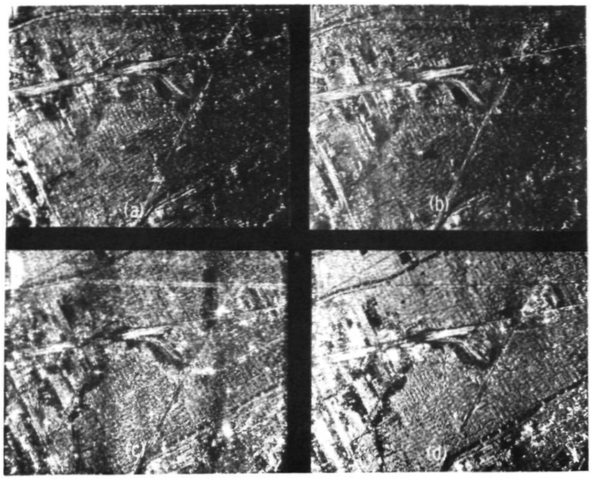

FIGURE 2–39.—Four-channel simultaneous SLAR imagery of a portion of Detroit, Mich. (*a*) An X-band, HH polarization. (*b*) An X-band, HV polarization. (*c*) An L-band, HH polarization. (*d*) An L-band, HV polarization.

formation at level II in the classification system.

Other time- and place-dependent data can also be obtained from radar imagery.

1. Monitoring traffic on waterways.
2. Search-and-rescue operations in coastal and fluvial environments.
3. Nighttime surveillance of movement across borders and possible contraband.
4. Monitoring use of recreation facilities during periods of inclement weather.
5. Documenting urban flooding related to local weather conditions.
6. Supplying local, State, and Federal agencies with timely information on traffic-flow patterns, concentrations of activity in urban and rural areas, recreational site usage, and so forth, so that management plans can be developed to maximize land use and to minimize the negative effect of people on the environment.

Functional Requirements

The following requirements are recommended for use of active microwave sensor data for study of urban scenes:

1. Resolution: A 5-m resolution is recommended; 10-m resolution is acceptable (fig. 2–40).
2. Swath width: A width of approximately 15 to 20 km is required.
3. Repetition: One pass over each scene every 14 days is required.
4. Wavelength: Two wavelengths, collected simultaneously, are recommended: shorter wavelength in the Ka- or X-band (1 to 3 cm), longer wavelength in the L-band (20 to 30 cm).
5. Polarizations: The HH and HV polarizations are strongly recommended and should be available for each wavelength.
6. Depression angles: Depression angles should range from 20° to 60°. The actual image swath should be centered within this range.
7. Timeliness: For nonemergency studies, data should be delivered to the users within 2 weeks of data collection. For emergency studies (e.g., floods, hurricanes, and disaster assessments), data should be delivered within 2 hr of collection.
8. Processing: Onboard processing is desirable for aircraft and Space Shuttle. Digital tapes are required for later processing to enhance data. Low-altitude aircraft underflights are required for documentation of ground conditions and for calibrations. Unmanned satellite data are to be telemetered and processed at data collection centers.
9. Format to user: Formats will be raw imagery at time intervals, a map format showing frequency of use, and printouts showing inventory of transient subjects in specified areas.
10. Unique justification for active microwave: Active microwave sensing can identify moving subjects and make nighttime and all-weather observations possible.
11. Identification of users: No independent evaluation of the potential users of SLAR imagery from urban areas has been conducted. However, a brief review of the literature indicates some potential users.

In a series of discussions (ref. 2–157) concerning urban planning and data needs for the Denver, Colo., metropolitan area plan-

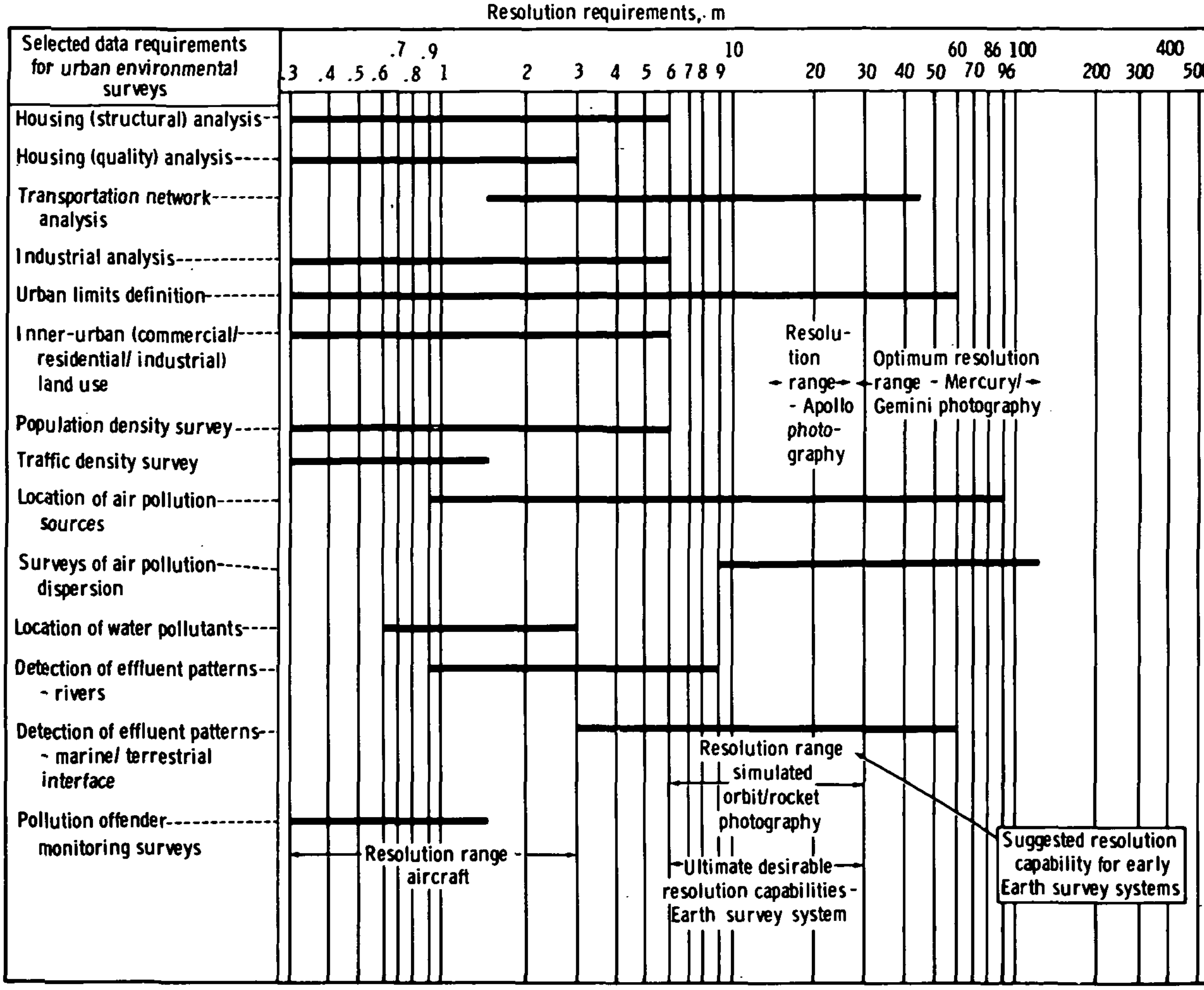

FIGURE 2–40.—Optimum level of detail (resolution) requirements for selected data categories related to urban environmental surveys.

ning community, the following potential users were identified:

1. State Planning Office
2. State Land Use Commission
3. Denver Council of Governments
4. State Highway Commission
5. City of Denver Planning Office
6. City Engineer's Office
7. Urban Drainage and Flood Control Commission
8. Traffic Engineer's Office
9. Zoning Board
10. Assessor's Office
11. City Water Board
12. Urban Renewal Authority
13. Model Cities Program
14. Community Renewal Program
15. Office of Economic Opportunity
16. Colorado Water Conservation Board
17. Regional Transportation District

The following applications for remote sensing were identified as having the highest potential (ref. 2–158):

1. Natural resources and economic development.
2. Recreation and culture.
3. Agriculture.
4. Transportation.
5. State planning agencies.

6. Regional planning agencies.
7. Local city and county planning agencies.

In the present context, the last four items are of special interest. To state definitively the complete listing of possible users would be an extensive task and would, in essence, identify all individuals, groups, agencies, and offices that are involved in various aspects of the structure, morphology, and extent of the urbanized area.

One metropolitan area should be selected as an example, and, within the selected area, all potential user agencies for SLAR should be identified. It is assumed that other States would have, within the same general categories, the same or similar organizational hierarchies, which would fit the general format of the original test case.

Recommendations

As previously noted, visual interpretation of SLAR data will probably provide the greatest immediate benefits. Later benefits will be derived from both visual and machine analysis because photographic interpretation techniques are indispensable for identifying those areas that cause confusion during visual interpretation.

Because only a few studies of the microwave response of urban landscapes have been accomplished, a well-documented and sustained program should be developed to explore sensor capabilities. The following sequence is suggested:

1. Identify study areas that include a complete spectrum of urban conditions.
2. Collect relevant SLAR imagery using a system comparable to that selected for satellite development.
3. Interpret the data by concentrating on the following items:
   a. Develop optimum land-use classifications with consideration of those classifications that are presently being used by the local planning and land-use agencies.
   b. Document the interpretation accuracies for combinations of wavelengths, polarizations, and resolutions.

Active microwave instrumentation should be developed with a multifrequency, multipolarization, and multiresolution capability; thus, aircraft and Space Shuttle missions can be flown to define the optimal resolutions, frequencies, and polarizations required to detect and identify transient phenomena. Data-processing techniques should be developed to further aid identification of transient subjects by moving-subject analysis.

SUMMARY AND RECOMMENDATIONS

A reliable and timely update of changes in a data base is a major need in land-use planning. These changes may be considered in a very short term period, such as disasters, and in mid- and long-term periods, such as developmental change. For each of these needs, active microwave sensors can be important.

For disaster sensing, radar is the only sensor that can obtain data with certainty on demand, regardless of obscuration. Radar can rapidly provide complete coverage and monitoring of the extent and progress of floods, hurricanes with destructive winds, coastal inundations, great fires, tidal waves, volcanic eruptions, earthquakes, landslides, and blizzards. To be timely, data on these events must be independent of night, clouds, rain, smoke, or fog; and only radar can provide that independence.

In the developmental change of land use, the urgency of timely coverage is reduced, and the status of radar becomes coequal or, in some cases, subordinate to sensors of the visible wavelengths. In these applications, active microwave sensors will provide missing data in areas partially obscured by clouds and will assure an orderly and systematic continuity of data. The assurance of complete data is a key consideration when monitoring regulation of progressive land-use change is practiced. In cloudy environments (even in the United States), imaging radar would provide strong support to aerial photography in the management of land use. In very cloudy areas, active microwave sensors would perforce become the obligatory sensor for a monitoring program. In many such situations, the decision to establish the ground information system will be made possible only by the assurance of data acquisition, which is given by the active microwave sensor components of the monitoring system.

The obligatory role of active microwave sensors in the monitoring of disasters requires that data be acquired at high resolution (8 to 10 m) over a wide swath (50 to 100 km) using a wavelength that is certain to penetrate clouds (3 to 10 cm). Furthermore, the data must be provided to the user within a few hours (12 to 48 hr) in a hard-image format.

The supportive use of radar for land-use data collection requires identification of surface cover by active microwave multispectral, multipolarization, multistage analyses. Therefore, instruments with 1-, 3-, and 10-cm wavelengths should be used together with combinations of polarizations. The data should be available to the user in intervals of a few weeks in both hardcopy and digital tape. Lower resolution (10 to 20 m) would be acceptable, but a high-resolution strip embedded within approximately 5 percent of the coverage would be highly advantageous.

A basic need for the development of an active microwave land-use change information system is a determination of optimum radar system parameters. For this purpose, a flexible variable-parameter aircraft radar system (or systems) should be developed, and a research program should be initiated to determine the radar and target interactions with respect to variations in resolution, wavelength, bandwidth, polarization, depression angle, azimuth angle, and swath width. The research will help determine the limits of interpretability and the spacecraft radar designs. Ultimately, the research program should initiate development of national and international emergency data dissemination facilities. Experiments are needed to define the abilities of radar imagery for detection, identification, and mapping of land uses to level III of the Anderson et al. land-use classification system (ref. 2–133).

A land-use monitoring system will require the same aircraft testing of land-use category mapping and inventory to level III, systematically viewed against variable radar-instrument parameters of wavelength, polarization, bandwidth, resolution, depression angle, azimuth angle, and swath width, which were previously listed for disaster monitoring.

Each category to level III should be systematically reviewed by repeated flights in representative areas of the United States to define radar performance in multispectral digital pattern recognition, manual updating, and interactive identification.

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APPENDIX 2A

EARTHQUAKE MECHANISMS AND CRUSTAL MOTION

To be competitive, a new system for crustal motion measurements must have at least one advantage over conventional geodesy; it must be more accurate, be more economical, or be capable of reaching inaccessible areas. Therefore, it is necessary first to ascertain the state of the art of conventional geodesy. The National Geodetic Survey claims a very high degree of accuracy and economy; therefore, correspondingly high standards must be set as criteria that a system must attain to be worth building.

Horizontal control and vertical control are performed by independent techniques in conventional geodesy, and the accuracies and costs are therefore estimated separately. First-order horizontal control is presently attained by building networks of triangles, each side of which is measured by a laser ranging device. Each triangle is solved by a side-side-side formula of plain trigonometry. This technique replaces the use of theodolites and an angle-side-angle formula working from a single invar-taped baseline, and this technique is far less sensitive to errors produced by horizontal refraction. Nevertheless, the principal source of error is still the varying index of refraction of the atmosphere. The atmosphere increases the time of propagation of a light pulse over what it would be in vacuo; therefore, the range measurement is increased by approximately one part in 3375 in the red wavelength characteristic of a Model 8 Geodimeter (6328×10^{-10} m). That quantity, in turn, varies by approximately 1 part in 300 for every Kelvin of temperature change along the line of sight and by approximately 1 part in 10^5 N/m^2 change of atmospheric pressure. Because it is not possible to calibrate the atmosphere more accurately than 1 K for a line of sight along the ground, the net accuracy of laser ranging is not more accurate than approximately 1 ppm—that is, 1 cm per 10 km (ref. 2A–1). The cost of first-order horizontal work is approximately $3000 per triangulation station occupied, regardless of the spacing between stations.[1]

Vertical control is obtained by a technique called differential leveling, which consists of sighting on a graduated rod (called a stave) by spirit level, reading the elevation, and stepping through the countryside at approximately 50-m intervals. Measurements are taken in both directions along the traverse—that is, all lines are fore- and back-leveled. Estimates of accuracy vary. In 1948, the International Geodetic Association redefined high-precision leveling as having a standard deviation (in meters) of $\sigma = (2.9 \times 10^{-3}) L^{3/2}$, where L is traverse length in kilometers (ref. 2A–1). This presumably includes both random and systematic errors, which were treated separately in an older definition. However, there is some evidence that sys-

[1] Private communication, H. Schmid and J. Bossler, National Oceanographic and Atmospheric Administration, National Geodetic Survey, Rockville, Md., Dec. 1973.

tematic effects may be larger than the definition implies. The National Oceanographic and Atmospheric Administration, National Geodetic Survey, examined rates of vertical crustal movement in the eastern part of the United States by comparing the 1929 combined level net of the United States and Canada with the releveling performed at a mean date of 1965. The discrepancy between these results and the tide gage data along the Atlantic coast totaled 4 mm/yr from Maine to New Jersey, or approximately 144 mm in 36 yr over 500 km, which is one-half larger than the definition would allow between two independent first-order levelings. The Survey Division of the Los Angeles County Engineers has stated that there is a discrepancy of approximately 1 mm/km (almost four times what the definition would allow) revealed by the failure to attain closure on the line between Long Beach and San Diego.

A serious limitation in conventional leveling is that it attains high accuracy only when traversing flat country. But flat country in the American Southwest typically connotes intermontane regions filled with loosely consolidated alluvium, which may be expected to display large vertical movements, depending on the amount of underground water, and which masks the important crustal movements beneath. The greatest advantage that a new system may offer, especially in its early development when the cost may be high and the accuracy low, is the location of stations on bedrock in hilly or mountainous country. Good strategy requires that developing such capability be given high priority in the system design.

The basic mathematical technique used for the proposed system was developed by Rinner (ref. 2A–2) and depends on what he called a transfer network. In this case, grids of radar-reflecting geodetic control points are flown so no fewer than six can be viewed from the airplane system at one time. Rinner's equations are used to solve simultaneously by multilateration for the relative positions of the six grids. The equations are then used to propagate the solution along a chain, adding new stations and dropping others as they pass through the zone of visibility of the radar.

Unfortunately, Rinner restricted his examination to numerical analysis of multilateration by using a high satellite; thus, it is necessary to analyze a case using the low-flying airplane. Nevertheless, a few generalizations from his work apply to this discussion.

1. The smallest total error in the three-dimensional positions of the geodetic control points on the ground is obtained when the height of the vehicle is approximately equal to the separation between ground points. Thus, for an aircraft flying at an altitude of 10 km, the control points should be placed at 10-km intervals.

2. It is not possible to solve for positions from a single overpass of the aircraft. It is necessary to make two overflights at different altitudes so the equations of position will not be singular. The errors in calculated position decrease linearly with the separation in altitude of the two passes.

3. The errors are approximately inversely proportional to the square root of the number of points that can be ranged at one time.

4. The horizontal errors increase with the square root of the number of links in the chain, but Rinner's numbers indicate that the vertical sigmas increase linearly with the chain length. This point must be carefully checked because it implies that the rate of propagation of vertical error in a system would be unacceptably large. It will be necessary to calculate the effect of Earth tides on the ground points.

Several requirements are imposed on the aircraft flight plans and on the distribution of the ground markers by the mathematics of multilateration. These requirements are summarized in the following theorem: A simultaneous ranging system can obtain no unique solution for marker coordinates if all the markers lie on a plane curve of the second order, or if all markers and aircraft ranging positions lie on a surface of the second order. Two implications of this theorem are as follows:

1. The aircraft must vary its altitude by a large factor—for example, by a factor of 2—during data acquisition, which can be done most simply by having the aircraft overfly the markers twice, once at high altitude and once at a much lower altitude. This dual overflight sets a strong upper limit to the spacing between ground markers. Even if a U–2 is used, which can fly one of the passes at an altitude of 30 km, the second flight must be performed at 15 km, and because little weight is added to the solution by points at elevation angles below 12°, there must be a complete set of markers in a square of approximately 75 km on a side. This fact implies that the ground markers (receivers) must be spaced fairly evenly at an average density of one every 30 km, even if the aircraft is a U–2. If a commercial plane is used, then the markers must be spaced at one every 15 km, because a minimum of six markers must be simultaneously visible from the aircraft to obtain a solution for relative coordinates.

2. The aircraft must vary its groundpath and altitude between the two passages. It seems probable that the aircraft must fly preassigned routes determined by computer simulation, which will not be straight lines, but the turning radii need not be smaller than 30 km.

One of the most troublesome problems in the system design is the detection of reasonable-size targets observed by the signal returning from the background landscape, and the most important factor in detection is the frequency of the system. The signal-to-noise ratio is set by the "clutter," the reflection from the countryside surrounding the target, and it cannot be improved by increasing the transmitted power because signal and "clutter" rise proportionately. The signal-to-noise ratio can be improved in only two ways: by increasing the size and efficiency of the target and by improving the resolution of the radar so that the smallest distinguishable area of the landscape is reduced to a minimum.

If the new system attains the accuracy of 3, 4, 6, and 10 cm, then the system will exceed conventional leveling in accuracy for spacing greater than 40, 60, 100, and 200 km, respectively.

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