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DISCIPLINE SUMMARY REPORTS

THIRD EARTH RESOURCES TECHNOLOGY SATELLITE SYMPOSIUM



DECEMBER 10-14, 1973

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**THIRD EARTH RESOURCES TECHNOLOGY
SATELLITE SYMPOSIUM**

**Volume III
Discipline Summary Reports**

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EDITOR'S NOTE

In order to achieve a uniform format, a considerable amount of editing was performed on these papers. Although contributors were afforded an opportunity to review the editing, the time allotted them for this purpose was short in order to expedite the timely publication of this document. Therefore, while care was exercised not to alter a contributor's context, this may have happened inadvertently, in which case the editor assumes full responsibility.

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PREFACE

The Third Symposium on Significant Results Obtained from the first Earth Resources Technology Satellite (ERTS-1) was held from December 10 to 14, 1973, at the Statler Hilton Hotel in Washington, D. C. The Symposium was sponsored by the National Aeronautics and Space Administration, Goddard Space Flight Center. The structure of this Symposium was similar to the one held from March 5 to 9, 1973. The Opening Plenary Session on Monday morning contained two papers of general interest to the entire audience, one on the status of the ERTS-1 system and a report on the Canadian ERTS program. The next two and one-half days were devoted to contributed papers in the various disciplines presented during three parallel sessions. These papers are contained in Volume I of the Proceedings.

The Thursday Summary Session, as before, was designed to highlight and summarize the significant results from the first three days and also to present some typical examples of the applications of ERTS data for solving resources management problems at the national, state, and local levels. This Session was highlighted by an introductory address by Dr. James C. Fletcher, NASA Administrator, and by a keynote address by Dr. John C. Whitaker, Under Secretary of the Interior, U. S. Department of the Interior. The presentations from this session are contained in Volume II of the Proceedings.

Volume III contains the Discipline Summary Reports. These were based on reports produced from a two-week long series of intensive interviews with the individual ERTS-1 Principal Investigators and then updated and extended from the material presented at the Third ERTS Symposium. The interviews were organized and directed by Dr. O. Glenn Smith of the Earth Resources Program Office at the Johnson Space Center and were held at the Goddard Space Flight Center from October 22 to November 2, 1973. The Discipline Summary Reports were written by Working Groups in each of the disciplines which were convened on Friday, December 14. These Working Groups were chaired by the respective discipline session chairmen and were composed of selected specialists in the various disciplines. Opinions and recommendations expressed in these reports are those of the panel members and do not necessarily reflect an official position of NASA.

Stanley C. Freden
Symposium Chairman

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AGRICULTURE, FORESTRY, RANGE RESOURCES

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EDITOR'S NOTE

This summary paper in the Agriculture, Forestry, Range Resources discipline area was compiled from presentations made to the Agriculture, Forestry, Range Resources Discipline Panel (see Appendix 1) between October 22 and November 2, 1973 and from papers presented at the Third ERTS Symposium, December 10 to 14, 1973. The members of the Working Group, which met on December 14 to extract the Symposium results, are listed in Appendix 2.

DISCIPLINE RESULTS SUMMARY

ERTS investigators, both domestic and foreign, have demonstrated the capability to monitor and inventory many different resources within the discipline of agriculture, forestry, and range resources.

In the area of crop specie identification, it has been found that temporal data analysis, preliminary stratification, and unequal probability analysis were several of the factors that contributed to high identification accuracies. Single data set accuracies on fields of greater than 80,000 m² (20 acres) are in the 70- to 90-percent range; however, with the use of temporal data, accuracies of 95 percent have been reported. Identification accuracy drops off significantly on areas of less than 80,000 m² (20 acres) as does measurement accuracy.

The Working Group felt, however, that too much emphasis is being placed on identification accuracy, especially when applied to an operational situation. Operationally, it would be an attempt to develop an accurate sampling system procedure to arrive at an accurate estimate of the population. Therefore, it was felt more effort should be directed toward developing and demonstrating a good remote sensing sampling strategy rather than trying to reach 100-percent identification accuracy. Although signature extension has been accomplished up to 80.5 km (50 miles) successfully, additional effort also needs to be directed in this area.

Forest stratification into coniferous and deciduous areas has been accomplished to a 90- to 95-percent accuracy level. Using multistage sampling techniques, the timber volume of a national forest district has been estimated to a confidence level and standard deviation acceptable to the Forest Service at a very favorable cost-benefit time ratio.

Range specie/plant community vegetation mapping has been accomplished at various levels of success (69- to 90-percent accuracy). However, several investigators have obtained encouraging

initial results in range biomass (forage production) estimation and range readiness predictions. If results continue to indicate good agreement between biomass and radiance level ratios or density levels of imagery, such data can be used not only as planning information for regional purposes but as range-carrying-capacity, decision-making information for the area manager at the field level on a near-real-time basis. A principal problem in implementing this quasi-operational application is the requirement that data be received by the area manager no more than 10 days after satellite acquisition, in a format he can analyze and implement.

Soil association map correction and soil association mapping in new areas appear to have been proven feasible on large areas; however, testing in a complex soil area should be undertaken. Trade-off studies on when computerized processing should be used to complement or improve photointerpretation results need to be accomplished.

At this point, stress detection using ERTS-1 data has met with only limited success. Iron chlorosis in a sorghum field was reported by Wiegand and a small pine bark beetle infestation was reported by Erb; however, Erb indicated it would never have been detected unless the cause for the misclassification in a supervised automatic data processing (ADP) analysis had been explored.

RESULTS SUMMARIES OF SUBDISCIPLINE AREAS

Crop Survey

Identification of major crops was accomplished by both photointerpretation and ADP techniques to accuracies ranging between 70 and 99 percent. Preliminary stratification of the data, use of temporal data, and unequal probability analysis were several of the factors that contributed to high identification accuracies. Signature extension of training field data was successfully accomplished up to 80.5 km (50 miles) for major crops with very little loss in accuracy and was moderately successful for bare soil and alfalfa over a south-to-north distance of 708 km (440 miles). An existing yield model was successfully used, which required meteorological data and acreage as inputs to arrive at production.

Identification and Measurement

Preliminary stratification of data by photointerpretation in the intensive agriculture area of San Joaquin County, California, significantly reduced the number of classes to be considered during computerized analysis, thereby reducing computer time and resulting in an overall accuracy of 80 percent from a single-date data set that was acquired at a nonoptimum time (Draeger).

Erb also reported that stratification can best be done using photointerpretation. In his investigation, which covered areas in the Corn Belt, the spring wheat region, the San Joaquin Valley, and the Imperial Valley, he reported that crop types were best classified by spectral pattern recognition techniques, after stratification, with single data set accuracies ranging from 70 to 90 percent. However, temporal analysis of two or more registered passes improved classification accuracy to the 95-percent range. Area measurement was accomplished to a 90-percent accuracy. It was reported, however, that where highly contrasting fields are adjacent,

the phenomena known as "blooming" is apparent, which obscures the true boundary and makes area measurement difficult.

In a three-county area in Illinois, Landgrebe reported an accuracy of 83 percent in identification of corn and soybeans. In this investigation, training fields from one county were tested in the other counties. There was very little drop in accuracy of this signature extension of 80.5 km (50 miles). In the signature extension done by Erb between Imperial County, California, and Butte County, California, alfalfa and bare soil were recognized to 70- and 80-percent accuracy, respectively. In this instance, the distance was about 708 km (440 miles) south to north.

Using unequal probability analysis on data from Missouri and Idaho, Von Steen reported a 10-percent increase in accuracy of classification over the assumption that all crops are equally probable to be in the scene. He also indicated that fields of less than 80,000 m² (20 acres) were difficult to identify accurately. Wiegand substantiated this conclusion by reporting 74-percent accuracy for 80,000-m² (20-acre) fields and 93-percent accuracy for 400,000-m² (100-acre) fields.

Winter wheat acreage in a ten-county area in Kansas was measured to an accuracy of 99 percent by use of temporal imagery. Yield predictions were made by applying an existing yield model based on meteorological data (Morain). Crop type, health, and vigor assessment by ratioing of the bands of the multispectral scanner (MSS) is being investigated. Crop type may be identified by the ratioing techniques. Iron chlorosis in sorghum on a single field was detected (Weigand). General health and vigor assessments are being conducted by various ratioing schemes (Kanemasu and Wiegand). The identification of rice grown in the Philippines was difficult to detect or identify due to very small plots and significant variance between plot growth stages. The variance between plots was due to planting maturity and harvesting dates not being seasonally constrained to a specific time – a tropic latitude influence (McNair).

Modeling

There was no model development for yield estimation; however, the investigative research on ratioing techniques may be inputs to a yield model if successful (Wiegand and Kanemasu). The multistage sampling technique used in Draeger's investigation was the application of a model to increase identification and measure accuracies. Morain applied an existing yield model which was based on meteorological data.

Interpretative Techniques

Intensive crop areas were identified by stratification and ADP analysis of the strata. The strata were identified by photointerpretation techniques delineating agricultural and nonagricultural areas. Two basic ADP analysis techniques were used. The first determined the spectral statistics representative of each crop (Draeger, Landgrebe, and Erb) and the second used a ratio of the MSS bands for crop identification (Wiegand). Photointerpretation procedures using crop calendars, temporal data, color composites, and imagery from MSS bands 5 and 7 (Morain and Lewis) were used to identify crops where fields were of sufficient size.

Usefulness

The technology demonstrated to this point-in-time could substantially assist in crop surveillance, providing information as to what type of crops are being produced, their acreage, and where they are located (Landgrebe, Draeger, Von Steen, Morain, and Erb). Land use on a regional basis may be identified and large area resources can be identified (McKendrick). Preliminary work has been done in applying a yield model for production estimation in the hard red winter wheat region (Morain).

Documented Procedures

Documentation is incomplete because investigations are not complete. Procedures that are documented are in the form of computer programs and analysis plans.

Future Directions

The developed analysis techniques need to be verified throughout a complete crop year. This, in general, could be accomplished by the completion of investigations currently under study or with continuation through the 1974 crop year. Signature extension to additional frames of data and testing in different geographical areas to determine limiting parameters are required. Automatic acreage measurement techniques need to be developed, tested, and qualified to an accuracy that is acceptable to user agencies. Yield models for production estimation, which are complementary to signature extension, and acreage mensuration need to be developed and tested. Band ratioing for leaf area index (LAI), or health and vigor indicators for both broad-leafed and parallel-veined plants, needs to be studied.

Forest Survey

Investigators using multistage analysis techniques of ERTS-1 data have demonstrated the capability to economically stratify, estimate volume, and locate known tracts of discrete forested areas. Additional multistage demonstrations need to be undertaken in national forests and commercially-owned forests in the Northeast and Southern United States to further test the utility of ERTS-1 data. These demonstrations need to be conducted with active participation by the eventual user to allow objective evaluation of the results and to effect technology transfer.

Investigations to detect forest stress in early stages were basically unsuccessful due to the subtle change that accompanies most stress. The spatial resolution, spectral coverage, and frequency of satellite coverage needed to accomplish this objective appear to be marginal.

Identification and Measurement

Timber volumes and classes were identified by a statistically designed, multistage sampling system, to a confidence level of 80 percent and sampling error of 8.2 percent at the district level of a national forest in California. The costs of the inventories using this technique were estimated to be \$2.70/km² (1.1 cents/acre) as compared to \$6.20/km² (25 cents/acre) using

current procedures. An accuracy of 95 percent for identifying conifers was obtained in this investigation (Nichols). Geographic coordinates for forest land ownership were projected on ERTS data identifying points within 183 meters (600 feet) of their true position. This indicates the level to which cadastral measurements can be made (Langley).

In the area around Winnipeg, Manitoba, Shlien was able to discriminate the vegetation classes of Jack Pines, Blue Spruce, Sedges, Trembling Aspen, Pasture, and Tamarack with greater than 85-percent accuracy using computerized analysis. Also in Canada, in the Boreal Forest region of Alberta, Kirby was able to use ERTS data to identify coniferous and hardwood stands, muskeg and burned-over areas, geological and hydrological features, and manmade features such as roads and clear-cut areas, and was able to map these features accurately at a scale of 1:250,000.

In the Choaburi Province of Thailand, a comparison of the last forest inventory conducted in 1961 with the forested area inventoried from the ERTS imagery showed a decrease of 23 percent in the forested area. Much of this decrease is attributable to illegal cutting practices and "slash and burn" agriculture (Cheosakul).

Large uniform wood lots in the state of Michigan were identified by gray scale levels with an accuracy of 85 percent, but the areas were not measured (Andersen). Timber classes to a level-3 category for pine stands, which identified site preparation or regeneration, was identified to an accuracy of 85 percent, and 14 forest classes were identified with an overall accuracy of 75 to 95 percent. Accuracy increased on large stands (Erb). Stress within forest stands was undetectable; only damaged and mortality areas were identified (Heller, Hall, Woll, and Murtha).

Modeling

Coefficients for each level of a multistage sampling system were derived statistically and applied to the data for estimation of timber volume. Source data was tree crown density as verified by ground checking (Nichols).

Interpretative Techniques

Photointerpretation of the ERTS imagery produced basic land use maps, identifying clear-cut, regeneration, and damaged or mortality areas (Nichols, Heller, Erb, Woll, and Hall). Temporal data was required for certain vegetation discrimination, that is, hardwood versus conifer identification verification. Timber classes and volumes were estimated by a pure multistage sampling system, which applied statistically-derived probability numbers to each level of information: ground, aircraft, and ERTS data (Nichols). A new technique for data interpretation (INTEL, for interpretative element) allows the analysis of a homogeneous group of pixels versus each pixel and performs a statistical evaluation of each INTEL (Langley). Small wood lots (20,000 m² (5 acres)) were identified and boundaries discriminated by center-pixels-to-boundary-area techniques, which select a pixel in the middle of a homogeneous area to use as a training set. The boundary pixels are then analyzed by ratioing the training set and adjoining field pixels to identify the area boundaries (Andersen). Timber classes were identified into stands, regeneration, and preparedness by supervised and unsupervised pixel counts (Erb).

Usefulness

An economic (cost/acre) regional timber classification and in-place timber volume estimation has been performed on 870 km² (215,000 acres) (Nichols). Resource surveys and forest inventories can be conducted on a periodic basis, identifying management systems and stages of harvest or production (Langley and Erb). Regional land use and resource maps are useful to all governing agencies and will supply the first echelon of information for a multistage sampling system (Andersen). Sequential data will show land use and/or timber harvesting changes (Woll).

Documented Procedures

All investigations using ADP techniques are well documented by having an operative data analysis system (Nichols, Langley, and Erb). Investigators using photointerpretation techniques have documented their techniques by interpretative keys developed by each investigator for his own analysis procedures (Heller, Hall, and Woll).

Future Directions

The demonstrated inventorying techniques need to be verified on larger areas or regions and in dissimilar forest and geographical areas. The demonstration should be in concert with the U. S. Forest Service and other users, utilizing the procedures that have been successfully demonstrated to date.

Range Survey

Range resources have provided a formidable challenge for many years for remote sensing investigators who have attempted to classify or identify the dominant specie or plant community on rangelands or wildlands. This has been primarily due to the nonhomogeneous nature of most range landscapes and also to the sparse vegetation in many of the arid lands that are used for range. However, it appears there are now two approaches being implemented: one for specie/plant community identification, and the other for estimation of forage products (biomass) available for livestock and wildlife. In the latter, considerable success has been achieved by several investigators using both photointerpretation and computer-aided techniques for the analysis of ERTS-1 data on a regional or multistate basis.

It should also be noted that if ERTS-1 data were made available in a timely manner (1 to 2 weeks) it could be utilized to definite advantage by area managers of the Bureau of Land Management for week-to-week relicensing or future planning. It should also be noted that there is a difference between U. S. Forest Service "grazing permits," which are essentially a year contract between the Service and the ranchers, and the Bureau of Land Management's grazing licenses, which are range-usage licenses that are incrementally renewed throughout the year.

Identification and Measurement

Broad vegetative class maps were made using ERTS data as an information source. The map accuracy of feature identification, location, and level of detail obtained were verified using existing maps or prior knowledge of the areas under study (Bentley, Tueller, Drew, and

Williamson). Range resources studied were desert shrubs, playas, reseeded grassland areas, pinyon-junipers, coniferous, and native grazing areas with an overall identification accuracy of approximately 74 percent. Measurements of clear-cut areas of 0.01 km² (3 acres) and water ponds 84 meters (275 feet) in diameter were discerned from the ERTS imagery (Tueller). A vegetative legend system based on satellite and aircraft data was further expanded (Poulton).

The greening effect of desert vegetation in Saudi Arabia was detected on temporal ERTS imagery and was related to the development of young forage and available moisture. Such a site is required by the desert locust for breeding and swarming. The success of this investigation demonstrates the feasibility of detecting potential locust breeding sites by satellite (Pedgley). In the African drought area, MacLeod illustrated how ERTS data were being used to monitor the rate of desertification and also the progress of controlled grazing areas that are easily detectable in the drought areas. Attempts are also being made to locate water by studying the old drainage patterns.

Modeling

The modeling performed in this subdiscipline was by Rouse. Information for other principal investigators was extracted directly from the data.

Interpretative Techniques

Broad area vegetative classifications were delineated by stratification on the ERTS imagery (Tueller). Color composites were used when working with areas which have greater than 50-percent vegetative cover. MSS band 5 was used to identify and monitor valleys, playas, stream courses, canyons, and alluvial fans, but band 7 was better for steep canyons where thick phreatophytic vegetation existed (Tueller). Gulf and Marshay cordgrass along the Texas Gulf Coast were classified by supervised ADP techniques to accuracies of 95 and 97 percent, respectively. These small areas are frequently inundated by water but are high productivity range areas (Erb).

Soil associations in the Nebraska Sand Hills area were mapped using vegetation as an indicator. Temporal data with one scene having complete snow cover and low sun angle were essential for the complete mapping. The rangeland biomass and water quantities were correlated to quantitative optical gray levels of the MSS band 5 (Drew). For the vernal advancement and retrogradation of vegetation (green wave effect), ADP techniques were used which correlated the green biomass to a ratio of bands 5 and 7 plus an empirical constant. The ratios were the difference of bands 7 and 5 divided by their sum. The square root of the sum of the ratio and a constant (to ensure a positive number) produced a transformed vegetative index (TVI). The TVI is correlated to the quality and quantity of vegetation existing at each of ten point sites distributed from southern Texas to the Canadian Border (Great Plains Corridor). Regression analyses indicated better than 90-percent agreement of above-ground, green biomass and moisture content to TVI (Rouse).

Usefulness

A forage (biomass) measurement on a regional and seasonal basis may be used by the Bureau of Land Management to allot grazing permits and support legal grazing allocations. The system

exists and is ready for implementation if data is made available on a timely basis. For ephemerals, which Bentley was studying, data is required 1 week after acquisition by the satellite.

Basic land use maps and sequential ERTS data may be used for monitoring grazing systems, fire hazards, water quantity, and range readiness. The procedures can be expanded to a global basis for arid-type lands (Tueller). Rangeland forage readiness and quantity information on a seasonal basis may be used by ranchers and supporting industries for the maximum utilization of resources (Rouse and Drew).

Documented Procedures

The duration of the investigations and completion of analysis processes have not allowed for complete documentation at this time. The photointerpretation investigations are documented in draft form in terms of photo keys developed, procedures used, and results obtained. These will be reported in final reports (Tueller, Drew, and Bentley). The investigation using ADP ratioing to determine TVI numbers and their agreement with actual biomass is at the midpoint of the contract. Therefore, the procedures are not fully developed, tested, or documented for an entire growing season.

Future Directions

All procedures identified need to be verified by a demonstration throughout a complete growing season. This should be in the area where the techniques were developed and extended to similar ecological areas. A statistical verification of biomass measurements for both ADP and photointerpretation techniques needs to be performed. The work on plant specie/community identification and inventory needs to be directed toward a common classification scheme which has been adopted by a potential user.

Soil Survey

Identification of major soil associations was accomplished by both photointerpretation and ADP techniques. Associations were identified by stratification using vegetation, topography, and temporal data as information sources. Combinations of the different MSS bands in the form of color composites were used to classify major soil associations under a wide variety of climatic, geographic, and topographic conditions.

Identification and Measurement

Soil associations for regions and a state were made by stratification using vegetation, topography, and drainage patterns as indicators. Areas of 12,000 m² (3 acres) where blowouts had occurred were observable in the Nebraska Sand Hills (Drew) and alkali and saline soils of 91.4 meters (300 feet) in diameter were detected in California (Colwell).

A soil association map of South Dakota was developed by using ERTS bands 5 and 7 to delineate the soil boundaries. After delineating major soil areas, more than 4,800 land-sale prices

were obtained and associated with the soils areas and averaged. The final product was a soil association land value map of the state of South Dakota (Myers and Westin).

Using LARSYS unsupervised cluster analysis, Baumgardner was able to delineate vegetation classes which were associated very closely to soil associations. By comparing his results to those of published soils maps, he was able to determine areas of disagreement and then ground check. In three specific cases, the data from the ERTS tapes were used to correct inaccuracies on the soils maps. Using computerized analysis, Landgrebe was able to separate seven soil types in the Indiana Wabash Valley area to an overall accuracy of 89 percent. A national soil survey was made of Greece, which identified major agricultural areas, regions that are not economically feasible for reclamation and major land use forms (Yassoglou).

Modeling

There was no modeling performed in the soils survey area. All information was extracted by direct photointerpretation or ADP techniques.

Interpretative Techniques

Photointerpretation techniques used imagery of band 5 to identify basic soil association boundaries in the northern Great Plains (Myers) and band 7 for detail analysis of vegetation in the steep ravine areas. Color composites of bands 4, 5, and 7 were used to identify hues of the vegetation throughout the study area. Density slicing techniques and topographic and temporal data were used to make soil association maps of the unique Nebraska Sand Hills region (Drew). Soil associations using color composites to identify different features were used in a wide variety of climatic, geographic, and topographic conditions (Baumgardner). Pure ADP techniques using training sets and pixel count discriminated organic and mineral soil in the Michigan area (Andersen).

Usefulness

Soil association maps as produced from ERTS will provide first-level regional planning or reclamation guidelines. The techniques as demonstrated may be used to map remote areas or counties where soil association maps do not exist.

Documented Procedures

The duration of the investigations and incompleteness of analysis processes have not allowed for documentation at this time.

Future Directions

The techniques and procedures that were demonstrated need to be verified by a demonstration in a different region, and a quantitative validation of soil boundaries needs to be performed. For investigations that are dependent upon vegetation as an indicator, a complete growing season is needed to identify all the distinctive features.

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APPENDIX 1

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LAND USE AND MAPPING

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EDITOR'S NOTE

This summary paper in the Land Use and Mapping discipline area was compiled from presentations made to the Land Use and Mapping Discipline Panel (see Appendix 1) between October 22 and November 2, 1973; from papers presented at the Third ERTS Symposium, December 10 to 14, 1973; and from a Discussion Group (Appendix 2) meeting on December 14, 1973.

INTRODUCTION

This summary, in addition to addressing the papers presented at the Symposium, addresses other ERTS-1 investigations within the land use and mapping category, as well as investigations reported in the other sessions when such work dealt with land use classification or mapping. This summary is divided into two basic sections—one dealing with land use classification and delineation, and the other dealing with mapping as addressed by investigations of a cartographic nature. The term "land use classification" is used in respect to the actual use of land rather than "land capability," "land suitability," or the "potential use of land." Furthermore, the classification of "actual use of the land," as defined by man's activities that are related to the land, may be only inferred, rather than directly interpreted, in the case of the identification and classification of some surface features or vegetation cover types. Also, in the case of some surface features or vegetational cover types, the specific activity involving man's use of the land may not be designated in a four-level classification system until level 3 or level 4 is reached.

Most investigators employed or implied a hierarchial land use classification scheme with more than two levels, such as proposed in the U. S. Geological Survey (USGS) Circular 671, but mainly addressed themselves to classifying and delineating surface features (land use) that would fall in the first two levels of a three- or four-level hierarchial scheme. Although not all investigators used a hierarchial classification scheme or concurred with the idea (computer-implemented classifications with digital data are not conducive to a hierarchial classification approach), the classification system proposed by the U. S. Department of the Interior will be used as reference in this summary paper (see Appendix 3).

LAND USE

Interpretative Techniques

Interpretation of multispectral scanner (MSS) imagery and computer-implemented classifications with MSS digital data on tapes are the two principal interpretative techniques utilized for land use classification and inventory. Conventional interpretation of MSS imagery is the most common interpretative technique. Conventional interpretation is defined, for this paper, as the viewing of imagery for the purpose of classifying and delineating surface features by relating image tone, texture, and pattern to surface features that define or imply specified uses of land or vegetation cover types.

Conventional interpretation techniques have been employed with both black-and-white imagery from individual bands and with color composites produced by combining two or more black-and-white images (usually bands 4 (0.4 to 0.6 μm), 5 (0.6 to 0.7 μm), and 7 (0.8 to 1.1 μm)). The most satisfactory results have been attained by interpreting the color composite. Color composites have been interpreted both in bulk image format (23 by 23 cm (9 by 9 inches)) and in a format resulting from further enlargement of a portion of the image. Enlargements to an approximate scale of 1:250,000 are most common, but suitable enlargements have been made to approximate scales up to 1:100,000. The scale of the enlargement, for a particular application, is usually determined by the scale of available maps, but it is also dependent on the quality of the particular image that has been chosen and the equipment available to the investigator. Suitable results have been obtained by either interpreting the bulk image color composite viewed with a magnifying optical instrument and recording the interpretation on an enlarged base made from one black-and-white image, or by making a visual interpretation of an enlarged color composite and delineating land uses on the same.

Some refinement of classification has been accomplished with color additive viewers and other color enhancements (including subtractive processing), but these techniques are more time-consuming than conventional interpretation techniques and are limited to those investigators that have the special skills and special equipment needed for enhancement techniques. It is not apparent that increasing the number of level-1 classes that can be identified and classified through color enhancement techniques, or improving the accuracy with which level-1 classes can be delineated, compensates for the added cost and/or processing time over conventional image interpretation. Furthermore, it is not always apparent that such improvement with color enhancement for general classifications showing level-2 classes compensates for increased extraction time and/or increased cost. However, it is apparent that color enhancement techniques can result in significant gain in deriving specialized information that would not be forthcoming from a generalized level-2 classification.

Because of the manner in which most investigations were conducted, it is often difficult to determine whether the achievement of satisfactory results was dependent on the interpretative technique employed or on the quality of a particular set of imagery, the time of year that the imagery was acquired, the particular surface conditions that may be unique to a given geographical area, and/or, the familiarity of the interpreter with the area. However, it is apparent that considerable gain in the accuracy of a classification can be attained through the sequential analysis of differences in vegetative cover and agricultural practices from season to season.

Computer-implemented classification based on the use of pattern recognition software and digital data has been limited to those investigators that have access to the computer facilities for which the necessary software and hardware had been developed. Both supervised and unsupervised (clustering) techniques have been utilized; but, in general, investigators prefer the supervised technique for applications involving large areas that are predominantly rural and the unsupervised technique for specialized classifications of small selected areas, such as urban areas and their environs. Investigators who have worked with both imagery and digital tapes are most enthusiastic about the potential of the digital data. Use of digital data permits the classification of surface features whose spectral differences are not discernible in the imagery and presents the possibility for classifying data in each individual data element (also called picture element, pixel, or cell). Other computer-implemented techniques, such as the computation of ratios of radiance values from two bands to portray patterns that relate to surface features, are in use but have not received widespread attention (Hannah).

Digital data from computer compatible tapes have also been used to produce a first generation, color composite transparency through a tape-to-film conversion (usually a false color composite using digital data from bands 4, 5, and 7, with film recording on color film). Such a product, when used with conventional image interpretation techniques, has been found to provide for a finer definition of surface features than provided by a 1:1,000,000 scale system-corrected, color composite bulk image or an enlargement of the latter.

In conclusion, it can be said that there are advantages and disadvantages to both the use of imagery and the use of digital data. Consequently, some balanced combination of the two with the associated interpretative techniques, rather than the exclusive use of any specific technique, is needed in order to derive the maximum information from ERTS data to satisfy all the various land use information needs.

Identification and Measurement

Generally, all level-1 and most level-2 classes (except for the urban and built-up category) were identified with acceptable accuracy with techniques based on the use of ERTS imagery (Sizer, Alexander, Clapp, Estes, and Place). All level-1, many level-2 classes (except for the urban and built-up category), and some classes beyond level 2 were identified with acceptable accuracy with techniques based on the use of ERTS digital data (Erb and Ingels). Advances have been made, and the possibility exists for increasing the number of classes identified and the accuracy of the identification of surface features through sequential analysis of differences in surface features between seasons of the year, especially for surface features with natural vegetative cover or which alternate between bare soil and crops.

Surface features covering 8,000 to 20,000 m² (2 to 5 acres) have been identified, but no consistency in identification and measurement is reported below 40,000 m² (10 acres), and minimum-sized unit area delineation of 160,000 m² (40 acres) or larger is most common (Alexander, Sizer, Hardy, and Erb). Identification of linear features as narrow as 15 m (50 ft) has been made frequently, but most delineations are limited to surface features of 80 m (260 ft) or greater in their smallest dimension. Computer-implemented classification with digital data, in which there exists a possibility for identification of a surface feature encompassed by an individual pixel, offers the most potential for refinement.

More evaluations of classification accuracy are needed, but generally, the surface features (land uses) covering 90 percent or more of the surface within an area of one township or larger are correctly identified for all level-1 classes; 85 percent or more of the surface area encompassed by most level-2 classes, except in urbanized areas, are being correctly classified and delineated. Certain surface features, for example, water bodies covering more than 40,000 m² (10 acres), are being correctly identified and accurately delineated to between 95 and 100 percent accuracy (Clapp, Erb, and Sizer).

The results of land use classifications are usually presented by recording the identification and classification of various uses of land on a format with geographical reference. When ERTS imagery is the basic data, the imagery is usually enlarged or projected to attempt registration to an existing map, even though the resulting product may have undefined geometric accuracy. Efforts to enlarge images and record land use delineations at a scale of 1:250,000 are common, but few investigators have attempted to record land use delineations at scales larger than 1:100,000. However, with a digital tape as the basic data source, map registration to a scale larger than 1:100,000 is considered feasible. Two investigators registered digital data to a 1:24,000 scale topographical map (Wray, Erb). Although there has been little work to determine what scales are most needed relative to the intended use of the information, it is commonly accepted that classifications of urban areas should be presented at scales of at least 1:24,000. Foreign investigators, working outside of urban areas, tend to think that scales of 1:250,000 are most applicable for the intended use of their classifications (Malan, Howard, and Brockmann). Some investigators emphasize the input of land use information into data banks rather than presentations on a map format, but all recognize the need for geographical reference.

Special purpose and selected area classifications in urban areas have not achieved the desired success in identification and measurement, but some data processing techniques that are not yet fully operational promise better results. The use of digital tapes has provided better results for urban area classification than the use of imagery with conventional interpretation techniques. However, difficulties in identifying some level-2, urban and built-up classes with suitable accuracy have been encountered in all interpretative techniques. Generally, the accuracy of classification for level-2 urban and built-up classes ranges between 60 and 90 percent, depending on the class or combination of classes, but with little success in separating commercial areas from industrial areas (Wray, Erb, Sizer, and Raje). As stated previously, it is considered desirable to present urban area classifications at a scale of 1:24,000, and the feasibility of doing this has been demonstrated. However, it is also considered desirable to classify urban features that occupy areas less than 40,000 m² (10 acres), and such classifications have not been demonstrated with ERTS data at acceptable accuracies. Nevertheless, progress has been made and attention has turned to the prospects of attaining acceptable results with digital data, because a surface feature within an individual picture element (about 4,000 m² (1 acre)) can theoretically be detected and potentially identified (classified) with computer-implemented techniques. At the present time, ERTS data, because of the repetitive 18-day cycle, are useful for detecting and monitoring urban area expansion. Also, because of the synoptic coverage, ERTS data can be used to derive information on extensive areas surrounding developed urban areas for the solution of long-range urban planning problems.

Usefulness

Estimation of benefits from land use classification is inherently difficult because the results of land use decision-making are reflected primarily in terms of environmental quality factors not conducive to quantification. An alternative measure of the usefulness of ERTS-1 data for land use applications is the demonstration of user interest. Of the 32 investigations reported in this discipline, 11 had investigators from the user community, the majority of whom were the principal investigators for their investigations. These investigator-users are from county planning commissions, state agencies with both planning and management responsibilities, and Federal agencies with operational resource management responsibilities.

In addition to those user representatives participating in the ERTS-1 program, informal relationships have been established with user representatives by a number of investigators. Considering only the 25 ERTS investigations in the land use category, records indicate that 92 users in 29 states were in contact with these investigators in capacities ranging from cooperation in the effort to personal briefings. Significant efforts are being made in defining the uses of ERTS-1 data, and a valuable educational process is occurring. There is evidence that the user can make better use of land use classifications derived from ERTS data when the limitations, capabilities, and data processing procedures are understood. The following are four categories of data, each related to "use."

- **Baseline data on the use of land**—For the most part, baseline information presented on maps and/or in statistical form, is used indirectly by administrators, managers, and legislators in a manner such that specific data cannot be traced to a specific action. For example, if a legislator knows that 10 percent of the land in the state is in the wetlands category (versus not having any information on the extent of wetlands), this information would be useful in considering wetlands legislation, but the exact manner in which such information is used varies. The potential use of baseline information derived from ERTS data varies from a high degree in areas where such data were nonexistent or obsolete to a lower degree in areas where recently acquired land use information existed at the time that ERTS-1 was launched.
- **Baseline data update**—Updating serves two purposes: First, it keeps the data base current and meaningful, and second, it adds another dimension of information by documenting the extent of change during a time period and/or monitoring change through a time period. For example, it would be meaningful for a legislator to have information about the extent of wetlands, but it would be even more meaningful to know the rate at which the wetlands areas are diminishing. The actual and potential use of ERTS data for updating depends on the rate of change taking place in a given area, the alternative sources of current data, and the detail in the original data base. Most investigators are enthusiastic about the potentials of ERTS data for updating, but they have not yet pursued update activity to any significant extent because their first concern has been to establish interpretation and data handling procedures.
- **Information management system**—Information derived from ERTS data as one data component of a data bank has received considerable attention. Most land use investigators realize that meaningful decisions in land management and/or land use

planning cannot be made until data on the actual use of land can be integrated with other data, such as data on environmental factors, economic factors, and ownership. Once various sources of data have been combined to indicate land suitability or land capability, this information can be compared with the actual use of the land.

- Operation of models—A strict definition of a land use model would incorporate the five following components:
 1. Acquisition: Data are acquired and manipulated into a useful information format to be supplied as a base for the model.
 2. Simulation: The information is then used to stimulate a real, ongoing process.
 3. Projection: A certain policy, decision, or course of action is then provided to the model.
 4. Prediction: The model then accepts the course of action, operates with the information, and then attempts to predict a future or past state.
 5. Output: The information is displayed or presented in a form that is meaningful to a decision-maker.

All components have feedback loops: Future informational states are used to influence the course of action, and the model proceeds again to predict the consequence of the new decision. Feedback relative to the quality of information (component 1), could also be used to define optimum sensors for land use classification. Although some users feel that certain situations require data with more detail than can be derived from ERTS data, there was no evidence presented that indicated how the use of more detailed data would affect a decision that would result in a better course of action.

In the strict definition of the word modeling, there has been no land use modeling in the ERTS investigations. There have been a few successful attempts to manipulate land use information for combination with other data. In so doing, questions regarding the use of land can be answered in a manner by which certain inferences can be drawn and related to land use policy. (This type of information manipulation, as defined in this paper, comes under information management systems rather than modeling.) To date, ERTS investigators have addressed one or more components of the model but have not integrated all five components. All five components must be combined into one model that would be operated to address real land use policy or land management decisions.

Many ERTS investigators in the land use and mapping category have identified specific potential applications involving land use information derived from ERTS data. Some of the most promising of these specific potential applications were the survey of impounded water for national dam inspection (Erb); wildlife habitat location for wildlife management (Thomson, Sizer); inventory and monitoring of large-scale surface mining activities (Sweet); and route location for major highway, power-line, and pipeline corridors (Clapp). However, inasmuch as

specific potential applications are treated in summaries by other discipline panels (agriculture/forestry/range resources, water resources, and environment), this summary focuses only on the use of information from comprehensive land use classification.

There are two general decision-making activities that require information from land use classification and inventory—land management and comprehensive land use planning. In the area of land management, land use inventory performed with ERTS data is of greatest use in general planning and policy determination rather than for decisions relating to the management of a small tract of land. The greatest potential is in planning and formulating management policy for large contiguous public ownership regions (local, state, or federal). The utility of land use inventory for comprehensive land use planning will be limited until land use policy is better defined by local, state, and federal legislation. However, there are many specific planning areas for which land use inventory derived from ERTS data is useful at present. Some such areas relate to the use of land in flood-prone areas, the availability of large open space for public recreation in near-urban areas, the use of land adjacent to wetlands and coastlines, and the preparation and review of impact statements. Land use inventory with ERTS data can presently be used, together with aircraft-acquired photography, for certain aspects of urban planning for large cities. Such an information system concept would view the two remotely sensed data sources as being complementary to one another. Aircraft-acquired photography covering the urban area proper would be acquired perhaps annually for detailed classification of the developed area. ERTS data would be used to capitalize on both the repetitive 18-day cycle and the synoptic view, which would provide detection and monitoring of new developments between aircraft flights. This information could then be applied to long-range planning problems anticipated through the study of past expansion patterns radiating from both the urban core and large urban area satellite community developments. The ERTS synoptic view would also be used, but less frequently, for more extensive coverage than that of aircraft-acquired photography. Of principal concern in the latter case would be the present use of land in the projected expansion areas—the outlying physical barriers (rivers, mountains, and wetlands) and other physical features (faults); large open space recreation needs for the urban populace; transportation network planning; and ecosystem interrelationships.

One documented cost study shows that the cost for producing an 11-class land use map for a 38,700 km² (15,000 square mile) area (which contained large urban areas) was 40 cents per km² (\$1.06 per square mile). The cost comparison indicated the proportion 1:10:15 for use of ERTS-1 data, high altitude aircraft photography (1:100,000 scale), and medium altitude aircraft acquired photography (1:20,000 scale), respectively; the man-hour effort showed a 1:7:31 ratio, respectively (Simpson). Most investigators realize that the use of ERTS data versus aircraft-acquired data is not an either/or situation, but rather that the two sources of data together form the basis for an adequate information system. Such a concept uses ERTS data for obtaining complete coverage for generalized land use classification and for selecting smaller areas that require aircraft-acquired data for more detailed and specialized land use classifications. The two sources of data, therefore, relate to one another and, together, provide the total needs of the system. Another variation of the system concept involves ERTS data and multistage sampling with aircraft.

Future Directions

Work still needed in the field, irrespective of interpretative technique or type of application, is summarized in the following paragraphs.

Demonstration applications should address real problems for which the data needs can be defined at the start. This approach will require direct interface with the intended user from start to finish. The demonstration should include test areas that are carefully selected so as to encompass all variations found in the total area for which ultimate application is expected, and should simulate operational implementation as closely as possible. The conclusion of the demonstration should include the formatting, presentation, and packaging of the data in a manner that is meaningful for its intended use.

Documentation of detailed step-by-step procedures involved in arriving at the final products should address the costs, skills, and equipment that would be involved in the actual implementation of the procedure, and should define the general accuracy of the final product.

Product evaluation should proceed along two lines: first, an evaluation of the accuracy of the classification, and second, an evaluation of how the products were actually used in decision-making processes. The evaluation of accuracy should not be carried out in a manner to imply that accuracy alone determines the usefulness of a product, but rather that accuracy limits must be defined before a product can be used correctly. It is necessary to standardize the accuracy evaluations through use of a sampling design based on a recognized statistical method. The evaluation of the products' actual or potential use should include shortcomings as well as positive aspects of use.

The most important aspect of comparative analysis is the estimation of the costs involved in the implementation of a given procedure to produce a given product. However, cost information must be presented together with information on accuracy, skills involved, equipment needed, and other factors characterizing derivation and use of the final product, so that a meaningful comparison can be made with alternative methods (including methods not employing remotely sensed data) that are accessible to a user. Such analyses should not compare the use of spacecraft-acquired data to aircraft-acquired data when the two data sources are part of the same information system.

Information management systems and modeling are two distinct needs, but are presented together because both are concerned with increasing the use of land use classifications and information derived from such classifications. The main work needed for information management systems is to define the informational output required to aid decisions relative to the use of land. Only after this has been done can the required input from land use information derived from ERTS data be defined. Part of this work will involve a determination of which needs can be met with the grid cell approach to digitization as opposed to those which may require the polygon approach when data input is derived from imagery or maps. Modeling, as previously defined in this section, which considers land use information as an input, has received very little attention. However, the operation of a model is considered useful not only as a decision-making tool, but also as a means of better defining data needs which, in turn, define

the sensor system that is adequate for a given situation. Other necessary work relates to specific interpretative techniques and/or specific applications.

The most promising work involving image interpretation techniques lies in increasing the number of classes and improving the classification accuracy through the sequential image analysis of differences in vegetation (due to natural seasonal change) and differences in agricultural practices (for example, plowed versus planted) during each season. This type of sequential image analysis, as defined, would not be carried out for the purpose of detecting change in the use of land; however, the development of techniques to allow the registration of two or more data sets would serve both purposes.

Work that may be needed in the area of preprocessing digital data (for example, atmospheric corrections) is not addressed in this section. Other work needed for computer-implemented land use classification based on the use of pattern recognition software applied to digital data is as follows:

- Modification and adaptation of existing pattern recognition software for implementation on general purpose computers as found in state and local government agencies, and development of low cost hardware for image display and training sample selection.
- Demonstrations in areas large enough to require the processing of four or more digital tapes per run, and the definition of the size, number, and distribution of training samples per class for each set of data processed during a given run.
- Determination of the needs and logistics for ground-truth gathering related to training sample selection for supervised techniques and ground truthing for unsupervised techniques. This effort should include the determination of aircraft-acquired photography needs as an extension of ground truth. One investigator suggested that coverage with medium scale (1:20,000) photography for 5 to 10 percent of the area to be classified, depending on ground accessibility, is necessary for efficient training sample selection for supervised techniques.
- Correction of geometric distortion in digital data and the development of techniques to register two or more sets of digital data for change detection and analysis of seasonal differences.
- Refinement of digital data manipulation techniques and geographic registration of data for selected areas, and of special purpose classifications (for example, urbanized areas).

MAPPING

Performance Results

The initial return beam vidicon (RBV) images had excellent geometric quality. The internal distortion is about 75 meters (rms) for a system-corrected (bulk) image. Mapping from ERTS

multispectral scanner (MSS) data with control only by orbital and sensor parameters (independent mapping) involves errors of the order of 2,000 meters (rms). This is compatible with a map of 1:6,000,000 scale. With the aid of ground control, a system-corrected (bulk) image, when fitted to a conventional map projection, involves errors of 200 to 450 meters, which is marginal with respect to 1:1,000,000 scale mapping. Fitting a geodetic grid to an MSS image reduces errors to the 50- to 100-meter range, which is compatible with 1:250,000 scale mapping. However, this involves the use of the existing projection of the MSS image, which is semiperspective and lacks the conformity of geodetic projections. Scene-corrected (precision processed) MSS imagery has errors in the 100- to 200-meter range, but because of degraded image quality is considered suitable for mapping at no larger than 1:500,000 or possibly 1:1,000,000 scale. On a portion (1/16) of an MSS image on which at least two control points can be identified, points that are part of a defined pattern (shore line, field lines, highways, and such) can be located to within 20 to 30 meters (McEwen, Colvocoresses).

Other important results have been obtained because of the unique characteristics of the MSS band 7. This is significant because aerial film cameras are not currently capable of recording this 0.8- to 1.1- μm waveband. These unique characteristics include:

- Apparent penetration of thin clouds and contrails under certain conditions.
- Definition of water-land interfaces with high precision, enabling the detection of water bodies as small as 200 meters in diameter and determination of water stage to a fraction of a meter through boundary correlation in flat, shallow areas.
- Superior definition of vegetation patterns, largely due to the differential sensitivity of band 7 to vegetation types.
- Superior definition of natural features. Geologists (and others) are selecting MSS 7 as the best single band for depicting the earth's physiographic structure.
- Superior definition of certain cultural features. For example, the pattern of major streets in the western United States is best recorded on band 7.

ERTS images can be successfully transformed into experimental monochromatic cartographic products of standard accuracy at 1:250,000 and smaller scales in standard map format. Multispectral (color) reproductions have also been achieved at such scales but not in standard map format that involved mosaics. The ERTS orbit is so stable that a designated nominal ERTS image format can be defined and utilized as the basis for a map series. The image (bulk) produced from the ERTS scanner by the electron beam recorder (EBR) has such high internal geometric fidelity that it has been defined as a map projection and applied directly to the mapping of the earth. Such a projection can be defined as a space oblique Mercator projection.

Usefulness

Because of ERTS' ability to record information for a very large region during a minimum time interval, such a system can produce basic data that eliminate the discrepancies resulting from

extending the collection process over long time periods as is required with aerial images. The system allows more frequent information so that changes that indicate trends in conditions can be quickly spotted and corrective action instituted when required. The broad coverage allows photomapping of large areas almost instantaneously. In the areas where information is sparse, or out of date, this can be invaluable to management and planners.

Probably the most important use for photomapping of the United States with satellite images is to provide a base map upon which land use data and other thematic information can be annotated and precisely referenced to the earth's figure and consequently to other annotated data. This can be done at scales of 1:250,000 and smaller from present ERTS-1 data. Some investigators have presented land use classifications at scales larger than 1:250,000 even though these products do not meet national map accuracy standards.

The ERTS system with its multispectral bands lends itself readily to isolation of such features as water, snow and ice, and infrared reflective vegetation, through the use of density slicing (Pilonero). The separate ERTS bands are particularly important for mapping areas or objects that have unique radiometric responses or that are imaged under unusual conditions of illumination, such as the polar regions. The Mississippi flood area, which has been thematically treated for water boundary isolation, is an example of the timely response that is possible using a particular ERTS band or combination of bands to depict a theme of historical and economic importance.

An experimental ERTS 1:250,000 scale orthophotoquad constructed with a specially developed computer program for grid fitting and plotting has demonstrated that national map accuracy standards may be attained (or at least approached) with ERTS images at this scale and format. A series of these 1:250,000 scale quadrangles is now in production by the U. S. Geological Survey with imagery from ERTS-1 as well as other image maps at 1:500,000 and 1:1,000,000 scale. The large area covered by each image enables each quad to be constructed from only a few images. Previously, photomaps at this scale required many aircraft-acquired images, and the extremely arduous mosaicing and tone matching resulted in prohibitively high costs as well as a time cycle that detracted from the usefulness of the final product. With the near-real-time advantages of ERTS, a series of photomap products can be produced in a fraction of the time and at a cost that allows frequent new editions. Although the ERTS photomap is not considered a replacement for conventional line maps, it represents an invaluable complement because of the additional information and near-real-time data that are depicted.

Future Directions

ERTS data can be used to determine the need for revision of existing line maps of national map accuracy standards (Kosco). It can also be used for the actual revision of nautical and aeronautical charts that do not have stringent accuracy requirements (Wilson). A summary of work needed for cartographic applications includes the following:

- Deriving a means of increasing the spatial frequency and quality while still maintaining the geometric fidelity

- Improving the system for absolute positioning of the image for improved mapping and mapping of areas lacking in control
- Improving methods of control identification and transfer in order to fit the Universal Transverse Mercator (UTM) grid to the bulk MSS image
- Exploring incorporation of photometric corrections for better overall definition of specific features; for example, water bodies
- Establishing a calibrated ground resolution target to quantify the resolution for each spectral band and determining the angular effect on resolution
- Spatial modulation of original digital tapes, rather than rescanning, to produce an accurate large-scale precision product on any required projection
- Explore modification of system corrected (bulk) printing of MSS to a space oblique Mercator projection that is conformal, continuous, and has minimal distortion

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APPENDIX 1

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APPENDIX 3

**TENTATIVELY PROPOSED REVISIONS FOR A LAND USE
CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA
(USGS CIRCULAR 671)**

Prepared by: James R. Anderson, Chief Geographer, U. S. Geological
Survey
October, 1973

LEVEL 1

1. Urban and Built-Up Land

2. Agricultural Land

3. Forestland

4. Wetland

5. Rangeland

LEVEL 2

1. Residential
2. Commercial and Services
(including institutional)
3. Industrial
4. Extractive (excluding strip
mining, quarries, and gravel
pits, etc.)
5. Transportation, Communications,
and Utilities
6. Mixed (including strip and
clustered settlement)
7. Open and Other

1. Cropland and Pasture
2. Orchards, Groves, Vineyards
and Ornamental Horticultural
Areas
3. Confined Feeding Operations
4. Other

1. Deciduous
2. Evergreen (coniferous and others)
3. Mixed

1. Forested
2. Non-forested

1. Herbaceous Range
2. Shrub-Brushland Range
3. Mixed

6. Water

1. Streams
2. Lakes
3. Reservoirs
4. Bays and Estuaries
5. Other

7. Tundra

(Proposed level-2 categories are currently under study in Alaska and will be reported separately.)

8. Permanent Snow, Icefields, and
Glaciers

(Proposed level-2 categories are currently under study in Alaska and will be reported separately.)

9. Barren Land

1. Salt Flats
2. Beaches (Including mudflats)
3. Sandy Areas other than Beaches
4. Bare Exposed Rock
5. Strip mines, quarries, and
gravel pits
6. Transitional Areas
7. Other

MINERAL RESOURCES, GEOLOGICAL STRUCTURE, AND LANDFORM SURVEYS

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EDITOR'S NOTE

This summary paper in the Mineral Resources, Geological Structure, and Landform Surveys discipline area was compiled from presentations made to the Mineral Resources, Geological Structure, and Landform Surveys Discipline Panel (see Appendix 1) between October 22 and November 2, 1973, and from papers presented at the Third ERTS Symposium, December 10 to 14, 1973. The members of the Working Group, which met on December 14 to extract the Symposium results, are listed in Appendix 2.

INTRODUCTION

Since the second ERTS Symposium in March 1973, exceptional advances have been made in each of the principal geology discipline subdivisions: mineral resources, geological structures, and landforms. Geology is a basic science rather than a technologically-oriented field, and significantly new fundamental scientific knowledge derived from ERTS data relates directly to practical applications.

For the first time, diagnostic ERTS imagery has been used to pinpoint surface conditions associated with known mining districts. These include enhancements which depict hitherto unrecognized surface alteration and allow analysis of ore-controlling fractures distribution in a regional context. ERTS has likewise provided observational data containing previously unrecognized surface anomalies in large oil-producing basins which correlate closely with known oil fields. These observational data offer promise of providing new and powerful techniques for oil exploration, especially if further work using more sophisticated enhancement-processing proves capable of emphasizing the anomalies. ERTS is showing a better-than-anticipated potential for producing accurate small-scale (large-area) geologic maps, often containing details that were previously not recorded on similar regional maps. The maps produced from ERTS imagery can be prepared more effectively than previously possible, mainly because of the synoptic, multispectral, and repetitive character of ERTS data.

ERTS has also provided extensive information on possible geologic hazards. Many new fractures have been identified in several regions of the Pacific Coast seismic belt that have histories of

recent earthquakes. This has obvious implications for engineering projects such as dams, aqueducts, and transportation routes. In the mid-continent area, ERTS data have been used to predict zones of roof-fall danger in a working coal mine from newly discovered lineations (probably fractures) used as indicators of hazards.

This paper is based on the following information sources: (1) investigator reports received routinely from April through December 1973, (2) material presented to the Discipline Panel (Appendix 1) at the ERTS investigations review in October-November 1973, (3) papers given at the Third ERTS Symposium in December 1973, (4) ideas expressed during the one-hour geology discussion session at the December Symposium, and (5) critiques by a working group (listed in Appendix 2) that convened on the last day of the Symposium. The overview section is followed by a results and applications section which contains discussion of (1) mapping and study of geologic features and processes, (2) resources exploration, and (3) geologic hazards. Geologic features and processes are treated first because some topics included in that heading serve as the scientific foundation for mineral exploration and hazards monitoring.

OVERVIEW

In the early phases of the ERTS program, much of the effort in the geological investigations was necessarily oriented toward science rather than applications; therefore, most economic or cost benefits are not expected to appear for several years. In the oil and mining industries particularly, this lag is the inevitable result of previously established patterns of exploitation. In the petroleum industry there is typically a 3- to 5-year minimum interval between the initial targeting of an area for exploration and the actual production of oil or gas. In mining, 3 to 5 years usually elapse between the first exploration and the first evaluation drilling, followed by another 5 years to develop the mines. While ERTS may help to speed up the early phases of development, the total period involved will not be shortened very much.

The practical use of ERTS by the mineral industries was succinctly defined during the panel session by J. B. Miller of Chevron Oil Company as follows:

- Defines areas of interest and sometimes focuses on specific structures and other surface anomalies as possible exploration targets
- Reduces time in reaching decisions on setting up a program and helps in planning other aspects of the program, including operations
- Provides better base maps than those already available in some regions of the world
- Assists geoscientists in gaining a better perspective of geologic factors and also aids in inspiring more imaginative overviews
- Saves time and money

Some estimates of cost savings to mineral industries were reported during this panel session. S. Pickering of the Georgia Geological Survey concluded that use of ERTS data can reduce field

time by about 30 percent for 20 field geologists at a budget of \$25,000/man-year; this amounts to a savings of \$150,000/year in operating costs of a single state geological survey. A comparable estimate was made by L. C. Rowan of the U. S. Geological Survey; time savings of about 25 percent for mapping in the western United States will afford significant cost reductions in any given project (budgeted at levels of about \$50,000 and four men/year). J. Everett of the Earth Satellite Corporation stated that ERTS data can be used to eliminate large areas of unfavorable mineral potential while targeting areas of high likelihood; this can produce savings of 20 to 50 percent in petroleum exploration programs; for example, eliminating seismic surveys, which cost up to \$5,000/km (\$8,000/line mile), where prospects are poor. Thus, ERTS is a much faster and less expensive exploration system than geophysical techniques such as aeromagnetism, gravity, and seismic profiling, provided the mineral deposits have some identifiable surface expression.

However, ERTS data only supplement rather than supplant the existing exploration techniques. Other methods will be employed much as they have been, especially for deeper mineral deposits. The sequence of exploration remains: (1) selection of likely areas, (2) basic mapping, (3) selective geophysical prospecting, and (4) drilling to determine the amount and extent of the deposits. ERTS' contributions are oriented toward item (1) above and, to a lesser extent, item (2).

The demand for geological data and geological benefits derived from ERTS will probably differ in degree and timeliness from those in other disciplines. Agriculture, for example, will extract benefits from data obtained continually on a seasonal schedule. Hydrology will also receive benefits from continuing data of seasonal or annual utility, in addition to sporadic data from unusual events such as floods. In geology, however, most individual benefits will be sudden, geographically scattered, and in some instances dramatically high in monetary value. Thus, discovery of a mineral deposit or an oil field may result from exploration initiated or accelerated by ERTS data; but once found, further observations of these sites will be relatively unimportant, except for environmental impact monitoring. Interest will then turn toward the search for deposits, hazards, or local changes elsewhere. A hypothetical sequence of geological finds is likely to show a series of individual big finds — some perhaps worth millions or even billions of dollars — scattered more or less randomly through the first 5 to 10 years of satellite operations. The frequency and magnitude of these finds will probably decrease over time unless new principles or methods evolve (in part the consequence of other ERTS-related geologic observations) or until new and better sensor systems replace those of ERTS.

ERTS products are now being used by many mining and petroleum companies, but as yet these organizations have not reported actual discoveries of mineral deposits through direct use of ERTS data. Nevertheless, it is now becoming obvious that ERTS has revealed many new geologic features which, as our understanding increases, should eventually lead to real, documented benefits. The expectation is high; only a few major discoveries will justify the entire investment in the NASA earth resources program.

We recognize that many ERTS applications to geology need only a few good observations of a given scene owing to the general static nature of most geological phenomena. (Important exceptions include certain dynamic processes such as volcanism, glaciation, offshore

sedimentation, and landslides.) It is obvious, then, that most applications in geology will not strongly justify repetitive coverage. However, repetitive coverage does assist in geologic interpretations because of variations in the effects of sun angle over the seasons, snow cover enhancement, and changes in vegetation and moisture that are associated with different rock types and/or structural controls. The geology may not change, but its appearance does.

Some convincing examples of the geologic benefits derived from repetitive coverage were presented at the Symposium. This was graphically demonstrated by a single scene in the Western Transvaal Province of South Africa (Grootenboer). A winter image was nearly featureless geologically, comparable to 1:1,000,000 scale maps, owing to the uniform tones of dormant grass and scrub. The midsummer image was dramatically different, owing to accentuation of rock units by differential vegetation and soil moisture changes. Similar differences in appearance were correlated with temporal changes in the Northwest Territories of Canada by Moore and Gregory. Seasonal variations in the Anadarko Basin of Oklahoma (Collins), aided in recognizing different aspects of lithology and structure. Differences from year to year in vegetation and moisture, among other variables, imply that new information can be sought indefinitely in repetitive coverage. At least 3 to 5 years, perhaps even 10 years, of seasonal imagery will be needed to show a full range of variations in vegetative cover, soil moisture, water in fractures, snow enhancements, and illumination conditions related to sun angle and atmospheric interference.

Despite the value of repetitive coverage, it is likely that most geological applications will be accomplished with currently available images, with the promise that improved resolution and measurements made in other regions of the spectrum from future satellites will add important extensions to our interpretative capability. There are enough tasks arising from available ERTS data to keep many geologists extracting and applying relevant data for many years. Envisioned is a continuing role for geology in earth resources well into the operational phases now considered.

RESULTS AND APPLICATIONS

Mapping and Study of Geologic Features and Processes

Identification and Measurement

Map Making – In regions of sparse vegetation, good geologic reconnaissance maps can often be prepared from ERTS imagery where distinctive outcrop patterns occur (Houston, Viljoen, and Abdel-Hady). Sometimes these maps are superior to ground-based geologic maps in that contacts may be better delineated in the overview. Good mapping from ERTS can be done at scales up to 1:250,000 (Bodenlos), usually cheaper and faster than by other methods (although the relative accuracies have yet to be assessed). Map editing to correct mistakes in existing maps is likely to be a common application for the next few years (Weidman, Houston). ERTS regional mosaics afford an excellent photobase for geologic overlays. However, ERTS images normally are suitable only for production of photogeologic maps. These depict “remote sensing units” (Knepper, Nicolais) rather than formal lithologic or stratigraphic units, at least until field checking demonstrates a correlation between the two categories.

Landforms Analysis – ERTS images, especially in mosaic form, provide an excellent means for depicting regional geomorphology. Among successful studies of this type are: (1) descriptive and genetic classifications of sand seas (McKee), (2) location of major areas of soft surface erosion (Morrison), (3) recognition of surficial effects of recent and active glaciers, including striking views of continental glacial deposits and permafrost features (Morrison, Ferrians, and Grybeck), (4) definition of features characteristic of intermontane basins, pediments, or semidesert plains, and (5) vivid display of volcanic landforms and deposits (Williams, Friedman) with particular ability to discriminate relative ages of flow units.

The first regional landforms classification map has been prepared by Rich for most of northern California. An in-depth study of recent surface deposits and landforms in the Paraguana Peninsula on the northwestern coast of Venezuela is reported by Albrizzio.

Structural Geology – The major contribution of ERTS to geology, evident almost as soon as the first images were examined, continues to be the exceptional ability to show large structural features, such as folded mountain belts, major strike-slip fault systems, domes and uplifts, and crystalline shield or piedmont terrain, of regional or subcontinental size. ERTS is remarkably effective in revealing new "linears," many of which prove to be faults, joints, or fracture zones upon field examination. Since the earlier ERTS studies, the nature of linears is becoming better understood, and they are beginning to be used in practical ways as well as in theoretical interpretations (Houston, Martin, Lathram, Isachsen, Goetz, Gedney, Scanvic, Mohr, Ebtehadj, Knepper, Viljoen, Collins, Wier, Drahovzal, Pickering, Muhlfeld, Abdel-Hady). Use of ERTS mosaics that cover entire states or even larger areas aids immeasurably in analyzing the regional aspects of linear features. Linears ranging in length from hundreds of kilometers to less than two kilometers are being disclosed. In some poorly mapped areas of the world, the number of hitherto undetected linears has increased by factors of 2 to 5 or more. To some extent, however, this may reflect the practice of leaving off much of the detailed distributions of lineaments from small-scale tectonic maps. In supposedly well-mapped areas, which include much of the western United States, new ERTS maps of lineaments in uplifted mountain blocks (for example, the Laramie and Bighorn Mountains and other large ranges in Wyoming) are far more detailed than those from previous efforts. The improvement in detecting linear features is of great importance in refining models of tectonic deformation, in understanding the tectonic framework of continental evolution, in associating earthquakes with their causes, in finding new targets to explore for fracture-controlled mineral deposits, and in noting potential hazards in mining and construction. As a result of ERTS, many tectonic maps are now obsolete and will require careful revision. Because of ERTS imagery, many closed structures, including folds and circular or arcuate features, are being discovered or seen in a new light. These include ring dikes, calderas, intrusive plutons and stocks, salt domes, and astroblemes.

Modeling

Most models applied to geologic problems are conceptual or interpretive in nature. Because geologic processes are generally relatively slow, operational models which handle continuous inputs are not widely used in geology. However, the testing and application of proven models and the derivation of new ones using ERTS data are coming into their own in many areas of geology. Such models usually require about 2 to 3 years to formulate after the first data are

obtained. One common approach to geologic modeling in the ERTS program is to test concepts and methods by studying the phenomena or features in well-known areas. Thus, the surface expressions of mineralization or petroleum accumulation in established mining districts and oil fields are first described and characterized, from which models for recognizing these resources elsewhere can then be developed.

Examples of four models will illustrate the approaches being attempted with ERTS data. Morrison has integrated ERTS data with aircraft results to produce a series of maps showing the status of surfaces underlain by soft sediments as these are altered by erosion. McKee has now classified the major sand (dune) seas of the world into a series of morphological types, to which the genetic factors and dynamic processes that bring about their distribution and modification can be related. Saunders, Abdel-Gawad, Hoppin, Mohr, and other investigators have to varying degrees correlated their regional mapping of linears with existing models of the tectonic development of their areas; in some instances revisions of the existing models will result. Isachsen has made ground studies of linears mapped with ERTS imagery. This process injects a sense of realism into lineament interpretation and shows the need for caution in drawing conclusions on linears that have not been field-checked.

Interpretative Techniques

Methods used in geologic studies have almost exclusively been those of conventional photointerpretation. For the most part, optical enhancement techniques such as color additive viewing have added little that is new to the information contained in black and white transparencies. Color composites, however, do assist in delineating certain rock units when mapping is undertaken. The use of snow-enhanced images to emphasize topographic relief and associated fractures has been convincingly demonstrated by Wobber.

Specialized computer processing appears useful for some applications. These include MTF corrections (involving high-frequency restoration and boosting) to produce new images with increased resolution, spatial (directional) filtering to improve contrast and bring out subtle linear features, and to produce multiband ratios. Under the right conditions, geologic unit maps (both supervised and unsupervised) can be generated by machine-processing (Melhorn and Levandowski). So far, most computer-based attempts to improve linears recognition have obscured or distorted the results compared with the straight-forward detection possible in the photoimages. The one exception is the optical spatial filtering technique adapted to the computer-regenerated imagery as developed by Goetz.

Knepper, Gedney, Lathram, Houston, and others are finding stereo-viewing to be especially helpful in recognizing linears, defining direction and magnitude of dips, determining lithologies by their relative resistances to erosion, recognizing landforms, locating glacial deposits, and assessing slope stability. Ambiguities associated with tonal differences are often resolved when relative relief can be established through stereo coverage. Fuller utilization of the stereoscopic capability from overlapping ERTS imagery is recommended.

Applications

Most results from ERTS data fall at first into the province of basic geologic knowledge. Some of this knowledge can quickly be used in practical economic applications while many applications will be deferred until broad, innovative models for utilization are effected.

Some applications are now ongoing; others are being considered; and new ones remain to be proposed. Small-scale reconnaissance mapping can now be extended to many parts of the world where good maps are still scarce. Houston's report on mapping in the ice-free valleys of the Antarctic and Krinsley's playa maps exemplify this. Map editing, mainly to correct contact locations or to plot new fractures, is a major application that should be initiated as a routine for all small-scale maps in the world. Classification and mapping of higher-order landforms are now strong possibilities for the United States and other regions covered by ERTS. Such a map has many uses for engineering, land use planning, and environmental geology, as well as geomorphic analysis. So far, no one is attempting this very significant application except for a few "local" demonstrations (for example, Morrison, McKee, Krinsley, Rich, Smedes, and Houston). At present, about one-fourth of the Western United States has been mapped from ERTS data for linears distribution. It is reasonable to complete this mapping for the entire United States without much more effort. Such a regional or subcontinental map of linears, even though many will prove to be nongeological, should be invaluable for tectonic synthesis of crustal structure, for mineral and oil exploration, and for hazards assessment. It is estimated that ERTS can increase the number of known major fractures by a factor of 2 to 3 in parts of the United States and no doubt even more in other parts of the world; perhaps five times in East Africa, according to Mohr.

Future Directions

Many of the comments in the previous subsections define work still to be done. Foremost on any list is a detailed analysis of what the linear features on ERTS images really are. The study by Isachsen exposes the pitfalls. For example, probably half of those linears plotted on Isachsen's early ERTS maps of eastern New York can be eliminated as geologic features when compared to published maps or examined in the field. Greater confidence in identifying linear features of geologic significance must be established if the user community is to accept the results. Computer processing, while promising for lineament analysis, must be applied with caution because fractures usually do not have constant expression along strikes. A fault, for example, may appear as a straight canyon, a row of sag ponds, and a mountain front. A combination of interactive optical and computer processing improves detection, but human judgment remains essential in discriminating structural features from other kinds of lines.

The study of geomorphology from ERTS data is a fertile field that has been hardly touched by investigators. Landform maps can be effectively used by engineers, landscape architects, and regional land use planners and developers. A systematic approach to such efforts is surely needed now, culminating in a landforms photo atlas. Correlation of ERTS surface maps with environmental geology maps (with emphasis on setting up land use and engineering surface units) is a natural coupling that remains to be done. Other uses include mapping of drainage networks and old beach lines and terraces and a systematic study of arctic and alpine surface

features. Among dynamic processes that are especially amenable to study with ERTS imagery are shoreline erosion and offshore sedimentation, redistribution of soils and soft sediments following transport by sheetwash during flooding, surface conditions favorable to ground water recharge, and development of cave-karstland topography.

Where ground truth and other photogeologic information are available, some rock types can be discriminated from one another in ERTS images with reasonable reliability. However, use of ERTS-type sensors (probably supplemented by others in different wave regions) to identify specific rock types by lithology and/or chemical composition has so far met with little concrete success. A few rock types are readily and consistently recognizable, primarily because of their unique appearance and geologic associations (for example, basalts in flows). However, usually neither lithologic nor stratigraphic units can be identified directly from the spectral reflectance (color and brightness) information sent back by ERTS; that is, there appears to be no physical basis for rock identification using reflected radiation in the near-visible infrared. Thus, unique solutions to identity have not been found. But specialized processing must be developed if better results are desired for lithologic identification, a key to more comprehensive mapping, by remote sensing. Band ratioing (Goetz, Vincent, and Rowan) seems to be a positive step toward this objective. It may also prove useful to develop a classification of rocks using the clustering techniques applied to vegetation analysis. As signatures for major rock types accumulate, these signatures can then be plotted on suitable cluster diagrams.

Resources Exploration

Identification and Measurement

Under appropriate conditions, both metals and nonmetallic deposits should be detectable from ERTS if these have adequate surface expression. This usually involves recognition of such proven "ore guides" as surface alteration ("gossan" or limonite stains, clays, and sulphates), structural controls (mainly intersections of fractures, foliation, and such), and surface exposures of host structures (stocks, veins, folds, and domes). Results in mineral exploration since the March 1973 ERTS-1 Symposium have been promising.

Areas of base metal mineralization in South Africa and Southwest Africa were better located using ERTS data (Viljoen). Six new copper-bearing intrusions discovered in central Alaska (following one of the northeast lineament trends as predicted earlier by Lathram and Fisher from Nimbus and ERTS studies) are also evident ERTS images, and known porphyry copper deposits in Arizona have been correlated with structural controls now verified from ERTS (Erskine). Metallic deposits from known mining districts in central Colorado (Knepper, Nicolais) are shown to associate with intersections of arcuate and linear features, a relationship inadequately confirmed prior to ERTS. The well-established principle that mineral deposits tend to concentrate along fractures, especially at intersections, seems to be supported by discovery in ERTS images of new linears passing through mercury deposits in California (Rich), lead ores in Missouri (Martin), and uranium deposits in Colorado (Saunders).

Of outstanding significance as a future exploration tool is a new technique using ERTS spectral band ratios to distinguish iron-enriched zones; this approach is potentially applicable to other

types of mineral deposits. Iron ore in Wyoming has been singled out (Vincent) and hydrated iron oxides (gossans) were recognized as a pronounced ring of aureole around the Goldfield, Nevada, mining district (Rowan).

Little has been reported on using ERTS to search for nonmetallic deposits. Woodman was unable to find sand and gravel deposits in Maine owing to resolution limitations but Abdel-Gawad appears to be "seeing" eocene (gold-bearing) terrace gravels in California. Morrison has also recognized conditions favorable to accumulation of gravels in glacial deposits in the midwest. Pickering has picked out developed kaoline and marble areas in ERTS images of Georgia. Trona (sodium carbonate) deposits are identifiable in Wyoming (Houston) and new potential areas are recognized there.

ERTS data are gradually being put to use in petroleum exploration. Reports of oil company interest continually appear, but documentation to date has been sparse. The first well-documented study (Collins), in the oil-producing Anadarko Basin of Oklahoma-Texas, represents an apparent breakthrough in the application of remote sensing to exploration for hydrocarbons. The work has demonstrated an unexpected property of ERTS images to reveal subtle surface expressions of outcrop bands, linears (many new), and closed features (some geomorphic or structural, but others defined by more or less circular tone patterns described as "hazy") that may correspond to deeper structures known from subsurface drilling and geophysics. In one area of the basin, 26 of 30 "hazy" tones coincide with known oil fields. Repetitive coverage offers the obvious advantage of allowing seasonally varying tonal anomalies to be separated from these more constant hazy anomalies that now apparently result from interactions between hydrocarbons and surficial materials. The significance of this one investigation, if it stands up under cross examination and if the anomalies it has found are shown to occur in other petroleum-rich provinces, cannot be overestimated. Work by Gedney and by Lathram in Alaska has identified hitherto unrecognized folds and faults in areas of potential oil fields. Lathram notes that certain structures associated with the North Slope-Prudhoe Bay petroleum province may extend eastward as much as 322 km (200 miles) beyond presently known limits.

ERTS can aid the search for shallow groundwater supplies. The approach involves looking for areas of moisture concentration, lithologic facies changes (indicated by tonal differences), vegetation associations, and stream pattern changes. Using ERTS imagery, Goetz has produced a fractures (mainly joints) map of part of northern Arizona (including areas where the Supai Formation is at or near the surface) which is now being used by the City of Flagstaff to prospect for subsurface water in the underlying Redwall limestone. On the Coconino Plateau, surface conditions have been recognized (color facies: red sandstones in the Kaibab limestone) from ERTS imagery, which have led to successful drilling for perched water zones in areas where water has not been recovered before. Drahovzal has discovered a major new lineament in Alabama which accounts for an unusual distribution of springs. Using ERTS, Martin has traced water losses from a small stream in the Missouri Ozarks to heretofore unknown linears.

Evidence is accumulating that ERTS can assist in looking for geothermal anomalies of possible use as power sources. Geothermal regions in Iceland could be detected (Williams) and snow melting by volcanic heat from Mount Wrangell in Alaska was visible (Benson). Thermal-related features on volcanoes in the Cascades were picked out as surface landforms and markings by Friedman.

Modeling

Some models for ore concentration are emerging, especially from work by Rowan, Liggett, Knepper, Erskine, Jensen, Rich, and Saunders. The model relating ERTS observations to subsurface data from the Anadarko Basin (Collins) is an exciting start to the formulation of a general purpose model for oil exploration from space. Models relating calorimetry to snowmelt are in the process of definition from work by Eaton, Friedman, and Williams.

Interpretation Techniques

Standard photointerpretation is the prime approach used by most ERTS investigators as an exploration tool. Enlargement of images to scales up to 1:250,000 are particularly helpful. The band-ratio technique, especially when coupled with a color display of the ratio signals, will probably become the most productive of the more sophisticated computer-oriented processes for composition analysis, although spatial filtering and additive viewing have yielded some distinct accomplishments.

Applications

Most applications for resources exploration are self-evident. In the midst of the current energy crisis and the anticipated or existing shortages of raw mineral resources, any new approach to exploration is welcomed. ERTS is likely to make some very important contributions as an exploration tool, owing to its ability to pick out linears, highlight surface alteration above ore bodies, and provide a regional overview of crustal structure favoring mineral concentration. ERTS may be the prime mover in exploration programs that eventually should result in discoveries amounting to billions of dollars of extractable mineral wealth.

Future Directions

New and better sensors and processing techniques for enhancement of small differences in composition of rock types and in structural features within areas of possible mineralization are demanded. For example, addition of a sensor channel operating between 1.1 and 1.4 micrometers could provide critical data for detection of limonite (hydrous iron oxide) and other alteration products.

More importantly, the basic capability of ERTS to provide information on mineral or petroleum guides must be verified. This can be done in the near future by carrying out comprehensive studies of known mineral- and oil-producing areas. One rationale is to prove that known deposits can be detected and evaluated from ERTS; then its validity as an exploration tool can be properly substantiated.

At present, the most promising new approach for using ERTS in mineral exploration appears to be the band-ratio techniques developed by Goetz and by Vincent. These techniques must be applied to many more test cases, particularly at known porphyry copper and uranium deposits. They should also be applied to the search for surface manifestations of oil and gas. More

follow-on field work is also essential. Geochemical surveys and drilling are paramount in verifying suspected deposits. Before linears can be accepted as reliable ore guides, their age relations to each other and to the time of mineralization must be established.

Geologic Hazards

Identification and Measurement

ERTS has already proved capable of assessing natural conditions that could prove hazardous in road building; for example, playas in Iran whose water contents vary seasonally can be monitored on a continuing basis before selecting the best route (Krinsley). Conditions that increase the danger of landslides, such as moisture changes or undercutting, are sometimes recognized in ERTS images. Very large landslides can be seen from ERTS (for example, in Iceland and Alaska), but conditions responsible for new slides are seldom immediately evident in the imagery. Material instability depends on slope angles, surface composition, and moisture content. Where stereo coverage is available, the slope angle can be estimated. More work on compositional identification and moisture measurement can contribute to a landslide prediction model.

Regional characteristics of terrain undergoing extensive erosion accelerated by man's activities are being defined by Morrison in parts of southern Arizona. By coupling ERTS and aircraft imagery, he has produced maps showing changes in the alluvial-filled lowlands cut by arroyos caused by over-grazing in the last 80 years. The effects of sand migration on inhabited areas can be assessed, using the studies by McKee as guiding principles. After examining sand seas in their regional contexts, McKee has proposed a genetic classification of these deposits that ties in with causative factors, some of which might be controlled to modify migration patterns and rates.

ERTS is leading to a new approach in derivation of earthquake hazards maps. By plotting earthquake epicenters on ERTS image bases (preferably mosaics) on which new linears have been identified, the degree of correlation between earthquakes and surface fracture traces is being better substantiated. This has now been demonstrated effectively by Gedney for Alaska and by Abdel-Gawad for California.

Fractures seen as regional linears can be a problem in construction and mining activities. Several extensive lineations in southwestern Indiana cross operating underground coal mines. Roof falls at the Kings Station coal mine in Indiana were correlated with the newly discovered regional linears passing through that area (Wier). Further mining there should take into account the presence of these fractures, both in planning and in development. ERTS can also be used to monitor the changes, influence, and recovery of surface mining operations such as coal strip mines, uranium mines, stone quarries, and sand pits.

Pre-eruption warnings of impending volcanic activity have long been a hoped-for objective among volcanologists. This predictive capability is now in sight owing to the network of data collection platforms (DCPs) instrumented with tiltmeters and seismic event counters located on 16 volcanoes. Continuous readings are providing an ever-increasing base of definitive data. A

DCP on Volcano Fuego in Guatemala successfully foretold of an eruption that occurred shortly thereafter. A similar warning was monitored during 1973 activity at Kilauea.

Modeling

The several investigations concerned with hazards assessment have yet to formalize any models, but all are focusing in that direction. Ward, Friedman, and other ERTS investigators studying volcanoes should eventually develop a realistic approach to eruption forecasts as their data become statistically significant. In time, also, earthquake monitors should be able to verify the relation between seismic events and newly located fractures; this of course will require years of measuring seismic activity to develop and test a model. An ultimate product could well be an improved concept of plate tectonics as the underpinning for fundamental causes of earthquakes.

Interpretative Techniques

In addition to photointerpretation of ERTS images to seek evidence for changes in surface conditions and effects of dynamic processes, the use of DCPs as a data-gathering technique is admirably supported by ongoing measurement of volcanic activity. These platforms could also be effectively used in areas of high landslide risk (at control points), along active faults in seismically dangerous regions, in areas subjected to frequent sand storms, and on surging glaciers.

Enhancement techniques directly applied to hazards detection are of considerable value but remain to be demonstrated. Low sun angle images are frequently optimal for linears mapping and hence detection of hazards associated with rock failure. In general, aircraft-acquired data now are superior to ERTS as a practical information source for hazard control, but a melding of the two levels of observation should offer an even better assessment technique.

Applications

Many applications have already been described in the preceding discussions. One obvious use now underway is the monitoring of the Alaskan pipeline route to determine earthquake, snow- and landslide, and flood dangers. Permafrost effects, common in the high latitudes, are recognizable from ERTS (Ferrians); this assists in decision-making where these effects are likely to hinder Alaskan oil field and pipeline operations. Recognition of faults near dam sites, nuclear power plants, or in the path of major transmission lines will aid planners before development. ERTS imagery is very well-suited to preparation of small-scale regional maps showing environmental and engineering geology units. Large-scale versions of such maps made from aerial photos and field surveys are already in common use. No one has yet attempted to produce this type of map from ERTS, although Morrison has similar maps of erosion conditions and pleistocene glacial deposits made from ERTS.

Future Directions

The DCP system is capable of providing helpful information for many more geologic hazards than are now being investigated; suitable instruments to gather data and evaluate hazards potential should be developed and tested. New techniques for hazards recognition must be

sought. This would involve finding more spatial and spectral recognition criteria than now specified. The interrelationship between some hazards and linears must be better understood. A closer interaction between geologists and civil engineers is called for if use of ERTS in monitoring and alleviating geologic hazards is to be effective. More presentations of ERTS results at meetings of applied specialists outside the immediate realm of geology is to be encouraged.

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APPENDIX 1

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WATER RESOURCES

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EDITOR'S NOTE

This summary paper in the Water Resources discipline area was compiled from presentations made to the Water Resources Discipline Panel (see Appendix 1) between October 22 and November 2, 1973, and from papers presented at the Third ERTS Symposium, December 10 to 14, 1973. The members of the Working Group, which met on December 14 to extract the Symposium results, are listed in Appendix 2.

INTRODUCTION

The emphasis in this report is on the applicability of the results and analyses produced by the investigators dealing with water resources parameters. In addition, the steps that might be taken to improve and implement these results on an operational basis or in large projects are suggested. The focus of the paper is on the contribution of ERTS-1 to water resources monitoring. Contributors from other systems (for example, aircraft systems) are only considered briefly in discussions of ERTS-1 results, although it must be recognized that aircraft support was vital to many of the ERTS investigations.

As a means of providing a framework to organize the report presentation, a matrix (Table 1) has been prepared showing the degree of feasibility in several implementation categories. The matrix is subdivided to show this information for seven subdiscipline categories. A scale from 1 to 5 is used to describe the current status of each implementation category. The feasibility index is the total of ratings given to each subdiscipline and serves as a numerical scale with which to compare the various subdiscipline categories concerning their closeness to operational implementation. In the ratings given in the matrix, the contribution of the Data Collection System (DCS) on ERTS-1 is excluded. This aspect of ERTS-1 and its effect on the monitoring of water resources will be treated in another section. The emphasis of the matrix information is on the contribution of the ERTS-1 remote sensing system.

DISCIPLINE RESULTS SUMMARY

ERTS-1 Spacecraft System and the Multispectral Scanner (MSS) Capabilities

It was generally evident to the investigators that the spectral capabilities of the ERTS-1 satellite have provided very useful information. A desire was expressed for a thermal infrared and microwave capability. The spatial resolution was considered adequate, in general, for snow and ice mapping. When mapping of features was desired for legal requirements, however, the spatial resolution was not considered adequate. For instance, in wetlands mapping involving state government requirements, and similarly in flood area assessment and flood plain mapping, data giving boundary delineation commensurate with 1:24,000 scale mapping are needed. For these purposes an increase in spatial resolution to the 10- to 30-meter range appears to be necessary. The most consistently expressed deficiency in the ERTS-1 system was the frequency of coverage; the frequency was found adequate, however, for surveying the physiographic and land use characteristics of watershed systems and in flood plain mapping, groundwater surveys, and wetland surveys. This frequency of coverage problem can be overcome to a degree by supplementing ERTS-1 coverage with data from other systems such as aircraft, the NOAA-2 Very High Resolution Radiometer (VHRR), or the U. S. Air Force DAPP system. The latter two systems provide daily observations in the visible portion of the electromagnetic spectrum, and twice daily coverage in the thermal infrared. The spatial resolutions are 1 kilometer or better.

Identification and Measurement

When the identification and measurement columns of the water-resources matrix are reviewed, certain general facts are reflected in the ratings: When rather distinct contrasts were involved, parameters were easily identified. For instance, snow has been found to be most easily and best observed in the 0.6- to 0.7- μm region. There are problems, however, in delineating snow in heavily vegetated and shadowed areas, and occasionally highly reflective bare rock can be confused with snow. Clouds can be distinguished from snow-covered terrain through familiarity with the characteristic geometric properties of clouds versus terrain (dendritic drainage system, for example). In the case of surface water, the 0.8- to 1.1- μm reflectance is quite low and the contrast is quite good between dry soil and vegetation and moist or water-covered surfaces. This spectral advantage is reflected in the feasibility of identification for surface water mapping, flooded area assessment, and wetlands surveys. The typical variability of the hydrologic phenomena, as it relates to the 18-day repeat cycle, creates the higher measurement ratings given to glacier monitoring and surface water mapping versus snow mapping. The fact that resolution is not quite adequate for legal requirements lowers the measurement ratings of the flood analysis and wetland surveys categories. The difficulty in watershed surveys is that important parameters such as slope, infiltration, and evapotranspiration cannot be observed directly. Digital and automated classification techniques were reported as being most successfully used in delineating surface water and wetlands areas. Because of the problems caused by vegetation, shadows, and exposed bare rock, there is still some considerable work to be done in applying automatic classification techniques to snow mapping. It is noteworthy that an error analysis performed by Meier indicates that snow cover area measurements using imagery input are accurate to within ± 10 percent. More of this type of analysis needs to be accomplished in the other subdiscipline categories.

Table 1
Water Resources Subdiscipline – Implementation Matrix

Subdiscipline Categories	Implementation Categories						
	Identifi- cation	Measure- ment	Documen- tation	Model- ing	Pilot or Demo. Projects	Feasi- bility Index	Antici- pated Benefits
Watershed Surveys	3	3	3	3	2	14	4
Snow/Ice Surveys							
Snow Cover Mapping	4	3	4	3	3	17	5
Glacier Monitoring	4	4	3	2	2	15	3
Lake Ice Mapping	3	2	2	2	1	10	2
Surface Water Surveys							
Surface Water Mapping	4	4	5	4	4	21	4
River Monitoring (Discharge, erosion, and channel characteristics)	3	2	2	3	1	11	2
Flood Analysis							
Flood Area Assessment	4	3	4	2	3	16	3
Flood Plain Mapping	3	3	3	2	2	13	3
Water Quality Surveys	3	1	3	2	2	11	2
Estuary and Wetland Surveys	4	3	4	3	3	17	4
Water Use Surveys (Irrigation and Evapotranspiration)	2	1	1	1	1	6	1
Subsurface Water Surveys							
Ground Water Surveys	2	1	2	2	2	9	2
Soil Moisture Surveys	2	1	2	2	2	9	2
Total	41	31	38	31	28		

Notes:

Identification

1. Inferential identification with low confidence or only a very few of the relevant parameters identified.
5. The parameters are very easily and quickly identified in ERTS-1 data.

Measurement

1. The measurement of identified parameters is done with minimal accuracy and frequency.
5. The accuracy and frequency with which parameters can be identified meet standards for immediate application.

Modeling

1. Only the very vaguest ideas exist as to how remotely-sensed data can be used to manage or understand phenomena.
2. Qualitative decision-making models exist or can easily be developed into which ERTS-1 data can be inputted.
3. A few quantitative empirical physical models and strategy models specifying the use of ERTS-1 data have been reported.
4. Quantitative models exist or can easily be developed into which ERTS-1 data can be inputted.
5. Accurate, numerical models employing ERTS-1 data exist.

Pilot Project

1. Very little or no demonstration of the operational feasibility for using ERTS data has been shown.
2. Some limited demonstration of the operational feasibility for using ERTS data has been shown.
3. Several good but scattered demonstrations of the operational feasibility for using ERTS-1 data exist.
4. Many demonstrations of the operational feasibility of ERTS-1 data exist, and a pilot study is the next step.
5. A documented pilot project has been completed.

Anticipated Benefits

1. Lowest
5. Highest

Modeling

Noteworthy modeling efforts were reported in the surface water mapping area. For example, surface water area is being related to the maintenance of wildlife in Florida and is used as an index of water availability in the Texas High Plains. Empirical models are being developed in snow mapping and watershed runoff prediction. Strategy models and decision models could appropriately be developed for applying ERTS-1 data in regional flood mapping and in defining land value in wetlands and marsh areas.

Models are also being developed or tested to quantitatively assess the contribution of remotely sensed data on the accuracy of specifications or predictions provided by the models. There is considerable work being accomplished on the Lake Ontario Basin in conjunction with the International Field Year of the Great Lakes. In addition, work on the use of remotely sensed data for watershed modeling is in progress or being sponsored at several NASA centers under the Supporting Research and Technology (SR&T) Program. Because model development requires several years of developmental effort (typically 3 to 5 years), it is important that every effort be made to continue support for those modeling efforts where substantive progress has been demonstrated and documented.

Feasibility and Anticipated Benefits

In examining the feasibility and relative anticipated benefits columns of Table 1, it may be quickly noted that surface water mapping is considered more feasible than snow cover mapping. The reverse is true for anticipated benefits related to snow mapping, such as hydroelectric power, irrigation water supply forecasting, and better reservoir management in the western United States. It was felt that repetitive snow cover mapping would provide greater benefits than those provided by ERTS-1 in surface water mapping. Furthermore, the savings and benefits forthcoming from better watershed surveys provided by ERTS-1 and subsequent planning of flood retention structures and other waterworks will be higher than those derived from improved flood and flood plain analyses and glacier surveys. No cost versus benefit figures were available to quantitatively substantiate these conclusions. In the rest of the subdisciplines the correlation between feasibility index and applications benefits is rather good.

Pilot Projects and User Involvement

Another overall impression gained from evaluating the efforts described by the investigators is that the next general step is to involve users more heavily and perform pilot applications in parallel with operational activities. The principal reason for needing pilot projects is that quantitative comparisons must be made of the improvements in time, cost, and information content before the vast majority of user organizations can justify the expense and manpower commitment needed to institute operational systems using remotely sensed data. The status, in general, of identification and measurement in water resources substantiates the conclusion that pilot studies are appropriate. Studies in which data collection platforms (DCPs) were being employed were consistently best prepared for the operational system; examples of this were cited in New England, Florida, Arizona, and the Delaware River Basin. Beyond these instances,

existing pilot studies were most advanced in snow mapping, flooded area assessment, estuary and wetlands mapping, and surface water mapping. In the last case, very noteworthy efforts are being pursued in the mapping of surface waters in Texas by the Texas Water Development Board and the U. S. Army Corps of Engineers.

Another key feature needed to spur the application of ERTS-1 data and satellite data in general is an indication that an operational earth resources satellite capability may exist in the near future. It was noted that any commitment by operational organizations to the utilization of new data or techniques involves considerable manpower and money that affects several years of operation. Typical management or operational agencies have frequently expressed the opinion that the value in remotely sensed data, such as that from ERTS-1, is obvious.

Research and Development

The greatest need seems to be for more quantification of measurements from ERTS-1 in each of the subdisciplines. It appears that one way to achieve this is to explore in greater detail the interpretation techniques using ERTS-1 digital data. In all subdisciplines the use of digital analysis techniques would provide the most objective solutions at the highest possible ERTS-1 resolution. An associated problem is the need to develop an effective way to transfer the digitally analyzed products to map bases suitable for the user community. It is felt that such efforts would allow ERTS-1 to become a useful operational tool.

The summaries just presented are very general. The following sections treat each subdiscipline in detail and provide more information with which to evaluate the impact of ERTS-1 on the monitoring of water resources.

RESULTS SUMMARIES OF SUBDISCIPLINE AREAS

Watershed Surveys

Identification and Measurement

The synoptic coverage of ERTS imagery permits fairly easy identification of basin extent and broad physiographic features such as drainage area, stream network character, land use, and water coverage. Hoffer has indicated that digital techniques permit the estimation of the area of a watershed in Colorado to within 2 percent of other existing data (topographic maps). Seasonal variations may be observed although differing identification techniques seem to be needed in the dormant and growing seasons (Blanchard). It has been found that MSS bands 4 (0.5 to 0.6 μm), 5 (0.6 to 0.7 μm), and 7 (0.8 to 1.1 μm) offer the best discrimination, when used in simple linear combination, to distinguish watersheds with high runoff from those with low runoff. Unfortunately, several important watershed parameters such as infiltration, evapotranspiration, and slope are not easily extracted from ERTS imagery, even by inferential approaches.

While the resolution is not sufficient to locate small rivers, the overall stream network extent of watersheds can be identified. On the Pawnee River Basin in Kansas, more detail on stream order has been extracted from ERTS than exists on comparable 1:250,000 scale topographic maps. Snow cover, important for runoff information, has been mapped with accuracies near 5 percent (Barnes). In general, it is necessary to monitor the areal extent of various land use classes in order to estimate the timing of peak flow, runoff volume, and effects on water quality. Typical land use classes of importance include fraction of impervious area, water area, base soil, and forest cover. Forest cover estimates from ERTS-1 have been correlated with those from conventional photointerpretation ground truth to within 2 percent (Hollyday). Carlson has reported that it has been possible to extract some forest area information suitable for input to hydrographic models.

The frequency of ERTS-1 data appears to be adequate for most features of watershed basins that undergo only seasonal or long-term changes such as occasional physiographic changes and land usage. However, the 18-day cycle (coupled with the fact that data are sometimes compromised by cloud cover) is not fully sufficient to monitor more dynamic watershed events such as flooding and snow cover changes. More frequent coverage is desirable.

Modeling

A few quantitative empirical physical models involving the use of ERTS-1 data have been reported. Carlson has extracted forest-covered areas in the Chena River Basin in Alaska as inputs for a hydrologic model. It was possible to get good comparison between snow cover predictions of the model with the snow cover area extracted from ERTS-1 imagery. Blanchard has attempted to discriminate between watersheds with high and low runoff, and the present opinion is that the accuracy of equations predicting runoff may be improved by 10 percent using ERTS data.

Furthermore, it has been found that an apparently usable relationship does exist between the difference in the mean reflectances from the 0.6- to 0.7- and 0.5- to 0.6- μm bands over a watershed and curve numbers used in rainfall runoff equations employed by the Soil Conservation Service. Polcyn reports that the results achieved to date offer considerable encouragement for using remotely sensed data in water-balance studies on the Lake Ontario Basin. The principal problems involved are the volume of data coming from ERTS-1 that must be processed so as to utilize these data in models and the determination of the best algorithms or discriminators to be derived from ERTS-1 data for eventual injection into watershed models.

Pilot or Demonstration Projects

To date, the demonstration of operational feasibility for use of ERTS-1 imagery in watershed problems is somewhat limited (not including aspects of watersheds, such as flooding, which are in themselves water resources subdisciplines discussed elsewhere). One example, however, was the State of Maine personnel who used ERTS imagery for simple land classification, flooding, and snow cover observations in order to determine Penobscot River watershed characteristics relevant to highway and culvert placement and design (Stoeckeler).

Snow Cover Surveys

Identification and Measurement

It is relatively easy to identify snow using ERTS-1 MSS bands 4 (0.5 to 0.6 μm) and 5 (0.6 to 0.7 μm) with band 5 being the best single band (Barnes). Although some identification difficulty does arise due to confusion of snow cover with clouds, cloud-free areas can usually be defined through recognition of drainage patterns and other watershed physiographic features. In some cases involving very thin clouds, it is possible to see through the clouds more in the 0.8- to 1.1- μm region than in other MSS bands. Identification of snow in heavily forested areas presents a problem with ERTS (Meier, Barnes), but use of high altitude aircraft data can help overcome this (Meier). This problem is more severe in early winter when snowline and the high altitude tree line overlap. Differentiation of snow cover from exposed rock is also difficult, but color composite images help (Barnes). Barnes also reports that ERTS band 7 may be used to distinguish between wet and dry snow. Low sun angles can also create shadowing effects that somewhat hinder identification (Barnes, Meier).

An error analysis by Meier indicates that the areal extent of snow cover can be measured using photointerpretation with a relative difference of ± 10 percent, compared to measurements made from high altitude aircraft during the critical snow melt period. An experienced observer who was quite familiar with a particular watershed could most likely improve this estimate to within ± 5 percent. Barnes notes that agreement between operational aircraft snow surveys (visual estimates of snowline made from aircraft and noted on topographic map) and ERTS measurements usually agree within ± 5 percent. ERTS measurements of areal extent of snow cover have been done six times as fast as measurements made using high altitude aircraft photography (Wiesnet). Also, ERTS measurements have been compared to measurements made using the NOAA-2 VHRR, and the two measurements agree to within 5 percent. Wiesnet also performed an ERTS/NOAA-2 comparison that was used to provide a reliability check or calibration standard for the daily VHRR data from NOAA-2 over the same area covered by the higher resolution ERTS. The combined ERTS/NOAA-2 capability of resolution, spectral coverage, and frequency may come close to meeting the identification and measurement requirements of snow cover mapping. There is some difficulty in establishing the absolute areal extent measurement accuracy of ERTS, since no standard exists to provide a measurement of the actual snow cover. Both the identification and measurements have generally been done using photointerpretation (directly from images or density sliced images).

Modeling

This section will primarily address those models that relate snow cover and snow cover changes to volumes of water released. The more complex runoff models, which relate the various parameters (including snow cover) characterizing a given watershed to streamflow, have been treated under the watershed surveys subdiscipline. Both Meier and Carlson report modeling efforts to compute water release as a function of snow cover, using heat balance inputs and snow pack altitude intervals. These models have potential for using snow-covered areas derived from ERTS-1, along with heat balance inputs, to compute predicted runoff. Both Meier and Carlson reported only very preliminary results obtained thus far, and both cited the need for

more frequent observation of snow cover than presently provided by ERTS to fully test their models.

Pilot Demonstration Projects

Several good but scattered demonstrations of the operational feasibility for using ERTS-1 data exist, including the investigations of Barnes, Meier, and Weisnet. These investigators reported on some degree of contact with water resource user organizations (Barnes/Salt River Water User Association; Meier/USGS, Bonneville Power Administration, and USACE; Weisnet/NOAA's Operational Snow and Ice Mapping Organizations).

Lake Ice Mapping

Identification and Measurement

Weisnet reports that the following ice features can be identified from ERTS imagery: shuga, light and dark milas, fast ice, icefoot, ice breccia, brash ice, fracturing, ridging, rafting, sastrugi, thaw holes, rotten ice, ice island, dried ice puddles, hummocked ice, and leads. Using ERTS-1 bands 4 (0.5 to 0.6 μm) and 7 (0.8 to 1.1 μm), it was possible to identify melting ice by reflectance difference and the characteristic lacy appearance of rotten ice. This observation of melting ice was confirmed by both air temperature measurements before and after the ERTS pass and lake temperature measurements from the NOAA-2 VHRR made at the same time. The types of lake ice identified should be mapable, and both Weisnet and Bryan report efforts along these lines, but measurement accuracies were not quantified. Remote measurement of ice thickness appears to be limited to inference from ice type and coverage information. Jelacic was able to locate the lake freeze transition zone (zone above which lakes are frozen over and below which lakes are clear). It was then possible to roughly correlate this transition zone with movement of polar highs and lows.

Modeling

Weisnet reports that given the ability to identify and map the ice features previously cited it appears feasible to determine thawing. No strategy models using ERTS-1 to facilitate ship navigation in the Great Lakes have been developed because the 18-day coverage is not adequate.

Pilot Demonstration Project

Limited demonstration of the operational feasibility of ERTS data has been shown, but NOAA will attempt a more ambitious operational feasibility demonstration using ERTS-1 in combination with the NOAA-2 (VHRR) during the winter of 1973-1974.

Glacier Monitoring

Identification and Measurement

Glaciers are readily observed in the ERTS imagery (Houston, Ostrem, Meier, Barnes, and Belon). Recognizable glacial features include cirques, terminal moraines, and crevassed areas. Surging glaciers can easily be distinguished from their characteristic wiggly folded moraines (Meier). The transient snow line on glaciers can be seen in MSS bands 4 (0.5 to 0.6 μm) and 5 (0.6 to 0.7 μm), both in black and white and color composites at a scale of 1:250,000 (Meier, Barnes). It also appears possible to rapidly determine the accumulation area ratio (AAR) for a number of glaciers in widely separated or remote regions. Nine independent measurements of AAR were made for three different dates for the small South Cascade Glacier Basin (6.1 km^2). The standard deviation of individual values from the mean for a given date was 3.4 percent (Meier). It is also possible to measure the advance of surging glaciers (Meier); for instance, the 1,800-meter surge of the Yentna Glacier in Alaska in 1972 has been observed.

Modeling

According to Meier, as indicated in the measurements section, it appears possible to rapidly delineate snowlines and determine the AAR for a large number of glaciers. AAR has been proven to be a useful index to the mass balance of a glacier. By measuring the distribution of AARs at a given time in a given region and relating these to the data obtained at a glacier research station in the region, the micrometeorological point measurements can be extended to meso- and even macroscale meteorological conditions.

The causes of glacier surges – and why some glaciers surge while others do not – are questions of great scientific interest, since this periodic sudden slippage is common to many other phenomena in nature, perhaps even to the mechanism of earthquakes. Surging glaciers may advance over large areas and cause devastating floods by blocking and suddenly releasing large quantities of meltwater; thus, there is also much practical interest in monitoring their behavior. Dust bands and medial moraines observed in the ERTS imagery have given clues to the mechanism causing the Bering Glacier in Alaska to surge (Meier) in the 1960's.

Observed characteristics including dashed and zigzagged lines in an old terminal moraine suggest that the Mt. Hayes Glacier in the Big Delta, Alaska, which is now retreating, was once a surging glacier (Belon). Recently Meier identified new surging glaciers in the Himalayas. In addition, the Lowell Glacier surge in Canada has been recently observed, and using ERTS-1 data, its position was mapped at 1:250,000 in a few hours. Using aircraft data, this task previously took approximately 1 week. A potential problem situation is possible in association with the surging of the Tweedsmuir Glacier, which at present is surging some 6 meters per day. Overall, the ERTS-1 satellite is invaluable for monitoring this type of glacier and its surges.

MacDonald has had particular success in using ERTS-1 to map rather unknown regions in the Antarctic and the Arctic. The impact is particularly high in Antarctica. The ERTS-1 derived maps are invaluable in guiding scientific investigations being conducted by several countries in

this region. MacDonald has also achieved results showing the changes in the map of Alaska that are due to the availability of ERTS-1 imagery.

Pilot Demonstration Project

Some limited demonstration of the operational feasibility of using ERTS data to identify and monitor glaciers has been shown. Since this is primarily a problem of scientific interest, the operational applications criteria is not strictly applicable.

Surface Water Mapping

Identification and Measurement

Because of the strong contrast between water and surrounding surfaces afforded by ERTS-1 near infrared observations, surface water is one of the most easily delineated parameters in the hydrologic cycle. Reeves has applied ERTS-1 data to identifying transient playa lakes greater than 10,000 m² (1 hectare) in area, using photointerpretation on the Texas High Plains. Further analysis using ERTS-1 data in digital format should allow identification of lakes as small as 5,000 m² (1/2 hectare).

Area of surface water can easily be obtained by manual or automatic processing of ERTS-1 data. The margin of error for this measurement can be conservatively estimated at ±5 percent for large areas (>100 km²). This measurement error is a function of the lake or surface water body size. Measurement of surface water changes with time is hindered by ERTS-1's 18-day repeat period and spatial resolution. Surface water area can change drastically between ERTS-1 observations, especially if measurements are hindered by clouds. Reeves has found that when using photographic techniques, area-change measurements are limited to lakes greater than 40,000 m² (4 hectares) in size because of resolution. The lower limit using digital processing is nearer 20,000 m² (2 hectares).

Modeling

Numerical water distribution models have been implemented by Higer in southern Florida, which combine area of surface water from ERTS-1 imagery with water stage obtained from ERTS-1 DCS as inputs. These models not only calculate the volume of water in previously unmeasurable swampy regions, but also act as inputs to water strategy models concerned with the release of water from one storage area to another. In addition, Higer has also implemented an ecological model that relates ERTS-1 derived water stage to the population levels of vanishing species (for example, the Woodstork). Work accomplished by Reeves in the Texas High Plains has direct application to strategy models being considered by the Texas Water Development Board for future water redistribution from other regions.

Pilot Demonstration Project

Higer has used his water distribution model, and his ecological model is currently being evaluated by the National Park Service in their study of the Woodstork. The Texas Water Development Board has run a demonstration study showing the feasibility of mapping surface water in Texas using ERTS-1 digital products in cooperation with NASA/Johnson Space Center. The U. S. Army Corps of Engineers in their National Dam Inventory task is using ERTS-1 data (both photographically and digitally) to locate dams greater than 7.6 m (25 ft) in height or impounding more than 61,500 m³ (50 acre-ft) in several areas of the United States.

River Monitoring (Discharge, Erosion, and Channel Characteristics)

Identification and Measurement

Generally, large rivers can easily be delineated by observing the strong contrast in the MSS near-infrared bands. Small streams may not always be detected in this manner and secondary interpretation of riparian vegetation patterns must be relied upon for location. Areas of active erosion along a stream can be located by tracing sediment plumes back to their source areas. Channel characteristics such as meandering, drainage pattern, and width variations (on large rivers) can be observed.

Discharge cannot be measured from ERTS-1 imagery or digital products. Likewise, erosion amounts cannot be quantified, but some ideas of relative amounts occurring may possibly be inferred. Channel characteristics, such as meander wavelength or sinuosity, channel width, and channel pattern can be measured with ERTS-1.

Modeling

Other subdisciplines such as watershed surveys and snow cover mapping have reviewed attempts to use ERTS-1 data to predict watershed discharge. River monitoring efforts have not included modeling in an effort to predict river discharge. Statistical modeling of meander wavelength relationships obtained from ERTS-1 in order to predict river discharge has been attempted by Colwell without much success.

Flood Area Assessment

Identification and Measurement

Observations to determine whether an area has recently been flooded can easily be made using the ERTS-1 near-infrared bands. Observation of standing water or the resultant decreased near-infrared reflectance due to excessive soil moisture or stressed vegetation (sometimes lasting as long as 2 weeks) will delineate flooded areas when compared with ERTS-1 observations of

the same area under normal conditions. Deutsch has used multispectral image enhancement to detect the areas affected by flooding along the Mississippi River in the spring of 1973. Lind has mapped flooding along the Lake Champlain shoreline in lowland areas. Deutsch has been able to map the areas of flooding along the Mississippi River at scales of 1:250,000. Unfortunately, this scale is not suitable for operational purposes – Scales of 1:62,500 and 1:24,000 are minimum requirements for flood mapping. Photointerpretation will only produce flood maps from ERTS-1 up to 1:100,000 scale. Digital mapping of floods may have some potential at scales of 1:62,500 and 1:24,000. This possibility is being explored by Rango. The presence of floodwater under trees is one potential detection problem for automatic flood mapping. Pickering of the Georgia Geological Survey also finds ERTS-1 data useful in flood plan delineation.

Modeling

Mapping of floods on a regional basis can be used in many types of decision-making models. Decisions can be made as to where flood relief efforts should be focused, where flood control structures are needed, and which areas are flood prone. Hydrologic information provided by the ERTS-1 DCS in Arizona during flooding was used in conjunction with reservoir regulation models for scheduling of water releases from dams in order to minimize flood damage. However, these models using ERTS-1 data are largely in the conceptual stage.

Pilot or Demonstration Project

Flood mapping at various scales has been done in Virginia, Vermont, New Hampshire, Iowa, Arizona, California, and the Mississippi Valley, but primarily by photointerpretation techniques. Efforts to use digital techniques have been minimal and are necessary before a pilot project can be conducted.

Flood Plain Mapping

Identification and Measurement

Flood plain features such as natural and artificial levee systems, upland boundaries, vegetation and soil differences, flood alleviation measures, and land use and agricultural patterns are easily identified through tonal differences on ERTS-1 color composites (Rango). Major river flood plain features can easily be delineated, whereas ERTS-1 resolution prohibits the identification of similar features on small stream flood plains by photointerpretation. Fall and winter imagery are best for flood plain analysis because of the lack of vegetation obscuration during these seasons. Flood prone areas can be mapped through photointerpretation using the flood plain features just identified, but at scales no larger than 1:100,000. This allows flood plain mapping to be useful for regional planning but it is not suitable for local applications. Limited digital attempts at mapping of flood plain features seem feasible at scales of 1:62,500 and 1:24,000 (Rango).

Modeling

Delineation of flood susceptible areas from ERTS-1 at 1:100,000 scales allows input to qualitative decision-making models that could easily be developed. These models would be used to determine flood plain areas that should be avoided in the construction of new industry or planned communities.

Pilot or Demonstration Project

Rango has shown how ERTS-1 data can be used to produce maps similar to flood hazard maps produced by the U. S. Geological Survey and U. S. Army Corps of Engineers in their efforts to map areas of flood susceptibility along river systems in the United States. The ERTS-1 maps are at 1:100,000 scales, whereas the maps of the above agencies are at scales of 1:62,500 and 1:24,000.

Water Quality Surveys

Identification and Measurement

Indications of water quality can be observed in a limited manner through the use of ERTS-1 imagery in band 4 (0.5 to 0.6 μm) and 5 (0.6 to 0.7 μm). This is based on detection of algal blooms and sediment loads as primary indicators in lakes, streams, reservoirs, and coastal waters. Investigators who have demonstrated this capability include Pluhowski, Grabau, Klemas, and Lind. Primary parameters such as DO, pH, conductivity, and chemical pollutants cannot be identified directly, but there is some indication that they can be inferred in association with suspended solids. Limited attempts have been made to establish a direct correlation between suspended solids and other water quality parameters by Ludwick and Yarger with minimal success.

Concentrations of sediment load as indicators of water quality have been measured under limited conditions — on clear days with the sun angle between 46° and 54° . The rms measurement error between 0 and 900 ppm is 20 ppm. Between 0 and 60 ppm the measurement rms error is ± 5 ppm (Yarger). Pluhowski reported a turbidity detection threshold of 5 Jackson Turbidity Units. The use of DCPs to get direct in situ water quality measurements has been demonstrated by several investigators. Due to the lack of direct correlation between sediment load and water quality, this is not considered a significant water quality measurement tool.

Modeling

Modeling has not been utilized to any significant extent in water quality studies. Qualitative, decision-making models can be developed which can use ERTS-1 data as input.

Pilot or Demonstration Project

Water quality studies using ERTS-1 imagery have not revealed any significant operational utilization and have not indicated the immediate feasibility of pilot projects. The work by Lind, Klemas, and Pluhowski offers limited operational potential.

Estuary and Wetland Surveys

Identification and Measurement

In most cases of interest, estuaries and wetlands can easily be identified in ERTS-1 imagery using band 7 (0.8 to 1.1 μm). However, the resolution is inadequate for precise applications such as those required for legal determination of wetland boundaries. Certain wetland vegetation types can be confused with upland vegetation, especially in specific growth regions, lending a small uncertainty to wetland identification. Primary investigators in this area include Klemas and Anderson, who have demonstrated that common wetland vegetation types can be separately identified with high confidence, and Higer, who has identified major Florida wetlands. The impact of man on coastal wetlands has been identified by Anderson.

Areas covered by wetlands can be measured by a variety of techniques ranging from photointerpretation of imagery to automated techniques using density slicing and multispectral classification. The accuracy of these measurements is compromised due to the resolution limitations of the data as well as some uncertainties in the classification process. Specific vegetation types and their extent, which are important indicators of wetland value and productivity, have been measured by Klemas and Anderson, but with somewhat degraded accuracy. Selected ground-truth and aircraft data are required for correlation with ERTS-1 imagery.

Modeling

A few specific examples of the use of ERTS-1 data as inputs to quantitative mathematical models in the field of estuary and wetland surveys have been reported. These include Klemas, who is modeling wetlands value related to ecological productivity and developmental potential of wetland types, and Higer, who is using surface water volume as derived from ERTS-1 data as input to two models, a water management model and an ecological model.

Pilot or Demonstration Project

The operational feasibility of using ERTS-1 data for estuary and wetland surveys has been demonstrated in several investigations. These include the Dismal Swamp study by Anderson with the Georgia State Geological Service and the southern Florida water management study by Higer with the Central and Southern Florida Flood Control District. Polcyn indicates that ERTS-1 may be quite applicable for meeting the requirements of Michigan Public Law #248,

which requires that all wetlands in the state be mapped by the spring of 1974. The basic investigations of both Klemas and Anderson also serve to demonstrate that the feasibility is high for use in operational or management problems.

Irrigation and Evapotranspiration

Identification and Measurement

The presence of irrigation methods is best identified in the arid and semiarid regions of the United States with ERTS-1. These areas under irrigation are observed from ERTS-1 by noting the striking contrasts of pattern and high, near-infrared reflectance associated with the relatively lush vegetation growth in irrigated fields as compared to the surrounding drylands. Round fields associated with large, circular, sprinkler irrigation systems can be observed. In more humid regions of the United States, however, irrigated fields blend into the surrounding natural vegetation and are very difficult to delineate. Generally, the high, near-infrared reflectance associated with healthy vegetation can be equated to areas where evapotranspiration is taking place. In dry regions, lush vegetation growth can sometimes be observed along stream channels and reservoirs. In many instances these growths are phreatophytes and indicate the occurrence of excessive evapotranspiration. This same approach can be used to detect the presence of leaks along irrigation canals, by looking for areas along canals where anomalous vegetative growth is occurring.

At the present time there is no method using ERTS-1 data that will enable the calculation of the absolute amount of evapotranspiration occurring in a particular region. The amount of water being consumed by irrigation is nearly as difficult to measure from ERTS-1 as evapotranspiration. It is possible to monitor the relative reflectances of various irrigated fields in addition to observing soil moisture changes associated with the application of irrigation water. Relative amounts of irrigation consumption might thus be inferred, except that the frequency of ERTS-1 observations is not very applicable to this operational need. Polcyn and Falconer report that ERTS-1 and other remotely sensed data appear to be quite useful for defining land use and subsequently for extrapolating more accurately the point estimates of evapotranspiration in the Lake Ontario Basin.

Modeling

Water-use models exist, but at this time qualitative decision-making models will not accept any type of ERTS-1 data described above as inputs.

Pilot or Demonstration Project

With the exception of the possible detection of a water leak along an irrigation canal in the Central Valley of California using ERTS-1 data (Burgy), there has been no demonstration of the operational potential of ERTS-1 data.

Ground Water Surveys

Identification and Measurement

Since ground water or subsurface water cannot be seen directly from ERTS imagery, its presence must be inferred from identification of surface features that are generally correlated with or are an indication of subsurface water. Vegetation is such an indicator. Identification of phreatophyte and/or riparian communities has been reported by Burgy and Turner. MacLeod reports persistence of green vegetation during the dry season in West Africa as a probable indicator of ground water within 30 meters of the surface. He also reports identifying plant communities surrounding sandstone pediments that abound in the Sahelian zone of West Africa. Failure to observe drainage channels over large areas that are known to be receiving large amounts of rainfall may be an indication of ground water (MacLeod). Geologic features such as fracture zones and especially intersections of fractures are well known indicators of groundwater. Such features are reportedly identifiable in the ERTS imagery. Changes in areal extent of playa lakes 40,000 m² (10 acres) or larger can be observed, and the significance of this observation to groundwater is related to aquifer recharge. The accuracy of classification of phreatophyte and/or riparian communities as well as the accuracy of areal extent has not been quantified, nor have the vegetation or surface features reported as identifiable by MacLeod.

Modeling

Very qualitative decision-making models exist that can use information derived from the ERTS imagery. In the case of the surface vegetation, the model assumes a relationship between surface vegetation and presence of subsurface water. In the case of the large unchanneled areas of West Africa subject to heavy precipitation, the model presumes the infiltration of the precipitation to subsurface supply. In the case of the observation of the recession rates of the playa lakes, the model assumes that those playa lakes that resupply the aquifer will have measurably faster recession rates than those playas receding because of evapotranspiration alone.

Pilot or Demonstration Project

Some limited demonstration of the operational feasibility of ERTS data has been shown by MacLeod, and particularly by Reeves. The results achieved by Reeves have contributed to a decision by the State of Texas Water Development Board to undertake, with some NASA technical support, a wet lake census of Texas lakes of 40,000 m² (10 acres) or larger. It has also been reported that the surface indicators have been used to successfully locate water in Pennsylvania and in Tennessee.

Soil Moisture Surveys

Identification and Measurement

Relative variations of soil moisture in unvegetated or bare-soil areas can be seen. Reeves has reported that the path followed by a rainstorm can be seen in ERTS-1 imagery. Other isolated observations of a similar nature have been reported. The presence of moist soil is evidenced by the relatively low reflectance in the near-infrared spectral regions. This capability has proven to be useful in delineating flood-affected areas where the moist soil delineates the extent of the flood even though the flood waters have receded.

No successful results in obtaining quantitative measurements of soil moisture from ERTS-1 have been presented. If such results are available, it is quite likely that they are applicable only to the region or location where they were developed, or to very similar regions. There is, nevertheless, some considerable utility in getting relative measurements of soil moisture in space and time. Blanchard notes that as watersheds become more moist, the variance around the mean watershed reflectance becomes smaller. Information of this kind may be useful as input to models specifying the dryness of the watershed prior to rainfall inputs.

Modeling

No models using ERTS-1 data for acquiring any sort of soil moisture information are known. As has already been indicated, the information could possibly be useful in irrigated regions and in watershed models where the antecedent moisture in the soil profile is an important boundary condition.

Pilot or Demonstration Project

Dependent on the reception by various governments in West Africa, the drought analysis efforts reported by MacLeod are a possible demonstration project. The results, even though they may be qualitative or relative, should provide valuable input for the improved usage of water resources in West Africa. The techniques and experience should be usable in other developing areas of the world where water resources information of any kind is unavailable or widely diverse.

The Impact of the Data Collection System

The data collection system has been applied in several instances and has produced very reliable and timely results. The enthusiasm that has been expressed many times by the investigators indicates that every effort should be devoted to continuing the data flow from ERTS-1 and developing some type of operational system with a DCS capability.

There are several instances where the DCS has proven effective. For instance, the DCS is being employed for river monitoring in New England, the Delaware River Basin, the Susquehanna River Basin, Florida, Arizona, and Alabama. In the majority of these cases the data are being delivered in near-real time. Data are received in many instances in time periods of less than 1 hour. On the St. Johns River in Maine, the DCP installation provided very valuable and new information during the 1973 spring floods (Cooper). In Arizona, the DCPs provided snowmelt information this spring in a reliable and effective manner (Schumann). The management of the Arizona Salt River Project has expressed appreciation to the NASA Administrator, Dr. James Fletcher, for the DCS implementation in their region, and they have noted the contribution it made toward very effective management of the runoff from the abnormally high 1972-1973 snowpack (Schumann).

In order to further improve the DCP capabilities, Paulson has modeled a DCP system involving one or two satellites and various methods of incorporating stored information from other periods into DCP message bursts. The overall conclusion reached was that with improved information storage and better utilization of the available data transmission DCP capability, the reliability and frequency requirements of the U. S. Geological Survey for river-stage information across the United States can be attained. It is hoped that a nationwide pilot project can be initiated in the near future to test the results of this analysis.

PROJECTED APPLICATIONS

Snow Extent, Change, and Runoff Prediction

Accurate monitoring of snow extent and change could permit increased accuracy in both short- and long-term predictions of runoff. Improved accuracy of runoff prediction would produce better allocation and control of the available water supply for power development, domestic and industrial water demand, irrigation, and flood control.

Several ERTS-1 investigators have reported on the feasibility of identification of snow and the ability to measure its extent (Barnes, Wiesnet, and Meier). Snowline altitudes can be estimated to the nearest 60 meters under favorable conditions and the areal extent of snow cover can be obtained to within ± 10 percent by the average analyst. If an investigator is very familiar with the area and very careful, this accuracy may be improved to ± 5 percent. The accuracy with digital techniques is most likely higher. Analysis of ERTS-1 imagery over the Salt and Verde River Watersheds of Arizona shows that more detail can be derived from ERTS-1 imagery than is normally obtained from routine aircraft surveys (Barnes). Both Barnes and Meier report difficulties with identifying snow in heavily forested areas, identifying bare rocks from snow, shadow effects, and clouds that appear like snow. Digital techniques, however, may help overcome these problems. Barnes reports that MSS bands 4 (0.5 to 0.6 μm) and 5 (0.6 to 0.7 μm) are most useful for snow mapping, and band 5 is the best single band.

Additional work required includes higher frequency of coverage than the ERTS-1, 18-day repeat period. Wiesnet reported an interesting possibility of the joint use of ERTS and NOAA-2

VHRR as an interim way of getting the greater frequency of coverage from NOAA-2, which is twice daily, and using ERTS for the high spatial resolution. An operational demonstration will require much more timely delivery of data (quick-look data are very desirable even at the expense of resolution). The problem of shadows, bare rock, clouds, and vegetated areas all need to be explored using multispectral, digital, and objective classification techniques.

Lake Ice Surveillance for Navigation

Accurate identification of lake ice and classification of ice types would provide information for shipping in the Great Lakes and allow more efficient routing of shipping through ice covered waters and possible extension of the shipping season. The imagery provided by ERTS over large lakes such as the Great Lakes provides remarkable, synoptic views of ice coverage. Such imagery would be of great value in any ice-information system designed to allow the shipping season to extend into the unused (lakes frozen or partially frozen) portion of the year. Such ice information would allow ships and supporting icebreakers to seek ice-free passage or nearly ice-free passage. An extended shipping season translates directly into economic benefits when the vast amount of shipping potential and capital investment in ships, ports, and facilities in lakes such as the Great Lakes is considered. The frequency of winter-long cloud cover (50 percent over the Great Lakes) coupled with the 18-day cycle prevents acquisition of imagery of sufficient frequency to be of operational use. Because of the dynamic nature of ice movement on lakes at moderate latitudes, an ice photo has a useful lifetime of a day or two. Further, the sensor complement of ERTS-1 is probably not sufficient to determine ice thickness, although interpretation techniques might be developed. Also, means do not currently exist to get ice imagery into the hands of the shipping captains in a timely fashion.

ERTS-1 data are not a suitable basis for an operational system of lake ice surveillance for navigation. Such a system could ideally involve an all-weather microwave sensor plus frequent (almost daily) coverage. The imagery provided of lake ice by ERTS-1 would be valuable in developing such a system or perhaps in visually calibrating such a system. The use of ERTS-1 in combination with data from other space platforms or even DCPs should be investigated.

Polar Snow and Ice Mapping

The ability of the ERTS-1 satellite to provide synoptic coverage in the remote regions is never more valuable than when it provides up-to-date inputs to mapping activities in the polar regions. These data or maps serve as accurate guidance for planning and conducting explorations and scientific expeditions in the polar regions, thereby contributing indirectly to increasing our understanding of the world's weather, shipping routes, and other geophysical areas of effort.

The feasibility of attempting this effort is quite high. The only problem is continued coverage and satellite operation over these areas. Continued collection of ERTS-1 data and continued mapping of the polar regions should be done on a continual basis and as much as possible on a seasonal basis.

Surface Water Mapping

Using ERTS-1 data, global estimates of the actual area covered by surface water can be made for the first time. Previously only rough estimates were available. By knowing the kinds of water bodies indicative of various physiographic areas, indices of the volume of water available in a particular region may be obtained. By locating surface water area in relation to urban centers, irrigated areas, and industrial development, plans can be made for future water resources development. Surveys of regions possessing many lakes, such as the Texas High Plains, can be done very rapidly with ERTS-1 as compared with an extremely long conventional aircraft lake census. Surface water area obtained from ERTS-1 in these regions can then be used as inputs for regional water redistribution decision-making models used for future planning; for example, planning models for the redistribution of playa lake water in the Texas High Plains combined with importation of Mississippi River water. Surface water measurements combined with water stage measurements obtained from the DCS as demonstrated in Florida allow the calculation of water volume. Finally, ERTS-1 data can be used to meet the objectives of the International Hydrological Program for surveying all lakes greater than 100 km² in area.

The use of ERTS-1 data for such efforts as outlined above is extremely feasible; in fact, the U. S. Army Corps of Engineers is already acquiring these data for surface water surveys in various regions of the United States. The reason that the feasibility is high is that surface water can easily be delineated and measured using the ERTS-1 near-infrared channels. Secondly, the measurement of the surface water area is very adaptable to automatic data processing using ERTS-1 images and digital tapes. In areas where lake area changes rapidly, changes can be detected on lakes greater than 40,000 m² (10 acres) in area.

Not much needs to be done to make these techniques operational. Refinement of the automatic surveys must be completed. The transferral of the digital lakes census products to base maps that can be immediately utilized by the concerned agency appears to be resolved. Particular attention needs to be focused on mapping of surface water in problem situations involving various degrees of water turbidity, shadows in mountainous regions, regions with dark, bare soil, lava beds, and cloud shadows. It is not clear how much of the time, in general, a man-machine mix is needed, or the degree of involvement required on the part of the man.

Flood Area Assessment and Flood Plain Mapping

Regional flood area assessment using ERTS-1 will be invaluable as a method of delineating areas of potential flood damage and focussing relief efforts of local, state, and Federal agencies, of mapping out areas susceptible to flooding on the flood plain, and of locating areas of extensive flooding where additional flood control works may be necessary. These factors are important in the United States and also in developing countries where no other form of flood evaluation is available. Satellite remote sensing such as that available from ERTS-1 can be used as a regional flood plain mapping and planning tool that will help reduce flood damage. ERTS-1 can be used to locate the areas susceptible to flooding (on the basis of flood plain indicators observed before flooding) and their relationship to safe areas. ERTS-1 could be used to locate the sites of planned cities. In areas where towns already exist, further expansion could be more logically regulated. ERTS-1 could eliminate the need for some of the currently extensive, ground-based, flood hazard surveys.

Flood area mapping using ERTS-1 can be done using image enhancement techniques and transferred to base maps at scales up to 1:100,000. The flooded areas are easily delineated by observation of standing surface water or by observation of areas of low, near-infrared reflectance due to excessive soil moisture of stressed vegetation, a result of recent flooding. The area estimates of flooding over large regions are accurate to at least 5 percent. Mapping of flood plain indicators of flood susceptibility is relatively straightforward for major river systems. The scales of mapping are the same as those above for flood area mapping.

For flood area assessment, additional efforts must be made to use digital products for mapping to get the best resolution available. The largest scale for this mapping must be determined by further experimentation, but the goal would be 1:24,000. In addition, a major problem exists in the transferral of the classified results from computer analysis to a usable base map. This must be solved before it will be accepted by any user, and an analysis must be performed to determine the accuracy with which digital mapping can be performed. For flood plain mapping, the same digital mapping problems associated with flood area mapping must be solved. Additionally, some specific studies relating reflectivity differences observed in ERTS-1 data to various flood plain indicators must be conducted. This will involve both aircraft underflights and supporting ground-truth field surveys.

Playa Lakes as Reservoirs and Sources of Ground Water Recharge

Because of improved agricultural practices and the increased use of irrigation in the High Plains of Texas and New Mexico, the supply of water in the Ogallala formation (groundwater) is being rapidly depleted. As a substitute for this general water supply, it has been speculated that the naturally occurring playa lakes might serve as natural reservoirs for water that could be ponded so as to seep into and recharge the aquifer. To do this would require that those lakes with little seepage, which could serve as natural reservoirs, be separated from those with high seepage, which would serve as aquifer recharge sites. By continuous monitoring over several periods, the ERTS-1 observations might separate these two areas. The problem with this approach is that evaporation is continually occurring and is subject to varying weather conditions. If evaporation over long periods can be assumed uniform over the area, then anomalies or differences may be related to the problem mentioned above. Long-term viewing may reveal if this is feasible. In general, this application is fairly speculative. Five years of observation is probably necessary.

There is a need for a project designed to monitor the playa lakes over a long time period. Ground observations must also be conducted to check conclusions reached about certain playas being appropriate for reservoirs or aquifer recharge.

Shoreline Erosion

The observation of shoreline erosion and the ability to locate those areas undergoing erosion would allow more efficient planning of actions intended to ameliorate the erosion process and its consequences. An additional use of the observation of sediment patterns resulting from the erosion process is the inference of dynamic lake or stream processes as indicated by the sediment patterns and their changes.

ERTS-1 imagery can provide information of sufficient resolution to map turbidity patterns along lake and river shorelines (Pluhowski, Yarger, and Lind). Quantitative relationships have been established between turbidity levels and image densities (Yarger, Lind). Images thus may be used to help identify extent of shoreline erosion by inference from turbidity plumes. However, it must be recognized that many factors other than shoreline erosion (such as river discharge pollution and storm activity agitating the bottom) may be significant or dominant contributors to a given observed turbidity plume. The frequency of ERTS passes is not great enough compared to the time scale of lake and river dynamics to make the task of linking a given observed sediment concentration to a particular section of shoreline an easy one. It may be necessary to investigate a given shoreline region over a long period of time to establish the necessary relationships. ERTS imagery may prove more useful in assessing the efforts to reduce shoreline erosion processes by the use of barriers or retaining walls. In this case, a successful reduction of shore erosion could result in a measurable relative change in sediment loading.

It is necessary to develop techniques, strategies, or models to establish the extent to which the sediment patterns identified from ERTS-1 imagery are related to shore erosion processes. Supplementary thermal data would be helpful in establishing which apparent erosion patterns might be due to pollution rather than actual erosion processes. Off-shore DCPs and/or aircraft data would be helpful in supplementing the ERTS-1 data by filling the data gaps between ERTS-1 passes and by helping identify those aspects of ERTS-1 data related to shoreline erosion.

Navigation Channel Planning and Maintenance

Satellite imagery will help identify the areal extent of the navigation channels, monitor changes, monitor effects of anomalous disturbances such as storms and floods, and provide land use information needed for planning purposes. ERTS-1 has demonstrated the possibility of mapping turbidity plumes associated with river discharge into lakes (Pluhowski). The quantitative characterization of the turbidity levels has been possible by considering image densities (Yarger, Lind). It appears that this kind of information will be very valuable for both navigation channel planning and maintenance. The imagery will not replace the need for conventional techniques, but will complement them.

The effort needed essentially involves getting the imagery to the potential user community in a timely manner. Work must be done to determine the relationship of the information the imagery will provide (sediment dispersion patterns) to actual channel activities and maintenance problems. These are not yet established. The user community is in the best position to determine these relationships.

Dispersion/Circulation Models in Large Waters

A large body of water is a complex system with many inputs, certain outputs, and many important internal processes. One of the more important of these internal processes is circulation. Circulation is a key to the water body's ability to handle the many inputs it receives (including sediment and pollutants of various kinds). Circulation also determines the

distribution of inputs within the water body. Thus, knowing circulation processes is the key to predicting the behavior of the water body and determining the time histories of inputs to the water body. Where present in sufficient quantity, suspended sediment seems a natural tracer for gross circulation patterns in large bodies of water. ERTS-1 observation of these patterns appears feasible as reference data to test or modify existing models or, in conjunction with in situ measurements, to provide input to models.

Efforts need to be devoted to analysis of math modeling techniques for large waterways to identify input parameters that can be measured or inferred from ERTS-1 imagery. More detailed studies of ERTS-1 imagery are needed to analyze distribution patterns and density variations as they relate to the dynamics of water movement. In situ measurements should be made in sediment plumes for correlation of plume content (pollutants) with circulation patterns. This effort could lead to prediction of sediment-settling and deposit-building on bottoms and shorelines, and in pollution distribution and impact on specific areas of the water bodies.

Wetlands Value Mapping

Wetlands mapping is intended to show the areal extent of the wetlands, the vegetation types present, their amounts and distribution. This information is felt to be a good indicator of the wetlands potential for supporting wildlife or its development potential (that is, the wetland value). The value of wetlands is influenced by such factors as type and vigor of vegetation, water depth, and amount of water inundation. To the extent that these factors are consistent over large areas, limited value mapping is feasible. In general, however, this is feasible only in gross terms.

An essential step in wetland value mapping that needs further work is a definitive means of defining and calculating wetland value and identification of the factors that influence value. A systematic analysis is required of the susceptibility of wetlands to degradation due to natural and manmade causes as a function of value type, to be used as a guide in controlling utilization and development of wetlands. It is possible that much of the above has been accomplished although it has not been reported in the available ERTS-1 literature. Once these factors affecting wetlands value are identified, they should be examined for their likelihood of accurate monitoring by ERTS-1. Their sensitivity to size, shape, and boundary characteristics should be examined to establish the necessary scale and resolution required for useful applications, with a full understanding of the nature of the sensitive wetland parameters. Definitive classification techniques should be developed and applied to a wetlands region having a complete data base as a test of the approach. If successful, a full pilot project should be initiated covering a new area of particular significance.

Data Collection System

Stream Gage Monitoring—U. S. Geological Survey

At present there are approximately 18,000 stream gages in the United States. Of these, some 10,000 could be monitored by the DCS and a satellite downlink. The system has been proven

and awaits the next turning of the operational implementation process, namely, the appointment of a responsible service agency, the training of the necessary people, and the systematic implementation of the gages. The manning and maintenance of these gages is an annual expense of about \$2,000 per gage; thus, the potential savings are many millions per year.

Flood Control—COE, USGS, DOI, DOA

The DCPs are presently capable of monitoring stream behavior on a near-real-time basis. The recent monitoring of flood waters (Schumann) is an example where the timely release of stored water kept flood damage to minimum of cost and discomfort, where without this data, considerable inconvenience could have been expected due to flooding in the Phoenix area.

Water Resources Management—Power Companies—Pacific Northwest

The timely acquisition of stream data is required for input into reservoir/watershed operating models. These data have been obtained on an experimental basis at several high priority locations. A savings of 5 to 10 percent of the reservoir water above present methods of control represents millions of dollars in power-generating capability.

Bays and Estuaries—COE, EPA, State Governments

The long-term data acquisition that is necessary as parametric inputs for dynamic bay modeling is being obtained from the DCPs. At present, this is on a small numbered set to demonstrate the system. These models, when completed, will be used for the planning of future ship channels, extracting resources (for example, shell and sand), and managing levels of waste and effluent.

Ecology of Swamps, Drainage Areas, and Wetlands—Federal and State Governments

The DCPs have been used to monitor the extensive wetlands in southern Florida. These data are now being put into a model for optimizing the water level in the Shark River Slough, which is the major water source for the Everglades National Swamp. The coastal swamps and wetlands are the protective nursery for about 90 percent of the marine life for the contiguous seas. Thus, their proper protection and maintenance is vital to the well-being of the people in these regions. It is expected that the role of the DCP will fill a real need in monitoring the conditions of these large and thinly populated regions.

Development of Watershed Models Using ERTS-1 Data for Watershed Characterization

There are two general types of watershed models, namely planning models and management models. Planning models are used to specify the size of certain events such as floods, given certain rainfall events on a given watershed. Management models are used to predict the runoff from a watershed given a continuous series of input meteorological conditions. These models are used for flood warning, flood damage reduction, multiple uses involving reservoirs and demand

schedules for irrigation and navigation, and for predicting the effects of land use change on watersheds.

ERTS-1 data depict surficial land use features and their changes with season or as manmade effects occur. This is certainly an improvement over using mapped data that are not updated very often. It might be possible to develop relationships (empirical) using ERTS-1 data, which could adjust coefficients in hydrologic equations to account for observed land use changes and spatial extent. It seems quite possible that ERTS-1 data can be used over large watersheds to provide improved and more frequent estimates of impervious area, vegetation cover, and perhaps density, surface water storage in lakes and swamps, and snow cover.

More situations and models need to be revamped and checked against conventional techniques to ascertain the improvement that remotely sensed data provides. Existing models need to be revamped to accept a stream of ERTS-1 data. Comparisons of models performing with and without data need to be accomplished.

OVERALL CONCLUSIONS

It is quite clear that substantial progress has been made in applying ERTS-1 data to water resources problems. Nevertheless, more time and effort still appear necessary for further quantification of results, including the specification of thematic measurement accuracies. Furthermore, more modeling can be done very profitably. In particular, more strategy models describing the processes wherein ERTS-1 data would be acquired, analyzed, processed, and utilized in operational situations could be profitably accomplished. It is generally observed that the ERTS-1 data applicability is evident in several areas and that the next most general and substantive steps in the implementation of the data in operational situations would be greatly encouraged by the establishment of an operational earth resources satellite organization and capability. Further encouragement of this operational capability would be facilitated by all investigators striving to document their procedures as fully as possible and by providing time and cost comparisons between ERTS-1 and conventional data acquisition approaches.

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EDITOR'S NOTE

This summary paper in the Marine Resources discipline area was compiled from presentations made to the Marine Resources Discipline Panel (see Appendix 1) between October 22 and November 2, 1973, and from papers presented at the Third ERTS Symposium, December 10 to 14, 1973. The members of the Working Group, which met on December 14 to extract the Symposium results, are listed in Appendix 2.

INTRODUCTION

For organization purposes, this discussion is divided into four subdiscipline areas: coastal processes, ice, living marine resources, and ocean dynamics. This report also describes specific applications for marine resources that were determined as of the time of the Symposium, and discusses the Panel's suggestions for future investigation directions.

PROGRAM PERSPECTIVE

Before proceeding with the evaluation of results and applications from the ERTS program, an attempt was made to view the ERTS activities in light of the NASA remote sensing program in marine resources and the general problem areas to which remote sensing techniques may be usefully and profitably applied. The intent was to suggest a marine resources discipline structure (measurement techniques versus application areas) against which future marine resources investigations could be recommended, categorized, monitored, evaluated, and reported. Two main investigation areas were defined, coastal and ocean, being more or less divided by the fundamental nature of the geometry and processes that take place in each. The final two sections of this report discuss the Panel's suggestions for future marine resources investigations within the framework of these two investigation areas.

SUMMARY OF ERTS-1 INVESTIGATION RESULTS IN MARINE RESOURCES

A majority of the investigations in the marine resources discipline dealt with coastal processes. Techniques have been developed for defining coastal circulation patterns using sediment as a natural tracer, allowing the formulation of new circulation concepts in some geographical areas and, in general, a better capability for defining the seasonal characteristics of coastal circulation.

An analytical technique for measurement of absolute water depth based upon the ratios of two MSS channels has been developed. The technique requires some knowledge of bottom reflectivity, water transparency, and surface characteristics. Initial evaluation of the technique indicates that it is useful in coastal areas of low to moderate turbidity for depth measurement up to 9 meters (5 fathoms) and for updating the locations of reefs and shoals. Suspended sediment has found wide use as a tracer, but a few investigators have reported limited success in measuring the type and amount of sediment quantitatively from ERTS-1 digital data.

In general, the problem of separating and measuring water color components such as turbidity, chlorophyll, and bottom reflection is a complex one requiring further basic research in order to understand the component properties of a total water signature. In addition, further development of atmospheric correction techniques in the visible and near-infrared spectral bands is required.

Significant progress has been made in developing techniques for using ERTS-1 data to locate, identify, and monitor sea and lake ice. Ice features greater than 70 meters in width can be detected, and both arctic and antarctic icebergs have been identified. Because of the large daily overlap of ERTS-1 coverage at high latitudes, some tracking and quantitative measurements of ice movement are possible. The concept of using ERTS imagery to replace some present aircraft surveys of arctic sea ice on a cost-effective basis appears valid.

In the application area of living marine resources, the use of ERTS-1 image-density patterns as a potential indicator of fish school location has been demonstrated for one coastal commercial resource, menhaden. Further development of these satellite techniques may yield the only practical method of monitoring and assessing living marine resources on a large scale.

Ocean dynamics is another area where large-scale synoptic coverage is required. ERTS-1 data have been used to locate ocean current boundaries using ERTS-1 image-density enhancement, and some techniques are under development for measurement of suspended particle concentration and chlorophyll concentration. The interrelationship of water color and surface characteristics (sea state) are also being studied to improve spectral and spatial interpretive techniques. It has been suggested that sun-glint/sea-state effects are indeed seen in many of the ERTS frames. Calculations show that this is possible wherever the solar elevation angle exceeds 55° . A number of the features noted in the imagery, therefore, may be sea-state (or roughness) related, since the reflective properties of the water surface vary substantially with roughness of the capillary wave level. Further investigation of this effect is required since it has a major impact on interpretation of visible band spectral data.

Table 1 gives a summary of the status of 14 measurement techniques using ERTS-1 data that were defined by the Panel. Although all of the remote measurement techniques applicable to marine resources are listed in the table, only those measurements that may be wholly or in part obtained from ERTS-1 data are treated. The table also gives a brief summary of needed work for each measurement technique.

Table 1
Summary Status of ERTS-1 Measurement Capability in Marine Resources

Measurement Techniques	Potential Info from ERTS	Status of Capability From ERTS	Needed Work
Ice	Yes	ERTS can be used to locate ice, identify ice types, determine certain surface characteristics, and map ice distributions to 1:250,000 scale. Icebergs >70m wide in fast ice or ice pack can be detected and heights >50m can be estimated. Repeated coverage at high latitudes due to orbital overlap allows limited measurements of ice movements and deformations.	Analysis procedures require documentation. Application of automatic processing techniques for determining ice concentrations should be investigated, and methods to derive quantitative information (that is, deformation and strain data) should be further developed. Thermal IR channel is essential for providing wintertime data; application of microwave for all-weather observations should be investigated. Design and conduct operational ice-monitoring demonstration.
Temperature	No	—	—
Currents	Yes	Circulation pattern inferences made from ERTS using sediment as tracer. Oceanic current boundaries detected as color or sea-state differential but limited by MSS gain. Image density patterns suggest areas of coastal upwelling.	Refine and document specific application of current pattern determination. Document procedures. Choose simple coastal test site and define how ERTS data may be used as input to circulation math model.
Suspended Sediment	Yes	Limited success in quantitative measurement of suspended sediment concentrations in special coastal test areas where sediment dominated. Oceanic particle concentration measurement technique is under development. See water color.	Continue development of interpretation techniques in coastal areas. Improved surface truth required. Dependent on development of water color component separation techniques. See water/bottom color.

Table 1 (Continued)

Sea State	Yes	ERTS data has suggested that changes in sea state or internal wave patterns may be detected using sun glint patterns. Measurement of sea-state conditions has not been attempted.	Investigate conversion of presently available software for sea-state inference from sun glint patterns to ERTS configuration. Carefully choose test site and acquire adequate surface truth. Several appropriate test sites already suggested by previous satellite work.
Salinity	No	—	—
Other Chemicals	No	—	—
Plants	Yes	Identification and measurement of phytoplankton populations have been attempted using ERTS-1 image density as an indicator of chlorophyll concentration. Preliminary techniques are highly dependent on water type (coastal versus ocean). Measurement in selected ocean test site is under development. Kelp beds located on west coast of U. S. (See Land Use Summary.) See water color.	Basic surface and low altitude research required for separation of marine plant signatures. See water color. Continue development of relationship between plant signatures and plant type and quantity.
Animals	Yes	Feasibility of modeling distribution of menhaden by correlation of behavior with oceanographic parameters has been demonstrated. Project complete; limited technique demonstrated but not verified. Marine mammal habitat information derived in Arctic.	Direct location and identification of animals from ERTS not presently possible. Continue development of relationships between oceanographic parameters (color components) and marine animal behavior. Verify results from previous work.
Topography	No	—	—

Table 1 (Continued)

Land/sea Interface	Yes	No development work in this area reported. Marsh vegetation classification technique covered under Land Use Discipline.	Implement development work for measurement of marshland water areas and shoreline length measurement. Marsh vegetation classification techniques already under development in Land Use. Basic research required for specification of resolution needed for conversion of above measurements to marsh productivity information for coastal zone management.
Bathymetry	Yes	Quantitative technique has been developed and feasibility demonstrated, but reliability and accuracy not verified. Shallow clear water depths measured to 8.2m.	Document present techniques. Choose application test site and verify accuracy and reliability
Water Color	Yes	General signatures measured from ERTS. Techniques for separation of water color components not developed. Feasibility of using relative total color differences for inference of menhaden distribution demonstrated but not verified. Use of differences for current boundary detection also demonstrated.	Basic research required for separation of water and bottom color components. Should be implemented on surface and low altitude. Careful design of surface truth program required. Concurrent ERTS experiment useful for development of atmospheric correction techniques and separation of large-scale effects like sea-state and atmospheric variations. Several types of water and bottom types should be selected for test sites. Verify use of relative color differences for living marine resources and current ocean dynamics applications.
Bottom Color	Yes		

Coastal Processes

Coastal and Estuarine Circulation

The differing amounts of suspended sediment in the waters issuing from rivers, sounds, or specific shore regions act as tracers and permit the transport of that water to be observed in ERTS images. Combined with ground truth, the synoptic view from ERTS permits deriving circulation information that would not have been obtained otherwise. This type of data is being used to map current circulation patterns, upwelling, and sediment transport off the coast of California (several seasons) (Pirie), provide information on circulation patterns within the entire Delaware Bay (Klemas), and reveal unexpected circulation patterns in the northern portion of Cook Inlet, Alaska, and in the Gulf of California (Wright, Lepley).

While no mathematical circulation models have as yet been developed as a direct result of the ERTS program, it is clear that the synoptic scale surface circulation maps provided by ERTS represent an extremely important input to the development and testing of such models. This is particularly true in large or remote areas where conventional measurement programs are difficult to carry out. It is significant that there are areas where the actual circulation is different from the anticipated pattern – the northern Gulf of California as was reported in March 1973, and now the northern portion of Cook Inlet, Alaska, and areas of reversed littoral drift off the coast of California.

The determination of current direction from the ERTS data consists primarily of recognizing particulate (suspended sediment) patterns in single-band imagery. Generally, the red band is preferred as offering the best compromise between depth penetration and lack of atmospheric obscuration. Special analog or digital processing will generally be required to enhance the patterns on this imagery, as the data is at the extreme of the film-brightness scale.

The circulation models that may ultimately be derived from circulation concepts suggested by the ERTS data can be used for such applications as harbor planning, prediction of channel dredging effects, location of sewage outfalls, and power plants. Knowledge of upwelling sites may be important to fisheries management. For example, ERTS data is being used by Klemas to help Delaware develop a strategy for equipment to be used in controlling and abating accidental oil spills. Since obtaining synoptic current patterns by conventional methods has been prohibitively expensive in the past, it has not been done. Therefore, it is difficult to compare the cost benefit of using ERTS data with other systems.

In the case of near-shore circulation, the procedure consists largely of a single step examination of single ERTS frames (preferably after some gray-level enhancement has been employed). Documentation of the procedure and cost benefit information is still required. The techniques for determination of near-shore patterns are reasonably straightforward and are already in use. Usefulness for such applications could be improved if the satellite imagery gray scale at the lower end of the brightness range could be expanded and if investigations would make use of the data available from other satellites. Procedures and cost benefits must be documented.

Bathymetry

Depth charts representing different solar illumination and water transparency conditions for two geographical areas have been constructed. Calculation of water depth contour to 9 meters has been demonstrated for the Little Bahama Bank. Depth charts were also constructed for areas in Lake Michigan. These data represented low sun angle and poor water quality conditions but gave useful results to depths of 2 meters. An algorithm based upon forming ratios of ERTS MSS bands 4 and 5 has been developed to calculate absolute depth values. This analytic technique requires some knowledge of bottom and surface characteristics and water quality, or a single known depth, to determine absolute depths. Computer processing is used to produce synoptic scale depth maps by a repeated application of the ratio algorithm to individual scan spots.

The resources that would be required to update existing depth charts on a global scale by conventional means would be prohibitive. The dynamic nature of many submarine features, particularly in the heavily-trafficked coastal areas, can quickly invalidate observed profiles. The synoptic and repetitive coverage afforded by satellite-borne sensors could be effectively applied to overcome these deficiencies. Even without an absolute depth capability (which requires some prior knowledge of spectral attenuation in the water and bottom properties), relative maps would be extremely beneficial in planning bathymetric surveys, in flagging areas that require special observations, and in storm-related bottom changes.

The analytic technique that has been developed to determine depth profiles has been adequately documented and may be readily applied by other investigators. The generation of depth maps based upon calculations at individual scan spots can be accomplished using standard off-the-shelf mapping software. The techniques developed thus far need to be verified through an adequate ground-truth program under a broad range of water surface, water quality, and bottom conditions. Techniques need to be developed for separating the effects of these conditions from the desired depth information, as well as for determining atmospheric effects.

Sediment Load and Type Determination

Quantitative relationships linking observed radiance values on the computer compatible tapes (CCTs) with ground-observed sediment loads have been developed under special and limited test cases (Klemas, Grabau, Pirie). Sediment load and type information derived from ERTS data would provide an input to the development of circulation models. Accuracy improvements of 10 to 20 percent in the prediction of California coast sand transport are being demonstrated by Pirie through the introduction of circulation pattern information obtained from ERTS-1 data. This apparently small improvement may make the difference between a useful or inadequate sand transport prediction model. The model, in turn, would provide inputs for land use planning along the entire California coastline.

Classic learning-set and test-set procedures have been applied to the development of ERTS four-channel multispectral signatures relating radiance values to sediment loads and types. Attempts have been made to correct for atmospheric effects through the combined use of attenuation models and climatological data. While the sediment type signatures are not yet

uniquely determined, preliminary coded maps indicating sediment load may now be generated for selected areas. Sediment load information may be applied to environmental surveys, sediment transport problems, erosion studies, and circulation models. Full documentation of the initial procedure employed in sediment load and type determination from ERTS imagery will be forthcoming (Grabau). This will not be a final verified procedure as further development work is required.

Further work using ERTS satellites in the quantitative measurement of water color components such as sediment load and types should be restricted to the following: (a) Cases where one component dominates, and should include the development of atmospheric corrections for that special case as well as an adequate allowance for surface quantity and distribution (time and space) measurement to allow verification of the techniques. The technique and the application should be documented by the investigator including description of hardware, software, interpretive techniques, verification procedures, product processing, production procedures, and data product format. (b) Cases where the discrimination of different water colors may be used to delineate separate water masses or different sea states, which in turn provide useful information. An example is the determination of the Loop Current Boundary in the Gulf of Mexico by an apparent abrupt water color change (Maul), which is useful information for recreational and commercial fisheries, for the determination and prediction of Gulf storm intensities, and for scientific oceanographic purposes.

Ice

Sea and Lake Ice

ERTS imagery can be used to map sea and lake ice distributions, identify ice types, and determine certain ice surface characteristics. Using ERTS imagery, therefore, seasonal variations in ice cover can be monitored (except during the winter dark period at high latitudes), including the spring ice breakup and fall refreezing. ERTS presents the first opportunity to observe ice on a synoptic scale with sufficient resolution to map such features as developing leads, ice deformation, movement of ice floes, and changing surface characteristics (that is, percentage of meltwater). Ice features as small as 70 meters wide have been detected, ice floe speeds of 2.8 to 4.3 km/day have been measured, and ice mapping at a scale of 1:250,000 is possible. No mathematical models have been developed in the studies completed to date. However, information from ERTS will provide useful inputs to existing ice models and to numerical weather prediction models, as indicated in the following paragraphs.

To date, ERTS contractors within the ice subdiscipline have worked exclusively with imagery. No digital techniques have been developed in either a relative or absolute sense. Ice can be located using a single spectral band; the visible bands (ERTS-1 bands 4 and 5) are the most useful for mapping total ice extent. Ice type and certain ice surface characteristics can be derived most reliably through multispectral analysis, comparing the reflectances in the visible and near-infrared bands. Color composite data have not been found to be particularly useful for ice monitoring; automatic processing techniques such as density slicing may have application for measuring ice concentrations and percentages of open water and meltwater.

Information from ERTS can be used as input to existing numerical ice models. In fact, ERTS may be the only means to obtain the synoptic scale information that is required in numerical models; the required information includes locations of ice edges, percentage of open water within the pack, and ice type (that is, new ice, first-year ice, or multi-year ice). Ice boundary and open water information can also provide input to numerical weather prediction models. The ocean and atmosphere energy exchange in polar regions is significantly affected by the presence or absence of ice cover. This exchange in turn represents a significant portion of the earth's overall heat budget. Numerical prediction models have just begun to include ice cover variations as part of their initial state parameters. While impact studies have yet to be complete, it is felt that the ice-cover effects will play an important role in our ability to provide accurate long-range (2- to 3-week) ice-cover forecasts. Ice distribution derived from ERTS imagery on a quick-look basis, such as is currently being done by the Canadian Ice Forecasting Center, can be used in operational ship routing and for monitoring ice movements that could present hazards for off-shore oil drilling operations. An additional application of information relating to the temporal variation of ice cover, leads, and open water areas is the use of those data to infer sea mammal migration patterns as well as to infer locations of sea mammal populations. The identification and measurement of ice features has generally been done using single-step interpretive techniques. Documentation of procedures is required. In order for ice-cover information to be more readily available in near-real time for ship routing and numerical weather prediction, an automated ice/ice-type procedure will be required. Work can begin using existing data to determine spectral signatures of ice types and ice concentrations. Thermal infrared measurements will provide wintertime ice information in high latitudes. Also, microwave instruments would provide an all-weather capability, but at a degraded resolution; tradeoff studies could begin using ERTS and Nimbus Electrically Scanning Microwave Radiometer (ESMR) data.

Icebergs

It has been demonstrated (Hult) that ERTS can be used as a survey device to determine the abundance and dimensional characteristics of antarctic icebergs as a function of general location. Icebergs suitable for towing may then be harvested and transported to user areas for fresh water and thermal pollution abatement. With the polar overlap of ERTS imagery, even the prevailing 80 percent cloud cover yielded sufficient usable imagery for such an application. Iceberg heights down to 50 meters have been estimated.

As in the previous discussion of sea and lake ice, the interpretive techniques consist largely of imagery examination. In the case of icebergs surveys, a number of interpretive keys may be used: Icebergs stand out in relief against fast ice and are easily recognized; in open water, tabular icebergs have sharper edges than sea ice floes; wind and current often produce an open water wake effect behind icebergs; iceberg shadows can be detected on the surrounding pack ice providing a rough estimate of iceberg height.

It has been proposed that ERTS data be used to determine the characteristics, abundance, and accessibility of antarctic icebergs suitable for harvesting. The cost of obtaining ERTS equivalent information through any other means would be prohibitive; satellite reconnaissance is the only feasible means known for conducting such a survey. The present study indicates that the cost of

obtaining fresh water in Southern California from icebergs could be as low as one-third the cost of obtaining water from other sources. The decision criteria for selecting harvestable icebergs has been fully documented. Repetitive, all-season monitoring is required to provide a seasonal climatology of iceberg evolution in the sea ice belt surrounding Antarctica. Thermal and microwave alternatives should be considered. An antarctic read-out station would be required for operational implementation of an iceberg harvesting program.

Living Marine Resources

Three of the 22 ERTS investigations were categorized under the marine resources subdiscipline of living marine resources: Stevenson, Maughan, and Szekiolda. Szekiolda's work is concerned with phytoplankton population dynamics as may be indicated by chlorophyll concentration, but is still in the chlorophyll technique development phase with no quantitative technique verification as yet. Stevenson and Maughan cooperated in an investigation concerned with the use of environmental parameter remote sensing techniques for assessment and management of the menhaden fishery in the northern Gulf of Mexico. It should be noted here that the menhaden work was unique among the marine resources investigations in that it successfully combined the efforts of NASA, NOAA (the user agency), and the commercial fishing industry (one ultimate benefactor from the techniques under development).

Qualitative information on turbidity in the red band (band 5) was used to corroborate the relationship between menhaden school distribution and oceanographic parameters. Although no quantitative relationships between ERTS data and surface parameters were developed, it is conceivable that sufficient information exists in the ERTS data based on the modeling work accomplished thus far to predict distribution of menhaden in the future after additional understanding of biological and environmental relationships are gained. Measurement of oceanographic parameters on a 0.8 km (½-mile) grid was identified as a requirement for further development of environmental and biological relationships.

A simple but statistically significant model of menhaden school distribution versus the oceanographic parameters of salinity, water color, water depth, and turbidity (secchi) was developed by Stevenson using surface truth. Information on turbidity in band 5 was used to qualitatively corroborate the model prediction of school distribution on one ERTS pass on August 7, 1972. Additional data is required during the menhaden fishing season for verification. No significant interpretive techniques using ERTS data were demonstrated, although a qualitative relationship between band-5 image density and secchi visibility was shown using surface measurements and microdensitometry and color enhancement techniques.

Although the frequency of availability of ERTS data is not adequate for operational application to assessment and management of the menhaden living marine resource, the potential application has been demonstrated. The development, assessment, and management of living marine resources in the coastal and oceanic regimes is one of the largest and most beneficial areas for remote sensing application. All procedures used in the menhaden resource investigation have been documented, including surface measurement, field operations, aircraft data analysis, menhaden distribution model development, and project management techniques.

The application of remote sensing from aircraft and satellites to the assessment and management of living marine resources is in its infancy. On the basis of the results obtained by Stevenson, Maughan, and Szekiolda, it is evident that basic research is required in the measurement and interpretation of water color and its components. Basic research is also required on the water surface and from low altitude aircraft in conjunction with ERTS passes to understand the components that make up water color, to develop atmospheric correction techniques in the visible and near-infrared parts of the spectrum, and to be able to specify optimum spectral bands and resolutions for future satellites. In addition, the results on the menhaden resource discussed above must be verified.

Ocean Dynamics

A time series of the boundary of the Loop Current in the Gulf of Mexico, covering an annual cycle of growth, spreading, and decay, has been obtained using ERTS data. The current can be observed either by color or sea-state effects associated with the cyclonic boundary. Detached eddies spun off of the main body of the current may also be detected. No mathematical circulation models have been developed as a direct result of this ERTS investigation (Maul). Because of the disappearance of the Loop Current's thermal signature during the summer season, the synoptic scale ocean color measurements provided by ERTS would represent a heretofore unavailable input for the development of circulation models. No ratio of channels technique was found to be useful in delineating the current boundary. Computer enhanced imagery was required to extract useful oceanic information. Theoretical calculations using radiative transfer theory are being used to study the spectral variations in the optical properties of the water and its content (suspended sediments, yellow substance, and such).

The time series of the Loop Current has offered a tentative explanation of a number of observed phenomena in the Gulf of Mexico region during the past year (Maul). These include the occurrence of late fishing this summer off Alabama, the poor results from deep-sea fishing off Key West, and the occurrence of the Florida east coast red tide in 1972. The real-time identification of the pattern of the Loop Current or any other major stream could find useful application in ship routing, fisheries management, and meteorological forecasting (for example, hurricane intensification related to ocean surface thermal patterns). The computer enhancement techniques used to extract surface current information have been fully documented.

Additional work is required to distinguish between surface reflective properties due to sea-state effects and true color changes. In the case of color changes, recent work (Maul) has suggested that it may be possible to distinguish between suspended sediment and yellow substance and to measure suspended particle concentration. Another investigation (Apel) has suggested that internal waves along continental shelves may be monitored and studied using ERTS-1 data. The work required at this point is of a theoretical nature and generally falls within the basic research category.

MARINE RESOURCES APPLICATIONS

This section describes the specific applications for marine resources determined as of December 1973. The criteria used for selection of the four applications described herein were: (a) the

measurement techniques used for the application must already be developed and ready for verification and user evaluation, and/or (b) the user community must already be using and evaluating some remote sensing techniques and highly cost-beneficial applications would result at an earlier date from the continued development of measurement techniques and information systems. The former criteria would apply to coastal circulation, coastal zone bathymetry, and ice monitoring, while the latter would apply to the living marine resource application identified herein. No immediate specific application was identified for the subdiscipline of ocean dynamics, although it is recognized that ERTS-type satellite data will continue to support and contribute to the investigations of the oceanographic and meteorological scientific community.

Coastal Processes Applications

Management of the Coastal Zone

The differing amounts of suspended sediment in the waters issuing from rivers, sounds, or shore regions subject to erosion act as tracers for that water in the coastal zone. The synoptic ERTS images, combined with ground truth, aircraft imagery, and knowledge of tides and winds, lead to an understanding of the two- and three-dimensional current patterns in the region. This permits a prediction of the transport of suspended sediment, spilled oil, or thermal plumes that would occur during the construction or operation of coastal or offshore facilities. Generally, the complicated and variable circulation patterns would be expensive and difficult to diagnose without the ERTS synoptic view.

The Environmental Protection Agency (EPA) must approve or disapprove environmental impact statements written by other agencies, and has the responsibility for enforcing regulations to prevent degradation of the coastal zone. The Atomic Energy Commission (AEC) is responsible for issuing permits for planned offshore nuclear power plants. The National Oceanic and Atmospheric Administration (NOAA) is responsible for fisheries, mapping coastal regions and currents, maintenance of a data bank, and administration of the Coastal Zone Management Act. The Army Corps of Engineers maintains harbors and inlets and is concerned with preserving beaches, marshes, and with the environmental effects of construction (such as dams and levees). The coastal states pass their own legislation to preserve their coastal values and to regulate users. All of these agencies must prepare federal environmental impact statements when a significant change is planned. Current information is fundamental to their predictions and decisions.

A number of investigators have been working in this field. Their success seems to improve as they increase their use of aircraft imagery, ground truth, and image enhancement techniques along with the ERTS data. Using all these, the Corps of Engineers has plotted detailed currents as a function of season off the coast of California. The techniques they describe can be adopted by other users in other geographical areas. Adequate ERTS imagery exists for many geographical locations (low cloud cover, various stages of the tidal cycle, and several seasons) for comprehensive analysis in other coastal and estuarine environments. The interpretive technique could well be varied and improved upon, as necessary, for the kinds and amounts of suspended sediment and the ground truth and aircraft imagery obtained in any particular location. The procedures used by the Corps of Engineers could be documented in a how-to-do-it manual that could be used by those faced with the responsibility of furnishing baseline data in their geographical area.

Updating Coastal Zone Depth Charts

The updating of navigation charts for selected areas is an achievable direct application. It was estimated by Polcyn that multispectral scanner (MSS) depth charts can be processed using present techniques at a cost of 58 cents per km² (\$1.50 per square mile). In the United States, the U. S. Lake Survey, the Coast and Geodetic Survey, the Naval Oceanographic Office, and the National Ocean Survey are agencies that will benefit directly from a remote depth measurement capability. The ability to determine absolute depths has been demonstrated where certain water and bottom characteristics are known. Relative depth measurements can be subject to potential misinterpretation due to water turbidity changes, sea-state effects, and nonhomogeneous bottom characteristics. Ground-truth surveys could be used to establish calibration areas in conjunction with satellite-derived maps. A joint effort involving a user agency should be conducted to verify and determine the applicability of the derived techniques to a broad range of environmental conditions. The methodology of incorporating a ground truth calibration area to scale the satellite-derived analysis should be investigated.

Ice Monitoring in the Arctic

The ERTS program has substantial practical application for ice monitoring. The directors of the U. S. Navy and Canadian agencies responsible for ice reconnaissance in the Arctic have both spoken enthusiastically of the potential of ERTS with regard to mapping arctic ice. In fact, the Director of the Canadian Ice Forecasting Center has stated that the concept of using ERTS imagery to replace certain currently flown ice survey flights at a considerable savings in cost is valid and may be pursued in the future. In addition to the interest of the responsible government agencies, at least one sector of private industry, oil exploration, is vitally interested in applications of ERTS data for ice monitoring. In connection with offshore drilling operations in the Arctic, the petroleum industry will be one of the principal users of ice data in the next few years. The U. S. Navy Ice Forecast Office, the Canadian Ice Forecasting Center, the U. S. Coast Guard Ice Patrol, and the shipping industry are also users of this data.

The feasibility of using ERTS imagery for sea ice monitoring has been demonstrated. ERTS resolution is sufficient for detecting ice features as small as 70 meters in width. Ice types and certain ice surface characteristics can be identified using the multispectral ERTS data. One of the first operational uses of ERTS data will be for ice monitoring. Ice information from the Canadian "quick-look" ERTS facility was supplied to a ship making seismic measurements in Arctic waters. As a direct result of the ERTS data, the ship was able to penetrate further than had been anticipated, realizing substantial cost benefits.

The work needed in this area is as follows: Statistics of ice distribution must be compiled from the ERTS data collected for two summer and fall seasons; techniques for identifying ice types and ice surface characteristics must be verified and documented using additional ground truth; quantitative information on ice movement, deformation, and strain must be obtained using imagery; interpretation techniques must be developed for quantitative ice-type signatures, using digitized data.

Management and Utilization of Living Marine Resources

Living marine resources include all forms of both plant and animal stocks living in the ocean, including coastal and estuarine areas. It appears that now is the appropriate time in our technological development to identify the specific contribution remote sensing can make in management or utilization, or both. Remote sensing information can be a valuable contribution to the resource information base critically needed to support and enhance timely knowledge of the resource dynamics, distribution, and abundance. New tools of the type being developed under the ERTS program (Stevenson, Maughan, Szekiolda) open an entirely new approach to the assessment and monitoring of fish stocks by developing the relationships between biological parameters such as fish and phytoplankton distribution and environmental parameters such as water color, and using these relationships as input to predictive models of animal distribution. Remote sensing data may be the most effective way to provide certain types of information necessary for improving harvest efficiency of currently important fish stocks, and to identify the potential availability of under-utilized fishery resources.

Users of information for marine resource management include NOAA, the State Department, the Department of Health, Education, and Welfare (HEW), U.S.-supported international organizations such as the International Commission for North Atlantic Fisheries, the North Pacific Fisheries Commission, the International Tropical Tuna Commission, the International Gamefish Association, and raw material availability components of commercial and sports fishing interests, such as processors, marketers, and equipment manufacturers, state management agencies, and interstate commissions for marine fisheries. Users for utilization information include producing elements of commercial fisheries, individual sport and commercial fishermen, financial and risk underwriters, and regulatory agencies.

The ultimate information required for this application requires the measurement of temperature, currents, suspended sediment, sea state, salinity, plants and animal location and identification, land and sea interface characteristics, bathymetry, water color, and bottom color. It is recognized that the capability to measure most of these parameters from satellites is in the development stage and, furthermore, that ERTS-1 cannot provide data for the direct measurement of temperature, sea state, and salinity.

Aside from the work required on measurement techniques, this application area requires that combinations of these measurements be used to provide products based on models relating the nature of the resource behavior and the measured oceanographic parameters. In most cases these relationships have not been developed by the user, and in many cases remote sensing may aid in developing that relationship. An example is the development of relationships between menhaden distribution and combinations of water color, bathymetry, and salinity in the Mississippi Sound, as demonstrated by Stevenson. This work should be continued so that the remote techniques being developed will bring all the required application developments to an operational status at the earliest possible time.

Development of relationships between the resource and oceanographic parameters would allow assessment and prediction of resource behavior for conservation and utilization management. Development of these relationships is primarily the responsibility of the user, but effective use of remote sensing from satellites and aircraft can be made for gathering the oceanographic

information. This is a step-by-step process and requires close coordination with the user. With regard to ERTS, the developments described by Stevenson should be verified and expanded. This can be done most profitably as a continuation of the present work, since substantial information exists on that test site and resource. Effective use of aircraft could also be made in this program. However, in defining a follow-on program, due consideration must be given to the biological window in relation to availability of ERTS satellite data.

FUTURE MARINE RESOURCES COASTAL APPLICATIONS AREAS

Living Marine Resources

Responsibility for long-term development and conservation of our coastal living marine resources occurs at both the federal (NOAA and HEW) and state (Departments of Wildlife and Fisheries) levels. Their responsibilities include assessing the quantity and availability of the resources, monitoring the health of the resource, and managing the utilization of the resource. In addition, the general public sportsman must also be identified as a user if prediction information on the location and availability of sports fish can be supplied to him in a timely manner for recreation and conservation purposes.

Living marine resources include the commercial and sports fish and shellfish as well as appropriate plant life such as kelp, which may be cropped or conserved. Additional potential is in the surveillance of fishing efforts for domestic and foreign fishing regulation, which is expected to emerge as the management of major marine resources becomes a workable system. It is also worthwhile at this time in our technological status to start thinking of living marine resources in terms of both natural as well as cultivated resources, because of the impending development of mariculture techniques for commercial purposes. Remote sensing will be a valuable aid in the selection and monitoring of open-range mariculture sites, using oceanographic parameters and coastal geometry as selection criteria. Remote sensing information will also be a valuable aid in the assessment and development of new commercial fisheries, based on the development of techniques such as those being initiated and investigated under the ERTS program. These techniques involve developing the relationships between biological parameters such as fish behavior or phytoplankton population and oceanographic parameters such as water color, and using these relationships to model the distribution of the resource. Information that may potentially be acquired from either aircraft or satellite includes animal location, identification, tracking and quantification (biomass and availability assessment). From aircraft, present sensor resolutions allow the detection of schooling fishes or large marine animals. Some feasibility work in this area is in progress but little has been documented. Problem areas here are the large areas that must be covered by aircraft and the development of techniques for specie identification. However, some application demonstration has been done by NOAA/NMFS/FEL at MTF in the Mississippi Sound, using daylight aerial photography and low-light level intensifier TV systems aboard low altitude aircraft at night to obtain biomass information on schooling menhaden, which excite bioluminescent organisms around them. Present resolution from satellite altitude does not allow this type of work.

Management of Coastal Zone

The coastal zone is a uniquely important function of our environment. A large fraction of our population lives within a hundred miles of the coastal zone, and uses it in many ways. It is a source of food, recreation, and transportation. Much of our garbage and other discards end up in it. In the future, it will be used even more intensively for dumping, to produce petroleum, and as sites for offshore power plants and offshore ports.

These manifold and conflicting user requirements require intelligent management, which in turn must be based on adequate information. Responsibility for coastal zone management will rest with NOAA at the federal level under the Coastal Zone Management Act. However, much of the responsibility will be shared by the coastal state governments and agencies on a local or regional interest basis. The ultimate user in coastal zone management will be specific to the particular application problem being addressed but will primarily be a legislative body or federal or state agency. Much coastal zone management information can be obtained by remote sensing.

Commerce in the coastal zone can utilize remote sensing and associated ground truth in activities such as siting offshore ports and offshore power plants, assessing the possible environmental impact of offshore gas and petroleum wells, dredging to preserve conventional ports and shipping lanes, dumping of garbage and chemical wastes, and offshore mining, especially of sand and gravel. Information of importance to commerce includes the measurement of currents and the sediment suspended in them; sea state and the wave diffraction caused by structures; the extent and location of sea ice and possible shipping lanes through it; the salinity of the water and pesticides and other chemicals that can be carried by it; bathymetry; land and sea interface characteristics and the color of the water (an indication of productivity due to chlorophyll-bearing plants, or to upwelling); and bottom type.

Recreation in this zone includes sports fishing, boating, swimming, and other human activities near the coast. Fishermen want to know about water parameters that affect the presence of fish (that is, salinity, temperature, suspended sediment, bathymetry, water color, chlorophyll content, sea state, currents, and possible chemical species dissolved in the water). Most of these cannot be discerned from ERTS on a timely basis since ERTS imagery is obtained only every 18 days and then only if there is not too much cloud cover. However, the general motion of bodies of water and depth changes in shallow water (affecting boating) can be of value in discerning factors that will affect selection of areas for recreational uses.

Because the coastal zone is used for commercial and other applications, the location of new facilities, as well as their operation, must be managed to minimize undesirable environmental impact. To do this the value of each region for its existing use must be known, as well as the interactions of any new use with the existing use. Some of the parameters that contribute to zoning decisions are suspended sediment, bathymetry, salinity, the type of dynamics and location of the land and sea interface, and biological productivity (chlorophyll or water color). Since some of these are not particularly time-dependent, the 18-day ERTS cycle does not preclude using ERTS imagery to discern their parameters.

Another problem is that of sensing and repairing natural changes to the shoreline. Beach erosion, in which sand is transported from a beach area and is not replaced by other sand, is an

example. Frequently, the construction of inlets, groins, or other structures affects the littoral drift of the replacement sand. In this case ERTS is valuable in diagnosing the problem, showing when sand transport and deposition occurs around features such as harbor entrances, and furnishing information for remedial measures. Besides bathymetry, other information of value includes currents, suspended sediment, sea state, salinity, and land and sea interface characteristics. Some of these are discernible from ERTS.

The marshlands are complicated, dynamic land and sea interface areas that are usually of importance because of high living marine resource productivity and mineral and gas productivity. However, man's exploitation of these resources often impacts the environmental state of the marsh with both good and bad results. In addition, natural changes are taking place that may or may not be desirable. Some of these natural and manmade impacts are channelization, leveeing, marsh breakup, salinity intrusion, and the effects of coastal circulation and sediment transport. Application of remote sensing in the marsh can be of value in the assessment of environmental impact as well as in future management of the marsh area. Information of interest includes currents, the sediment suspended in them and the source of that sediment, salinity, chlorophyll content, the types of plants or animals likely to inhabit the region, and land and sea interface characteristics such as shoreline length and percentage of land and water. ERTS-1 data is especially useful for developing measurement techniques.

In 1972, Hurricane Agnes dumped an unprecedented quantity of fresh water into the rivers and coastal zones of the eastern United States. The effects of this gigantic pulse of fresh water were profound, both in sediment transport, changes in bathymetry, and effects of the extended period of low salinity on marine life. At the time, the mapping of salinity changes provided new information on current flow and interaction in entire regions, such as the Chesapeake Bay. The most significant effect of most storms, however, is due to bathymetric changes plus, of course, damage to onshore facilities and to recreational boating. Unexpected shallow water or sunken obstructions may be a hazard to shipping.

The ability of ERTS to locate regions where sea ice is likely to flow seasonally is of interest to those who plan to locate offshore structures (such as oil drilling rigs) in arctic waters, enabling them to design their structures or their program to obviate the hazard. Information of interest includes ice, suspended sediment, salinity, bathymetry, and land and sea interface characteristics. Generally, the usefulness of ERTS for disaster and hazard assessment is limited by its infrequent coverage and the need for good visibility to obtain data.

For disaster and hazard assessment to become an operational applications area, a satellite system with increased frequency of coverage and with all-weather day and night capability needs to be developed. With the existing ERTS-1 system, more emphasis should be placed on developing techniques for making quantitative measurements and for accounting for atmospheric effects in the data. Also, no work has been reported in the land and sea interface area. This could be a most fruitful area for ERTS investigators. Further modeling work will be necessary. ERTS is suggesting concepts for model development in areas such as circulation dynamics and sediment transport. These concepts must be fully explored and techniques for quantitative analysis developed when possible.

FUTURE MARINE RESOURCES OCEAN APPLICATION AREAS

Oceanography, Meteorology, and Marine Biology

The scientific disciplines of oceanography, meteorology, and marine biology play a basic role in our understanding of the natural phenomena on our planet, and in improving our capability to use them in the most efficient way for the well being of our society. These disciplines, even though scientific in nature, are the basic stepstones for many direct applications of major economic impact. The main scientific subdisciplines that would directly profit from the NASA Marine Resources Program are as follows:

Oceanography

Many oceanographers are interested in the study of the sea state, wave generation and propagation, and surface currents, not only because of their academic importance, but because they are the main inputs to many major applications: Predictive sea state and current maps could cut ship travel time by 10 to 20 percent and improve travel safety; wave statistics over major shipping routes would allow better ship design; accurate current maps would be of major help to the fishing industry; a warning system for sea storms would be of great importance to many coastal areas; and waves and current information are basic for the evaluation of the effect of the sea on the shoreline and the transport of sediment and sand.

Many scientists are interested in accurate determination of the geoid and other perturbations to the ocean surface such as tides, tsunamis, and upwelling due to storms. The ERTS data is not useful in this field, and a spacecraft with a high accuracy altimeter is needed. Such an instrument is under consideration for Seasat.

A newly emerging area of scientific investigation of extreme value to the expansion of utilizing ERTS-type satellite data is the study of relationships between surface horizontal environmental parameters and vertical oceanographic dynamics. Encouragement in studies to develop the predictive relationship between surface parameters such as color, salinity, turbidity, and temperature will lead to expanding the application of remote sensing data to subsurface and bottom-living marine resources such as shrimp, oysters, and snapper, particularly in the coastal areas.

The input data required from NASA spacecraft include products detailing ocean surface waves, sea state, and current, and temperature maps. ERTS imagery is a major step forward, but it has limited capability because of system design (imaging spectrum) and uncontrollable factors (cloud coverage and sun illumination). The first improvement is to include a thermal infrared channel to measure surface temperature and to conduct more research on the use of image radiance to measure sea state, and on the detection of current edges. For an oceanographic operational system, new instruments must be added, that is, imaging radar and scatterometer. More work is also required to quantitatively relate sediment content to radiance.

Meteorology

The wind speed and direction near the ocean surface are major inputs to all predictive meteorological models. At the present time, the only potential method of getting this information on a global scale is by measuring the sea state and then inferring from it the local wind velocity. Presently, the best known remote sensor for sea state measurement is the active radar, but ERTS imagery might be useful if a reliable and accurate relation between the surface roughness and the reflected sun light could be found.

The extent of ice coverage in the polar regions is a major input to meteorological and heat exchange models and to navigation maps. Varying ice boundary and open water information may be inputs to numerical forecasting models. The ocean-atmosphere energy exchange in polar regions is significantly affected by the presence or absence of ice cover. This exchange in turn represents a significant portion of the earth's overall heat budget. While impact studies have yet to be completed, it is felt that the ice-cover effects will play an important role in the ability to provide accurate long-range (2- to 3-week) forecasts. Numerical forecasting models have just begun to include ice cover variations as part of their initial state parameters. The capability to use increased ice cover information already exists. Automated techniques to extract the needed information in a timely and accurate manner are lacking. In order for ice cover information to be available in near-real time for numerical weather prediction, an automated ice/ice-type procedure will be required. Work can begin using existing data to determine the spectral signatures of relevant ice cover situations. Microwave instruments would provide an all-weather capability, but at a degraded resolution. Trade-off studies could begin using ERTS and Nimbus ESMR data.

Marine Biology

The main application in this field is the detection and mapping of plankton population, organic sediment, chlorophyll, plant life, and fish schools. The visible and infrared bands seem to be the best regions of the spectrum for this purpose but research is still needed to determine, with a satisfactory accuracy, the spectral response of these organic elements, and then to relate these elements' concentration to fish population.

With regard to plants in the coastal and ocean environment, information that may potentially be remotely acquired includes plant location, identification, tracking, and quantification (biomass and availability assessment). Floating or suspended plant masses, not individual plants, are of prime concern, but in some cases location and identification of bottom plant communities in clear water may be possible and desirable. Present technique development is centered around location and biomass quantification of phytoplankton using chlorophyll as an indicator. It is not known at present whether further work in water-color component separation will lead to a technique for quantitative measurement of chlorophyll with ERTS-1 instruments. Present documented remote measurement techniques exist for low altitude aircraft but are severely restrictive in measurement, range, and accuracy, due to atmospheric effects, interacting water color components, and other unknown relationships.

Basic research on the contribution of chlorophyll and other pigments to water color should be conducted using aircraft and surface instruments. This should be accompanied concurrently by

an ERTS investigation in an area where phytoplankton is the predominant water-color component, provided that adequate surface measurements and atmospheric data are acquired for correlation, atmospheric correction, and verification when the basic research yields an acceptable quantitative technique. In addition, procedures for relating plant quantity to color signatures should be defined and documented by users. In many cases this relationship is complicated by diurnal variations in pigments and the combination of population species, requiring costly surface truth efforts for verification. Responsibility for developing this relationship lies with the user but is critical to the application, that is, determining productivity or development of relationships with animals of recreational or commercial value or of scientific interest.

In those ERTS-1 projects where extensive oceanographic surface truth data was obtained (Stevenson, Maughan), new precision and accuracy criteria have been identified for environmental parameters both in time and space. Stevenson reported that the frequency and density of observation for fishery-significant environmental parameters precludes the efficient use of classical surface data acquisition systems. Investigation into the minimum environmental and biological data requirements needed to meet specific areas of applications such as fish resources is required. Trade-off and cost effective analysis may effectively establish the efficient utilization of remote sensing information in the general oceanographic data acquisition systems. It is also known that the locations and migrations of sea mammal populations in the Arctic are dependent on ice distribution. Ice information from ERTS can contribute, therefore, in the monitoring and management of these sea mammal populations.

Living Marine Resources

Application of remote sensing information to open ocean, marine resource management and utilization is not as easily identified as the coastal area applications. This may be due to the current paucity of living marine resource investigations in this area. However, the logical extension of the bio-environmental relationships presently identified in the coastal area to the open ocean is realistic. As the technology for application of remote sensing in coastal areas is developed, and as the accuracy and precision of instrumentation needed to meet the more precise measurements for oceanographic parameters in the ocean are made available, the extension to oceanic living marine resources will take place. In the interim, continuous monitoring of remote sensing instrument improvement and living marine resource assessment and prediction technology are required to capitalize upon the use of these methods at the earliest moment.

Ocean Transportation

The ERTS program has many potential benefits, one of which encompasses shipping and ocean transportation. At the present time, the International Ice Patrol collects iceberg drift data in the North Atlantic during three or four cruises in the spring and early summer. Because of the high variability of this area of the ocean, data collected there sometimes give an ambiguous picture in both space and time. Satellite data will cover a larger area more frequently and will contribute to the safety of shipping in the northwest Atlantic Ocean, north Pacific Ocean, and Bering and Beaufort Seas. An improved ship routing program results in safer, faster crossing, with

significant economic benefits such as reduced travel time, fuel consumption, and operating costs.

In addition to the potential application of satellites for monitoring the numbers and movements of icebergs, the data can be used to monitor pack ice in the Arctic. With the increasing activities in the Arctic related to the exploration for oil and other minerals, shipping in arctic waters will be increasing, requiring more accurate ice-condition forecasting. It has already been shown that ice information from "quick-look" ERTS imagery can be used operationally for ship routing and iceberg warning, where more frequent coverage is required since ice movements and rapid changes in openings in the ice can be important. Techniques for direct measurement of sea state must be explored and developed. Models defining current boundaries and direction need development.

The generation of accurate ship routing information requires wave charts, air and sea temperature difference, surface winds, and pressure fields. Satellites will provide information on sea state and coastal currents from sedimentation movement and bathymetry data in coastal zones that can be an input for preparing prognostic charts for efficient ship routing. The greatest immediate application potential exists in the Arctic where the capability to locate and identify sea ice and icebergs has been demonstrated.

Law of the Sea

It is anticipated that remotely sensed information would be helpful in establishing international boundaries for such things as fishing and shipping and for obtaining evidence in settling disputes arising from suspected violation of established international or territorial zones. More specifically, remote sensing would be of benefit in policing the sea lanes of the Arctic, ensuring access to ocean currents for efficiency in shipping, and establishing areas for fishing operations. In future potential applications of the harvesting of antarctic tabular icebergs as a fresh water supply, it appears that ERTS-type satellite observations will be the only feasible method of identifying and allocating specific icebergs to be harvested by various users such as the Department of Commerce. This application area is considered to be long range in terms of cost benefit but should be recognized for application potential as satellite measurement and monitoring capabilities are improved.

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APPENDIX 1
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EDITOR'S NOTE

This summary paper in the Environment Surveys discipline area was compiled from presentations made to the Environment Surveys Discipline Panel (see Appendix 1) between October 22 and November 2, 1973, and from papers presented at the Third ERTS Symposium, December 10 to 14, 1973. The members of the Working Group, which met on December 14 to extract the Symposium results, are listed in Appendix 2.

DISCIPLINE RESULTS SUMMARY

Environment applications are concerned with the quality, protection, and improvement of water, land, and air resources and, in particular, with the pollution of these resources caused by man and his works, as well as changes to the resources due to natural phenomena (for example, drought and floods). The broad NASA objectives related to the environment are directed toward the development and demonstration of the capability to monitor remotely and assess environmental conditions related to water quality, land and vegetation quality, wildlife resources, and general environment. The contributions of ERTS-1 to these subdiscipline areas are broadly summarized in this section and discussed more completely in the separate summaries that follow. It is emphasized that activities relevant to the environment also appear in other discipline reports.

Water Quality

Major accomplishments in water quality investigations include the establishment of techniques to permit semiquantitative estimates of the contents of suspended solids (in concentrations from 5 to 1,000 mg/l) and chlorophyll; the capability of recognizing dispersal patterns of large masses of turbid waters, thus giving instantaneous synoptic maps of surface circulation characteristics; and the ability to detect large-scale dumpings and outfalls using remotely sensed imagery and to differentiate acid iron wastes from other types of materials so dispersed and assess resident times. These accomplishments have shown the potential for an operational application in the area of detection of major pollutant sources and the monitoring of their movement and dispersion in large concentrations in lakes, rivers, bays, and oceans. Such

measurements could be inputs necessary for the development and verification of the circulation models required to plan effective waste disposal programs. Work needed to make these applications fully operational includes extensive testing with major ground-truth efforts in an attempt to make suspended-sediment content and type and chlorophyll determinations more quantitative and to explore more thoroughly the accuracy that can be obtained. Additional work is also needed to identify types and quantify pollutants in waste plumes, to upgrade data processing procedures, and to make these procedures available to the maximum number of investigators and users in a timely manner. More ERTS passes at higher gain settings on the multispectral scanner (MSS) would be of value and are recommended.

Land and Vegetation Quality

Ten investigators have reported studies ranging from the desert environment of the southeast United States to the North Slope of Alaska. In addition to the previously reported accomplishments (March 1973) in the classification of strip-mining areas for monitoring both the mined acreage and the reclaimed regions, another major accomplishment is the classification of permafrost and vegetation regions of Alaska where either poorly detailed maps or no maps had been previously available. The analyses ranged from sophisticated computer programs for handling computer compatible tapes (CCTs) and classifying pixel by pixel, to photointerpretation using relatively simple tonal analysis of the ERTS-1 image.

Four classes of urban quality have been distinguished and mapped for the City of New Orleans using CCTs. The monitoring of changes in protected areas (wetlands) due to construction was presented, and dredging and filling operations have been detected using photointerpretive techniques. Mapping desert vegetation has been reported as less successful; a possible explanation offered is that the high land reflectance saturates the detectors. Further investigation and more detailed analyses are needed. Detection of damaged vegetation due to highway salting practices was found to be difficult because the affected areas are small relative to ERTS-1 sensor resolution.

The detection of strip-mining practices and coastal zone changes is a major application nearly ready for use. Other important applications include monitoring construction changes and using ERTS-derived maps to choose sites for construction (particularly in Alaska). The urban-quality application is felt to have potential and should be verified in other cities before it is used operationally. Tundra scars due to vehicles can be monitored for changes to assure that they are not spreading. Ground truth for verification of mapping techniques and documentation of techniques are areas in which more attention should be focused.

Wildlife Resources

Present practices in wildlife management are based upon the definition of parameters that define wildlife habitat and its carrying capacity. Major accomplishments utilizing ERTS data have been the greatly improved characterization and mapping of vegetation, permafrost, surface water, and sedimentation, as well as the development of snow and ice maps. The feasibility of accomplishing these mapping and monitoring tasks and using them has been summarized, and the feasibility of operational applications to certain wildlife management practices has been

indicated. Numerous agencies are concerned with these potential applications for better management in logging, construction, recreation, hunting regulations, land partitions, and forest and range management where they impact wildlife populations. Work is needed in expanded ground truth, wider use of CCTs, access to more sophisticated software, and coordinated user collaboration.

General Environment

Recent findings have further verified that ERTS imagery can detect smoke plumes, aircraft contrails, urban haze, atmospheric aerosols, and certain short-lived events of national and international significance. ERTS imagery has been used to measure vertical aerosol burden over oceans at accuracies estimated at ± 10 percent. It has also been shown that air pollution interacts significantly with the meteorology of the Great Lakes, directly influencing the dynamics of cloud behavior and, in some cases, precipitation. Promising applications are the monitoring of aerosol content on a global basis and the study of mesoscale inadvertent weather modification. Additional work is needed to verify quantitative measures and to develop analytical models needed to interpret and apply the results.

RESULTS SUMMARIES OF SUBDISCIPLINE AREAS

Water Quality

A large number of investigations are involved with the use of ERTS data to measure and monitor water quality in rivers, lakes, estuaries, and near-shore coastal zones. Suspended sediment is a water pollutant that occurs as a result of natural processes as well as those caused by man. The sediment load of near-surface waters can be clearly identified, and in some cases the sources can be located and current directions mapped. Manmade pollution caused by industrial chemical dumping, sewage disposal, and oil spills has been identified; pollutant location, areal extent, and even dispersal can be measured. However, little or no work has been done to measure the quantity of material dumped. Thermal pollution of water by powerplants, factories, and such—an extremely important pollutant in rivers and estuaries—cannot be measured from ERTS-1, of course, nor can heavy metal pollution. Estimates of chlorophyll-*a* content as another water quality indicator have been made for offshore waters, such as the New York Bight. Several studies are concerned with using ERTS to monitor lake eutrophication. Algal blooms can be readily detected, but to date little progress has been made in detecting degrees of eutrophication before the lake reaches a hypereutrophic state.

Calculations based on simple atmospheric models have been used to obtain reflectance values that could be compared with values determined from ERTS-1 data in several studies; in two investigations, existing numerical models (Long Island-Block Island area by Yost and in Lake Pontchartrain by Hidalgo) were tested using ERTS-1 data and were found to be inaccurate. A study (Polcyn) of the Lake Ontario watershed has a major goal of delineating parameters necessary as inputs to a predictive hydrographic model of the lake and basin. In general, however, more data gathering is required before ERTS-derived information can contribute significantly to water quality modeling.

A number of innovative interpretative techniques evolved during the ERTS-1 investigations of water quality. A significant and potentially rewarding capability (Scherz, Yost, Wezernak, Yarger, Pirie, and A. Williamson) is that the determination of average reflectance from small areas of water having uniform characteristics can be related to suspended solid concentration in the water (between 5 and 1,000 mg/l). The high reflectivity of algae in the near infrared permits the detection of algal blooms in both lakes and rivers (R. Rogers). All of these data provide assistance for the eventual assessment of eutrophication.

Work needed to make applications in this subdiscipline fully operational includes extensive testing with major ground-truth efforts in an attempt to make suspended-sediment content and chlorophyll determination more quantitative and to explore more thoroughly the accuracy that can be obtained. Additional work is also needed to identify types of natural sediment and pollutants in waste plumes by their spectral signatures, to upgrade data processing procedures in extracting noise and removing atmospheric effects, and to make documented procedures available to the maximum number of investigators and users. One additional requirement is for inter-investigator comparative studies. A common test site with abundant ground truth would provide for the possibility of comparing the various techniques employed by different organizational groups, especially where different techniques are used to measure similar properties. Finally, it must be emphasized that essentially all the ERTS-1 data related to water quality have been extracted from only a few data levels due to the low reflectivity of water features compared to land features. It is recommended that more ERTS passes be made at higher gains on the MSS to improve the data quality for use by investigators concerned with water features.

Land Quality

Investigations related to land quality extend from arid areas (Arizona) to alpine and tundra areas (North Slope of Alaska), with analysis techniques ranging from photointerpretation of a single ERTS-1 image to sophisticated computer programs operating on CCTs. Progress in these investigations covers a similarly wide range.

The important identifications and measurements include delineation of strip-mining areas in which not only the stripped areas but also the reclaimed regions are measured, monitoring of construction practices, mapping to allow siting of new construction, and mapping of urban quality.

Schubert and MacLeod reported that they have mapped the strip mines in a 1,526-km² (377,000-acre) site in western Maryland. Their results agree to within 10 percent of the areas as recorded by the State. Since State records are not current, the discrepancy between actual mining areas and measured values is believed to be less. R. Rogers and Pettyjohn have performed a similar analysis over five southeastern Ohio counties. They suggested that the measurement of the reclaimed areas can be used to judge when performance bonds given by the mining companies can be returned. McMurtry and Ward have used ERTS-1 aircraft imagery and the Penn State University computer system to map the strip mines in central Pennsylvania. Trenched areas, recent workings, and partially vegetated areas, as well as vegetation areas damaged by acid drainage, were identified.

Yunghans reported that the State of New Jersey is satisfied that new construction (particularly in the protected wetlands) can be identified from ERTS-1 images so that ground personnel can evaluate compliance with regulations. The Cold Regions Research and Engineering Laboratory of the U. S. Army Corps of Engineers (USACE-CRREL) has prepared vegetation and permafrost maps of portions of Alaska with details that have never before been available; D. Anderson reported that such maps could be used in evaluating sites for the oil pipeline.

Hidalgo reported that he has classified the City of New Orleans into quartiles according to urban quality, using CCTs and software developed at Tulane University. Investigations were also concerned with the difficult task of monitoring desert vegetation. Lepley has had only limited success in delineating plant communities in the arid lands of Arizona. A possible reason for this is the high reflectance of the land, which nearly saturates the ERTS-1 detectors. Vegetation damage was also addressed in a limited way. McMurtry reported that the extent of the gypsy moth infestation in Pennsylvania was mapped using existing techniques. Vegetation damage due to highway salting practices in Maine was not widespread enough to be detected by ERTS, but aircraft imagery was of direct value (Stoeckeler).

Very little predictive modeling has been done in this subdiscipline. The subject is not particularly suited to modeling; that is, the analysis is quite direct. A classification is made and the object is either found or not found.

A variety of interpretive techniques have been reported. Mapping vegetation and permafrost in Alaska has been accomplished from tonal analysis of transparencies. This is an adequate technique for this application for the present. Although wetland construction can be monitored using photointerpretive techniques, Yunghans feels that computer analysis will be more effective. Those investigators who have used computer analysis feel that classification studies are, by far, most easily done using CCTs. McMurtry, MacLeod, and Schubert have developed a software package that can be controlled by remote terminal, thus allowing users without large computer capability access to their analysis techniques. The Bendix Corporation was reported by R. Rogers to have developed a computer-controlled technique for constructing geometrically-correct maps to selectable scales.

Useful applications that have been identified include the monitoring of strip-mining operations, the monitoring of new construction and its effects (filling and clearing in wetland areas have been particularly identified), mapping of vegetation and permafrost for siting of new construction (particularly in arctic and subarctic regions), and finally the analysis of ERTS-1 CCTs to give four environment classes.

Documenting procedures is an activity that needs to be stressed. MacLeod, McMurtry, and Alexander have shown reports that describe how others can use their analysis techniques. There exists a continuing need for closer work with user organizations to interpret the results in terms of accuracy, especially as applied to land and vegetation mapping accuracies. Such results are required so that the cost and benefits to users can be adequately developed. The feasibility of monitoring vegetation stress should be pursued.

Wildlife Resources

ERTS-1 imagery is being used in wildlife management to identify and measure a number of habitat parameters such as vegetation, soil, and water, which support the animal life under consideration. Under normal population densities, terrestrial wildlife species are not resolvable on ERTS-1 imagery. However, wildlife investigators have been successful in identifying and measuring habitat factors that have both direct and indirect influences on wildlife populations. The different combinations of vegetation, soil, and surface water as affected by altitude, climate, and latitude are very meaningful indicators of supportive systems for bird and mammal populations. A major advancement made in this discipline by ERTS-1 is a significant improvement in synoptic vegetation mapping capabilities. The repetitive coverage provided by ERTS-1 provides an opportunity to record phenological changes in habitat that have important influences on wildlife resources.

In the past, vegetation maps of certain wildlife habitats have been gross generalizations due to the difficulties of access to remote and sometimes hostile terrain. ERTS not only permits access to remote areas but also permits a synoptic view of the ecosystems. ERTS vegetation maps have between eight and ten vegetation classes with relatively detailed peripheral boundaries as compared to the former maps of two to four classifications having very generalized boundaries. When surface water mapping is combined with vegetation and soil maps, significant habitats can be delineated. Flood plains identified by water patterns and vegetative cover identify range forage for grazing animals. Range forage measurements in wildlife habitats are important, for there is often competition in real life for the forage between domestic and wild ungulates. Specifically, it has been pointed out that many different habitats can be identified. Four separate permafrost habitats have been delineated by D. Anderson for regions in Alaska. J. Anderson has found that as many as ten vegetative classes can be identified. However, accurate ground truth is needed to verify complex vegetation classification systems. Two investigators have identified specific habitat features important for game management purposes. The Bureau of Sport Fisheries and Wildlife (BSF&W) found pond data in numbers of ponds of one pixel size or larger to be potentially useful in models predicting the breeding ground production of mallards and other waterfowl species (Work, Gilmer, and Klett). The University of Montana defined grizzly bear habitats for efforts involved in the relocation of this diminishing animal species to remote wildlands where man-bear encounters will be reduced, and where the habitat will support the animal so that it will not wander out to civilized country looking for food (Craighead, Sumner, and Varney). Other measurements relevant to animal habitat studies include effects due to forest fires and gypsy moth infestations (McMurtry).

Most of these results have been developed using photointerpretive visual techniques with aircraft observations or photography for more detailed checks. Ground truth was sometimes done through other individuals or institutions active in the study area. Some use was made of the CCTs; however, more work should be done for this specific application. Need was also noted for increased processing rates at both ground station and subsequent automatic data processing (ADP) facilities as operational usage for management decisions is approached.

The work needed in wildlife management is for more ground truth to verify remotely sensed data. Many principal investigators have made use of aircraft; however, field data are essential for future efforts. Digital techniques should also be pursued. Work designed to improve pixel

resolution capability such as proportion estimation should be investigated thoroughly. Development and application of multistage sampling techniques will result in the most effective use of satellite, aircraft, and ground-truth data collection systems.

General Environment

The activities in this subdiscipline include air quality and meteorology and short-lived events. These categories of investigation represent environmental areas not covered in the previous subdiscipline breakdown.

Air Quality and Meteorology

The ability to detect certain-types of air pollution from ERTS-1 imagery has been noted by a number of investigators. For example, Lyons has shown that the interaction of air pollution and meteorology over the Great Lakes leading to inadvertent weather modification can be observed. Griggs found that radiance measurements over water could be used to calculate the vertical aerosol burden to an accuracy approaching ± 10 percent. Ward showed a similar variation over Harrisburg, Pennsylvania. Copeland has confirmed that ERTS can be used to detect smoke plumes and aircraft contrails. E. Rogers, in studying haze in the Los Angeles Basin, found a correlation between radiance and visibility, but concluded that the radiance values over land were not a particularly sensitive measurement of air pollution. Cloud-seeding results have been monitored in the Colorado River Basin by Kahan, using the ERTS data collection system (DCS) capability.

The use of analytical models in conjunction with ERTS-1 data has been studied by Lyons and Griggs. Lyons is modeling the Great Lakes area to study the interaction of air pollution and the dynamics of cloud behavior and has shown verification in a qualitative sense. Griggs is using models of the atmospheric aerosol distribution as part of his data analysis technique to convert radiance values to aerosol burden. Several investigators are considering the use of ERTS-1 imagery for verification of models to predict plume and contrail dispersion, but no definitive results are available to date.

Global aerosol monitoring and air pollution-meteorology interactions are problems where data at ERTS resolutions can potentially make contributions. Work is still needed, however, to better quantify the observed values. In addition, work is required to understand the significance of a measurement of vertical burden of pollution and the interrelationship of this measurement with available analytical models.

Short-Lived Events

In cooperation with the Center for Short-Lived Phenomena of the Smithsonian Astrophysical Observatory, the ERTS system has attempted the observation of various events to evaluate the potential of space imagery for additional information. Of 51 events requested, ERTS-1 was able to provide imagery on 19. These included volcanoes, oil spills, earthquakes, forest fires, and

vegetation changes. The evaluation showed that the processing lag would have to be reduced to 10 days or less, depending on the event, to be of maximum value in the information-distribution function of the Center, but that the imagery at a later time could be of value to scientists or user organizations concerned with the particular event.

PROJECTED APPLICATIONS

Detection and Monitoring of Lake and River Water Quality

ERTS data can possibly be used to detect, locate, and monitor a number of pollutants that affect water quality in fresh water lakes and rivers. Included are suspended sediments, chemical wastes, oil spills, acid mine drainage, sewage wastes, and perhaps thermal pollution. Lake eutrophication, with attendant algal blooms, can also be monitored. More specifically, suspended sediment studies can be used to monitor circulation patterns and estimate river and lake sediment loads; sewage pollution studies can detect previously unknown or illegal outfalls and monitor the movement of large quantities of sewage. The locations of fresh water sources in relation to the movement of sediment, industrial wastes, and sewage may be possible. Hydrologic models can obtain input from ERTS, such as vegetation coverage, drainage patterns, and erosion (Halliday, Cooper).

A number of current ERTS-1 studies have shown that estimates of sediment load can be made (Scherz, MacLeod, and Kritikos) and that current patterns in lakes can readily be identified (Scherz, Polcyn, Wezernak, and Hidalgo). Some types of chemical/industrial pollution have been detected, for example, waste from paper mills (Lind). Sewage pollution, oil spills, and acid mine drainage, because of low reflectance and small scale, are difficult to detect and monitor, but some success has been reported (MacLeod, Wezernak, Deutschman, and McMurtry). Lake eutrophication monitoring investigations have met with limited success (Scherz, R. Rogers) and techniques for chlorophyll measurements (Yost) may be valid for larger lakes. Input to a hydrologic model for the Lake Ontario Basin has been made from ERTS by Polcyn. Scherz demonstrated how study of an ERTS image of Lake Superior could have prevented the placing of a fresh water intake pipe in an area of high sediment load.

Basic research into the relationship between spectral reflectance and sediment load should be performed so as to make it possible to get quantitative measurements of river and lake loads and movements. Lake eutrophication studies should be stressed as there is a great interest in monitoring and protecting our lakes from manmade nutrient loading at this time. More emphasis should be placed on automatic data processing and data enhancement techniques. Attempts should be made to relate ERTS data to current models of water quality management.

Detection and Monitoring Of Coastal Zone Water Quality

There is a continuing need to monitor and evaluate factors that affect the quality of the water in the coastal zone so that proper measures may be taken to preserve this resource. It is necessary to detect and monitor large-scale ocean dumping and to detect certain kinds of

wastes, to monitor current directions at given times using natural tracers, to detect and monitor changes of suspended sediment concentrations and possibly chlorophyll content of the upper levels of the water column, to detect large oil spills, and to detect and monitor effects of major sewage and thermal outfalls. These capabilities can contribute to major, cost-effective applications that are especially needed now when construction of offshore supertanker terminals is anticipated, and when accelerated construction of offshore nuclear power plants is a certainty.

Large-scale ocean dumping can be detected (Wezernak, Yost, and Yunghans), and dumped acid iron wastes can be differentiated from some other types (Wezernak). Furthermore, dispersal of such waste can be traced (Yunghans) using ERTS and aircraft imagery. Estimates of suspended sediment content can be made from ERTS-1 reflectance values (Wezernak, Coulbourn, A. Williamson, and Pirie), and surface longshore patterns can be recognized from turbid plume patterns (Yost, Yunghans, Hidalgo, Pirie, and D. Berg). The detection of oil on inland water has been achieved (Deutschman) and thus the detection of large, offshore spills may be possible.

ERTS cannot supply all of the measurement and monitoring capability required for an optimum detection and monitoring system. Other satellites will be required (NIMBUS-G and others), as well as DCS applications. Additional work on the relationship between reflectances and turbidity and chlorophyll in various marine environments (including suspended material of various kinds and sizes) is needed to verify and/or establish techniques, with adequate consideration given to water surface and atmospheric effects on reflectance. Furthermore, because of the variety of techniques employed by different investigators, a common evaluation test site should be selected where all techniques can be tested against abundant water property measurements and with ERTS measurements made at higher gain. Much more work in physical modeling is also required to evaluate dispersion characteristics of dumped wastes and outfalls. ERTS data on surface circulation patterns can provide inputs to these models, but more importantly, can verify these models.

Strip Mining And Construction Monitoring

The ability of ERTS-1 to transmit images that allow differentiation to be made between bare soil and several densities of vegetation has suggested to several investigators (MacLeod, Ward) that strip-mining scars could be delineated from ERTS data. From the vegetation classification, reclaimed land can be mapped. This is possibly the application that is most nearly operational. The resolution of the ERTS-1 MSS is suitable, the 18-day coverage cycle is more than adequate so that cloud-cover problems are reduced, and all the investigators listed have developed techniques to map both strip-mined areas and reclaimed land. These land classification schemes can also be used to identify construction in progress as well as damaged vegetation when the damage is extensive.

Detection of changes associated with construction sites is less ready to become operational. To be useful in discovering illegal construction acts, the timeliness of the images must be improved from the month(s) it now takes to be received to one week. More verification of analyses is needed. The feasibility of strip-mine mapping has been shown, as has the construction

monitoring for a highway (R. Rogers). The applications in Alaska are of special importance since the harsh environment there has impeded other sources of data.

Little or no work should be needed for the strip-mining application. MacLeod reported that a classification of an ERTS-1 image of western Maryland covering over 1,526 km² (377,000 acres) gave the strip-mined area to within 10 percent of the State data. (The accuracy is probably better than this because new areas have been mined which the State has not yet entered into its system, but which were detected through ERTS-1.) R. Rogers, who worked with an Ohio site, and McMurtry along with Ward, who used the Penn State University system and worked with Pennsylvania sites, reported equally encouraging results. The MacLeod program can be run from a remote terminal (IBM 360 compatible). MacLeod reported that classifying the 1,526 km² (377,000 acres) took less than 1 hour.

Wildlife Habitat Assessments

Habitat delineation through ERTS sensing of vegetation, water, and soil is a direct evaluation of the carrying capacity of different ecosystems for various wildlife species. Maps showing habitat features can be prepared using ERTS data.

The foundation of wildlife management is an assessment of the supporting food and protection base for the wildlife, and that base is primarily vegetation, water, and associated food chains. Hence, the first step to ecosystem definition in the University of Alaska study (J. Anderson) is detailed vegetation mapping. In another University of Alaska study of caribou habitats (Lent), it was emphasized that vegetation mapping is critical in identifying fall and spring habitats. An analysis is underway to determine whether winter migration routes could be identified by relative amounts of snow accumulation on a chronological and snow-melt basis. An independent study at the University of Montana utilizing ERTS data showed the feasibility of using the data for evaluating grizzly bear habitat by mapping the vegetation suitable to support this animal in its home range (Craighead, Sumner, and Varney). In another study for the Bureau of Sport Fisheries and Wildlife (Nelson) to provide information needed in annual waterfowl management programs, ERTS-1 data are being used to identify critical habitat factors such as numbers of ponds for breeding and brood rearing, plus other parameters associated with waterfowl habitat (Work). Efforts should continue in all cases with more emphasis on ground truth and verification.

The second area for expansion of effort is an increased use of CCTs and less reliance on photointerpretive techniques. Users are already identified and in all cases are continuing some logistic support. Continued work is needed in the application of multistage sampling techniques using ERTS, aircraft, and ground-truth data to accomplish the monitoring and assessment of wildlife habitat effectively.

Monitoring Atmospheric Pollution Burden

Another application of ERTS imagery is the study of atmospheric pollution and the interaction of this pollution to produce weather modifications. The possibility of inadvertent weather

modification due to man's activities has been widely noted and the subject of recent international meetings (SCEP, SMIC). The need for monitoring cloudiness and aerosol burden was stated at each of these meetings. ERTS offers the possibility of studying global aerosol burden and thus the possibility of global weather modification, as well as studying local pollution sources and the interaction of these sources with local weather patterns. In addition, ERTS can see high-altitude contrails and thus be a useful tool in assessing the impact of aircraft operations on cloudiness and climate.

The ability of ERTS-1 to detect certain types of air pollution has been noted by a number of investigators (Lyons, Griggs, E. Rogers, and Copeland). Lyons has shown that the interaction of air pollution and meteorology in the Great Lakes can be studied. Griggs found that the radiance measurement over water can be used to calculate vertical aerosol burden to within approximately 10 percent. Work is needed to further validate these observations. Attempts should be made to make measurements of aerosol burden at other locations. Additional work is required to understand the significance of the vertical burden measurement in terms of the use of this type of data to predict changes in global heat budget. Work is also required to apply these data to models to predict aerosol dispersion and resulting changes in climate.

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EDITOR'S NOTE

This summary paper in the Interpretation Techniques discipline area was compiled from presentations made to the Interpretation Techniques Discipline Panel (see Appendix 1) between October 22 and November 2, 1973, and from papers presented at the Third ERTS Symposium, December 10 to 14, 1973. The members of the Working Group, which met on December 14 to extract the Symposium results, are listed in Appendix 2.

SUMMARY OF DISCIPLINE RESULTS

The image enhancement and geometric correction and registration techniques developed and/or demonstrated on ERTS data are relatively mature and greatly enhance the utility of the data for a large variety of users. Pattern recognition was improved by the use of signature extension, feature extension, and other classification techniques. Many of these techniques need to be developed and generalized to become operationally useful. Advancements in the mass precision processing of ERTS were demonstrated, providing the hope for future earth resources data to be provided in a more readily usable state. Also in evidence is an increasing and healthy interaction between the techniques developers and the user/applications investigators.

RESULTS SUMMARIES OF SUBDISCIPLINE AREAS**Enhancement**

Enhancement (as distinct from pattern recognition and classification) is defined here as that set of processes particularly devised to assist a photointerpreter in his task. In general, it will not result in any map-type products. Although classification in the usual concept is also followed by further interpretation of its products, it will be considered here that the decision process involved in classification separates it from enhancement, in which no decision process is involved. The piecewise nonlinear step function used for density slicing, and the products derived therefrom, are considered enhancement, but are not considered further here, as they are

relatively primitive, although useful for some applications. Papers considered to be primarily concerned with enhancement were Colwell and Algazi, Serebreny, Ross, Yost, Goetz and Billingsley, Taylor, and Nielson. Papers with other primary concerns, but in which enhancement for photointerpretation is utilized, were Malila and Nalepka, Belon, and Bodenheimer.

A time-lapse display system, using a television display and obtaining input data from film, was developed by Serebreny. This dynamic display has proven useful for understanding the dynamics of changing data. The interaction and time-lapse capabilities aid the analyst in the task of converging on quantitative descriptions of image enhancement parameters and of the dynamics of time-varying phenomena. The system allows simple manipulation such as ratioing and can display image parameters such as two-dimensional cluster diagrams for analysis. Another approach to time-lapse composites depicting temporal evolution was demonstrated for agriculture scenes by Gramenopoulos.

Algazi has continued to work on manipulation for photointerpreter analysis with nonlinear stretching to make maximum use of the histogram data and to best present a series of gray levels to the human eye. Histogram equalizing has been used to minimize banding. Analysis of eigenpictures (those pictures formed through eigenvector analysis) showed that the axis rotations required for the first two eigenpictures are essentially independent of scene content. This points the way toward producing these eigenpictures as standard products. Eigenpicture display has also been demonstrated by Taylor. Analysis of several scenes suggests that specific interband combinations (axis rotations) optimized for particular types of target areas (for example, forests and urban areas) may allow presentation of the data as three-variate. Through proper display, this in turn will allow presentation of the data in color. This display, although presenting colors differently than usual, provides improved differentiation of various materials.

Photographic enhancement has been used by Yost, Ross, and Nielson. Isoluminous pictures, in which the brightness component has been eliminated, display color components unaffected by brightness. This display enhances the human's ability to visualize image color differences. Ross has developed a technique for estimating contrast reduction due to atmospheric haze, and techniques for high-contrast photographic reproduction to compensate for this effect were demonstrated. It has also been shown that a first-order correction for the return-beam-vidicon (RBV) shading can be obtained by masking with a picture of an area containing no features, such as over water.

Nielson, using Agfacontour film, applied density slicing in forestry, water, and land use studies. ERTS multispectral scanner (MSS) imagery, because of the uniformity of the data and small scan angle, lends itself to this relatively simple technique, particularly in level areas.

Digital ratioing, utilized by Goetz, is a technique that clusters regions of like spectral reflectivity, regardless of brightness differences caused by geometric factors such as surface orientation. Comparison of a normal color-additive image and one produced from selected ratios indicated the separability that can be obtained between mineralized areas and other areas of similar visual color. Digital spatial frequency filtering was also demonstrated by Goetz to enhance geologic features and make linear structures, joints and faults not otherwise discernible on unenhanced images. For investigations requiring the ultimate in resolution, Goetz

demonstrated that digital correction of the modulation transfer function of the MSS may be applied to optimize the resolution of image products.

The techniques described seem reasonably mature (although considerably more work must be done in applying them), with the exception of the eigenpicture display. The set of manipulations involving spectral band combination (principal components, maximum dispersions, ratioing, and the like) bear more investigation as aids to display, interpretation, and analysis.

Radiometric Corrections

Radiometric corrections are corrections to the data magnitudes arising from a variety of sources, the most common of which are calibration errors, data recording and processing errors, and solar and atmospheric effects.

Calibration corrections are conventionally made at the GSFC ground data handling system for ERTS. The only investigation that emphasized an activity in this regard was that of Bernstein, who developed and demonstrated a digital correction of RBV shading effects.

MSS data problems (dropout, banding, and so on) have been experienced by investigators and reported at the ERTS Symposium held in March 1973. Several investigators discussed the interpolation of data to compensate for dropouts. Most significant were the results presented by two investigators on the effect of banding in the ERTS data caused by the incomplete calibration correction for the variances in response of the six detectors* in each ERTS MSS band. McMurtry presented results in which the means and standard deviations were computed for a forested area in Pennsylvania for each detector of each ERTS MSS band. Although the means and standard deviations varied slightly for each detector, it was pointed out that the mean value of one detector of MSS band 3 was at a value of 3.5, which was less than one-tenth the value of the mean for all the other detectors. Additionally, the standard deviation of the corresponding detector of MSS band 4 was six times larger than the standard deviation for the other five detectors. An algorithm was developed for correcting these effects and is reportedly in standard use by the investigator for improvement of classification results. Swanlund also investigated detector variability and performed a six-class classification of a forested area in Minnesota utilizing subsets of detectors separately. This resulted in a classification accuracy of 87.5 percent when detectors 1, 3, 4, and 6 were used for classification and training. When detector 2 (consistent attenuation in MSS band 1) and detector 5 (random attenuation in MSS band 3) were trained on separately, classification accuracies of 89 and 86.5 percent, respectively, were obtained. These results were contrasted with the 75-percent accuracy obtained when all detectors were used together.

The findings of McMurtry and Swanlund show variations in different bands and detectors, indicating that banding is most likely a problem in the processing of ERTS data and not a

*The term "detector" is used here to denote the entire signal channel from a detector element through the electronic amplifiers and recorder to the final output product.

systematic problem associated with ERTS. In April 1973, GSFC modified its procedures in data conversion/calibration, and it is thought that large effects of this type are removed from data digitized after that date. Additional refinements were made in November 1973 to remove banding at high radiance values.

Malila, Rogers, and Thomson presented results of investigations that were concerned specifically with the development of techniques for the assessment and/or removal of atmospheric effects from ERTS data so that determination of surface radiance and reflectance can be made and/or classification performances improved. The removal of, or adjustment for these effects are considered necessary in the classification and pattern recognition processes where ground-truth sites are used as training samples and the signatures are extended over other areas in the recognition process. If variations in the atmosphere are large enough to introduce significant variations in the signature, then the recognition performance will suffer. Sun angle and scan angle effects are also involved. The degree to which the atmosphere affects the measurements depends on the turbidity and the humidity of the atmosphere. These effects can be described theoretically and can be estimated by the use of radiative transfer models. For a very clear, dry atmosphere, the atmospheric effects may be small enough in some studies to be neglected. Also, in applications of ERTS data where specific knowledge of target reflectance is unimportant (for example, fault-line detection and water-land interface mapping), but relative changes in reflectances are important, atmospheric effects often can be and usually are disregarded.

In general, however, the distribution of atmospheric constituents is not measured at the time of an ERTS pass, so that radiation models could be used to calculate atmospheric effects. Hence, investigators must develop alternate techniques (which may use the models) for circumventing atmospheric effect problems. Malila developed a technique for using ground-based-visibility (or optical-depth) measurements for the purpose of selecting a model atmosphere that is assumed to be characteristic of actual atmospheric conditions prevailing during the experiment. A technique using water bodies and dark objects in the imagery for estimation of path radiance, used in assessing atmospheric variations in the imagery, was also described. A comparison of the model calculations with ERTS-derived values for water bodies is given in Figure 1. Ross demonstrated a photographic technique for eliminating haze effects using reflectance from water bodies in ERTS bands 6 or 7.

Roger's investigation resulted in the development of a radiant power measuring instrument (RPMI) for making the ground-based measurements of solar and sky radiance that are necessary for correcting ERTS data for atmospheric effects. He also developed a technique to use the RPMI to transform ERTS data into absolute target reflectances. The measurements were applied to determine the variation in atmospheric transmittance and scattered energy to the spacecraft from the atmosphere in the ERTS bands. Both Malila's and Rogers' results indicate a possible bias in the ERTS absolute calibration data. Further refinement and evaluation of the techniques developed by Malila and Rogers will be required before these techniques can be routinely applied to correct ERTS data.

Geometric Correction and Registration

Users of ERTS-1 data have established a variety of requirements for geometric correction and registration of ERTS data. The most commonly identified are:

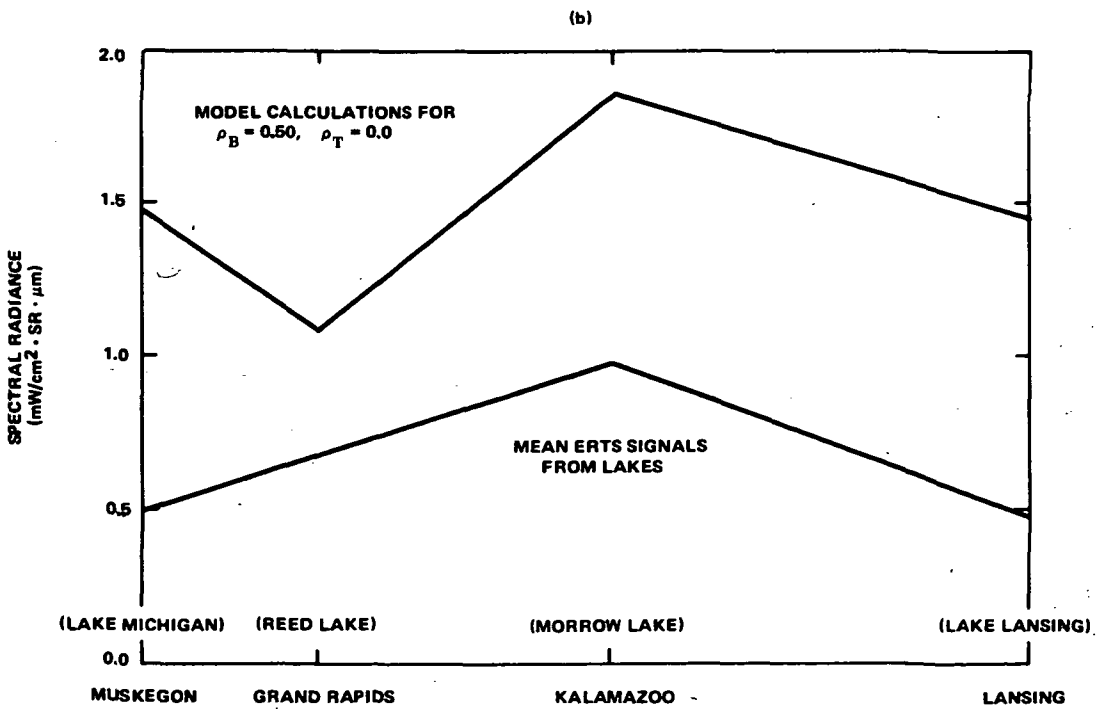
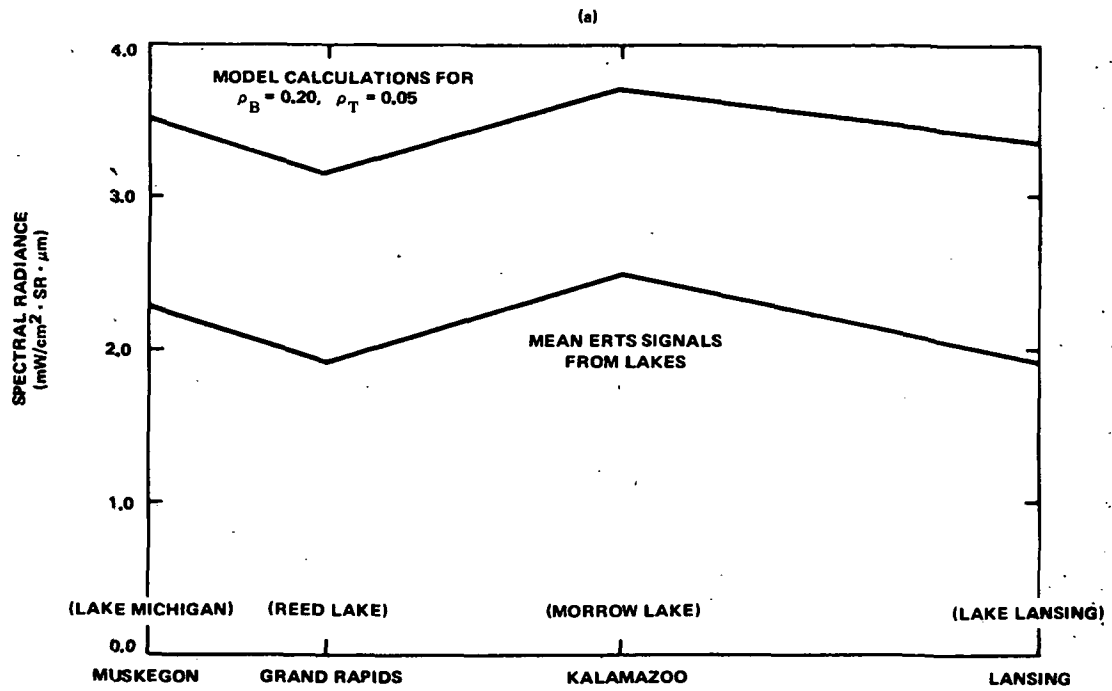


Figure 1. Comparison of model calculations with radiances extracted from ERTS data for water bodies.
(a) Muskegon to Lansing transect, $\lambda_c = 0.65 \mu\text{m}$. (b) Muskegon to Lansing transect, $\lambda_c = 0.95 \mu\text{m}$.

To accurately define the location of the small areas within the data that contain the ground-truth region to be used in training a classifier; to overlay a ground-truth product (map, high resolution photo, and so on) on classification maps; location of a specific object relative to a conventional reference system; overlay of separate passes of ERTS data over a region for temporal analyses; and generation of geometrically correct thematic maps.

The first four items in the preceding paragraph require some type of registration function, and the last requires a geometric correction operation. Frequently, both registration and geometric corrections are utilized to solve each of the above requirements.

Two separate approaches were reported concerning the location of training-field data. Hoffer reported the development of a preprocessing technique that utilizes the latitude value of the spacecraft as input to a nominal correction function to eliminate the skew (earth rotation) in the line printer output of ERTS data. This process provides a printout at a scale very nearly 1:24,000, which can be used to overlay a U. S. Geological Survey topographic map. Although the fit is not exactly precise, this approach has the advantage of providing subsequent results in the same format since the data tape is corrected. Malila and Peet reported a procedure that employs a least-squares affine transformation algorithm to warp earth coordinates from topographic maps or aerial photographs to match ERTS data coordinates. The advantage of this approach is that no interpolation or deletion of ERTS data is involved in the process.

In the area of geometric correction, Bernstein and Taber reported on results associated with feasibility studies for precision processing of ERTS data on general purpose computers and on minicomputers with special purpose hardware. Taber developed a distortion model utilizing ground-control points, spacecraft ephemeris, and attitude and rate data for the corrections. The resampling problem associated with geometric correction was also examined by implementing nearest neighbor bilinear, sine x/x , and cubic convolution interpolation schemes. The bilinear interpolation scheme caused loss of resolution; the nearest neighbor scheme was fastest. One test image was interpolated at the midpoints between pixels, and a ± 30 -point sine x/x interpolation was used as a standard to measure intensity errors. The error histograms shown in Figure 2 indicate that the cubic convolution is far superior to the bilinear and nearest neighbor and almost equal to the ± 5 -point sine x/x interpolation. Quantitative evaluation of these interpolation transformations by examination of their effect on data analysis (for example, classification) is being pursued by Taber.

Bernstein investigated the problems associated with both RBV and MSS correction and registration. For the RBV, a digital reseau detection algorithm that allows for the removal of the internal distortions was developed and demonstrated. The results are given in Table 1. Also evaluated were the effects of MSS band number, target type, and time differential on the identification and location of natural and cultural features within the data using automatic correlation (IBM sequential similarity detection algorithm), with the stored digital images of these features used as ground control points. The time required for the correlation processing was also evaluated, and the results are given in Table 2. For the geometric correction/registration, ground control points were utilized to model the pitch, roll, and yaw of the sensor over the period of an ERTS frame, and the points typically generated a bivariate correction function of fifth order polynomials using a least-squares error correction. An error propagation model yielded expected results on the order of one pixel rms for the ERTS MSS

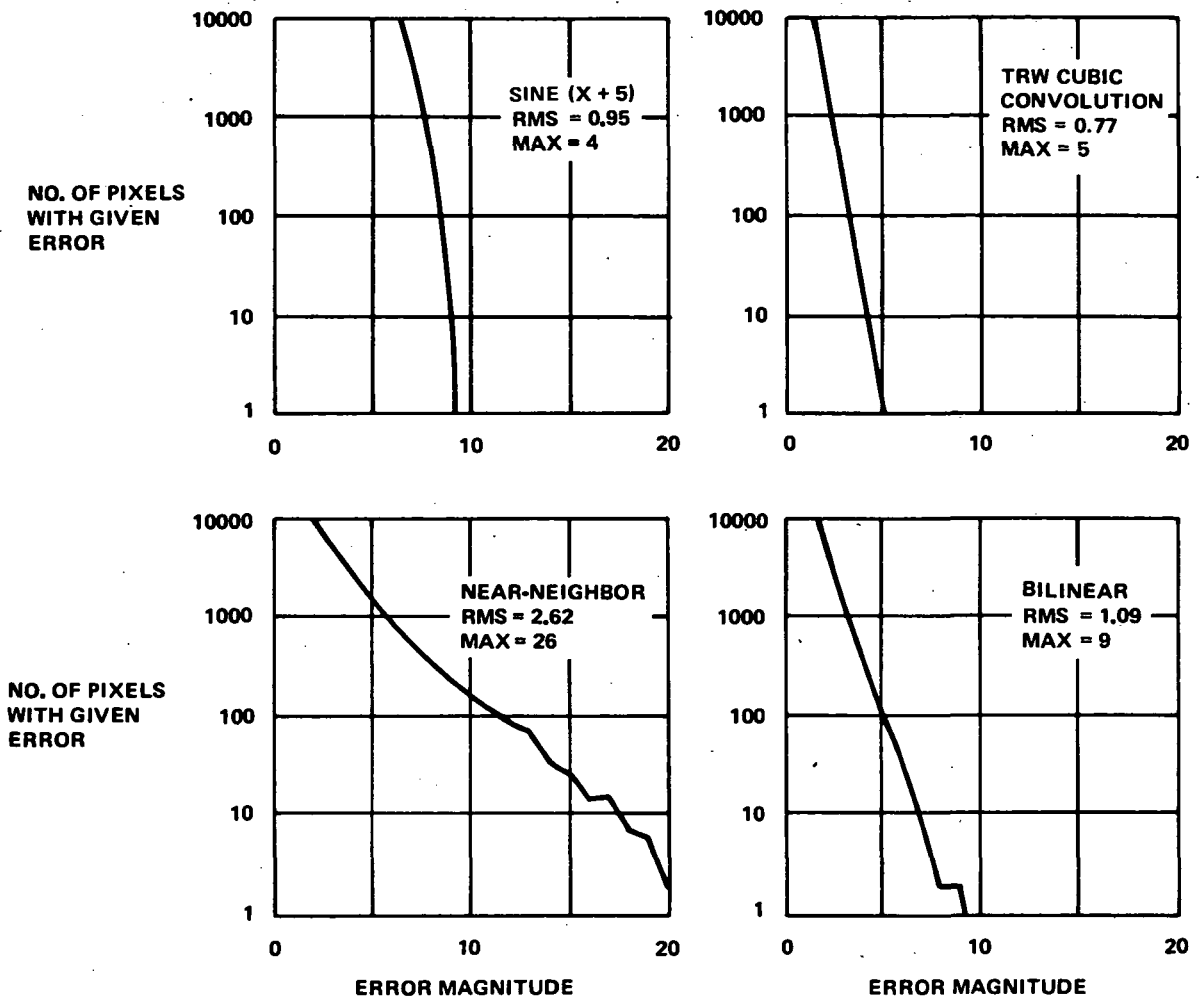


Figure 2. Error between registered images due to resampling.

system (Table 3). An analysis of accuracy versus number of control points was also made for the MSS, based on a corrected frame utilizing the above techniques. The results (Table 4) indicated that 9 to 12 ground control points were sufficient for a single frame. This number (nine) is one point over the theoretical minimum for the technique used.

A number of investigators illustrated the registration of temporal scenes from ERTS. However, most involved conventional optical techniques. Taber performed digital geometric correction of two temporally separated scenes and then differenced the intensity values. The resulting difference image is a dramatic demonstration of misregistration caused by the nearest neighbor line length correction introduced by the NASA Data Processing Facility (NDPF). Peet effectively registered scenes by relating points between two images by affine transformation equations. Hoffer registered six temporally separated scenes to form a 24-channel data set that was used to show snow cover changes. Bernstein illustrated the effectiveness of his geometric

correction process by overlaying two geometrically corrected images. Two separate ERTS scenes were interlaced over an urban area, which resulted in an apparent increase in resolution.

The digital registration/geometric correction technology appears to be well advanced although evaluation of the techniques must be completed. A study to determine the best choice of a standard reference grid should be initiated. Development of an efficient technique for constructing a ground control data base appears necessary for an operational digital system.

Table 1
Digital Reseau Detection Results

True Reseau – Real Reseau In Search Area		
	Reseaus searched for	486
	Reseaus correctly found	486
	Reseaus incorrectly rejected	0
False Reseau – No Real Reseau In Search Area		
	Reseaus searched for	486
	Reseaus correctly rejected	486
	Reseaus incorrectly accepted	0
Scenes Used:	Monterey E-1002-18134 25 July 1972	Phoenix E-1014-17375 6 August 1972

Pattern Recognition and Classification

Major emphasis reported in pattern recognition and classification involved evaluation of existing technology against the specific characteristics of ERTS for applications feasibility. In the March 1973 ERTS Symposium, it was widely reported that the high altitude and small field of view of ERTS as compared to aircraft data greatly minimized the problems associated with scan angle in signature extension. Furthermore, the repetitive coverage of ERTS provides an important new aspect in the temporal analysis of data. Significant refinement, extension and/or verification of technology in pattern recognition and classification was presented in the areas of spatial pattern recognition, signature extension, and signature analysis.

Gramenopoulos, Haralick, Swanlund, and Davis reported positive results in the development and demonstration of techniques for the use of spatial features and/or texture in pattern classification. Three of the investigations demonstrated an improvement in the identification of level-1 land use categories; the other utilized spatial information in geologic terrain classification. In general, these techniques need additional refinement, to be demonstrated in other geographic areas using more complete features to further assess their broader use, and the results need additional quantification. Also, as with any newly demonstrated technique,

Table 2
Initial SSDA Results

Target Type	Band 4		Band 5		Band 6		Band 7		Temporal Separation/ Location
	No. Found/ Tried	Average Time (Sec)	No. Found/ Tried	Average Time (Sec)	No. Found/ Tried	Average Time (Sec)	No. Found/ Tried	Average Time (Sec)	
Large Land-Water Interfaces Interstate-Grade Highways Airports	5/5 1/1 2/2	46 51 12	5/5 1/1 2/2	29 47 4	5/5 1/1 2/2	4 40 8	5/5 1/1 2/2	15 45 22	17 Days Chesapeake Search: E-1062-15190 Window: E-1079-15140
Large Land-Water Interfaces Airports Small Land-Water Interfaces Non-Interstate Highways	4/8 0/0 1/1 0/0	50 — 49 —	7/21 1/2 1/1 16/16	27 9 30 9	15/21 2/2 1/1 15/16	5 11 8 27	17/21 2/2 1/1 14/16	14 27 29 50	18 Days Chesapeake Search: E-1080-15192 Window: E-1062-15190
Large Land-Water Interfaces Interstate-Grade Highways Airports Small Land-Water Interfaces Hills Fields	4/6 2/8 0/2 2/3 1/2 1/1	4 5 — 12 6 4	6/6 6/8 0/2 3/3 2/2 1/1	3 12 — 12 6 3	5/6 6/8 1/2 3/3 1/2 0/1	3 37 48 49 5 —	5/6 6/8 1/2 3/3 2/2 0/1	7 20 7 6 52 —	36 Days Phoenix Search: E-1049-17324 Window: E-1085-17334
Large Land-Water Interfaces	1/2	5	2/2	4	2/2	3	2/2	6	72 Days Phoenix Search: E-1049-17324 Window: E-1121-17330
Large Land-Water Interfaces Interstate-Grade Highways Airports Small Land-Water Interfaces Hills Fields	2/4 4/8 2/2 2/2 2/2 0/1	3 39 49 64 52 —	1/4 4/8 2/2 2/2 2/2 0/1	2 7 8 8 16 —	2/4 2/8 1/2 1/2 0/2 0/1	2 3 6 3 — —	4/4 4/8 2/2 2/2 2/2 0/1	7 60 71 62 63 —	90 Days Phoenix Search: E-1121-17333 Window: E-1031-17325
Large Land-Water Interfaces Interstate-Grade Highways Airports Small Land-Water Interfaces Hills Fields	3/4 3/5 0/2 1/2 2/2 0/1	5 11 — 63 50 —	4/4 3/5 0/2 1/2 2/2 0/1	3 4 — 9 15 —	2/4 0/5 0/2 0/2 1/2 0/1	2 — — — 8 —	4/4 2/5 2/2 1/2 2/2 0/1	5 54 61 59 59 —	180 Days Phoenix Search: E-1121-17334 Window: E-1031-17325

Note: Times are for 360/65 FORTRAN Program.

Table 3
Digital Processing Geometric Accuracy – ERTS MSS Data³

	RMS Vector Error-Absolute (Meters)	Max Error of 90% of GCPs (Meters)	National Map Accuracy Standard
Digital Data ¹ (39 GCPs)	60.6	103	1:125K-1:250K
Film Data ² (21 GCPs) Notes:	135	175	1:250K-1:500K

¹ Measured Using Computer Shade Prints from Corrected CCTs.

² Measured by USGS from Film Data Recorded from CCTs, Nov. 1973.

³ Scene Processed, Chesapeake – 23 Sept. 1972, E-1062-15190.

Table 4
MSS Geometric Correction Accuracy

Number of GCPs Used to Compute Attitude	RMS of 39 GCPs (m)	Max Error of 39 GCPs (m)
8	698	1828
9	85	174
12	75	144
15	68	156
39	65	202

Scene ID: 1062-15190 (Chesapeake, September 1972)

data-analysis and/or processing systems need to be developed to make these techniques more cost effective and more readily applicable.

Both optical and digital analysis techniques have been used. In particular, the investigation by Gramenopoulos involved analysis of Fraunhofer diffraction patterns for five level-1 land use categories disseminated over a variety of sites to establish the existence of spatial signatures with ERTS data. Spatial signatures were established for urban areas, mountains, and agricultural areas; as may be expected, spatial signatures were not significant for water and desert areas. The spatial signature for urban areas reportedly became evident only in ERTS band 7, with the agricultural signature dominant in ERTS band 5. Slater also showed by optical means that bands 5 and 7 contained the greatest spatial frequency information for agricultural and urban areas. After establishing the signatures optically, Gramenopoulos employed digital Fourier transforms

over 32- by 32-pixel arrays to extract spatial features for inclusion with spectral data into a Gaussian maximum-likelihood classifier. The importance of transforming the spatial features to a Gaussian distribution as assumed by this classifier was recognized and resulting improvements were demonstrated. Results of classification with and without spatial features for four categories of level-1 land use in the Phoenix, Arizona, area are shown in Table 5.

Table 5
Identification Performance Comparison
ITEK Analysis – Phoenix, Arizona

Processing Conditions	Agricultural	Mountains	Desert	Urban Areas
Spectral Features Only	93	96	87	86
Spatial Features Only	89	80	97	74
Spectral Plus Spatial Features	97	96	89	95

A study was made by Swanlund to test the effectiveness of the various spatial frequency transforms: the Walsh Hadamard, Slant, Cooley-Turkey, and Karhunen Loev. The comparison was made for 4- by 4- and 8- by 8-pixel array sizes with the Karhunen Loev transform giving the best performance as shown in Figure 3. The Slant transform, coupled with spectral features, was used in a linear discriminant classifier applied to identifying forestry features (hardwood, conifer, urban, open, water) in Minnesota. The improvement in performance due to including spatial content and array size is shown in Figure 4. Haralick developed and demonstrated a technique for combining spectral and textural features into a linear classification program. Results of this analysis procedure for seven land use categories (coastal forests, woodlands, grasslands, urban, water, and small and large irrigated fields) in the Monterey Bay, California, area illustrated that the use of textural features (64- by 64-pixels) improved the total average classification accuracies over all classes from 70 percent using texture only and 74 percent using spectra, to 83 percent using both.

Davis obtained spatial features of amplitude and frequency versus angle by digitizing optical diffraction patterns using a 64-element photodiode detector array located in the image plane. The amplitude function was related to geologic terrain types in Kansas.

In the area of signature extension, Malila and McMurtry reported important findings. Malila employed an empirical mean-level adjustment to adapt the signatures of data taken from one ERTS pass for application to the data taken on a pass the following day. The effects of this adjustment on classification (assumed to be required because of changes in sun angle and haze conditions) are given in Table 6. McMurtry employed the empirical correction approach, which normalizes means and variances to adjust data sets separated by 18 days and 240 km (150 miles), reportedly with great success. The only result reported involving temporal pattern recognition (other than optical overlays, density-slice overlays and such, reported under Image Enhancement) was that of Hoffer, who overlaid classification maps to determine the variability in snow accrual and melt.

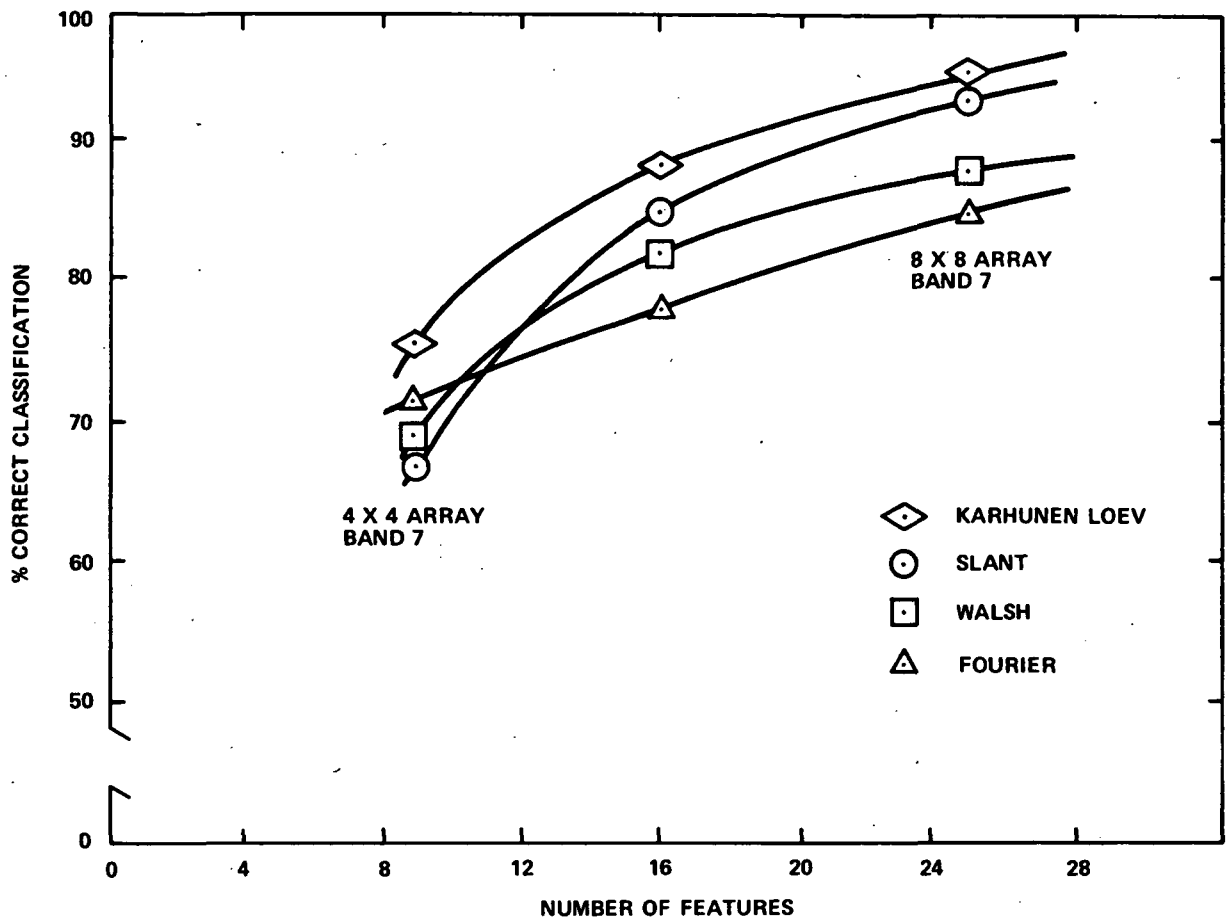


Figure 3. Comparison of texture algorithms for automatic classification.

Table 6
Summary of Classification Results for One
Area Viewed on Two Successive Days

Signatures	Data Set	Wheat % Correct	Trees % Correct
Day 1	Day 1	87	96
Day 1	Day 2	65	88
Day 1*	Day 2	71	92
Day 1**	Day 2	78	91
NO. Test Areas		10	27

*Empirical mean level adjustment.

**Theoretical level adjustment (Photometer Plus Model).

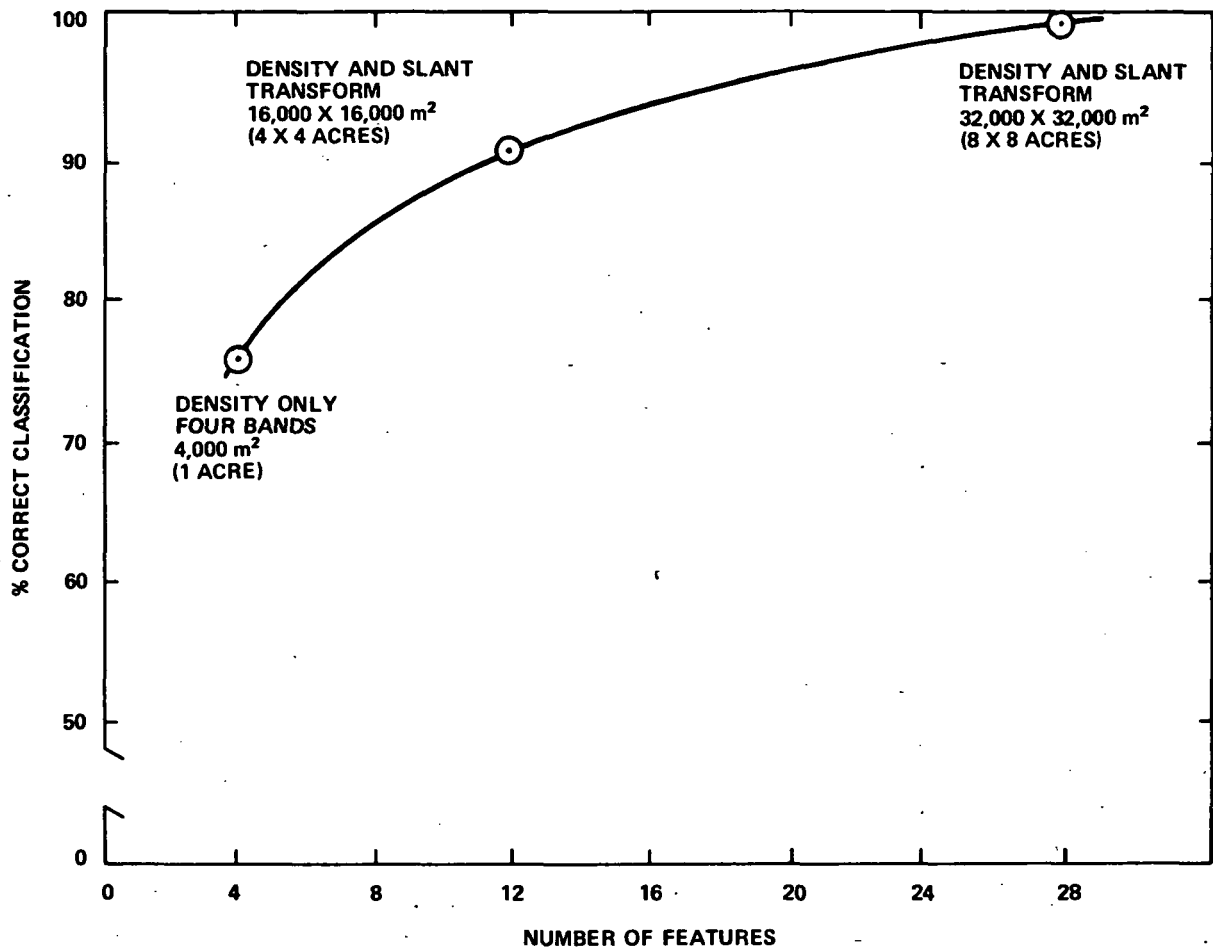


Figure 4. Automatic classifier performance using texture and density.

A proportion estimation algorithm (also called mixtures algorithm) was used by Malila to assist in classifying ERTS pixels that were not selected as a pure material and were assumed to contain signatures of more than one class. This technique was used for estimating surface water area in a region in Michigan containing lakes and ponds, with the results shown in Table 7. It was noted that this technique may be of value only where the classes are well separated spectrally and where a minimum of alien objects are present. The case presented involved water, trees, and bare soil.

Hoffer, McMurtry, Gramenopoulos, and Haralick reported on the use of clustering algorithms, primarily to locate homogeneous areas as input to a classification algorithm. The algorithms presented by Gramenopoulos and Haralick were recent developments. Haralick developed a noniterative gradient clustering algorithm using spatial and spectral features. The approach by Gramenopoulos involved an algorithm that computes the Euclidean distances between vectors and selects groups of vectors whose distances are small. In this approach it is important to utilize approximately equal numbers of vectors for each terrain class, which requires human

Table 7
Summary of Water Area Estimation Results

	Photointerpretation	Fractional Pixel Procedures		Whole Pixel Procedure
		3-Channel Proportion Estimation	1-Channel Proportion Estimation	Conventional Recognition
Number of Water Bodies Detected	19	18	17	13
Total Water Area (Meters ²)	1,041,958	1,006,739	892,118	879,120
Percentage of Photointerpreted Area	100%	97%	86%	84%

interaction with the algorithm to select the vectors that are used to form the cluster centers. Gramenopoulos reported this interaction gave improved accuracy in classification of terrain classes.

Hoffer performed spectral analysis indicating that in mountainous areas the spectral response of level-2, forest cover types vary as much from stand density, aspect, and slope as they do between species. Similar spectral responses were also found for many water bodies, terrain shadows, and cloud shadows, preventing simple spectral discrimination, and it was not possible to reliably differentiate between snow and clouds on a spectral basis due to detector saturation and available spectral range. However, on cloud-free scenes, automatic techniques were very effective for determination of area and temporal variations of snow cover.

Hoffer developed a program to predict the location of shadows relative to topographic relief of the scene and the sun angle. This technique was used to eliminate some of the confusion caused by topographic shadowing.

Data Handling and Processing

A number of systems have been established or modified to process ERTS data. Some of the systems consist of software packages only; others include equipment intended only to correct geometric and radiometric distortions, while others provide user-oriented output products such as map overlays and enhanced images. Of particular significance is the fact that a number of systems (Belon, Bodenheimer, McMurtry, Hoffer, and Serebreny) are producing useful products or providing useful services.

One significant system was established at the Geophysical Institute, University of Alaska. This system has all the markings of a regional data center and consequently provides insight into the requirements for fully operational centers. This facility provides ERTS investigator support involving eight research institutes and academic departments undertaking twelve projects covering ten disciplines. In addition, support is provided to other users not formally tied to the ERTS program. It catalogs and files Alaska ERTS images as well as images produced by aircraft, meteorology satellites, and others. Supplementary information is also filed, including topographic and land use maps and remote sensing literature. A modern photo laboratory is available, which is used to copy images for users and to produce custom products. Other laboratory tools are available, including a color additive projector, digital color display system, plotter, and so on. A computational facility provides multivariate analysis and classification maps.

Another system (McMurtry) that was modified to process and analyze ERTS MSS data is the Pennsylvania State University analysis system. This system is a significant and key element in support of the Pennsylvania State ERTS investigations. The close interaction of techniques specialists and user personnel has helped develop a viable system that generates useful products such as maps and overlays. An effective hybrid approach is used to process ERTS data. A combination of machine analysis and photointerpretation is employed using ERTS MSS digital data, computer output, and high altitude aircraft photographs. Effective products have been produced for forestry and land use management.

The data processing facility at the University of Kansas (Haralick) was also updated to provide user support and combines a large computer and minicomputer with an interactive user terminal. Other support systems were the Stanford Research Institute (Serebreny) interactive terminal, which can produce time-lapse images, the University of California system (Algazi), which has a display capability optimized for human perception and human-derived information, the LARS system (Hoffer), which provides full computer capability for multivariate analysis, and the University of Tennessee analysis facility (Bodenheimer).

Digital processing techniques have been developed for geometric and radiometric correction of ERTS data. Pseudo-operational capabilities for correcting ERTS images were described by Taber and Bernstein. Throughput equivalent to the present NDPF analog geometric system (Table 8) has been demonstrated by Bernstein. Compression of ERTS MSS data was described by Spencer

Table 8
Image Processing Times and Scene Throughput

	370/145	370/158	370/168	NDPF Prec Proc	370/145 & MSP
Processing Times (min)	29	9.0	3.2	30-40	4.5
Scene Throughput/16 hours	33	107	300	28	213
Scenes/Month	990	3210	9000	840	6400

Note: 1 MSS Scene – 4 Spectral Bands

without loss of information. It is significant that approximately 2-to-1 compression can be achieved with variations of differential compression techniques under the constraint of zero distortion in the reconstructed image. May reported that the SSDI/Rice technique is a valuable candidate for spacecraft applications, permitting a doubling of the data transmission to ground, and the SSDI/Huffman algorithm is one suitable for ground-based data compression with an increase of 4 to 1 in the packing density of the digital tapes.

Summary of Sensors and Systems

Sensor technology includes the definition of requirements for sensors for earth resources applications and the evaluation of the general applicability of existing sensor hardware, especially the ERTS sensors and the data collection platforms (DCPs).

Slater developed a technique for the resolution evaluation of ERTS MSS film data that can be applied to future satellite-acquired imagery. The results, therefore, may contribute to the definition of sensor requirements for future mission planning. Major work is needed to verify the results. Danko demonstrated the usefulness of ERTS MSS channel-5 data for the identification of meteorology targets. The impact of spatial resolution on the identification of meteorology targets was also investigated. Albrizio presented a technique for determining the altitude and, hence, the type of clouds, based on measuring the distance from clouds to shadows. This information was used in determining locations for future airports and in other applications.

The radiant power measuring instrument was developed (Rogers) to obtain the complete set of solar and atmospheric measurements needed to determine target reflectance from the ERTS radiance. The measurements of this instrument can be used to check the calibration of the ERTS sensors. The RPMI is a portable instrument calibrated to measure both down-welling and reflected radiation within each ERTS MSS band. This instrument needs evaluation prior to further development.

The full dynamic range of the ERTS sensors has not been utilized. These sensors have been saturating for the important snow and cloud targets as indicated by Hoffer (Table 9) and Danko. Broad-band sensing does not yield the information that can be provided by narrow-band sensing; for example, a narrowing of the spectral range of channel 7 would enhance the spectral value for geological applications (Lyon). Also, two additional channels would be useful for forest vegetation applications — 1.5 to 1.8 and 2.0 to 2.6 microns (Hoffer). However, several investigators have found that for a given application, much useful information can be extracted from consideration of one channel only.

Some operating experience has been accumulated with DCPs in adverse climatic conditions (Hoffer). This experience was favorable but more evaluation of the DCPs in an operating mode is recommended. The DCPs provide a capability of measuring ground truth in a local area, but if data is needed to make corrections for an entire scene, then many DCPs might be necessary per scene. Most of the investigators utilized aircraft data for interpretation of ERTS imagery.

Table 9
 Comparison of Spectral Response of Clouds
 and Snow Using ERTS-1 Data

	Channel			
	4 (0.5-0.6 μm) ¹	5 (0.6-0.7 μm)	6 (0.7-0.8 μm)	7 (0.8-1.1 μm)
Clouds	126.6 \pm 2.3 ¹	126.2 \pm 2.8	118.2 \pm 6.8	55.6 \pm 6.7
Snow	125.4 \pm 5.2	125.0 \pm 5.6	116.2 \pm 10.2	51.2 \pm 9.0

¹Numbers indicate mean relative response \pm 1 standard deviation using a combination of approximately 3000 data resolution elements, representing several areas of clouds and snow on each of these dates (November 1, 1972, December 6, 1972, and May 18, 1973). Saturation level is 128 for Channels 4, 5, and 6, and is 64 for Channel 7.

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APPENDIX 1

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