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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FUNDAMENTAL RESEARCH PROGRAM

INFORMATION UTILIZATION AND EVALUATION

Final rept.

Principal Investigator: John E. Estes

Co-Principal Investigator: Ludwig Eisgruber

WORKING GROUP

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NASA Contract Number NAS 9-16077

FINAL REPORT

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Appendices in Separate Volume

The Principal Investigator wishes to sincerely thank the members of the committee for their contribution of time and thought to this report.

I. Executive Summary

This document is the final report of the Working Group on Information Utilization and Evaluation, one of four groups formed to help define basic research requirements by the Renewable Resources Branch of the Earth and Planetary Exploration Division of NASA's Office of Space Science and Applications (OSSA). This groups charge was to identify fundamental issues involved in the development of an understanding of the use of remote sensing technology for the acquisition data and the means by which it becomes information in the renewable resources management decision process.

A primary conclusion of the Working Group is that in the second half of the 1980's NASA will face difficult choices among alternative fundamental and applied research, and development projects that could potentially lead to improvements in the information systems used to manage renewable resources. The Working Group on Information Utilization and Evaluation believes that effective choices cannot be made without a better understanding of the current and prospective problems and opportunities involved in the application of remote sensing to improve renewable research information systems. A renewable resources information system, as used herein, is defined in a broad context to include a flow of data/information from: acquisition through processing, storage, integration with other data, analysis, graphic presentation, decision making, and assessment of the affects of those decisions. An idealized resource management data/information system is seen as Figure 1 herein. It is the Working Groups assessment that successful research and development effort will require some prior fundamental evaluation of both the problems which need solution and the alternative means by which this may be done if NASA is to improve the effective and efficient integration of satellite remote sensing data into existing and future renewable resources information systems.

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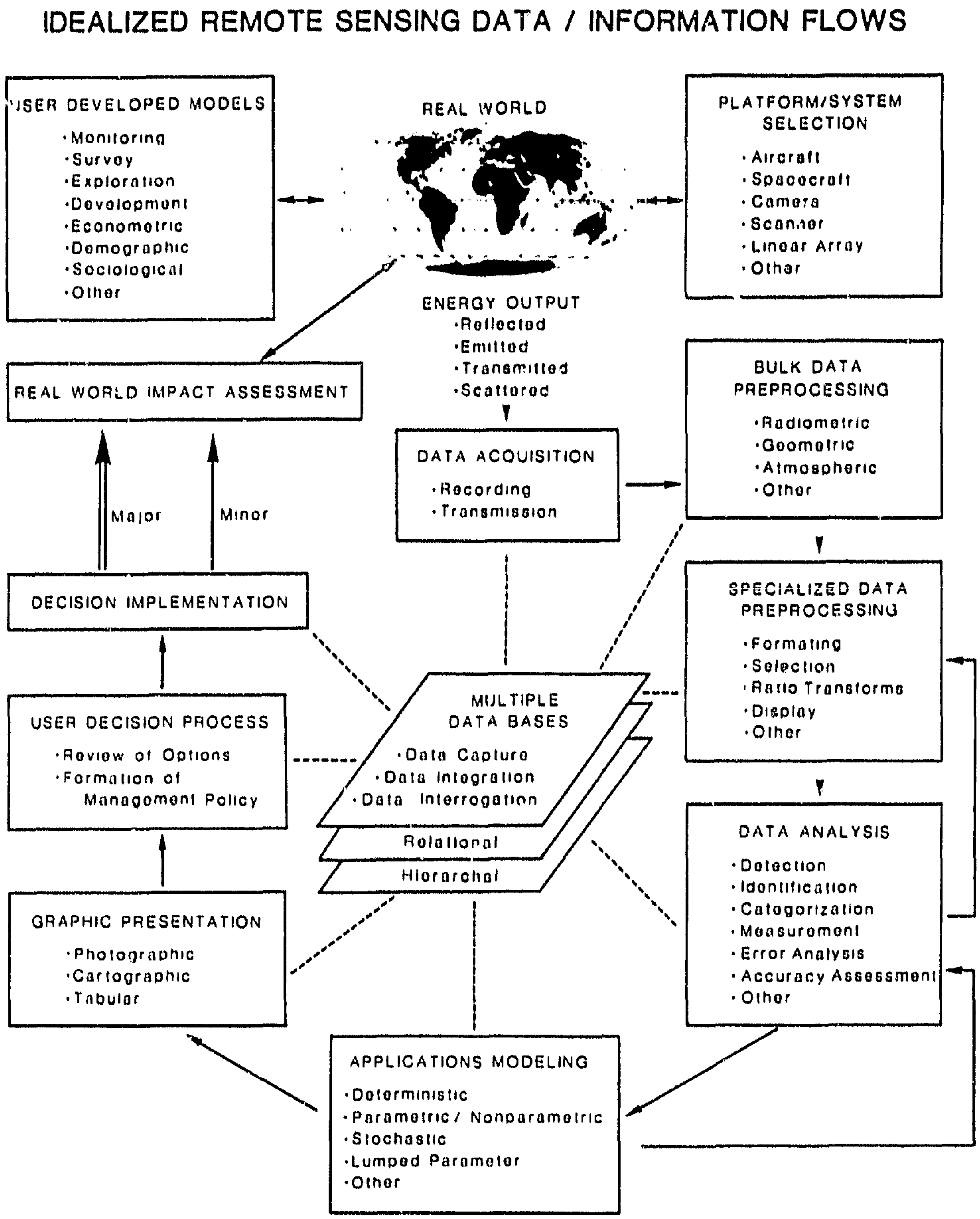

Figure 1. Source: Geography Remote Sensing Unit

Therefore, the Working Group on Information Utilization and Evaluation recommends that NASA undertake fundamental research to:

1. Investigate potential new technical developments that could significantly affect the input integration and analysis of remotely sensed data into future renewable resource information systems;

2. Develop the underlying and methodological basis for estimating the value of information systems and their modification; and,

3. Develop after through review and assessment by an improved understanding of the nature of the socio-economic, technological and institutional linkages involved in existing renewable resource information systems, their use and users, and related processes.

It is the Working Group's assessment that the research conducted in these areas to-date represents the weakest link in the chain of technologies required to yield practical social and economic benefit from advances in remote sensing. Advances in these areas will substantially improve the effectiveness of applications projects and utlimately provide the basis for broad public access to this unique information asset. The Working Group has prioritized their research recommendations and feel that while those major areas listed first are more important research tasks within each of the areas seen below must be addressed. Every effort has been made to avoid recommending work, even if it is crucial, which we are certain will be satisfactorily pursued because of sound commercial motivations in industry. The resulting recommended areas for NASA sponsored fundamental research in the ares of information utilization and evaluation are:

1. To conduct fundamental studies in those areas of artificial intelligence (AI) research which are addressing new approaches to knowledge representation and the associated processes of heuristic search, inference and learning. To pursue this research to gain an understanding of the potential for improving our capability to acquire, integrate, process, analyze, and use remotely sensed data. Initial priority subtasks here include the conduct of fundamental research which:

A. Explores and demonstrates the linkages between: AI research expert systems, image analysis decision logic and data bases for renewable resource management decision making.

B. Develops optimum methodologies involving expert systems to reduce requirements for sensor and ground truth data acquisition; and renewable resources inventory techniques which make allowances and adjustments for loss of data and ultimately the availability of real time satellite data.

C. Investigates expert systems to serve as a guide to data/information for non-expert users and for explanation of derived data (from analysis) or from conclusions obtained via remotely sensed data.

2. To investigate basic issues relative to the operation of geo-referenced data base/information systems for enhanced utilization of data/information derived from remote sensing data. Subtasks here include:

A. Work towards optimal strategies for processing and integration of disparate data types through fundamental research on improving our understanding of the generic functions involved in spatially oriented data manipulation.

- effects of data structure on data input, storage, query languages, and archiving formats;
- effects of positional accuracy on estimates derived from multiple data planes;
- performance and capacity requirements for the large record size and special purpose processing required for imagery and geographic applications;
- data availability, archiving and the opportunity costs of data storage; and,
- decentralized data base/information systems on cost/benefits ratios.

B. Work with Data Base Management Systems (DBMS) research community (academic and industry) as they expand DBMS to support scientific engineering data. This work includes fundamental research to:

- assist in the specification, and development of DBMS functions (e.g., query language extensions) to facilitate linkage of image and non-image spatial data;
- develop prototype systems for realistic applications; and,
- evaluate and test products of DBMS research for spatial data.

C. The development of models at varying levels of aggregation of information systems with public, private and international components. In these first two areas in particular Working Group members felt that NASA should make every effort to keep the commercial computer systems as well as other private industrial firms in the data base/information systems and resource survey area informed of their needs in the area of data bases. This communication should be two-way and NASA should continue to make every effort to keep abrest of advances in computer sciences.

3. To improve techniques and methodologies for documenting the accuracies of the products of remote sensing. There has been in the past year a significant literature accumulating in the reviewed literature. The Working Group recommends that NASA keep a close watch on the research being presented on this topic. The Working Group still feels, however, that productive fundamental research here should include research which:

A. Investigates potential tradeoffs in developing classification, cartographic, and mensuration accuracy for renewable resources applications.

B. Examines sampling theory applied to spatial distributed, temporally varying, renewable resources parameters at varying scales. Key issues here include:

- development of procedures with greater sensitivity to deviations from "normal conditions;"
- identification of key parameters and correlation coefficients between image derived data and ground conditions for use when no dependent source of verification exists; and,
- exploration of nonparametric tests of data.

C. Develops relevant measures which characterize data/information (e.g., minimally sufficient statistic).

4. To institute long range research on the theoretical basis and methodological approaches for estimation of the value of renewable resources data provided by remote sensing. Key issues here include the:

A. Development of a general theory of the economica of resource management information systems.

B. Augumentation of current research in economic theory which treats information as a commodity.

C. Examination of alternative means of assessing the public good and multiple use aspects of data/information.

D. Exploring the impacts of timeliness, reliability, accuracy and assured product delivery on cost benefit potential.

E. Development of improved techniques for measuring tradeoffs between use of existing and new information systems for renewable resource decision-making.

5. To conduct an examination of both the probable and possible future environments which will impact renewable resources data bases and information systems.

Finally with respect to the organization of the research proposed here the Working Group believes that one reason for the paucity of research in the area of the informations utilization and evaluation is that few scientists have conducted more than one study in this area. The lack of continuing involvement explains in part the absence of a general theory, methods to analyze and test such as theory, and empirical analysis of alternative information systems. As a consequence, the scientific base for the design of better systems to use aerospace remote sensing is weak. This lack of continuity of specific tasks oriented support is a problem in many other areas as well.

The Working Group, therefore, recommends that NASA support research to overcome these deficiencies by funding the equivalent of a "Center for Research on Information Systems" for a period of three to five years. The Center should focus on fundamental conceptual and methodological matters and test hypotheses relevant to information system design. The Center should be associated with either an academic institution or a private nonprofit organization rather than a government agency where short-term appraisals or current issues could draw resources away from the fundamental research effort.

Not all research would necessarily be done at the Center. While the Center would be the prime contractor, some segments should be subcontracted to individuals and groups at other institutions with the most appropriate skills. Conversely, while the Center would not conduct all of the research, it should retain substantial direct involvement and not simply organize

The Center should have an advisory committee with six to eight numbers. At least one third of the committee members should represent private industry. The remaining members should be drawn from universities and state and federal agencies.

Finally, this examination of the fundamental research required to achieve an improved understanding of how data/information is used and valued has allowed Working Group members to realize that understanding existing problems and anticipating new ones in these areas is a difficult process requiring expertise as well as vision and foresight, thinking and rethinking to achieve a more meaningful appreciation of the ways in which remote sensor systemc can impact user needs and applications in a future time frame. We also fully realize that this report serves only as a small initial step in that direction. Yet, we also believe most strongly that a beginning must be made and we urge the readers of this report to pay careful attention to its summary and conclusions and to its recommendations.

II. Introduction

Since the launch of the first Landsat in July 1972, NASA has supported a considerable amount of applied research which has pointed the way to work still needed. For space technology to advance and to be applied to significant renewable resources management, questions certain basic research problems remain to be addressed. As new applications of remote sensing technology are made, changes become possible in data collection systems, processing techniques, and information systems. New technology cannot be developed and properly utilized without a better understanding of how it can contribute to the decision-making process.

This document is the final report of the Working Group on Information Utilization and Evaluation, one of four groups formed to help define basic research requirements by the Renewable Resources Branch of the Resource Observation Division of NASA's Office of Space and Terrestrial Applications (OSTA). This group was to identify the basic issues involved in the development of remote sensing technology for the acquisition and application of information. These issues, it was agreed, had to include a consideration of decision-making processes, its context (i.e., bureaucratic, social, economic, environmental, and political), and the various ways data are transformed into information and affect decisions. Special attention was to be given to large renewable resources information systems (see Figure 1) - how they evaluate them, by what criteria to ascertain accuracy, how to assess performance and how to anticipate future information requirements. As defined herein renewable resources information systems are broad in scope and employ as one source of input data derived from satellite remote sensor systems. An idealized system is seen in Figure 1. In this figure the reader should note that elements of the system flow from the users decision as to the

the models he/she will employ through the selection of a sensor/platform to data acquisition processing storage, manipulation, integration with other types of data to analyze presentation, use in a decision context and in the monitoring of the effects of such management decisions.

This introduction is followed by a brief background section which provides the reader with the context within which this report was assembled. Recommendation on the fundamental research required to improve the potential of Satellite Remote Sensing for Renewable Resource Surveys concludes the body of the report. Finally, this report contains a series of Appendices which include added information on the Working Groups activities and deliberations.

Appendix A contains the summary and conclusions reached by Working Group members in the process of this study. Appendix B provides interested readers with a more detailed background on the Working Groups assumptions, activities, and directions. Appendix C contains summaries of materials presented at the workshops held in the course of this study while Appendix D contains key correspondence leading to the inclusion of specific material. Appendix E lists individual Planning Session and Workshop participants and summarizes affiliations while the final Appendix F contains the visuals employed at the briefing for NASA Headquarters personnel in May 1981.

III. Background

The future potential of aerospace remote sensor systems is truly extraordinary. The opportunitites they provide, however, will require public decisions concerning satellite sensors, ground facilities, and analysis systems of great complexity and cost. While the potential benefits of future systems are large, there are data management and storage problems. Various systems could provide information bearing on important national and global resource planning and management concerns, but the legal, social, and economic problems which they create are of national and international significance.

OSSA currently has a number of applied research and development projects (e.g., AgRISTARS) which apply existing knowledge to design, engineer and demonstrate the capabilities of aerospace remote sensing as a resource management information source. The Fundamental Research Program is intended to complement these projects by focusing on concepts and issues at the frontiers of the relevant sciences. A successful program will provide essential building blocks for future applied projects to support the design of sensors, ground facilities, and institutions to facilitate national and possibly increased international use of remote sensing systems in the late 1980's and 1990's. The research will be conducted by scientists who are familiar with current and potential applications of aerospace remote sensing technology to renewable resources. Research results are expected to be communicated worldwide by the publication of papers in recognized scientific journals and other types of appropriate publications.

The Program Definition Study of Basic Research Requirements in remote sensing is divided into four general areas of study:

(1) Scene Radiation and Atmospheric Effects Characterization;

(2) Pattern Recognition and Image Analysis;

(3) Electromagnetic Measurements and Data Handling; and,

(4) Information Utilization and Evaluation.

Working groups composed of scientists and practitioners from universities, research institutions, industry and government have been established for each research area. Members were familiar with potential applications and with the problems associated with information from remotely sensed data. These groups have planned and conducted workshops where qualified experts could hear and discuss one another's views concerning the current state of knowledge, on-going work at the frontiers, and areas where research could produce significant results. The workshops provided opportunities for groups to draw broadly on the knowledge of the scientific community and deepen their understanding of relevant issues before preparing recommendations to NASA.

Each working group is to develop a prioritized list of research topics and a preferred method for implementing and coordinating its recommended program of basic research. Each group leader is supported by selected members of the working group who are responsible for documenting findings and recommendations in a report to NASA. These reports will help NASA define a three-to-five year research program to broaden and strengthen the scientific base for future applied research and development programs directed at better use of aerospace and remote sensing in monitoring the Earth's renewable resources.

The Working Group on Information Utilization and Evaluation organized and held its initial planning session in April, 1980 at Santa Barbara, California. Members of the group include:

Glen Bacon, IBM Corporation
Nevin Bryant, NASA Jet Propulsion Laboratory
Christopher Clayton, University of California
Ludwig Eisgruber, Oregon State University
John Estes, University of California
Forrest Hall, NASA Johnson Space Center
Ida Hoos, Space Science Laboratory, University of California
Robert MacDonald, NASA Johnson Space Center
Bruce Scheer, The Planning Economic Group, Boston
Ronald Shelton, Michigan State University (deceased)
Charles Vars, Oregon State University

a second planning meeting was held in July 1980 at Johnson Space Center to: (1) identify broad areas in which basic research is appropriate and (2) plan workshops to address these research needs. (Participants in each meeting, as well as workshop, are listed in Appendix D.

The Working Group on Information Utilization and Evaluation conducted three workshops. The first workshop on Information and Decision Processes was held at Asilomar, California in September, 1980; the second workshop on Data Base Use and Management at San Jose, California in January 1981; and the third workshop on Data and Information Performance at Houston, Texas in February 1981. The Working Group also held a special session at the conference on Remote Sensing for Resource Management sponsored by the Soil Conservation Society of America at Kansas City in October 1981.

IV. Research Recommendations

Introduction. In the second half of the 1980's NASA will face difficult choices among alternative applied research and development projects that could potentially lead to improvements in the information systems used to manage renewable resources. The Working Group on Information Utilization and Evaluation believes that effective choices cannot be made without a better understanding of the current and prospective problems and opportunities to improve renewable resource information systems. A successful research and development effort will require prior fundamental evaluation of both the problems which need solution and the alternative means by which this may be done.

Therefore, the Working Group recommends that NASA undertake fundamental research to:

1. Investigate potential new technical developments that could significantly affect the input integration and analysis of remotely sensed data into future renewable resource information systems;

2. Develop the underlying theoretical and methodological basis for estimating the value of information systems and their modification; and,

3. Develop after thorough review and assessment an improved understanding of the nature of the socioeconomic, technological and institutional linkages involved in existing renewable resource information systems, their use and users and related processes.

The premises underlying these recommendations are quite simple. Effective choices among future NASA R & D projects can only be made once the agency understands the problems and opportunities to improve renewable resource information systems. When contemplating R & D decisions, the first step must be to determine whether and why there are problems. Relevant questions include: where, why, and to what extent do systems fail and succeed today? Are systems likely to perform differently in the future, and if so, in what respects? Are the gaps between actual and "ideal" performance likely to be persistent and important, or only transitory and relatively unimportant? These questions should be addressed and answered by research in the second and third areas noted above.

While assessing the nature of the research tasks to be accomplished to help find solutions to these problems, NASA should identify further developments in the capabilities of remote sensing systems that could improve overall renewable resources information system performance. In the view of the Working Group the alternatives to be investigated should encompass a broad range of institutional as well as technical developments. Examples include the examination of probable and potential operating environments and information needs in the 1990's, as well as studies of strategies for processing disparate types of data, potential linkages between artificial intelligence oriented "expert systems," and improved techniques to assess the accuracies and other performance characteristics of remote sensing systems. Of course, new developments in data handling and management systems also deserve careful attention.

Ultimately, however, NASA will have to value the consequences of alternative projects and actions to modify existing or potential remote sensing components of renewable resources information systems. Such valuations will be difficult but necessary if NASA is to select the "best" projects and actions. The major questions to be answered are: How should information system performance be measured and evaluated? How should different combinations of improvements in system performance be compared with one another? What are the impacts of changes in timeliness, reliability, accuracy, and assured product delivery? Clearly some valuation problems may not lend themselves to quantification. The choice among alternatives will never be easy, for systems are complex, the future is uncertain, and tradeoffs are inescapable. Nonetheless, the Working Group believes that a long-range research effort to develop a better basis for valuing modifications in information systems can contribute to the design of an increasingly effective R & D program for NASA.

The preceding discussion has described the broad fundamental research recommendations of the Working Group on Information Utilization and Evaluation. The following materials describe the recommended research topics more specifically. Neither the discussion nor the listings of research tasks should be considered all-inclusive. Rather they represent a distillation of the presentations at workshops, conversations with knowledgeable individuals, and discussions among the Working Group. The appendices provide a more complete description of the many research topics identified during the project. What follows, however, is a prioritized ranking of the most important research topics identified by the Working Group for recommendation to NASA.

The following, recommended research topics, then, represent a distillation of the discussions held by information utilization and evaluation working group members over the course of this project. The material sifted in the preparation of the recommendations presented herein was large in volume and broad in scope. The recommendations listed below represents our best efforts to encapsulate material pertinent to NASA goals and missions which were presented in planning meetings, workshops, conversations with knowledge base of individual working group members themselves. In these recommendations we have attempted to carefully screen those areas of private sector and academic research efforts where NASA can derive real benefits from following research in progress from those where work is required and appropriate for NASA to find. The following five research recommendations are ranked in priority order. Within each of these major recommended research areas individual tasks are also listed in order of their priority. Working Group members feel strongly that NASA should do its best to implement programs of fundamental research directed at as many of the topics listed below as practical. Recommended research areas are the following:

1. To conduct fundamental studies in those areas of artificial intelligence (AI) research which are addressing new approaches to knowledge representation and the associated processes of heuristic search, inference and learning. To pursue this research to gain an understanding of the potential for improving our capability to acquire, integrate, process, analyze, and use remotely sensed data.

This recommendation involves the initiation of a limited number of key applications oriented fundamental research programs. The committee feels that it is from within the context of such decision oriented research efforts that an improved understanding of the basic nature of the resource management decision process will flow. We feel that such understanding is essential if we are to strengthen the weakest link in the chain of the use of remotely sensed data (i.e., its employment in a management decision context). Some basic characteristics of "expert systems" that involve levels of systems, processing, analysis and human factors considerations crucial for ultimate acceptance of information generated are that:

1) They include a data base of information which is directly related to a given problem. This data base can be of many types and have input from a variety of sources, including the judgemental knowledge of expert in a given area on the probability of certain events or phenomena begin related or happening given a defined set of conditions;

2) Such systems should be able to explain their decisions in terms of a line of reasoning that the ultimate user of the system can understand;

3) They should be capable of justifying their performance by responding to questions expressed in plain simple language;

4) These systems should be able to "learn" new information quickly by interacting directly with experts in their given area;

5) Their knowledge base must be easy to modify so the perceived errors can be corrected rapidly before they recur in another case; and,

6) Interaction should be designed with the user in mind (i.e., programmed in terms of prompts, answers and information volunteered by the system as well as by the user).

Research exploring the linkage of such systems in the remote sensing geographic information system resource management decision process is needed in the following areas:

Discipline Concepts - Traditional image analysis systems have no true "understanding" of the discipline involved. Although explicit decision trees can make programs more relevant, true discipline knowledge and the heuristics for problem solving are neither explicitly represented nor used. In fact, "commonsense" is often absent when existing systems fail, and this justifiably alienates users. In contrast, expert systems make explicit use of production rules that relate observations to inferences. Research is required to move these systems into the image analysis chain.

Conversational Capabilities - Research is needed to develop computer-based linguistic capabilities for capturing knowledge from collaborating experts and for communicating with users in terms that have clear and concise meaning to them.

Explanation - Resource management decision systems currently providing information to users seldom explain the basis for decisions made with respect to a given product or display in terms understandable to users. This can mean the user depending upon his own knowledge base can either have excellent, if he truely understands the system, or little or no basis for deciding whether to accept its results. In contrast, the heuristics of an expert system could provide an explanation of the underlying reasoning. Research here is reuqired to begin to meaningfully demonstrate the potential of those systems.

1. Subtask Expert Systems Fundamental Research Topics Include:

   A. Exploration and demonstration potential linkages between artificial intelligence oriented "expert systems," image analysis logic, and data bases for resource management decision-making. Within the management process as material on which decisions are based becomes more complex, decision processes become less deterministic and more heuristic. Because of this the committee foresees the potential of a highly productive fundamental research effort aimed at exploiting expert systems within a resource management context.

   B. Develops optimum methodologies involving expert systems to reduce requirements for sensor and ground truth data acquisition; and renewable resources inventory techniques which make allowances and adjustments for loss of data and ultimately the availability of real time satellite data. As a variety of data types exist on many environmental parameters methodologies for the incorporation and assessment of the utility of these data could prove very helpful in identifying key gaps in existing systems. Such information might also be used to identify those gaps likely to persist through a considerable time period.

   C. Investigates expert systems to serve as a guide to data/information for non-expert users and for explanation of derived data (from analysis) or from conclusions obtained via remotely sensed data. Inherent in the use of expert systems is the development of "user friendly" interfaces with the systems being employed. This includes the development of improved data base management systems as discussed in area 2 below.

2. Investigate basic issues relative to the operation of geo-referenced data base/information systems for enhanced utilization of data/information derived from remote sensing data. Subtasks here include:

   A. Work towards optimal strategies for processing and integration of disparate data types through fundamental research on improving our understanding of the generic functions involved in spatially oriented data manipulation. Some issues here include the:

      - effects of data structure on data input, storage, query languages, and archiving formats. Alternative methods for optimizing spatially-related (e.g., geographically ordered relational, or modified hierarchical) data base structures need to be examined in light of the requirements for capture, storage, integration, manipulation and access access a multiplicity geo-referenced data planes.
      - effects of positional accuracy on estimate derived from multiple data planes. All mapping involves global and local positioning from the analysis of several mapping phenomena, errors are cumulative. Investigations need to be undertaken to determine: a) the sensitivity of models to positioning errors in input data sets; b) the potential for satellite data to improve the integration of spatial phenomena in functions such as trend surface mapping and development of multi-stage sampling designs.
      - performance and capacity requirements for the large record size and special purpose processing required for imagery and geographic applications. Factors such as timeliness and repetitiveness of satellite overflights will continue to be essential drivers of satellite systems. All stages in ground data acquisition, calibration, geocoding, archiving, transfering, and analysis need to meet the satellite overflight requirements if an end product is to be provided. Given certain assumptions in future analysis requirements, what are the key stages in data preparation which need to have improved through-put? How would each stage in data preparation and analysis best be served (i.e., centralized or decentralized function)? Are basic structural changes implied if operational capability is to be achieved?
      - data availability, archiving and the opportunity costs of data storage. Costs of storage and archiving are decreasing, however, the volume of data produced by remote sensor systems is high. We need to examine the large range implications of data loss on renewable resource surveys. Other areas here include universal cataloging systems for a variety of satellite data rather than the ad hoc procedures developed to date; and,

- decentralized data bases/information systems on cost/ benefits ratios. Do field users have need to combine there specific data bases with a common minimal data base? What is an optimal decentralized data base structure to allow rapid and efficient access by remote users of renewable resources data.

B. Work with the Data Management Systems (DBMS) Research Community (academic and industry as they expand DBMS) to support scientific engineering data. This should include the development of prototype DBMS's which link user friendly expert systems and the large storage and file structure systems presently required to store, integrate and manipulate the spatial data sets which are derived from remotely sensed and other renewable resources survey data sources. To do so will require a program of development testing and evaluatior of appropriate DBMS's for spatial data.

C. Develop models at varying levels of aggregation of resource information systems with public, private and international components. As data are derived from sources at a variety of levels are aggregated and disaggregated in the decision process misrepresentation can occur. What is called for is an effort to understand the nature and magnitude of the potential errors inherent in this process.

A number of the task sub-areas, discussed above, are based upon conclusions reached at the San Jose Workshop on Data Base Management and Use. In particular working members felt that it is imperative for NASA to make every attempt to keep the Commercial Computer Systems industry informed of their needs in the area of data bases. This communication should be a two-way flow, however, and NASA Earth and Planetary Exploration Division should make a concerted effort to keep abreast of the rapid advances in computer science so as to better integrate the potential of new developments into future satellite sensor systems. The Working Group believes then that NASA should work with the data base management systems community (academic and industry) to support research on the linkage, management, and use of image and non-image spatial data. The research community is currently working to improve our ability to manage large data files and perform special purpose processing. Major breakthroughs will be forthcoming, but they will address the problems associated with large spatial data sets only if NASA communicates its long-range needs to the research community.

3. Conduct fundamental analyses of the question of techniques and methodologies of documenting the accuracies of the products of remote sensing.

This area also includes a research issue for the fundamental research program area studying Data Handling and Measurement Systems. That is, the development of procedures necessary for both present and future renewable resources satellite sensor systems to approach "mensuration" system status for given applications. Research here include:

A. Investigate the impacts on sensor systems, processing and analysis techniques to the development of standards for classification, clarification and mensuration accuracy of remotely sensed data. It is important to note here that in the area of thematic accuracy assessment there is a considerable amount of material beginning to accumulate in the reviewed journal literature. It is apparent that this is an area of current attention by a number of individuals both with government and academia in the United States and abroad. NASA may not need to fund work herein, but should realize that this work may have profound implications on future satellite sensor systems development.

B. Continue to examine the fundamental aspects of sampling theory as they apply to spatial distributed, temporally varying, renewable resources parameters at local, regional, national, and international scales. Key research issues here include:

- development of procedures which exhibit a greater sensitivity to deviations from "normal conditions;"
- identification of key parameters and determination of correlation coefficients between remote sensor scene derived data and ground conditions for use when on independent source of verification exists; and,
- the exploration of the potential of nonparametric tests of data.

C. Development of relevant measures which characterize data/information (e.g., Minimally Sufficient Statistic).

For many types of renewable resource survey problems classical statistical approaches are "nearly applicable." Nearly applicable as most of the assumptions upon which classical statistical approaches are based are violated in their application to specific resource inventory problems.

What is required then is to examine the potential for fundamental research directed toward the development of new statistical sampling strategies which are more robust and sensitive to environmental variation. This is an important area for fundamental research as sampling is still a major concern and yet a number of the participants in this study also felt that methods for achieving improved verification of local identification and classification employing non-sampling approaches are also important and certainly needed.

4. Institute a long-range program to provide a better understanding of the theoretical bases and methodological approaches capable of being employed for estimation of the value of renewable resources data produced by remotely sensed data.

   Research tasks in this area would include:

   A. Development of a general theory of the economics of resource management information systems.

   B. Augumentation of current research in economic theory which treats information as a commodity.

   C. Examination of alternative means of assessing the public good and multiple use aspects of data/information.

   D. Development of improved techniques for measuring trade-offs between use of existing and new information systems for renewable resource decision-making.

   E. Investigation of the impacts of timeliness, reliability, accuracy and assured product delivery on cost benefit potential.

The Working Group finds that there is no generally accepted framework for estimating the value of modifications in public sector components of information systems. A number of factors contribute to this methodological problem. First, there is no market price for the output of most public information systems, and therefore value cannot be estimated in conventional ways. Second, the quality of an information system is based on its multiple characteristics, including accuracy, timeliness, reliability. continuity, and so on. Moreover, some types of information possess the characteristics of a public good (the use of the good by one individual does not reduce the amount available to others), and its private value may differ substantially from its social value. Third, many sources of information are available to decision-makers, few are regarded as certain, and choices among types of information to obtain and use are made within uncertain environments that confront decision-makers. Fourth, conceptual problems recur for information systems because of changes in reality and the agenda for decisions. Learning, development, and innovation are common, and information systems evolve.

Some good work has been done to address each of these problems. Nonetheless, only rudimentary models have been developed, tested, and empirically estimated. Several methodological approaches have been used, but controversy continues concerning the appropriate methodology. No methodology has yet proven successful in general applications; in fact, different applications raise more questions than they have answered concerning the appropriate methodology.

The Working Group believes that a high priority should be assigned to the development of the underlying theoretical and methodological basis for estimating the value of information systems and their modification. The goal would be the formulation of quantitative models capable of contributing to the evaluation of trade-offs between existing and potential new information systems. Such models would be able to describe and explain existing systems and to provide the means to identify and estimate the magnitude of future consequences of new systems with alternative features.

One methodology which the Working Group recommends for addressing these issues involves the review and assessment of existing information systems. Existing information systems, their use and users, and related processes need to be reviewed and their performance assessed before potential future systems can be evaluated. The objective should be the review and documentation of multi-purpose, government and private systems with international dimensions. It is not feasible to analyze all systems where remotely sensed data are currently being or potentially could be used. Therefore, research should focus on selected information systems where remotely sensed data are or may be combined with data collected by other means.

Information systems develop to help decision-makers make decisions to solve problems. Since problem-solving requires some understanding of the nature of the problem to be solved, information must be viewed as the product of some process of inquiry. From this perspective, knowledge about a problem is dependent on the system of inquiry used to obtain that knowledge. To contribute to solving problems, an information system represents the reality relevant to those problems and the decisions to be made. As a consequence, the goals and values of the decision-maker affect the design of an information system, and the decision-maker must be considered as a major component of the information system.

Most studies on the value of information assume, for example, that a farmer, an elevator operator, and a buyer all use the same information in the same way, but evidence indicates this is unrealistic. Some information is available as a public good, but it is not equally used by all who receive it. For these reasons, the identification of major market and nonmarket users of information, their sources of information, and the adequacy of these sources become important if new systems are to be satisfactorily evaluated. Particular attention should be given to the documentation of how the behavior of public and private users and producers of information are changed when information is viewed as a public rather than a private good. Data and information dissemination systems need to be analyzed. These studies should examine the accessibility, decentralization, economies of scale, confidentiality, and property rights of existing systems.

Information systems have multiple components and data sources because decision-makers seek different types of information on the various "fields of reality" with which they must deal. Decision- and policy-makers typically utilize data and information with a wide variety of attributes. Attributes such as function, scale, timeliness, precision, and others should be examined in the context of systems where tradeoffs among attributes and institutional constraints can be directly addressed.

Systematic reviews and documentation are also needed to understand how the attributes of data and information derived from it interact and affect analytical and decision processes. These investigations should document analytical systems and processing strategies that extract information for decision-making from data based on disparate concepts. Special attention should be given to why, how, and with what effects are data from multiple sources used within existing information systems.

Information systems are used in both an ordinary and extraordinary mode, and the reviews of existing systems should not focus on one mode of use and exclude the other. In the ordinary mode of use, information accords reasonably well with expectations and only routine adaptations are called for within the operating environment. In ordinary circumstances recurrent mismatches between observations and expectations do not occur, there is no need to change the information system, and a review will reveal the strengths of the system. In the extraordinary mode, however, information does not accord with expectations, and non-routine actions are taken. Learning, development, and innovation are then initiated to transform the information system. These processes are not well understood, in part because existing systems have not been thoroughly reviewed and documented.

The final research area recommended by the Working Group on Information Utilization and Evaluation is:

5. Conduct an examination of both the probable and possible future environments which will impace renewable resources data bases and information systems.

This recommendation differs from general recommdation #4 in that more emphasis in this area would be put towards examination of future environments rather than beginning with existing systems as is proposed in #4.

What has been stressed is a better understanding of the user management decision process. Throughout this document is the need to achieve acceptance of the basic reality that remote sensing is not, in and of itself, a unique information source. It is, however, when used properly a very powerful multi-dimensional data source. Yet, remote sensing will only realize its full information potential when data produced by remote sensor systems is effectively and efficiently integrated with data from other more "conventional" sources in the management decision process. This requires that we improve at a fundamental level our understanding of not only the management decision process but of the type and characteristics of the data bases employed by resource management decision makers as well. For in "management environments."

where cost effectiveness is the inflexible justification for present and especially future generations of satellite technology (with reference to value and returns), one finds it at present somewhat comparable to quantifying pie-in-the-sky. It is not easy to complie credible numbers to satisfy congressional policy makers. Nor is it an easy task with the traditionally axe wielding OMB. What we can expect from not only the executive but even from the public at large is to some extens already the handwriting on the wall. In an era of Federal fiscal restraint, it is unrealistic to count on bit investments and quixotic to make claims that cannot be wholly substantiated. Technology cannot be rationalized by non-existent demand. The public has its own perceptions of pundits and in the present political climate not all premises carry the same amount of credibility.

This brings us back into the morass of factors impeding proper assessment of the use and value of information with respect to the resource management decision process. It also, in all likelihood, explains the dearth of such evaluations. The social context within which such evaluations must occur today renders them mutually impossible. But, is this to say then that none should be done? Quite the contrary. Starting with the premise that the social context is crucial, we might do well to consider another social context--not the one that serves as a kind of gridlock but one that provides us with what seems to be a generally agreed upon paradigm for the future and from which a series of scenarios could be extracted to serve as drivers for pursuing fundamental investigations of the nature of mangement decision data bases and their impacts upon the decision process. The new world of the future as envisioned in the Global 2000 report might be a good framework. It is the global situation needs of the year 2000, and on, to which tomorrow's technology must respond, and it is clear that remote sensing and the information it can provide could be a key factor in meeting the challenges which transcend all national borders and internicine warfare among government agencies at all levels and even the commercial sector as well. Because it is the far horizon that has more certainty and for which there is a greater agreement than the present, the information utilization and evaluation working group feels that NASA should consider it as the proper framework for guiding the scenarios suggested here, and thus unfetter ourselves with preoccupation with fabricating a story designed to please rather than to enlighten.

Finally, with respect to the organization of the research proposed here the Working Group believes that one reason for the paucity of research in the area of the economics of informations sytems is that few scientists have conducted more than one study in this area. The lack of continuing involvement explains in part the absence of a general theory, methods to analyze and test such as theory, and empirical analyses of alternative information systems. As a consequence, the scientific base for the design of better systems to use aerospace remote sensing is weak. This lack of continuity of specific tasks oriented support is a problem in many other areas as well.

The Working Group, therefore, recommends that NASA support research to overcome these deficiencies by funding the equivalent of a "Center for Research on Information Systems" for a period of three to five years. The Center should focus on fundamental conceptual and methodological matters and test hypotheses relevant to information system design. The Center should be associated with either an academic institution or a private nonprofit organization rather than a government agency where short-term appraisals or current issues could draw resources away from the fundamental research effort.

Not all research would necessarily be done at the Center. While the Center would be the prime contractor, some segments should be subcontracted to individuals and groups at other institutions with the most appropriate skills. Conversely, while the Center would not conduct all of the research, it should retain substantial direct involvement and not simply organize the research. (The Center could become the lead institution in a consortium which conducts research over a longer term and larger scale than that by NASA). This approach would assure a focus of responsibility, as well as coordination, continuity and visibility.

The Center should have an advisory committee with six to eight numbers. At least one third of the committee members should represent private industry. The remaining members should be drawn from universities and state and federal agencies.