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A STUDY OF ENVIRONMENTAL MONITORING AND INFORMATION SYSTEMS

FINAL TECHNICAL REPORT

By

James S. Gardner
Principal Investigator

JANUARY 1972

Prepared for

U.S. Army Engineering Topographic Laboratories
Research Institute
Fort Belvoir, Virginia

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Institute of Urban and Regional Research
University of Iowa
Iowa City, Iowa 52240

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SUMMARY

Environmental information has a variety of uses. The report emphasizes one such use: the monitoring and periodic description of environmental quality. Operational and planned schemes for environmental monitoring are briefly reviewed. The status of remote sensing or data collection is discussed in relation to pertinent environmental elements and variables. The attributes or variables by which the physical environment may be described are outlined along with a measure of human activities, land use. On the basis of the review, the organizational structure of an environmental information system is outlined and discussed.

It is very apparent that the amount of environmental information is enormous and promises to increase in volume at an increasing rate. This and the numerous efforts to monitor various aspects of the environment suggest priorities in the development of an environmental monitoring and information system. Top priority is given to the development of a Co-ordination and Resource Data System which would monitor data gathering and research activities related to environmental matters. The emphasis is placed on avoiding duplication, an essential prerequisite in a field as diverse and complex as environmental science.

FOREWORD

This project was designed to examine environmental data collection, processing and use in an automated context. The primary emphasis was to review the status of environmental monitoring and to outline the structure of an information system.

The work was carried out in the Institute of Urban and Regional Research at The University of Iowa between September 1970 and September 1971. While the principal investigator is responsible for the report, others have contributed heavily to its content. John Hultquist, Administrative Co-ordinator at the Institute, contributed to Chapters V and VI. James Hesler, Research Assistant, assumed major responsibility for the review of remote sensing in Chapter III and the topographic and geological discussions in Chapter IV. During segments of the study period, Clayton Lloyd and Jan Bertness, both Research Assistants, contributed to the review of environmental variables. Their contributions and assistance are appreciated.

Frank E. Horton, Director of the Institute of Urban and Regional Research, provided direction, assistance and managerial support throughout the study. Anthea Craven and Sue Moore, staff at the Institute, are to be acknowledged for their typing and organizational contributions.

TABLE OF CONTENTS

This report deals with environmental monitoring. As the recognition, if not the magnitude, of environmental problems has become more acute in the last five years, the need for various forms of environmental monitoring has been recognized.[1] The need derives from a desire to learn what has happened, is happening, and is likely to happen to man's environment. The first desire is essentially a problem in historical research. The second desire derives from a need to relate specific human activities to measurable effects in the environment. The third desire relates to prediction, a capability that is essential if man is to plan his future activities with the greatest benefits in mind.

Research has been carried on in all three spheres for a considerable period of time. Marsh's work, The Earth as Modified by Human Action, and the more recent volume, Man's Role in Changing the Face of the Earth, have attempted to describe what has happened.[2] Much of the recent work in watershed management[3] and the volume, Man's Impact on the Global Environment[4] are directed towards understanding what is happening. The desire for a prediction capability has led to the development of a large number of functional hydrological, atmospheric, biological, regional, economic and other "models" or systems.[5]

Our ability to satisfy these desires has been greatly enhanced by the development of automated data collection, storage and processing. Although this technology exists, important questions on what data is to be collected remain. Our ability and desire to collect and handle data may well exceed our ability to discriminate what is important. Moreover, there are dangers in considering what should be done. A vast amount of environmental information already exists in varying degrees of obscurity. The possibility of utilizing this information ought not to be ignored.

Research Objectives and Procedures

The primary objective of the research reported here was to develop a system or structure that would be useful in measuring environmental change. It was thought desirable that the system should have the following capabilities:

1. Be able to define environments in terms of a composite of their elements;
2. Be able to monitor changes in these elements over time;
3. Include measures or indices to characterize the state of environmental elements;
4. Be able to store and retrieve information about the environment for a range of scales.
5. Be able to predict the consequences to environmental quality of changing environmental variables.

The objectives and capabilities determined certain tasks including:

1. To outline and specify the pertinent variables to describe the environment;
2. To examine the functional relationships between variables;
3. To explore the methods and techniques for collecting data on the variables with special emphasis on: direct and remote sensing and the sampling of point, line and continuous populations;

4. To examine the present status of environmental information collection and manipulation including: data sources, monitoring systems, indices or summarizing statistics, information systems, and functional systems and predictive models;

5. To structure the data storage, processing and retrieval system.

Problem Areas

During the research two sets of problem areas became apparent. The first set has to do with meeting the research objectives whereas the second set relates to environmental description and measurement in general regardless of research objectives or system design. The former are of concern here and the latter will be made apparent in the various sections of the report.

The problems encountered in meeting research objectives developed primarily from the general nature of the original proposal. The proposal did not specify the use or user of the system. This creates problems in anticipating the type of queries that would be presented to the system which, in turn, makes it difficult to specify the type of data to be collected and the form in which it should be stored. Most operational environmental monitoring or data collection and storage schemes operate for a specific purpose or user and are directed toward a specific set of environmental variables. Although the use(s) or user(s) of the system outlined in this report is not specified it is probably of value to suggest a few possible uses.

1. Setting guidelines, supplying baseline data for, and forecasting possible consequences of, various types of planned activities in a given area including resource extraction, military operations,

construction, research, etc.

2. Surveillance and policing of environmental quality standards.

3. Short-term management of an area, a use that requires "real-time" information of high quality.

4. As an information and example source for educators.

Another problem that arose in meeting the research objectives had to do with the size or type of area to which the system could be applied. This is a critical point in discussing how data entries should be addressed. This is closely related to the ubiquitous problem of scale, a problem that all data collection systems must resolve. Scale is significant because it determines, at least in part, the spatial variation that one may expect in a given environmental attribute. As the spatial variability of the attribute increases, careful attention must be paid to the sampling design used to collect the data. In discussing the measurement of environmental variables it was thus difficult to specify sampling procedures.

The last major problem area centered on defining functional relationships between environmental variables. In most instances, functional relationships between variables that describe the same element are well-defined. For example, within the environmental element, atmosphere, the relationship between the independent variable, temperature, and the dependent variable, humidity, is well understood. It is in defining relationships between variables from different environmental elements that major problems arise. This is the case even where a considerable amount of empirical research has been conducted on relationships such as those between vegetation cover or density and runoff. Our knowledge of functional relationships between environmental variables is incomplete or evidence for functional relationships is contradictory. The outcome is that predictive models are either impossible to construct or must operate within very wide limits of confidence.

Definitions

Though not the first step in carrying out the research, an important first step in discussing the findings is to establish working definitions of the concepts and terms used in the study.

Varying usages of the term "environment" have caused considerable confusion in the past.[6] In the study, the term "environment" has been defined generally as the factors of the lithosphere, atmosphere, hydrosphere and biosphere that are of significance to man. The environment being considered thus includes natural-physical features. Socio-economic characteristics of the environment are being considered only through the variable, land use. It is anticipated that land use will provide a bridge should the system be made more comprehensive to include the socio-economic sphere.

A vast array of activities may be included within the concept of monitoring. This will become apparent later in the report when a number of so-called "environmental monitoring systems" are reviewed. Here, monitoring is defined as an activity which is intended to be repeated and serves to: establish baselines or initial states, detect trends, enforce regulations, provide forecasts or warnings and/or define possible hazards.[7] The establishment of baselines or initial states is primarily a descriptive function. Although their initial intent is non-repetitive, surveys such as those of natural resources should not be ruled out of the rubric of monitoring because they may provide valuable initial state data. In addition, the information they provide may be used in a planning, if not a forecasting capacity.[8]

Data collection technology has reached a point where monitoring can take place in several different frameworks. Monitoring may occur in a continuous "real-time" sense through the development of sophisticated communications networks and remote sensing. Continuous, though not real-time, monitoring is possible with continuous graphical recording devices such as those commonly used in meteorology and hydrology. Monitoring may also be carried out in a temporal cross-sectional sense. Rather than a continuous record, periodic surveys or images are produced. Periodic air photographs, maps and censuses are examples. If the objective is to establish trends and/or define an initial state, one of the purposes of monitoring, it is wise to consider information on what has happened. Thus historical research of documentary, photographic, cartographic, linguistic, etc. material may be important.

The concept "information system" may mean different things to different people. A variety of types of information systems, automated and otherwise, are in existence.[9] One type of information system contains information on material of certain specific topics. This is not unlike a library file or "clearing-house" function. The type of information system we are considering in this report, stores and manipulates "real" data for specified variables.

The Report

The major part of the report reviews the status of environmental information. In particular, the form, collection and use of this information are discussed. It quickly becomes apparent that a vast amount of environmental information is already available. The present concern for environmental quality has accelerated the collection and the development of the technology for collection of the information. Increasing attention is being directed to the character and quality of environmental data that should be collected. The collection of data by remote means is receiving considerable research and development support. The report reviews the status of this rapidly developing technology from the point of view of gathering data on variables pertinent to environmental description and monitoring. A number of variables are discussed in a major review chapter. These relate to the description of the lithosphere, hydrosphere, atmosphere and biosphere. A place for including description of human activities through land use classification is discussed. These reviews provide the basis for presenting the organizational structure for an environmental information system. The amount of data and the vast scope of the environment suggest a system of enormous proportions and complexity. In view of this, top priority is given to the development of a Co-ordination and Resource Data System. The suggested task for this system is to monitor present environmental data collection activities, environmental research activities and developing schemes for data collection and research. In the final chapter conclusions are outlined along with recommendations for further research and implementation.

References are provided at the end of each chapter. In themselves, they provide a basis for further examination of the issue being discussed. A general bibliography, addressed to environmental information collection and utilization is appended at the end.

References

1. This need has been articulated in virtually every recent publication having to do with environmental problems. Official recognition of the need in the United States appeared in: National Academy of Sciences, 1970, Institutions for Effective Management of the Environment, Report of the Environmental Study Group, Environmental Board, NAS, National Academy of Engineering, Washington.

2. George Perkins Marsh, 1884, The Earth as Modified by Human Action, New York, Scribners, 629 pp; and W.L. Thomas (ed.), 1956, Man's Role in Change the Face of the Earth, Chicago, University of Chicago Press.

3. One of the most recent and comprehensive reviews of the state of the art in watershed management is: W.C. Boughton, 1970, Effects of Land Management on Quantity and Quality of Available Water, Water Research Laboratory, University of New South Wales, Manly Vale, Australia, Report No. 120, 330 pp. Another useful volume in this regard is: The Design of Hydrological Networks, Proceedings of a Symposium held by the International Association of Scientific Hydrology, Quebec June 15-22, 1965, 816 pp.

4. The report of The Study of Critical Environmental Problems (SCEP), Man's Impact on the Global Environment, 1970, Cambridge, MIT Press, 319 pp. Also: S. Fred Singer (ed.), 1970, Global Effects of Environmental Pollution, New York, Springer-Verlag, 218 pp.

5. See for examples: Richard J. Chorley and Peter Haggett (eds.), 1968, Models in Geography, London, Methuen, 816 pp.; H.R. Hamilton, et. al., 1969, Systems Simulation for Regional Analysis: An Application to River Basin Planning, Cambridge, MIT Press, 407 pp.; N.H. Crawford and R.K. Linsley, 1966, Digital Simulation in Hydrology Stanford Watershed Model IV, Stanford University, Dept. of Civil Engineering, Technical Report #39.

6. See: D.A. Maelzer, 1965, "Environment, Semantics and System Theory in Ecology", Journal of Theoretical Biology, 8: 395-402; J. Major, 1969, "Historical Development of the Ecosystem Concept", in The Ecosystem Concept in Natural Resource Management, G. Van Dyne (ed.), New York, Academic Press, p. 9-22; and Ian Burton, 1968, "The Quality of the Environment: A Review", Geographical Review, 58(3): 472-481.

7. Ralph L. Darby, et. al., 1970, Technical, Intelligence and Project Information System for the Environmental Health Service. Vol. II: EHS Information Network Analysis, Columbus, Battelle Memorial Institute, PB 194411.

8. O.C. Herfindahl, 1969, Natural Resource Information For Economic Development, Baltimore, Resources for the Future and Johns Hopkins Press, 212 pp.; A. Young, 1969, "Natural Resource Survey in Malawi: Some Considerations of the Regional Method of Environmental Description", in Environmental Land Use in Africa, M.F. Thomas and G.W. Whittington (eds.), London, Methuen, p. 355-384.

9. U.S. Department of Housing and Urban Development, 1968, Urban and Regional Information Systems: Support for Planning in Metropolitan Areas; Ralph L. Darby, et. al., 1970, op. cit.; Federal Water Quality Federation, 1969, STORET SYSTEM HANDBOOK, Division of Technical Support, Pollution Surveillance Branch; U.S. Department of H.E.W., 1968, Storage and Retrieval of Air Quality Data, Public Health Service, Consumer Protection and Environmental Health Service.

Introduction

The amount of information that has been generated about the environment is overwhelming. If present trends continue, the rate at which this information will accumulate will increase. The extent to which this information is, or will be of value in solving environmental problems is questionable. The information is found in a variety of forms including: photographs, maps, written documents, satellite imagery and sets of measured data. One thing that characterizes all of this information is that it is historical. As such it may be of use in reconstructing past environmental conditions and present base-line conditions. If the information is temporally and spatially compatible it may be of use in defining changes or trends in environmental conditions through time and space. Thus, already available data and information derived from it, could be of use in answering some questions related to the present status of environmental conditions and the change of these conditions in the recent past.

However, the applicability of this information is fraught with some problems. First, the source or storage location of the information may be so obscure as to create enormous problems in second-hand data collection. Second, a lack of evidence as to how the data or information were collected in the past may raise questions as to its validity. Third, variation in techniques of data collection, if known, may make the data incompatible with other data collected at the same time or place. The units of measurement may lead to problems of incompatibility as well. Fourth, the environmental variables measured in the past may bear little relationship to variables relevant to present problems. These and other difficulties have discouraged the use of historical data and have detracted from concerted efforts to assess the degree to which environmental conditions have changed.

There are several notable exceptions worthy of comment however. The numerous studies of climatic change are possibly the best examples.[1] Fewer studies have attempted to assess long-term trends in water quality.[2] The values and pitfalls of the use of historical water quality data have been articulated.[3] Numerous studies have attempted to characterize vegetation, animal and general landscape changes.[4] The importance of this type of research should not be underestimated. It is of value in determining the environmental background content and in isolating natural trends and cycles. For example, estimates of background radiation are mandatory in meaningful studies of the changing content of free radioactive material in the environment.

The difficulties in using historical data result in most approaches to environmental monitoring discussing new methods and techniques of measurement and new, more relevant, variables to be measured. As efforts to make data and information more compatible have increased, so have efforts to design new monitoring and information storage and retrieval systems for more and more specific purposes. The latter negates the former to some degree. This report is presented at the risk of accentuating the trend. Hence, it is the purpose of part of this chapter to briefly outline some of the presently operative and projected environmental monitoring and information systems.

Environmental Monitoring Systems

Our research has revealed an incredible number of operational or planned environmental monitoring activities. For a recent report, the Smithsonian Institution's Center for Short-Lived Phenomena has listed and reviewed well over a thousand such schemes in various parts of the world.[5] Moreover, the Battelle Memorial Institute has published a directory of information gathering facilities that would be of value to the efforts of the Environmental Health Service.[6] Hence, there is little point of entering into an extensive review. It will suffice to make a few general comments on the nature of the systems reviewed in the above works and supplement these with mention of several more localized systems.

Most environmental monitoring systems may be classified according to the size of the area being addressed by the system. This will obviously influence the level of detail in the system and the uses to which the information may be put. The system may be grouped into global, regional (at the international scale), national, regional (at the national scale), state, urban and neighborhood schemes. The emphasis in the Smithsonian Institution's directory is on the global and national scales. That in the Battelle directory is on the national scale.

Many of the global-scale systems and those at the international regional level are associated with agencies of the United Nations and the International Council of Scientific Unions. They usually monitor one environmental element or interface. MONSEE, Monitoring the Sun-Earth Environment, is an example of the latter.[7] World Weather Watch is an example of the former in that it monitors and stores atmospheric data.[8] Although global in scale, World Weather Watch is composed of national and regional systems. Other global systems focus on man-made factors such as background air pollution and fallout.[9] In addition to these systems which are, at least in part, operational various other systems have been proposed. One such proposal developed out of the Study of Critical Environmental Problems and is somewhat more comprehensive in its approach.[10] This study is careful to point out the need for careful baseline sampling as a precursor to full-fledged monitoring.

International regional monitoring systems are relatively few. The Co-operative Study of the Kuroshio Region, The Pan American Air Sampling Program and the International Co-operative Studies of the Mediterranean are examples of programs part of which involve the monitoring of environmental variables.[11]

Many individual nations have programs that involve collection of environmental data and monitoring. For the most part, this takes place in the soil survey, forest survey, geological survey and wildlife survey format. In these formats the collection of data may or may not be repetitive. Monitoring of atmospheric (weather) conditions is ubiquitous at the national scale, although the spatial detail and number of variables monitored varies between nations. The industrialized nations have developed wide ranging monitoring schemes directed at such phenomena as: air pollution, radio-active fallout, pesticides and seismicity. There is little need to outline specific systems here as the Smithsonian Directory has already done an admirable job of that.

Several systems operative in the United States are worthy of mention in that they incorporate both monitoring and information storage and retrieval functions. Some tend to emphasize the information system function, taking the monitoring or information gathering aspect as given. Others emphasize the monitoring aspect, taking the information system aspect as given. However, there is increasing recognition that data collection and data storage are intimately related, especially if continuing use of the data is anticipated. Moreover there is increasing recognition of the fact that our ability to collect data and generate information[12] is outdistancing our ability to store it in the most useful and accessible fashions.

The monitoring and storage of information related to hydrological variables provides some example of operative systems. STORET, a storage and retrieval system, and WAMIS, a water management information system, have received considerable attention in the United States.[13] Here, the main emphasis is on the storage and retrieval of information and less on the monitoring function. An information system, verging on incorporation of monitoring functions, has been proposed in the previously mentioned work of the Battelle Memorial Institute.[14] It is noteworthy that this system includes several physical environmental variables encompassing several different environmental elements. Other physical environmental data storage and retrieval systems that may be of interest include well-data and ground water systems[15] and air pollution monitoring and data storage systems.[16]

National monitoring and information systems have regional components. If detailed enough, such systems would be of value for interests of a regional nature. At the same time, several information and information manipulating systems have been designed for specific regions or specific types of regions. Most often the emphasis in these systems is on a forecasting or predicting function and as each are constructed around known functional relationships between variables and/or parameters. Examples of those designed for specific regions are the Connecticut Air Pollution Model, the Connecticut River Pollution Model and the Susquehanna Model.[17] Examples of systems designed for specific types of regions include various watershed, airshed and ecosystem models.[18]

Monitoring systems are operative at city and smaller scales. It is at this scale that a monitoring system becomes of use in detecting such things as sources of noxious material and in enforcing standards. Air, water and sewerage monitoring systems at this scale normally are made up of dense sampling networks and sampling is continuous in time. Environmental monitoring takes place at even smaller scales to forecast occupational hazards in such settings as mines and factories and in the immediate vicinities of potentially dangerous installations such as nuclear reactors.[19]

A review of present environmental information gathering efforts clearly indicates a vast amount of data are already available. Despite this, the need for more data and information is being expressed even more frequently.[20] This would suggest that the right kind of data referring to the most appropriate segments of the environment are not being collected. The worth of additional data and the nature of the variables must be carefully studied before new data gathering systems are proposed.[21] Perhaps the development of a system, more comprehensive in the environmental elements it addresses itself to, and utilizing already available data collection schemes would be a constructive step. Careful attention should be directed to a system that more completely links the sensing (measurement), data storage, data analysis, information retrieval and forecasting functions. The use to which data will be put should be carefully scrutinized prior to the collection of additicnal data. Moreover, the social and economic implications of automated information and forecasting systems should be carefully reviewed before the implementation phase.[22]

Possibly the most pressing problem in environmental data collection has to do with the generation of information out of the data.[23] What is it we want to know from the data? What type of summarization methodology and technique will provide the most information about what we want to know? This problem area is well-recognized. Classifications and typologies have been useful in this regard in the summarization of biological, climatological, geological and pedological data. The use of a variety of summarizing statistics as indicators of central tendency and dispersion have been of use, particularly in the case of data that represent continuous distributions through time such as temperature and humidity. The development of indices which summarize data in combinations of two or more variables is a relatively recent trend in the environmental sciences but is certainly a useful and promising trend at a time when environmental quality is of general social concern.

Environmental Quality Indices

Increasing emphasis has been placed on the development of environmental quality indices comprised of a number of different environmental variables. The benefits of such an index relate to planning and development of priorities amongst environment-related government programs. Part of the desire for indices is based on the efficiency provided by them. For policy makers and planners, the myriad of variables that is necessary to describe the status of the environment would be cumbersome. Hence, a single index or series of indices would provide a powerful tool. Moreover, it is pertinent to point out that an index or indices would be of value not only as indicators of what is happening to environmental quality but to quickly describe the character of the environment in a given area in which operations such as resource extraction, flood control, military exercises, etc. were being contemplated.

Given that the environment is defined to include a number of variables, the question of what variables should enter the formulae for producing indices is problematic. Probably of primary concern, at least at the present time, are those substances in the environment for which rather low levels of human tolerance are known. Substances in or components of the environment that, through change in their character of concentration, could set large-scale ecosystem changes in motion are also of concern. For example, the concentration of carbon dioxide in the atmosphere, though well below life tolerance levels, may initiate large-scale climatic changes. The diversity and population of species in a given area would be another important environmental characteristic. Though of little direct and obvious consequence to men, an index of diversity in a community could be used as an indicator of a composite of environmental conditions. Of course, knowing the meaning of diversity would be contigent on our understanding of ecosystem processes.

Also of concern at this time are a group of environmental substances, commonly termed "resources". Indices to characterize the general resource situation have been developed, albeit at a very general scale.[25] In this case, the quantity of the substance available is of primary concern. As the prospect of scarcity arises, quantity and quality are closely related considerations. Of particular concern here are the quantity and quality of substances such as: water, fuels, timber, metallic ores and industrial metals.

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Regardless of the variables or environmental characteristics that enter into the computations, an index is always a composite parameter. Direct measurements of variables such as air temperature could be included as could indirect indicators like species population and diversity.

The development and computation of an environmental quality index should involve at least three steps.[26] The first step is obviously the selection of variables or quality characteristics. The second step requires the standardization and development of a compatible rating scale for the variables. Step three recognizes that the contribution of each variable need not necessarily be equal. Hence, a weighting system for the variables is necessary. As yet, very few indices have taken into consideration rating and weighting, primarily because of the arbitrary nature by which weighting and rating criteria are chosen.

A number of environmental quality indices have appeared in the literature and indeed, some have been operationalized for forecasting purposes. Most indices refer to the quality of a specific environmental element such as water or air. Although our knowledge of what constitutes soil fertility has changed, one might consider fertility as an index with long-standing recognition and utility. Indices of diversity in biological communities could be considered quality indices although the quality meaning of species diversity has not been well articulated.

A major difficulty in creating a comprehensive index is that quality criteria vary greatly between environmental elements and for different uses to which the element may be put. Air quality criteria are most often related to human health and tolerance levels. Water quality criteria vary between uses such as drinking water, industrial water and cooling. In the case of soil should fertility or structural-engineering characteristics or both be used as criteria? These examples illustrate that quality indices are closely related to the purposes or functions of the environmental elements as they relate to man and his activities.

It is in the area of air quality that indices have been developed to the most useful level. "Pindex" is one of the most sophisticated index systems for air quality.[27] This index sums particulates, sulfur oxides, nitrogen oxides, carbon monoxide, hydrocarbons, oxidant, solar radiation and particulate-sulfur oxide synergisms. The computation of "Pindex" uses rating scales and weightings based on the human tolerances for the substances. Several other air quality indices have been used in conjunction with meterological information to forecast regional air pollution episodes.[28] Many of these do not use weightings, compatible rating scales and a comprehensive list of atmospheric components. Sulfur oxides and particulates are the most frequently used components. Indeed they may well be the most important.

Water quality indices have been researched but not put into use like the air quality indices.[29] Using the judgement of a "large and diverse panel" of experts, Brown established that the following are the most persistent components in determining water quality: dissolved oxygen, biochemical oxygen demand, turbidity, total solids, nitrates, phosphates, pH, temperature, coliforms, pesticides and toxins.[30] As such, these components provide the basis for a proposed water quality index.

In ecology and the biological sciences generally, considerable attention has been devoted to the diversity of communities and the development of indices to characterize this diversity.[31] The use of diversity indices in developing environmental quality indices is dependent on our ability to determine if a more diverse community is good or bad. Nevertheless, indices of diversity are good descriptive tools even though there is not a consensus on what variables or parameters should enter the computation of the index. Most indices of diversity take into account both the number of species in a community as well as the relative abundance of each species.[32] Recently, the relative productivity of a community has been considered as an important variable in the computation of a diversity index.

The development of indices is an integral part of environmental monitorin and the manipulation of environmental data. This is especially true in view of the complexity and volume of environmental information. Files of data are virtually useless in decision-making. Transformation of data into indices will aid in planning and environmental management. Indices will be of use in characterizing man's impact on the environment as well as forecasting the environment's impact on man. It is in the latter area, specifically the forecasting of air pollution levels, that indices are presently of the most use.

Of course, the development and usefulness of environmental indices is dependent on knowing what are the most pertinent variables and on the quality of the original data. The technology of environmental data collection has been a growth area and promises to be in the future, especially as the potential uses of various remote sensors become articulated. Because of the attention directed toward it and because of its potential for use environmental data collection, the next chapter reviews the status of remote sensing.

References

1. See for example: R. A. Bryson and W. M. Medland, 1970, "Climatic Effects of Atmospheric Pollution", in Global Effects of Environmental Pollution, S. F. Singer (ed.), New York, Springer-Verlag, p. 130-138; H. E. Landsberg, 1970, "Man-made Climatic Changes", Science, 170: 1265-1274; J. M. Mitchell, (ed.), 1968, Causes of Climatic Change, Meteorological Monograph, Boston, American Meteorological Society, 8(3): 160 pp.; Report of the Study of Man's Impact on Climate (SMIC), 1971, Inadvertant Climate Modification, Cambridge, MIT Press, 308 pp.

2. W. C. Ackermann, R. H. Harmeson and R. A. Sinclair, 1970, "Some Long-term Trends in Water Quality of Rivers and Lakes", Tran. American Geophysical Union, 51(6): 516-522; M. G. Wolman, 1971, "The Nation's Rivers", Science, 174(4012): 905-918.

3. T. D. Steele, 1970, "Beneficial Uses and Pitfalls of Historical Water-Quality Data", in Data and Instrumentation for Water Quality Management, J. E. Kerrigan (ed.), Water Resources Center, Madison, Wisconsin, p. 346-363.

4. The most accessible collections of these types of studies are: W. L. Thomas (ed.), 1956, Man's Role in Changing the Face of the Earth, Chicago, U. of Chicago Press; and J. R. Detwyler (ed.), 1971, Man's Impact on Environment, New York, McGraw-Hill, 731 pp.

5. Smithsonian Institution, 1970, National and International Environmental Monitoring Activities, Center for Short-Lived Phenomena, Cambridge, Mass. 292 pp.

6. Ralph L. Darby, et. al., 1970, Technical, Intelligence and Project Information System for the Environmental Health Service, Vol. 5, Directory of E. H. S. Information Facilities with Selected Supplementary Resources, Columbus, Battelle Memorial Institute, PB194414.

7. Inter-Union Commission on Solar-Terrestrial Physics, 1969, Guide for International Exchange of Data in Solar-Terrestrial Physics, Solar-Terrestrial Physics Notes No. 6.

8. World Meteorological Organization, 1966, The Essential Elements of The World Weather Watch, Geneva, 26 pp.

_______________, 1967, World Weather Watch, The Plan and Implementation Programme, Geneva, 56 pp.

_______________, 1970, World Weather Watch, Third Status Report on Implementation, Geneva.

9. Examples are: The Global Radiation Monitoring Network; Monitoring Background Air Pollution; Fallout-Sampling Network; Endangered Ecosystem Monitoring Programs.

10. The Report of the Study of Critical Environmental Problems, 1970, Man's Impact on the Global Environment, Cambridge, MIT Press, see in particular p. 168-222.

11. The Pan American Air Sampling Program is devoted to monitoring radioactivity, The Kuroshio program monitors physical characteristics and marine life of the oceanic region involved, and the International Co-operative Studies of the Mediterranean will monitor marine processes and life in that region. For further details see: Smithsonian Institution, 1970, op. cit.

12. The idea that data and information may not necessarily be considered the same, and the problem of generating information out of data is discussed in: J. L. Lewis, J. H. McDermott and P. L. Taylor, 1971, "Making Information out of Data", Journal of the Water Pollution Control Federation, 43(9): 1902-1911.

13. P. L. Taylor, 1970, "Experiences with a Water Pollution Control Storage and Retrieval System (STORET)", in Symposium on Data and Instrumentation for Water Quality Management, J. E. Kerrigan (ed.), Madison, Water Resource Center, U. of Wisconsin, p. 198-207; Federal Water Quality Federation, 1969, Storet System Handbook, Div. Technical Support, Pollution Surveillance Branch; J. A. Sena, 1970, "The Water Management Information System (WAMIS)", in J. E. Kerrigan (ed.), op. cit., p. 430-439.

14. Ralph L. Darby, et. al., 1970, op. cit.

15. J. E. Price, 1967, A Comparison of Traditional and Automated Methods for the Retrieval of Geologic Well Data, Unpublished M. S. Thesis, University of Iowa; J. M. Forgotson and J. L. Stout, 1964, "Future of Well-Data Information Systems", in Computer Applications in the Earth Sciences, D. F. Merriam (ed.), New York, Plenum Press, p. 61-72; L. G. Moore, 1970, "Experience with Storage and Retrieval of Ground Water Data", in J. E. Kerrigan (ed.), op. cit., p. 208-213.

16. D. D. Weers, 1970, "An Economical Method of Continuous Collection of Air Pollution Data in Computer Compatible Form", Journal of the Air Pollution Control Association, 20(6): 405-406; E. L. Stockton, 1970, "Experience with a Computer-Oriented Air Monitoring Program", Journal of the Air Pollution Control Association, 20(7): 456-471; G. E. Weistnantel, 1969, "Telemetering System Puts Air Pollution Monitoring On-line", Chemical Engineering, 76(27): 58-60; B. A. Brodaviez, V. H. Sussman, and G. B. Murdock, 1969, "Pennsylvania's Computerized Air Monitoring System", Journal of the Air Pollution Control Association, 19(7): 484- .

17. N. E. Browne, 1969, "A Simulation Model for Air Pollution over Connecticut", Journal of the Air Pollution Control Association, 19(8): 570-574; T. E. Hoover and R. A. Arnoldi, 1970, "Computer Model of Connecticut River Pollution", Journal of Water Pollution Control Federation, 42(2): 67-76; A. R. Hamilton, et. al., 1969, Systems Simulation for Regional Analysis: An Application to River Basin Planning, Cambridge, MIT Press, 407 pp.

18. N. H. Crawford and R. K. Linsley, 1966, Digital Simulation in Hydrology: Stanford Watershed Model IV, Stanford University, Dept. of Civil Engineering, Technical Report #39, 210 pp; S. N. Milford, et. al., 1971, "Developing a Practical Dispersion Model for Watershed Management", Journal of the Air Pollution Control Association, 21(9): 549-554; A. Eddy, 1969, "A Meteorologically Oriented Computer Model of an Ecosystem", Trans. New York Acad. Sciences, 31(6): 618-628; C. F. Cooper, 1969, "Ecosystem Models in Watershed Management", in The Ecosystem Concept in Natural Resources Management, G. Van Syne (ed.), New York, Academic Press, p. 309-325.

19. W. C. Reinig (ed.), 1970, Environmental Surveillance in the Vicinity of Nuclear Facilities, Springfield, Ill., Thomas, 405 pp.

20. See for example: R. A. Carpenter, 1970, "Information for Decisions In Environmental Policy", Science, 168: 1316-1321.

21. D. R. Davis and W. M. Dvonanchik, 1971, "Evaluation of the Worth of Additional Data", Water Resources Bulletin, 7(4): 700-707; M. Weishurd, 1971, "Ecology ... The Start of Something Big", Datamation, 17(8): 22-25; R. P. Ouellette, D. M. Rosenbaum and R. F. Greely, 1971, "Is There a System for Pollution Madness?", Datamation, 17(8): 30-33.

22. A. H. Molof, 1970, "Social Implications of Automation in Environmental Science", Technicon Quarterly, 2(1): 12-14.

23. J. L. Lewis, et. al., 1971, op. cit.

24. W. A. Thomas, 1971, "Indicators of Environmental Quality", Science, 174: 437-438.

25. The National Wildlife Federation in the United States periodically publishes for public view a "quality of environment" index of this type.

26. R. K. Horton, 1965, "An Index Number System for Rating Water Quality", Journal of the Water Pollution Control Federation, 37: 300-305.

27. L. R. Babcock, 1970, "A Combined Pollution Index for Measurement of Total Air Pollution", Journal of Air Pollution Control Association, 20(10): 653-659.

28. L. Shenfeld, 1970, "Note on Ontario's Air Pollution Index and Alert System", Journal of Air Pollution Control Association, 20(9): 612-613; City of San Francisco, 1968, Combined Pollutant Indices for the San Francisco Bay Area, Bay Area Air Pollution Control District, Information Bulletin 10-68; A. Teller, 1967, "Air Pollution Abatement: Economic Rationality and Reality", Daedalus (fall issue), also in America's Changing Environment, R. R. Revelle and H. H. Landsberg (eds.), Boston, Houghton-Mifflin, 1970, p. 39-55.

29. R. K. Horton, 1965, op. cit.

30. R. M. Brown, et. al., 1970, "A Water Quality Index - Do We Dare?", Water and Sewage Works, 117(10): 329-334; also in J. E. Kerrigan (ed.), 1970, op. cit., p. 364-383.

31. C. B. Williams, 1964, Patterns in the Balance of Nature, New York, Academic Press.

32. R. Margalef, 1957, "Information Theory in Ecology", General Systems Yearbook, 3: 37-71.

33. M. Dickman, 1968, "Some Indices of Diversity", Ecology, 49: 1191-1193.

Introduction

Four phases of environmental data and information collected are suited to remote sensing.[1] These include the inventory and mapping of resources, quantification of environmental variables, the description of the flow of matter and energy in an ecosystem and evaluating change and alternative solutions in the management of ecosystems. Of course this type of data collection may be and has been accomplished in other ways. For a variety of reasons, remote sensing promises certain advantages over other types of data gathering technologies. Because of this promise for the future and the fact that many monitoring and information systems already have incorporated various types of remote sensing, this report includes an extensive review of the "state-of-the-art".

There are several advantages to remote sensing even with the present technological and economic constraints. Data gathering is generally more rapid and in some instances more accurate. Remote sensors are able to cover large and inaccessible areas. Moreover, sequential coverage is possible making studies of change through time more feasible, at least at some scales.

This chapter directs itself first to a brief review of remote sensors and secondly to their utility in gathering data on the various environmental elements.

The Sensors

A variety of remote sensors are available. Most attention has been directed to those for use on airborne or earth satellite platforms. This is not to say they are the only types nor that they are not of use on the ground.

The three primary systems are: photography in the invisible and near-infrared region of the electromagnetic spectrum; optical-mechanical scanners covering the ultraviolet through far infrared wavelengths; and radar and passive microwave sensors that operate in selected bands.[2] Although the bulk of recent research has been directed to the use of the three primary systems, a number of more specialized sensors are discussed in recent literature. These include: the decibel recorder, the scintillation detector, the transitorized radio transmitter and the correlation spectrometer.

1. Photography

Photography, specifically aerial photography, has been used extensively in a variety of applications since the 1930's and today it remains the most widely used remote sensor. A number of reasons account for the continued importance of photography. One of the most important is that we have accumulated a great deal of knowledge regarding techniques of photographic image interpretation and data extraction. In essence, we are very familiar with the strengths and limitations of photography and have developed more expertise in its utilization that we have with other sensors -- where much basic work is still geared toward identification of the factors influencing image or signal return.[3] A second reason is that photography often provides superior resolution to that obtained from the more recently developed sensors. Perhaps the most important reasons, however, are that the camera is the easiest, cheapest, and most flexible sensor that can be used and because photo coverage is presently available for large areas of the world.

This is not to suggest that techniques of aerial and space photography are fully developed. Much attention is currently focused on the use of color and false color films as well as various film/filter combinations and color enhancement with optical or electronic devices. Some of these investigations are extremely promising. Smedes, for example, has suggested that with appropriate filters the three emulsion layers of color infrared film can be used as a 3-band spectrometer. He has shown that terrain classification and mapping using this technique results in "overall accuracy equal to or better than" that attained using the more complex and more expensive multispectral scanner.[4]

There are disadvantages to photography as well, however. One is that photography is limited by adverse weather and is best used during that part of daylight hours when shadows are reasonably short.[5] A second problem is that recording on film is limited to a relatively small part of the electromagnetic spectrum (from .38 to 1.3 μ) and therefore much of the infrared region cannot be imaged.[6]

Despite these limitations most researchers appear to agree that when only one type of remote sensor imagery is available, stereoscopic aerial photography is usually best.[7]

2. Multispectral and Infrared Line Scanners

Recognition that information from several spectral bands may yield more data than that provided by the same bands considered separately has led to the development of multispectral scanners. These devices permit simultaneous sensing of several or many spectral energy levels. One of the most useful characteristics of these devices is that they can record the middle infrared (1.5 - 5.5 μ) and the far infrared (5.5 - 14.0 μ) wavelengths. These regions cannot be imaged by conventional photography "for a number of reasons including the high level of background radiation which would arise from the camera and film itself at ambient temperatures."[8]

The most common multispectral scanners are aircraft-borne optical-mechanical devices. With this system forward motion is achieved by movement of the aircraft itself while the across-track dimension is provided by a rotating prism. The area mapped is a function of the total lateral field of view of the system and the length of the flight line. Because the field of view is fixed within the system, the width of the mapped area is a function of aircraft altitude.

Energy entering the prism mirror from a given point in the target area is split into channels, filtered, and is directed onto detectors sensitive to specific wavelengths. The resulting analog electric signal from the detector may then be recorded on separate channels of magnetic tape or it may be displayed on a glow-tube or cathode-ray tube. For one, two, or three channel devices film recording of cathode-ray tube display is common while tape is used in multi-channel scanners which may employ as many as 20 channels.

As would be expected, the availability of multi-channel information presents problems of interpretation and data extraction. Tanguay, <u>et</u>. <u>al</u>., have found that multispectral mapping of engineering soils data using as many as six bands is possible with the qualitative methods of traditional air photo interpretation.[9] Nonetheless, some form of automatic data extraction is essential for optimal use of multispectral data. One of the more comprehensive studies of automatic handling of multispectral data is Smedes study of terrain recognition and mapping. He notes that the spectral signature of a given material may exhibit a wide variety of changes, in response to a number of factors including time of day, season, latitude, and flight direction. Smedes doubts "that we can adequately sample the spectra of many classes of material under a wide enough range of conditions so that by the spectra alone, we could identify materials. Lacking complete samples of spectral signatures, we would have to rely on supervised computer techniques, thus requiring some prior knowledge of the terrain". Smedes further suggests that a great potential exists in computerized clustering techniques whereby the computer delimits "natural" classes -- the sample spectra of which are then compared with a master data bank of spectral responses to aid in identification of those classes.[10]

While much interest has been generated in multi-channel scanners only a very few of these devices exist. These sensors are still experimental and can be considered essentially as research tools.[11]

In contrast to the status of multi-channel sensors, the development of infrared scanners is more advanced. Several commercially-built systems are currently available and are sufficiently compact to be used in small aircraft. As of 1968 basic infrared scanners could be purchased for approximately $38,000. A number of commercial aerial survey firms now offer infrared imagery services.

Infrared mapping systems permit aerial sensing of thermal radiation emitted or reflected by the target. Thus infrared sensors -- like the multi-channel sensors -- are considered "passive" devices. The output of the system produces imagery or strip maps generated line by line as the aircraft moves across the target. The principle of operation, then, is the same as that of the multispectral scanner.

Sensing in the infrared region is influenced both by reflection and emission. During daylight hours solar reflection is significant in wavelengths up to about 3.5 μ but is negligible beyond. Earth glow is considered modest between 3.5 - 5.5 μ and this region has been found useful in forest fire detection. At approximately 10 μ earth - glow emission is maximum. Between 14 μ and 1 mm terrestrial remote sensing is impossible because of absorption by atmospheric water vapor.

Every material above absolute zero radiates energy in proportion to its temperature. Many fundamental vibrational resonances occur in the infrared region -- water vapor, for example, at 2.66, 2.74, and 6.3 μ while most rock-forming minerals emit in the range of 7 - 12 μ.[12] The significance of this is that when the fundamental vibrational resonance of a material is matched by incoming infrared radiation at the same frequency, the material exhibits a strong absorptive peak. Thus it should be possible, by observing changes in the reflection and emission of infrared energy by several objects, to distinguish between them as well as to identify them. Similarly, thermal inertia also varies appreciably between different materials and this property also lends itself to remote sensing use in the infrared region.[13]

Although thermal infrared imagery appears to offer great promise, several problems still exist that preclude its utilization at present for all but the most simple cases, such as forest fire detection.

Among the system problems that require improvement that of spatial resolution is probably most important. Spatial resolution of a scanner is determined by the instantaneous field of view (IFV) and the altitude of the aircraft. Because the IFV is, in turn, a function of the focal length of the collecting optics and the size of the detector-sensitive area, it is fixed. The result is that with increasing altitude spatial resolution becomes poorer. For example, spatial resolution of 1.5 milliradian IFV at 1000 and 10,000 feet is about 2.25 sq. ft. and 225 sq. ft., respectively. For comparison, an aerial camera with 6 inch focal length and resolution capability of nominally 15 line pairs/mm, at the same altitudes gives spatial resolution of 0.05 sq. ft. and 5 sq. ft., respectively.[14] A possible alternative to this problem might be to decrease the IFV. While this is technically possible, a smaller IFV is accompanied by a loss in temperature discrimination.[15] Unless sensors that are now classified become available we will be restricted to observing comparatively gross features from high altitudes. To obtain more detail will necessitate flights at lower altitudes and costs will be increased due to a greater number of flight lines to cover the same area.

A second major system parameter that influences the amount of information that can be obtained by infrared imagery is temperature sensitivity (ΔT). ΔT determines the thermal power difference that must exist between two targets before they can be distinguished. The two commercially available scanners described by Parker have ΔT values of $0.5^\circ C$ and $0.3^\circ C$.[16] These values, he indicates, are adequate to allow delimitation of most terrain features. According to McCullough, et. al. infrared scanners can detect much finer temperature differences (at least to $0.01^\circ C$) by increasing the IFV but at the expense of spatial resolution.[17]

Another problem with infrared line-scan imagery is that unlike framing camera systems, it is not planimetric. The scale of infrared imagery varies laterally from the nadir to the margins of the scan in direct relation to the secant squared of the angle between the given target point and the nadir. The scale in the flight direction will be accurate only if the ratio of aircraft velocity to height (V/H) is known with accuracy through the duration of the flight. This condition is usually not attainable. Because of such geometric distortions of the imagery it is extremely difficult to bring multiple images taken at different times and in different directions into a planimetric format, yet for optimal use of infrared imagery both day and night flights are needed.[18] Pascucci found that when mapping geology using thermal infrared and side looking radar the most efficient way to utilize the IR data is to annotate it on a radar-produced base-map.[19]

In addition to overcoming systems difficulties, a great deal of research is needed on the factors influencing the energies recorded in the infrared before these systems can be used in handling any but the simplest earth resource problems. Actual temperature differences, variations in emissivity, and atmospheric interferences are of about equal orders of magnitude in influencing recorded energies. One could also add "that the natural variances of plants, soils and water both in space and time through different days, weeks, seasons and years are at least equal in order of magnitude to the other variables. The extremely variable state of the atmosphere both vertically and horizontally makes infrared imagery difficult to use for quantitative purposes".[20]

3. Radar

Until quite recently very little radar imagery has been available to the scientific community. However preliminary investigations indicate that imaging radar systems have a great potential for resource surveys.[21]

The kind of radar which is best suited for such studies is side-looking airborne radar (SLAR). This radar produces a continuous-strip image that looks very similar to a very high altitude continuous strip photograph. Such systems produce an image on either side of the aircraft but the area immediately below the system is not recorded.[22]

Operationally, SLAR produces an image line-by line as the aircraft moves across the target area. The antenna transmits a short pulse of energy at right angles to the flight line. The signal first returns from that illuminated portion of the target nearest the aircraft and the strength of the signal determines the brightness of a dot on a cathode ray tube. As the signal returns from progressively more distant parts of the target the position of the dot on the cathode ray tube is changed in synchronism with the signal time delay until, at the time the signal has returned from the farthest point of the target, the spot has moved across the tube. Although the signal return can be recorded on magnetic tape, film recording is the usual technique. As the dot moves across the cathode ray tube, a line of film is exposed. The density of the exposed film is controlled by the dot brightness. Therefore film density is proportional to signal intensity. By the time the antenna transmits the next energy pulse the film has advanced slightly as has the aircraft. Hence, the signal return recorded on the new line of film represents a new portion of the target.

Because radar uses longer wavelengths, its resolution is poorer than that of optical or infrared systems. Wavelengths used range from .5 cm to 60. cm or longer. Real aperture systems (those with wavelengths of 3 cm or less) can achieve range (across-track) resolutions of 50 feet when they are flown at modest altitudes, "look" only a short distance to the side of the aircraft, and use wavelengths of about 1 cm. With higher altitudes, longer path lengths, longer wavelengths, and short antennas, resolutions become poorer (300 to 600 feet in azimuth are common).

Considerable improvements in resolution can be made, however, through the use of synthetic aperture techniques which can utilize the entire range of radar wavelengths. In synthetic aperture systems the phase and amplitude of the returning signals are stored and later combined by computer "as if they were produced by an antenna a great deal larger than the aircraft".[23] This permits the use of longer wavelengths and smaller antennas that will not adversely affect aircraft stability. But, more importantly, the synthetic aperture technique achieves finer resolutions than can be obtained by a real aperture defraction - limited system.

A number of factors influence the brightness of the radar image. Among the system parameters these include the radar wavelength employed and the polarization of the transmitted and received energy. The two most important target parameters influencing the image are surficial geometry (including overall geometry and micro-roughness) and the dielectric properties of the material.[24]

There are several advantages to the use of radar systems:

1) Imagery is uniform both during day and night;

2) Imagery is not affected by clouds and can be obtained in all but the heaviest storms. In addition, the atmosphere does not seriously influence ground returns;

3) Radar is particularly suited for imaging large areas. A number of workers have commented on the utility of radar in the identification of regional geologic structures, lineaments, and terrain features;

4) The longer radar wavelengths exhibit some ability to penetrate surficial materials;

5) Synthetic aperture imagery can provide extremely good planimetric maps;

6) Essentially the same analytical techniques used in aerial photo interpretation can be used with SLAR imagery.

Several disadvantages of imaging radar systems have also been noted:

1) Because of the side-looking nature of these systems, the data cannot be obtained at the same instant or in the same geometric format as that produced either by optical-mechanical scanners or framing

cameras;

2) Relief displacements are opposite to those in the optical region;

3) Because the long wavelengths exhibit much specular reflection, cultural objects tend to show severe scatter and target breakup. With broad band (panchromatic) images where there is much frequency averaging, this problem is not encountered;

4) Most evaluations of radar imagery consider such systems within the context of gross-scale reconnaissance work. For more detailed studies the two system parameters -- wavelength and polarization -- appear to have greater significance than they do in regional studies;

5) In evaluating the utility of radar in studies of geologic lineaments, it has been found that look direction (i.e., the orientation of the flight line) does exert some modest influence on the ability of the system to image these features;

6) Because the radar signal is influenced by the geometry (roughness) and dielectric properties of a target, the radar image of any target in which these properties are variable is subject to change through time. This has been shown for both crops and earth materials;

7) To date most research appears to have been conducted with K-, X-, Ka-band imagery. Work with other wavelengths does not often appear in the literature encountered.

At its present state of development, radar imaging of terrain, hydrologic features, surficial earth materials, and crop cover has been shown to have great promise. This is especially true when one is concerned with relatively gross surveys of remote areas or regions where adverse weather is common. Several workers have pointed to the desirability of obtaining dual-polarized, multi-frequency, or multi-date radar imagery to obtain the maximum amount of information from such a system. While it appears likely that radar imagery should be considered a primary sensor for resource surveying and monitoring, it is also apparent that further knowledge of the parameters influencing signal return is still needed and that refinements in radar systems are still forthcoming.

4. Microwave Radiometers

Radiometers are passive non-imaging sensors that receive emitted and reflected electromagnetic radiation at microwave frequencies (5×10^{-2} to 30 cm wavelengths). Output from these devices is in strip chart format.[25]

Electromagnetic theory indicates that all objects above absolute zero emit energy as a result of thermal agitation of charged particles. In essence, radiometers measure emitted thermal noise. In theory it is therefore possible to distinguish between adjacent targets and to even identify the nature of these targets on the basis of their spectral signatures. Theoretical calculations for emissivities of smooth homogeneous materials, such as sand and bare ground, are well established. It is, however, more difficult to calculate the emissivities of natural surfaces such as rough non-homogeneous terrain. The complexity of this task is compounded when it is realized that natural targets often exhibit variations in moisture content, vegetal cover, etc. over short distances and through time. Empirical research with respect to microwave emissivity has been carried out on a variety of materials including snow, soils, rocks, ice, and water.

One of the most interesting claims made for microwave sensors is that subsurface penetration and the detection of buried geologic features is possible. Pascucci notes that "the credibility of these claims, however, is somewhat impugned by their variability, ranging as they do over two orders of magnitude, or from two to 200 feet." In a test of this claim Pascucci contracted to have the sensor flown over sites in the Sierra Nevada foothills and in the California coastal ranges. At neither site did the microwave data reveal any of the numerous structural and lithologic features that are known to exist there. In fact, "only those signals caused by bodies of water could be confidently discriminated and assigned a map position".[26]

Pascucci also notes that microwave radiometers are said to detect changes in dielectric constants of soils developed _in situ_ and thus provide an indirect means of detecting lithologic change. He found no evidence in his study to verify this assumption. This negative outcome is thought to be due to three causes:

1) That signal component due to moisture content appears so strong as to effectively mask other contributing factors such as mineralogic composition, density, and temperature. It was noted that when the sensor passed over open water bodies the signal fluctuation ranged from 10 to 20 times greater than ambient variations.

2) Because of variations in aircraft speed due to head and tail winds it was difficult to correlate a specific signal with a map location.

3) The relatively high frequencies of the two radiometers used in the

study (10.0 and 30.2 GH_z) preclude significant penetration of the surface.[27]

Radiometers flown in conjunction with thermal scanners may eliminate the necessity to obtain independent field checks of target temperature that we now need in order to calibrate the tonal imagery from the scanners. It has also been shown that radiometer microwave brightness temperature is a measure of soil bearing strength which, in turn, is largely controlled by soil moisture content.[28] North indicates that radiometers can determine the thickness of oil slicks on water.[29]

Sensing of the Environmental Elements

1. The Lithosphere - Geology, Topography and Soils

In evaluating remote sensing it is well to keep in mind the interrelatedness of environmental phenomena. This is probably most easily recognized when one considers geology, terrain and soil. The environmental relationships are used to advantage in mapping programs. To cite an obvious example, geologists have long used topography, soils, and plants as indicators of specific lithologic units, both in the field and on aerial photographs. While such interpretative tools can be extremely useful, the interaction of the various environmental elements may also be a disadvantage. This is particularly true when one attempts to map a given element on the basis of remote sensor imagery. Computerized terrain mapping serves as an excellent example. While the desired outcome may be a map based solely on topography, the automatic mapping technique may well produce classes representing composite signatures of soil, vegetation, rock, and moisture conditions. Although such classes could conceivably be very meaningful, they do not necessarily represent distinct and mutually exclusive topographic units. In such cases we must always recognize precisely what it is that is being mapped. This problem will be considered in more detail later in this chapter.

Photographic Techniques

Among the various remote sensors that are commonly used to survey earth surface forms and materials, aerial photography is undoubtedly the most widely employed tool. In most areas of earth science research the air photo has become nearly indispensable.[30]

In earth resource investigations of all types, the aerial photograph usually proves to be an ideal base map. The Soil Survey Staff, for example, writes:

> "... no area should be selected for survey in advance of aerial photography or equally good base material unless the most compelling reasons exist for doing so.... (If) good material is (not) ... available ... costs for field work or map preparation, or both, may be very high.... such failures in initial planning lead to inaccurate soil boundaries, excessive costs, and substandard published maps."[31]

More important than their utility as base materials, air photographs can provide much detailed information about terrain and materials at a given locality. In addition, they are especially useful in revealing regional patterns. As a geological tool the aerial photograph offers greatest usefulness in the interpretation of stratigraphy, lithology, structural geology and geomorphology; in soil and engineering investigations information can be obtained from them on soil types and texture, drainage and moisture conditions, macro- and micro-topography, relief and slope, surficial materials and bedrock, vegetal cover and land utilization.[32]

Although photo interpretation does involve the use of some quantitative techniques of measurement, it is most often based on qualitative assessments of the photographic expression of earth materials. As such the usefulness of aerial photographs depends in large part on the skill, experience, judgement, and scientific knowledge of the interpreter. Interpretation of aerial photographs is considered by Ray to be a two-step process:

> The first step includes observation, fact-gathering, measurement, and identification of features on the photographs. The second step involves deductive or inductive mental processing of these data in terms of...(their) significance.[33]

A variety of criteria are used by interpreters to identify and interpret the objects recorded on aerial photos. For the purposes of this report it is sufficient to simply list them. (For a detailed discussion on their utilization the reader should consult the standard references on photogrammetry). Photographic interpretation is based on: the size, shape and shadow of an individual object; tone and color; texture; pattern; and the relation an object bears to associated features.

Color and false color photography

Until recently most photographic interpretation involved the use of panchromatic film. Many workers now report that better results are obtained when interpretation is based on color film-either alone or in conjunction with black and white imagery.[34] The chief advantage of color film is that

> "the natural appearance of images of objects makes more positive recognition and identification possible, generally,

the natural color tones have near unique significance, whereas, gray tones on black and white photos are usually ambiguous."[35]

Ray believes that in photogeologic studies, as a recognition element, color:

> "could be one of the most useful, if not the most useful, criterion for interpretative purposes.... It is a well-established fact that the human eye can differentiate about 1,000 times as many tints and shades of color as it can tints and shades of gray, characteristic of black and white photographs...."[36]

Mintzer summarizes the findings of several studies designed to assess the relative value of color vis-a-vis color infrared and panchromatic photography as they are applied to soil and terrain analysis. He reports that in some cases color infrared film has allowed for superior interpretation while in others, natural color has been judged better. In one case cited by Mintzer, vegetation was so dense that soil and terrain was effectively obscured. Here color infrared was found useful in delimiting soil or terrain categories on the basis of variation in vegetation.

> "Thus, ... interpreting the broad categories of vegetative cover, which are important in distinguishing broad soil changes, makes the application of color infrared aerial film a likely prospect for increased use in soils mapping."[37]

In study areas where vegetal cover is thin, Mintzer concludes that natural color aerial photography is better for detection and recognition of earth materials than either color IR or panchromatic films. In supporting this conclusion Mintzer notes that five main factors influence photographic tone:

1) intrinsic color of soil and rock

2) composition of soil and rock

3) moisture conditions of soil and rock

4) culture

5) vegetation

He states that:

> "The advantage of the natural color films over the other film types investigated was that the natural color appearance of the soils and soil conditions and the numerous shades of colors that could be differentiated made it possible to determine whether the tones were due to intrinsic soil color, moisture, vegetation or cultural features. With the ability to differentiate these factors, it was then easier to separate the color tones which were uniquely due to the soil composition. On black-and-white photography, it was difficult, if not impossible to separate these tonal factors. This made soils mapping from black-and-white photography more difficult to perform and necessitated more field checking. Infrared color photography although offering tonal differences was not as suitable for soils mapping as the natural color aerial photography. The unnatural colors present on the color infrared made it difficult to distinguish between the tonal factors of intrinsic soil color, soil composition and culture."[38]

While Ray recognizes the superiority of color photography for most photogeologic studies, he suggests the possibility that:

> "...two rock types of similar color might be differentiated more easily on certain black-and-white photographs than on color photographs because of mineralogic, chemical, or other differences that may permit significant contrasts in reflected light to be recorded when selected films and filters are used."[39]

To summarize then, it would appear that the decision as to the appropriate films that will be employed for a given project must be made by giving consideration to the character of the target area and the purpose for which the study is undertaken. In general, however, most workers agree that color photos are usually superior to black-and-white.

It should be noted that color photography is not generally available and that when such imagery is desired special flights must be ordered. The additional costs involved would suggest that acquisition of color imagery will mainly be limited to the special studies. Both Mintzer[40] and Pryor[41] for example, recommend large-scale color photos for studies of landslide-susceptible soils. Mintzer states, however, that the man hours saved by interpretation of color rather than panchromatic film offsets the higher initial costs.

Radar

The potential of radar as a tool for remote sensing of geologic, pedologic, engineering, and terrain characteristics has been considered by a number of investigators. Most agree with Delling, et. al., who suggest that the greatest utility of radar lies in its capability (1) to provide imagery at night or in areas of adverse weather and (2) to present "gross structural and topographic relationships ... in such a fashion that individual and seemingly independent features can be integrated into a regional format."[42]

Most papers that consider the geologic interpretation of SLR (radar) imagery devote considerable attention to the detection of lineaments -- linear topographic trends that are believed to reflect structural or lithologic discontinuities. While it has generally been shown that radar recognition of lineaments is superior to photographic identification the direction of look influences the recording and recognition of radar lineaments. Utilizing K-band radar imagery has been obtained for eight separate passes over a target area in the Boston Mountains.[43] It was found that when look direction of the radar system is parallel to the orientation of the lineaments recognition is not as distinct as when look is oriented normal to their trend. The influence of look direction on recording of lineaments is, however, judged not to be significant enough to invalidate the use of radar imagery for this purpose or to require multiple imaging passes using several look directions. With respect to detailed geologic studies of small areas, radar's greatest potential is thought to be in the direction of subtle lithologic change. In some cases lithologic variation may directly affect the radar image whereas in other cases lithology influences weathering and soil development which, in turn, are reflected in the character of topography and vegetation. Pascucci reminds us however that traditional geologic mapping may differ from radar imagery because lithologic taxonomy normally includes time whereas radar "sees" only two things: macro- and micro-topography and the materials' dielectric constant. Thus he writes:

> "Unless there is a significant change in material, a change in slope characteristics, or a change in surface roughness, there will be no change in the returned radar signal..."[44]

Pascucci further notes that small exposures (such as small intrusive bodies) identified by traditional geologic mapping programs may not be detected on SLR imagery. The reason for this discrepancy, he suggests, is not that small exposures are too small for detection but rather than they are too small to establish an identifying pattern large enough to be differentiated from the background. On the other hand, he points out that SLR imagery may distinguish rock types within an area mapped as one unit by conventional methods. As an example Pascucci cites the discrimination by radar of several igneous rock types within an area mapped simply as "granitic".

As has been mentioned previously, essentially the same analytical techniques used in air photo interpretation can be used with SLR imagery. Because the two sensors image different portions of the spectrum the tonal image of a given terrain material will often be recorded differently. For this reason quantitative assessment of tonal patterns from radar imagery is, at present, impractical for most earth materials.[45]

Automatic recognition of earth material by radar imagery may eventually become feasible. In order to develop this potential, considerable empirical information on radar scattering coefficient curves will be required. As additional knowledge of scattering coefficient curves is accumulated, these data, coupled with accurate terrain models and radar equations, can be applied to yield corrections for different incident angles. Thus, it may be possible to produce quantitative relationshps between signals obtained at different angles, different polarizations and different wavelengths that will result in accurate identification of a target material. Until scattering coefficient curves are available, however, interpretation of radar imagery will be facilitated if both radar imagery and aerial photographs are available.

Laboratory studies carried out at the Waterways Experiment Station indicate that standard pulsed radar may eventually be used to estimate moisture content of deep homogeneous soil samples and to detect surface vegetation of various heights.[46] In this respect it has been found that radar signatures of soils covered by vegetation are more significantly altered at the Ka-, X-, and C-band frequencies than at the P-band.

While standard pulsed radar used monochromatically cannot provide information on the presence or depth of subsurface interfaces, it is thought that a properly designed radar system could measure the depth to such an interface. Monocycle radar could be used to detect reflecting objects through an intervening medium of reasonable transparency but of highly variable refractive index. Examples of such media include dry, (nonporous) igneous rock, dry surficial sands, well-drained karst limestone, snow and ice, and frozen ground. The practical applications of airborne mapping by monocycle radar sensors may include the following: the depth of the water table in dry regions, location of caves, identification of shear zones, faults, and wet zones in nonporous rock.

Radar mapping of soils, like radar mapping of bedrock types, has produced mixed results when compared to conventional soil maps. Based on a study of soils in northern Oklahoma, Simonett concludes that recognition of adjacent soil types by radar is uneven -- i.e., in some cases soils are distinguishable at the series level; more frequently, at the association level; and in some cases, at neither.[47] He also indicates that separation at the association level is more likely in untilled sub-humid or arid soils than in cultivated or densely forested humid regions. Simonett's conclusion is similar to Pascucci's -- that is, radar "sees" or distinguishes soil not on the basis of criteria used by the pedologist but rather as a composite signature of various soil, moisture, topographic, and vegetal characteristics. He writes:

> "... where extreme differences occur in adjoining plant structures, in soil or plant moisture content, in soil texture, in topography, and...in areas of scanty vegetation..(and) small scale surface roughness, then discrimination on the radar image of soil units closely tied to these differences will usually be possible. Lesser differences will not be so easily detected, especially in cultivated areas, and careful timing of aircraft flights to coincide with the greatest seasonal vegetation contrasts will be necessary."[48]

Another potential application of VHF radio wavelengths is mentioned by Leighty who notes that these frequencies are capable of penetrating soil to some depth. This opens the possibility of remote determination of soil strength at shallow depths. The significance of this is that soil strength to a depth of about two feet is a major factor influencing terrain trafficability.

In addition to the use of radar to detect variation in earth materials and geologic structures considerable research effort has been devoted to terrain mapping and analysis by radar.

Although many of the same techniques are used to interpret photographic imagery and imagery produced by SLR it should be noted that the resolution of radar systems is less adequate. In addition, stereoscopic radar is not yet practical. These, however, are considered minor limitations that do not greatly hinder gathering of terrain data at medium scales and become important only when very detailed information is required.

The potential utility of radar in terrain description is well illustrated in Simonett's study of 28 drainage basins.[49] In this study comparisons are made between several standard descriptors of basin morphology derived from 1:24,000 topographic maps and from radar maps. Simonett offers several significant findings:

1) Most, but not all, (mapped) first order streams can be identified on radar maps.

2) Basin area, basin perimeter, bifurcation ratio, average length ratio and circularity ratio can be measured from both topographic and radar maps.

3) Correlation coefficients between stream lengths or drainage basin areas for both data sources are very high.

4) Regional slope calculations based on the two map types yield the same values.

According to Simonett it is possible to determine terrain slope angles by using two different monoscopic radar views of the same slope. Another study describes a method that utilizes the frequency of radar shadows in mountainous target areas to determine a frequency distribution of the terrain slope angles that are present.[50] Cumulative slope frequency curves derived from radar and topographic maps for six mountainous areas were compared. Slope determinations from topographic maps were based on 100 sample points from which usually a 500-foot orthogonal traverse was made. To develop a radar-based slope frequency curve, each target area was divided into eight areas of equal ground range (defined in terms of the slant range depression angle of the radar beam). Data for each observation was then corrected to account for the discrepancy between the flight line direction and the strike of each ridge crest. The percentage of crestline length in shadow was then calculated for each of the eight ground range zones. The rationale for the conversion of these data to a cumulative frequency curve follows:

> "Since the percentage of crestline length in shadow corresponds to the percentage of terrain back-slopes greater than the highest (radar) depression angle of the zone, the value was subtracted from 100 percent to find the percentage of terrain back-slopes less than the highest depression angle of the zone. A smoothed cumulative frequency curve was then plotted on the basis of data from each of the eight zones across the radar imagery."[51]

It was found that visual comparison of topographic -- and radar -- derived cumulative frequency curves of slope angles were similar for five of six test areas. The correlation between the two curves increases with an increase in map scale and a decrease in the map contour interval. In the single test area where the two methods did not agree, the ridge crests were rounded rather than angular and knife-like. Evidently this caused the radar method to over estimate the percentage of low terrain slope angles because of poor crestline delineation.

On the basis of this study it has been suggested that the radar shadow frequency method has the following advantages and limitations:

1) For areas of moderate to high slopes the technique yields a more realistic cumulative frequency curve of slope angles than can be obtained from 1:62,500 topographic maps using orthogonal traverses from random points.

2) The technique permits more rapid sampling of large areas with greater accuracy than conventional map interpretation methods.

3) The radar method is best suited to mountainous areas where topographic map coverage is usually quite poor.

4) To obtain maximum data retrieval, the landform region must extend across the entire radar image -- this therefore requires regions of at least 50 to 100 square miles.

5) Similarly, it is essential to have the complete landform region covered to insure that the full range of slope angles is represented in the frequency curve.

6) The region imaged on radar must be homogeneous across range.

7) There must be no preferential orientation of slope angles.

8) The model upon which the method is based assumes that the landforms have sawtooth profiles and that crests are well-defined.

9) The lowest slope value that can be discriminated depends on the far range depression angle of the radar system. This means that with many systems the method cannot discriminate slope angles less than about 15^{o}. In many terrain studies for landuse, traffic-ability, and similar analyses, critical terrain angles are often in the range of 0^{o} to 15^{o}. This is a serious limitation but this is a limitation inherent in present radar systems -- not in the method itself. With synthetic imaging radar systems depression angles of 1^{o} are possible -- especially when low altitude flights are used. Although such drastic system modifications are not probable, far range depression angles of about 5^{o} have been achieved.

Another technique -- radar scatterometry -- which has been found useful in measuring sea-state and ice roughness may also have applications to terrain analysis, but these are rather speculative. The radar scatterometer measures variation in the radar scattering coefficient and thus can perhaps sense terrain texture.

In the study of microrelief, ground elevations to a few tenths of a foot can now be obtained with the airborne lasar terrain profiler. This device can also determine the height of trees if an optical path to the ground is obtainable for as little as 5% of a forest.[52] Lasar microrelief profiling is an engineering technique that is usable today and is one that offers great promise for rapid acquisition of terrain profiles suited to most types of preliminary engineering efforts. By combining this imagery with air photos "it is possible to chart surface variations with much higher resolution and accuracy than is possible using small-contour topographic maps".[53]

Infrared

In contrast to radar imagery, comparatively little work has been carried out on the utility of thermal infrared mapping of terrain, earth materials, and other geologic features. Parket writes that a review of literature through 1968 on the applications of infrared sensing of soils and rocks illustrates a number of interesting potential applications but gives little justification for routine airborne IR mapping of terrain. He indicates that much of the work carried out to that time is concerned with "understanding the expression in imagery of the infrared radiation from terrain materials".[54] In large part such studies relate to military uses of infrared and not specifically to engineering characteristics, although there is some emphasis on terrain trafficability. Also some work relates airborne IR imagery to ground measurements of material properties and to meteorological conditions at the time of observation.

Before the potential of thermal IR scanning can be realized, the factors that influence infrared radiation by earth materials must be investigated more fully. Parket lists a number of questions that require additional basic research:

1) How do complex interactions of material properties and environment effect the radiation output and image characteristics of terrain features and materials?

2) Do these interactions produce detectable thermal differences?

3) What are the optimum temporal and environmental conditions for recording such differences?

4) Are results sufficiently predictable over a range of materials and environmental conditions that interpretation is facilitated?

5) What is the engineering value of the obtained information?[55]

There are four main areas in which Parket believes thermal infrared scanners exhibit potential for investigation and recognition of earth materials and processes:

1) Location of regions of geothermal activity.

2) Recognition of areas of standing water or surficial drainage patterns.

3) Delineation of boundaries of differing soil or rock types and the identification of such materials.

4) Recognition of variation in ground water discharge zones and thus, delineation of geologic structures as well as potential landslide areas.[56]

The utility of infrared imagery in the detection of geothermal activity is illustrated in two recent papers that investigate such phenomena in Yellowstone National Park.[57] The latter indicates that when thermal infrared imagery is used in conjunction with simultaneous panchromatic photography, it is possible not only to recognize thermal anomalies but also to distinguish between classes of features such as hot springs and open pools, fumaroles, and areas of steaming ground.

The infrared tonal image of a specific soil or rock depends on a number of physical and environmental factors including material composition, soil moisture, and soil temperature. Where vegetation is sparse such tonal differences may permit delineation of different materials and perhaps may even reveal such information as the mineralogic composition and various engineering properties. The tonal relationships of earth materials may change from day to night. Such changes may also permit the identification of materials. While these lines of information may not be unique to a specific material they can add corroborative data to air photo interpretation.

A study of rock type discrimination in Oklahoma illustrates this potential use of infrared scanning and further describes and elaborates on some of the factors that influence the IR image tone of earth materials.[58] The study area -- Mill Creek, Okla. -- chosen by Watson is characterized by relatively simple lithology (dolomite, limestone, sandstone, and granite), good exposures, and little vegetal cover. The major purposes of the study were 1) to discriminate between rock types and 2) to relate temperature differences of the rock types to differences in their thermal properties. The infrared scanner used in the study was flown over the target at an altitude of 1800 m to permit reasonably useful resolution of the data. Flight times were selected to provide maximum usefulness from both thermal and photographic data during daylight hours and to obtain optimal thermal contrasts at night. The flight times selected were: mid-morning (11 a.m.), mid-afternoon (2 p.m.), and pre-dawn.

The preliminary findings made by Watson follow:

"1) IR data ... contained significant stratigraphic and structural information . The relatively pure limestone and dolomite of the test area can be differentiated in the pre-dawn IR images, and facies changes between them can be detected along and across strike.

2) Daytime images display much stratigraphic and structural detail. Small-scale bedding detail is enhanced in the morning images of areas of low elevation difference, and constrasts of alternating formations that form ridges and valleys are enhanced in the afternoon images of areas of high elevation differences. The difference in features displayed in morning and afternoon images appears to be a function of the insolation ... on sunward and shadowed slopes of differing scale.

3) Fault or fracture zones are best displayed in the pre-dawn image; they appear cooler than surrounding ground, because of greater water content and concomitant evaporation. The abundance and throughgoing nature of lineaments (which coincide for the most part with joint systems) are more obvious in the infrared images than in aerial photographs. Lineaments striking NW are preferentially enhanced in the morning. Images and lineaments striking NE are preferentially shown in the afternoon images".[59]

On the basis of his preliminary findings, Watson concludes that pre-dawn is the most appropriate time for thermal mapping of rock types. It is at this time that one can expect maximum thermal inertia differences between lithologic units because the thermal contrast is high and the effects of insolation are at a minimum. He also concludes that the greatest temperature contrast and hence, the greatest response to the rock parameters of albedo and thermal inertia (excluding effects of vegetation and water content) occurs when solar insolation is greatest (that is, when the declination of the sun is equal to the latitude of the site and when clear sky conditions are encountered) and when sky radiation is low (that is, when the day and night effective air temperatures are low).

In summary, earth materials are discriminated on the basis of thermal inertia, albedo, and emissivity as well as a variety of other factors including site location (latitude), season (the declination of the sun), atmospheric effects (including character of cloud cover, transmission, and air temperature) and topographic orientation (slope and azimuth). The electromagnetic reflection and emission by rocks depends not only on such rock properties as color, composition, and topographic expression but on surface roughness, lichen-, plant-, and tree-cover, and chemical and vegetative staining. All of these factors must be taken into account if we are to develop a model of IR rock discrimination and identification.

Pascucci has investigated the use of thermal infrared (TIR) imagery to identify geologic features in the scrub- and grass-covered foothills flanking the San Joaquin Valley of California.[60] The results and conclusions of this study deserve mention because an attempt is made to compare the geologic interpretability of imagery obtained by side-looking radar, thermal infrared, and passive microwave radiometry with each other and with ground truth data obtained by traditional geologic field methods.

Pascucci found that some geologic contacts identified on TIR imagery correspond to those recognized on the radar (SLR) imagery. However he considers his map based solely on the interpretation of TIR imagery to be "notably unsuccessful" when it is compared to SLR and ground-truth maps. He therefore concludes that thermal infrared scanning "... even when used under nearly ideal conditions of aridity, absence of arboreal vegetation, and thin, discontinuous soil cover, has little geologic content". He does note that TIR imagery did indicate an ultrabasic intrusive that was not detected on the radar map but was identified on the ground-truth map. This leads him to suggest a second method by which TIR imagery might be used more efficiently:

"...to disregard the topographic information implicit in imagery acquired during daylight hours (TIR flown during daylight hours, especially if the day is sunny, produces an image having a radiant flux pattern of light and dark tones that closely follows the insolation pattern of sun and shade on the terrain; i.e., terrain radiation is primarily a function of differential solar heating and only secondarily of lithologic and structural features) and to scan the imagery looking only for temperature anomalies, which are then annotated directly on the SLR geologic overlay used as a base map. ....An important advantage of this second method of IR interpretation -- interpreting only thermal anomalies rather than the whole image content -- is the speed at which it can be accomplished, on the order of ten times as fast as a complete geologic interpretation".[61]

Using the method described above Pascucci identified a number of thermal anomalies.

"These anomalies ... consisted primarily of nine small lithologic units, undetected by radar, located along the contact between upper Jurassic marine sediments and metasediments and Pleistocene non-marine sediments... Although only one fracture and one fault were identified -- as thin, linear, dark anomalies, the dark tone (cool temperature) being due to the collection of meteoric water -- the fracture was one that, while detected by the radar, had not been identified by the interpreter".[62]

Regarding the utility of this method Pascucci comments:

Although problems were expected, none were encountered ... it is possible, however, that the ease with which ... (TIR annotation) was done was due to the similar conditions of illumination that prevailed, both the solar and radar radiation impinging on the terrain from a similar, southerly aspect angle.[63]

As a final comment regarding the utility of thermal infrared mapping of geological phenomena it should be recognized that Watson seems to have had much greater success in the interpretation of such imagery than has Pascucci. In part perhaps this may be due to differences in the areas themselves. But it should also be recalled that Watson found that pre-dawn imagery is most useful for discrimination of rock types. It appears that

Pascucci's analysis is based only on daytime imagery. While both papers illustrate the potential of thermal mapping we must still return to Parker's conclusion -- for this potential to be developed, a great deal more basic research will be required.

Additional discussion on the use of thermal mapping of terrain features (i.e., drainage patterns) will be found in the following discussion on sensing of hydrologic phenomena.

Microwave Radiometry

The potential utility of the microwave radiometer as a sensor of terrain and earth materials is perhaps one of the least studied of the more common remote sensors.

Edgerton describes studies he has conducted using a truck-mounted radiometer.[64] In particular he has investigated the relationship between microwave brightness temperature and soil bearing strength. Soil bearing strength depends upon several factors including the character of the soil material, the void ratio of the soil, and the water content. In general the strength of a given soil material increases with a decrease in both water content and void ratio. In this study Edgerton attempts to relate microwave brightness temperatures across a playa surface to <u>in situ</u> strength measurements made with a cone penetrometer. Results of the study indicate that penetrometer measurements on the surface and at a depth of three inches generally do not show a close relationship with radiometric temperatures. However penetrometer readings at a six inch depth were found to exhibit much better correlation -- especially with 13.4 GHz brightness temperatures.

He writes:

> "This relationship is somewhat unexpected since a good correlation has been shown to exist between soil temperatures measured at $\frac{1}{2}$ - inch depth and microwave brightness temperatures. It must be remembered that the dielectric properties of the soil material are governed primarily by the amount of free moisture occurring in the material. Additional factors such as the dry density (or void ratio) of the soil, soil texture, and structure must be considered in determining bearing properties...."[65]

It is concluded that a definite relationship exists between radiometric brightness temperature and soil moisture content. Changes in radiometric temperature are not linear with changes in water content, however. Nonetheless, this relationship, can be used to provide a qualitative estimate of bearing strength of cohesive soils. Through the use of multifrequency radiometers he believes that the vertical moisture distribution can also be determined. Finally, noting recent developments in microwave imaging systems and in color data processing techniques, it is suggested that mapping moisture distributions over sizable areas will develop into a new and useful terrain analysis tool.

It should be recalled that Edgerton's study utilized data obtained from a ground-based unit. While he states that similar data can also be obtained by airborne units this introduces a number of complications not encountered with surface sensors.

Scherz and Stevens write:

> "There is relatively little energy available in the spectral region that passive microwave units operate in. This would be of no consequence if one were sensing a stationary object and could gather energy over a long period of time. Airborne remote sensors, however, can not "look" at a given area for a long period of time....

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uay, et. al., involves assessment of soil engineering

ong a 70 mile transect through central Indiana. Data for

obtained by the University of Michigan 17 channel multi-

by Tanguay, et. al., had two main goals: 1) to determine

ngineering information that may be obtained by the scanner;

nysical attributes of the soil influences the information

determine which scanner bands are most appropriate for

kinds of information 2) to evaluate alternative methods of

A summary of the major findings follows:

e scanner wavelengths considered to be most informative

eering soils data are: thermal infrared (8 - 14 μ),

infrared (0.8 - 1.0 μ), red (0.62 - 0.66 μ), and either and results must be plotted.

The most satisfactory data extraction technique investigated by Tanguay, et. al., utilizes an automatic computer analysis method developed at LARS (Purdue University) for multispectral data. Given the coordinates for each soil type area this program determines the spectral response attributes unique to each soil class. All remaining areas are then recognized and classified according to their spectral responses. This technique permits the efficient preparation of engineering soils maps based on spectral responses of soil types where vegetation is not a limiting factor.

The authors conclude that:

> "... (there is a) need for further research in other geographic areas, on other soil types, and soil conditions. ... laboratory reflectance measurements (are) useful in understanding factors which influence the reflectance properties of soils and rocks but they also (show) the need for field measurements of these properties ... (field measurements show) soil moisture and the color to be of greatest importance and also (show) that meteorological changes have a critical effect on the soil thermal behavior. Much additional research is needed to quantify and predict the spectral and thermal properties of many soil types and textures under various conditions of moisture and irradiance".[71]

Smedes' study of a 12 square mile portion of Yellowstone National Park involves an assessment of the utility of terrain type recognition and mapping by computer processing of airborne multispectral data. Data on which the analysis is based were collected mainly with the University of Michigan 12 channel scanner-spectrometer (0.4 - 1.0 μ range). Two additional scanner systems were used to record a total of 5 channels in the thermal and reflective infrared region (1.0 - 14.0 μ). Simultaneous photography using color, color infrared, and black and white infrared films was also obtained.

Among the methods of computerizing terrain recognition that are evaluated, two involve the use of predetermined landscape classes. These classes are delimited by the investigator on the basis of field study and preliminary data processing. Smedes writes that the classes are selected "not on the basis of composition or genesis, as we traditionally do in the course of geologic mapping, but on the basis of their overall surface color and radiance (brightness) inasmuch as that is what the sensor was recording".[72] Within the test area Smedes initially found that 13 terrain classes could be recognized. Several of these were combined to produce 9 classes. In order to illustrate the kinds of terrain classes that the sensor "sees" these are described below:

1) Bedrock exposures -- largely unvegetated,
2) Talus -- trees absent or widely-spaced, slopes 0 to 45°,
3) Vegetated rock rubble -- more than 3/4 of area covered by low vegetation (grass, moss, and conifer seedlings), slopes 0 to 25°,
4) Glacial kame meadow -- vegetated by grass and sagebrush, approximately $\frac{1}{4}$ bare mineral soils, well-drained,
5) Glacial till meadow -- vegetation mainly grass and sagebrush, approximately 1/5 bare mineral soil,
6) Forest -- vegetation largely coniferous with some deciduous trees,
7) Bog -- moist sites supporting lush sedge and grass growth,

8) Water -- rivers and lakes, i.e., open water,

9) Shadows -- shade from clouds and deep shade adjacent to cliffs and forest.

From the above it can be seen that the terrain classes used in the study represent unique associations of rock, soil, vegetation, and drainage.

With one analytical technique investigated by Smedes an analog computer establishes an optimal signature for each predetermined class. This is accomplished through the use of a maximum likelihood function for each of the 12 X 12 combinations of a sensor response matrix. With optimum signatures established data for the entire study area is run through the computer and each class, one at a time, is mapped on a cathode ray tube. Results for all classes are then superimposed. The bulk of Smedes' study is, however, concerned with data processing by digital techniques rather than by analog methods. When predefined classes are used, previously unclassified areas are assigned to that class with which they exhibit greatest similarity. Other digital techniques require no predetermined classes. Of these Smedes writes:

> "These techniques utilize the fact that the radiance in different classes tends to cluster in different places in n-dimensional space. The programs allow the computer to determine these clusters and to plot each class based on clustering, whatever the class may be".[73]

This technique has the advantage that no a priori classification is required and that identification of classes is achieved through limited field checks or through photographic interpretation.

On the basis of this study Smedes makes several conclusions and recommendations regarding computer mapping of multispectral terrain data:

1) One of the overwhelming problems of automatic mapping of terrain classes is that spectral signatures of a given class vary widely with a number of factors including time of day, season, latitude, flight direction, and recency of rain. Because of this it is doubtful that identification of materials by spectral response alone is possible. This indicates the need for some prior knowledge of the terrain.

2) Statistical preprocessing of data is important because it normalizes data and minimizes the variations in illumination due to scanner "look" angle, topography, and shadows.

3) It is not necessary to utilize data from all channels that are available. A broad range of terrain types can be mapped satisfactorily using combinations of 3 or 4 channels in the 0.4 - 14.0 μ range. When channel selection is made, however, the effects of atmosphere and haze must be considered.

4) The most immediate result of this study is to indicate the feasibility of accurate automatic terrain mapping of numerous terrain units.

5) The utility of spectral data is greatest when combined with other non-spectral data to produce terrain information.

2. The Hydrosphere and Atmosphere

Several factors suggest that remote sensing is well-suited to the study of hydrologic and atmospheric phenomena. First, both water and air have characteristics that may be extremely variable over short time periods. Second, relative to other environmental elements both are inadequately monitored, particularly on a global scale. Third, it would appear quite unlikely that adequate monitoring of either will be possible using traditional methods alone. This derives from the ubiquitous nature of the two elements. The widespread and successful use of satellite photography and radar in meteorological applications in connection with World Weather Watch and related programs, illustrates the potential utility of remote sensors in these areas.[74] The use of remote sensors in hydrological studies has not kept pace with that in other areas.[75] This is especially the case with basic data acquisition. However, with the current interest in atmosphere and water quality the utility of remote sensors to detect pollution sources and areal extent is receiving considerable attention.[76]

Photography

In hydrologic studies photographic sensors remain the primary aerial tool. As has been noted in earlier sections, black and white, color, and color infrared films often permit direct detection of surface water and drainage patterns. In addition these films can aid in the indirect detection of surface and near-surface water by permitting the discrimination of surrogates such as variations in soil moisture and in vegetal vigor. Color infrared film, in particular, is suited for recognition of vegetation type and vigor. False color film has also been found to enhance tonal anomalies on water surfaces thus allowing more accurate mapping of current and dispersion patterns. Natural color films have value in water resource studies because of good depth penetration and because they too are useful in vegetation discrimination.

Aerial photography has also been shown useful in geological and ecological studies of marine environments. Regarding the utility of air-borne photography in shallow marine studies Kelly and Conrod write:

> "It may be argued that aerial photography is limited to shallow areas that lie along the coast and by the turbidity of the water in productive areas or areas with much land runoff, but features of 10 or 15 foot depths may be photographed even in such turbid water. Coastal regions however are the areas of the ocean that are of most immediate importance to man, since they can be most easily utilized and are most heavily polluted by man as he uses the resources in the ocean".[77]

A number of recent papers have suggested additional hydrographic and meteorologic uses for the data presently being gathered by the various meteorological satellites.[78] Rabchevsky, for example, indicates that the Advanced Vidicon Camera System (AVCS) and the Image Dissector Camera System (IDCS) of the Nimbus Meteorological Satellites can be used in the following problems:

1) Mapping the distribution and movement of sea ice,
2) Monitoring pack ice boundaries,
3) Detecting and monitoring leads,
4) Mapping the distribution of snow cover,
5) Recognizing drainage networks.

Of the above applications particular attention has been given to remote sensing of snow and ice cover. According to Baker comprehensive or repetitive surveys of snow and ice fields over large areas and on a timely basis has been found impractical using conventional ground-based and airborne techniques. It has been shown that satellites in appropriate orbits can, if they carry suitable sensors, monitor snow cover on what is essentially a continuous basis. Consideration of the resolution and spectral responses of available, leads Salomonson to suggest that the best system for this purpose is IDCS.

Before satellite data can be utilized, however, it is necessary to develop techniques that put satellite data in a form suited to hydrologic applications. The major problem of identifying snow or ice fields is to distinguish them from clouds. This may be accomplished by photographic interpretation or by automated snowfield delineation through data digitization and computer processing and redisplay.[79]

With the photographic interpretation method the daily mosaic or individual frames of digitized data are displayed on a cathode ray tube and are photographed to produce the 15 brightness levels originally recorded by the sensor. Snow field delimitation is made by interpretation based on 4 criteria:

1) Reference to concurrent cloud observations,
2) Recognition of terresterial features,
3) Day to day pattern stability,
4) Pattern appearance.

After identifying cloud-free areas snow fields are delimited by hand using several daily maps to produce a composite snow map. With this method the interpreter must have knowledge of the area under investigation.

A second method termed "Minimum Brightness Compositing" (CMB) involves manipulation of satellite data in digital form within a computer. The CMB chart is derived by processing several days (usually 5) of successive AVCS data. Because cloud-free land or water has a much lower albedo than ice, snow, or clouds, the multidate composite tends to retain only the slowly changing ice or snow fields. Most clouds are automatically screened out of the composite image because, compared to snow and ice, they are relatively transitory and because the composite is based on only the lowest brightness levels. Only stable cloud masses will be retained in the final image.

An alternative method of CMB display is accomplished by relating computer printed brightness values at each point of a data array to external brightness "benchmarks" such as the Greenland Ice Cap and cloud-free ocean areas.

Results of CMB snow and ice mapping are very promising:

1) According to Baker CMB output can be used to make areal estimates of snow cover within drainage basins. Baker's preliminary studies relating CMB areal coverage estimates to ground survey data usually differ by no more than 5 percent. Similarly Salomonson finds good agreement between mean monthly runoff for a drainage basin in the western Himalayas

and an IDCS-based estimate of percent snow cover within that basin during the period of snowmelt.

2) Baker has compared CMB estimates of snowlines to ground-truth data. He states that the method is very effective in relatively unforested areas but less so in heavy coniferous forest. The presence of prolonged cloud cover and the existence of narrow drainage basins also are related to greater disparities between satellite and ground-truth snowline positions. He further states that satellite-based snowline estimates are consistently higher than estimates based on aerial surveys.

3) With respect to sea ice, McClain has found that CMB printout values are systematically related to ice concentration and to ice surface conditions such as the presence of snow cover or meltwater puddles. McClain concludes:

> "... surface albedo and its variations are probably the most important regional factors affecting the heat and mass budgets of the Arctic Basin. Since it can be shown that adjusted CMB values derived from satellite vidicon data are highly correlated with albedos obtained by other means, the technique presented here promises to be a useful tool for sea ice researchers and forecasters".[80]

4) The snow and ice evaluations cited above are based on 3 - 5 km resolutions. Satellites scheduled for 1972 will have sensors with 1.5 km to 100 m resolutions. This should appreciably reduce the disparities between mapping by satellite and aerial data.

5) Salomonson concludes that it is now feasible to monitor

snow cover on a quantitative basis for entire drainage basins using routine meteorological imagery on a continuous basis. These observations plus data obtainable from the near and far infrared bands offer a valuable input for water management systems where conventional observations are either difficult and expensive to obtain or are unavailable.

Infrared

Infrared imagery and radiometry from both airborne and satellite platforms has been shown to have a number of applications to meteorologic and hydrographic problems.[81] One of the more interesting of these is the remote monitoring of sea surface temperatures.

Large water bodies exert significant influence on the air overhead and may markedly alter its temperature and humidity. If this modification process is to be completely understood and predicted the distribution of temperatures on the surfaces of water bodies must be obtainable on a timely and continuous basis.[82] While knowledge of the distribution of sea surface temperatures is highly desirable, observationally the data is difficult to obtain -- especially for large areas.[83]

Wendland and Bryson describe an airborne thermal mapping program for Hudson Bay. This study was carried out using an infrared thermometer. Flown at an altitude of 1000 feet, the instrument is sensitive to radiation emanating from a circle of about 40 feet in diameter. As the aircraft flew along a predetermined course data gathering was continuous when there was clear air between the sensor and the water. Interpretation of the recorded radiation temperature of the target can be determined when the Stefan-Boltzman relationship is known. The calculated radiation temperature however, may not necessarily equal sea temperatures measured by surface vessels because:

> "Infrared radiation emanates from the upper few microns of the sea, and measurements by ship usually involve a bucket and thermometer, or perhaps a calibrated sensor suspended in the upper layer of water. The radiation temperature is a true "skin" temperature, and is dependent upon solar heating, mixing of the surface water layer, and evaporation. These processes can cause the "skin" temperature to differ from a conventional bucket temperature by a few degrees".[84]

Another potential difficulty of the technique is that the instrument receives radiation in the 8 to 13 μ range. While this approximates the atmospheric "window", the atmosphere is not totally clear. Therefore the atmosphere absorbs some of the radiation reflected from the sea surface and reradiates it as air temperature. "Without a temperature-humidity profile beneath the aircraft, the effects of such spurious radiation cannot be known, and error is introduced.... Flight altitudes less than about 300 meters essentially eliminate the effect of atmospheric absorption and reradiation".[85]

The authors present maps of surface temperature patterns for several different time periods. These show that thermal mapping permits the monitoring of temperature changes both over time and space. Based on this evidence it appears that the technique can be considered fully operational -- at least for low altitude surveys.

Rao describes a similar technique for measuring sea surface temperatures using the scanning radiometer on the Improved TIROS Observational

Satellite (ITOS).[86] The scanning radiometer monitors emitted infrared radiation in the 10.5 - 12.5 μ region and views an area approximately 4 nautical miles in diameter. Rao describes a computer technique for discrimination between sea surface and cloud temperatures. Results of this technique indicate that the sea surface temperatures determined are comparable with surface vessel data.

With regard to hydrologic applications, Salomonson indicates that data from the Nimbus 3 High Resolution Infrared Radiometer can be used to map river courses and locate standing water bodies in remote areas.

A more significant hydrologic application involves airborne infrared imagery to locate sites of groundwater discharge into streams and other surface waters and to monitor industrial and domestic waste discharge. The utility of this technique is shown by Wood who has used low altitude thermal imagery taken in pre-dawn hours to identify springs and seeps along river banks as well as sites of effluent discharge.[87]

3(a). The Biosphere - Flora

In the inventory and monitoring of vegetation two constraints make remote sensing potentially very valuable in this area. First, facts about the floral population must be secured within a sufficiently narrow time span so as to avoid the "noise" introduced by natural seasonal changes.[88] Second, it is important to achieve early recognition and evaluation of stress conditions in vegetation.[89] Heretofore, most data collection has been done with time consuming ground surveys. The utility of remote sensing has long been recognized by workers in this field as evidenced by the fact that agriculturists were amongst the first to use aerial photography.[90] Moreover, a large proportion of current remote sensing literature is devoted to problems related to agriculture, forestry and native vegetation.

Before discussing the applicability of specific remote sensors to particular types of vegetation surveys two general comments that appear in much of the literature should be raised:

1) Many workers stress that to obtain the greatest amount of information from remote sensing of vegetation it is essential to acquire sequential imagery at several times during the growing season.

2) In order to obtain information on a plant community rapidly and because sequential imagery greatly complicates data gathering and information extraction and storage a number of papers propose the use of multi-stage sampling of vegetation instead of a total inventory.

Sequential Imagery

Traditional agricultural inventories that utilize aerial photographs flown at modest altitudes rely on such identification aids as the spacing, height, and width of crops. When interpreting high altitude or space photography one cannot utilize these aids, however.[91] Resolution is such that large portions of whole fields, rangeland, or forested areas become the smallest observational units that can usually be discerned. "Depending on scale, resolution, and the characteristics of an imaging system, different ground subjects may not be sensed as individual entities. Their signatures may become integrated and appear to represent a single subject when they, in fact, do not."[92]

Heller's study of disease among forest trees using color and false color film illustrates this problem. He found that with scales smaller than 1:31,700, small infestations of 1 to 3 trees (with a cluster diameter of about 5 m) could not be detected with acceptable accuracies. When he used photographs with scales as small as 1:174,000 acceptable levels of identification were limited to clusters larger than approximately 30 m in diameter -- about 20 infested trees. In such situations one is not dealing with the characteristics of individual plants but rather with composite tonal signatures of clusters of individuals.

A number of workers have investigated the utility of aerial and space photography and other imaging sensors for the identification of crop types, rangeland forage, and trees. Some of the most interesting work are studies by Lauer[93] and Colwell[94] on crop identification in the Phoenix and Imperial Valley regions. These two areas provide fairly complex test sites because as many as 8 to 10 main crop types are grown as opposed to much of the U.S. where only 2 or 3 major crops are usually encountered.

Colwell's study is based on the analysis of the results of photo interpretation by skilled interpreters who had varying degrees of experience. All test subjects were given an opportunity to become familiar with the study area through the use of ground truth-annotated training photos. Colwell found that crop type identification using single-date multi-band space photography seldom exceeds 60% accuracy. Using optimal film/filter combinations, accuracies up to or greater than 90% were possible for some crops while for other crops accuracies as low as 30% were also attained. It was also found that color image enhancements of black and white photos can significantly increase identification accuracies. The main problem encountered in the study was that interpretation was based on single-date photography taken at a season when many crops appear quite similar on high altitude film. The same problem was encountered when similar studies were carried out on timber species differentiation and the discrimination of range and brushland plants. Colwell concludes that sequential imagery at appropriate times through the growing season may facilitate species differentiation.

In addition to Colwell, many investigators have stressed the utility of sequential or multi-date imagery. The rationale of sequential imagery is best summarized by Schwarz and Caspall who write: "It appears that as maturation increases, the crops become separated into more unique regions in data space .... (because) each crop has a distinctive annual growth pattern. Times of planting and harvest and distinctive changes with maturation give unique temporal signatures to each crop".[95] Sequential imagery through the growing season can also facilitate identification of timber species and range or brushland vegetation.

For optimal use, the dates on which such sequential imagery is obtained must be selected on a rational basis, however. Thus, it is extremely important to have prior knowledge to the phenology of specific plants that are found in the target area.[96] To meet this need, it is necessary to develop a "crop calendar" for each species or group of species that are of concern within a given study area.

A crop calendar is an empirical catalog of seasonal response patterns for a given species. As such it takes into account seasonal and annual variations of response of that species within a local area. In essence, the crop calendar serves as a probability model for crop identification. A number of factors influence the crop calendar. The most important of these is the phenology of the crop itself. This, in turn, is influenced by such factors as the latitudinal location of the study area, local ecological conditions and local variations in planting and harvest times. Other factors influencing the crop calendar include the nature of the crop combinations encountered within the study area and the types of sensors used.

Once appropriate crop calendars are developed they can be used to determine when each crop or crop type within a particular region will exhibit a unique tone signature that will permit its discrimination and identification.

For many agricultural crops, crop calendars for a number of study areas are already available. Several workers have pointed to the need for similar calendars for forest and range species but development in these areas has lagged behind crop studies.

Multistage Sampling

Several workers in evaluating the potential of remote sensing in the context of vegetation surveys have concluded that a sampling scheme, rather than a total enumeration is a more tractable approach. According to Langley a resource information system based solely on remote sensing that provides complete and accurate data for every acre within a large target area is not now feasible because:

1) Correlation between remote sensor data and ground conditions is not perfect.

2) Certain detailed resource data, such as forest tree growth measurements, can only be obtained on the ground.

3) Even if such data were available, present data storage and processing techniques could not handle the volume of information that would be produced.[97]

In addition to these considerations several other factors suggest that multi-stage sampling is superior to total inventory.

It has been shown that while high altitude and space photography can image large areas, resolution is such that only gross vegetal classes can be discerned. Pettinger for example, believes that space photography is best suited for delineation of broad landuse classes such as: urban; agricultural cropland; rangeland; uplands and mountains; and watercourses. Colwell has found that color infrared space photography can be used to distinguish bottomland hardwood forests from upland mixed forest. Colwell further states that additional stratification of timber types is possible using image enhancement techniques or through the use of microdensitometry. Nonetheless, the nature of information requirements for resource management decisions and for monitoring vegetation change appear to exceed present capabilities of space imagery. Poulton, <u>et</u>. <u>al</u>., indicate that resource management decisions often require imagery at scales larger than 1:20,000 while to monitor vegetal change through time may require scales as large as 1:2,400.

Obviously to obtain sequential imagery at these scales for large areas would be quite intractable. In addition, such detailed coverage as a matter of course would be both unessential and inappropriate. As Langley, et. al., point out detailed studies of vegetation often require highly specialized data bases and user participation in information gathering.

The multi-stage sampling technique visualized by these workers involves the delineation of gross categories of vegetation or landuse on space photographs. Within each of the major groups, successive stages of sub-sampling are then carried out using larger-scale airborne imagery. At the last stage, measurements are obtained on the ground.

Langley, et. al., who have described this approach in greatest detail, suggest the multi-stage sampling procedure has a number of advantages:

> "1) The general design ... (allows) arbitrary probabilities of selection at every stage. The sampling probabilities are formulated from the additional information available at each stage by virtue of the increasingly finer resolution of remote sensor imagery.
>
> 2) A workable resource information system for forestry and agriculture could be made ready to utilize information immediately upon its receipt from ERTS and begin supplying needed answers to questions concerning the status of the resource base. In time... a minimum of aircraft and ground data (will be) needed.
>
> 3) ... information about specific variables is improved as the need arises. Hence, an exact definition of the make-up and accuracy of the data base is not essential at the beginning.
>
> 4) ... users will have the opportunity to participate at a level of sophistication that suits them.... They can obtain subsamples (using those sensors appropriate to the specific needs of their study and) can handle their own fieldwork and data processing for aerial and ground stages of their surveys".[98]

The use of multi-stage sampling is not a new technique to resource inventory studies. As early as 1940 aerial photos were used to delineate homogeneous forest tracts which were then cruised by ground survey teams in order to obtain yield estimates. Workers who advocate multi-stage sampling, then, are utilizing new technology with an established methodology.

In terms of actual operationalization of this approach, Colwell states that sampling efficiency (utilizing space photography as the first level of stratification) in timber yield surveys is improved by 60 percent. Poulton, et. al., write: "Space photographs provide a superior synoptic base upon which, generally, broad-level vegetational classifications and pre-stratifications can be made. Such classifications are considered the starting point for any range resource inventory program".[99] Because of the combined effects of photo scales and ground resolutions presently available with space photos, such classifications will usually consist of groups of individual ecosystems. Each ecosystem is considered a fundamental landscape unit having an analogous environment and characterized by a specific plant community. For purposes of inventory and monitoring of these ecosystems, refined surveys by supporting aircraft underflights are required.

A possible alternative to the use of several stages of subsampling might be to map range plant communities by such surrogates as terrain classes, micro-climatic conditions, soil types, and soil moisture regimes. While these associations "tend to be quite clear-cut in semi-desert regions",[100] it would seem that mapping via surrogates would be of more limited value, at best, in areas of more intensive agriculture. Further, such interpretive tools require photo interpreters with a background in ecology, as well as geology, soils, and climatology. Thus, this approach would not seem suited either to the mapping of large tracts or to automated processing techniques.

An alternative to the use of multi-stage sampling of vegetation is direct interpretation of small-scale aerial or space photography. Draeger has explored the potential of this approach for surveying large areas. He notes that while most studies of remote sensing are concerned with relatively small test targets, the ultimate application of these techniques must often be geared to areas of either watershed-, county-, or state-size. He suggests that although the utility of a technique may appear feasible in experiments on limited test areas, the results may not be directly applicable to large areas where problems of data handling, operator fatigue, and data variability may be encountered.[101]

Draeger first notes that there are no significant differences between crop identification accuracies obtained using space (Apollo 9) and high altitude aerial photography. This conclusion which has also been reached by several other investigators indicates that nominal resolution of high altitude (approximately 70,000 feet) aerial photography is approximately one order of magnitude better than space photography (Apollo 9). Despite their greater resolution high flight photos using the same film/filter combinations as space imagery yield little improvement in the interpretability of specific resource features.

Draeger's study employed skilled interpreters to identify all areas planted to wheat and barley within Maricopa County, Arizona. The imagery used in the study were taken at those times of year that are most appropriate for the identification of these crops. The optimum film/filter combinations for barley and wheat identification were also used. Training time for interpreters averaged about $7\frac{1}{2}$ hours, while average interpretation time per township was found to be 1 hour 8 minutes. Under these optimal conditions errors in crop identification were as high as 32% when compared to ground truth. Most errors however were on the order of 12 to 17%.

From the results of this study Draeger makes the following conclusions:

1) A fully operational agricultural inventory using small-scale photos is not beyond present technological capabilities.

2) The biggest problems to be faced in establishing functional inventory systems are associated with logistics and data processing -- To wit:

a) Ground survey teams are needed to yield ground truth data for calibration of imagery at proper times and over widely scattered areas.

b) Imagery must be obtained at appropriate times during the growing season to permit differentiation of specific crops.

c) Interpretation must be rapid so that results are still valid when released.

d) Interpretation must be compared with ground truth and appropriately adjusted prior to release of results.

3) The areal units of data collection and the timing of data collection should be geared to user requirements.

4) Most data handling problems are not much more complex than those presently faced by governmental agencies collecting agricultural data by conventional means.

5) Automatic image data extraction techniques presently under development are particularly well suited to agricultural surveys where nearly all image interpretation is based on tone or color discrimination.[102]

While Draeger's conclusions are of interest, it should be recalled that he is only concerned with determining crop acreage rather than yield. As will be seen below, surveys of vegetation yield, vigor, and stress are all interrelated and require large-scale multi-date imagery. It should also be noted that Draeger's study involves the discrimination of only two crops. Discrimination of more crop types would probably require more imagery in order to distinguish each of the crops. This would also probably increase interpretation time and decrease overall accuracy of discrimination. All these factors tend to suggest the need for automatic data extraction techniques to replace the complex deductive decisions of the human interpreter.

Stress Detection

For resource management and vegetation monitoring it is essential to recognize and evaluate the causes of vegetal stress. Stress symptoms in vegetation result from a lack of vigor that can be caused by a variety of abnormal growing conditions including insect attack, disease, moisture deficiency, air pollution and soil salinity. Because stress symptoms are similar regardless of the specific agent responsible, the particular cause must either be determined by ground survey or by deductions based on recognition of pattern of the rate and nature of spread.

At present most remote sensing of vegetal stress is centered on the use of color and color infrared photography. While thermal infrared imagery offers considerable potential in this area, the relatively low cost and widespread use of aerial photography with its high resolution capability will make photographic sensing the primary technique for some time to come.

As Heller points out, both color and color infrared photography indicate stress in a plant only after visible stress symptoms appear and the plant is dying or is actually dead. The study of Aldrich and Heller on the detection of spruce budworm - stressed Balsam fir is an excellent example of this problem.[103]

Identification of infested fir through the use of large-scale (1:1584) color photographs was made on the basis of foliage discoloration and eventual change in branch texture -- the latter, after the tree has died and twigs and small branches have broken off. Although the budworm outbreak in the northeastern Minnesota study area was noted as early as 1954, it was not until 1961 that visible signs of fir mortality were detected on the ground. The following description of the character of a spruce budworm attack is quite informative:

> "Spruce budworm larvae feed on new staminate flower buds, vegetative buds and eventually on new expanding growth... (It has been) found that 10 larvae per 15-inch branch sample will consume 75% of the new needles. Five larvae per branch can consume between 25 and 50% of the foliage, depending on how long the population has been at this level. Repeated heavy defoliation, with 50% or more of the new growth removed, can eventually kill a tree. Death can come after three years of heavy defoliation..., but it usually requires more than three years".[104]

Because budworm larvae concentrate on new growth it is easy to understand why even with large-scale photography, such infestation might not be detected until the stressed trees begin to exhibit discoloration of old growth -- i.e., until the plant is dying. For this reason methods that allow early evaluation of abnormal growth conditions, before visible symptoms occur, need development.

Thus far the most promising method of previsual stress detection is based on the fact that, in comparison to healthy plants, stressed plants are less able to meet moisture demands during the daily period of maximum thermal and transpiration load. Tests indicate that moisture stress due to insect attack, plant pathogens or drought conditions cause the leaves of stressed trees to register temperatures as much as $8^{\circ}C$ higher than healthy leaves.[105] Differences of this magnitude are certainly within detection capabilities of present thermal infrared scanners as previously described in this report. The resolutions attainable from such scanners, however, would necessitate fairly low altitude large-scale surveys.

Although previsual stress detection by thermal infrared imagery is within our technical capability there are several problems that limit its widespread use. Several of the more significant of these are discussed below:

1) According to Simonett, not all parts of a plant are uniformly affected by stress-producing conditions. It has been found that the uppermost leaves of a plant may be maintained in a healthy condition at the expense of leaves or fruit lower on the stem. Therefore drought conditions, for example, may cause fruit crop failure while the upper leaves may not exhibit stress.

2) Heller notes that too many objects have the same temperature range as stressed trees and therefore appear as targets we wish to recognize.

3) Weaver, <u>et</u>. <u>al</u>., have investigated the utility of thermal infrared imagery for distinguishing plant species. They conclude

that "moisture stress is believed to be a major factor affecting the tonal differences between plant species or species groups..." However, they also have found that "variations in tone within species were often greater than between species within single stands". Thus it is conceivable that within mixed stands it may be difficult to distinguish between different species on the one hand and between stressed and healthy plants of the same species on the other.[106]

4) Simonett reports that leaf temperatures at night tend to be close to local air temperatures. Therefore, tall mature trees may exhibit different image brightness than equally healthy individuals of the same species or of other species that are nearer the ground.

The problems outlined above all point to the necessity of obtaining basic physiological information on the nature of plant stress and on its manifestation on thermal imagery. Simonett suggests that more studies are needed on thermal imagery of entire plants rather than on single leaves, as has often been the case.

Heller concludes that previsual stress detection with thermal or other multispectral scanners is possible but additional development of better sensors and automated data processing techniques is necessary. Until previsual techniques become truly operational and practicable for a variety of ecological situations, detection of vegetal stress will continue to be accomplished mainly through photographic means.

Natural and false color films have generally been found more useful than panchromatic or black and white infrared films for locating and mapping stressed vegetation. As was mentioned earlier, both color and so-called "color infrared" film have been shown to record stressed plants only after visual symptoms appear.

In recent years workers have found that on Ektachrome Infrared Aero film (EKIR), viable plants are recorded as bright red or magenta and that species are often distinguishable from each other by variation in the shade of red recorded. Stressed or dying vegetation, on the other hand, tends to deviate from red.

Because EKIR film is often termed "infrared film" in the colloquial, there is a tendency to attribute all deviations from the red color of plants on the film as due to a lack of or a reduction in infrared reflectance. This idea has been furthered by claims that the intensity of red color is a sensitive indicator of plant vigor and that during the initial stages of stress, infrared reflectance begins to change before visual symptoms appear.[107] An example of this claim is Colwell's statement that "the more vigorously the vegetation is growing the more infrared reflective it is, and therefore the redder it appears as imaged on Infrared Ektachrome...."[108]

Most workers have related the success of infrared color film in the detection of stressed vegetation to a decrease in the infrared reflectance of the diseased plant's leaves. In particular, emphasis has been placed on the condition of the spongy mesophyll of the leaf--those cells within the leaf where oxygen and carbon dioxide are exchanged during photosynthesis and respiration.[109]

Whether color or false color photography or another imaging sensor is employed to detect unhealthy plants several workers have stressed the need for early recognition of epidemics within a plant community. Because early detection necessitates good resolution capabilities it is generally agreed that the use of space platform-borne sensors will be limited to recognition of the largest diseased areas. Heller notes, for example, that the expected resolution of the ERTS return-beam vidicron and 4 channel line scanner is about 100 m. Normal resolution of Apollo 9 photography on low contrast targets is similar -- about 300 to 400 feet.

At this time color and false-color aerial photography probably is still our most efficient tool. For large-scale color photography to be successful, three system requirements must be met:

1) The aerial camera must have a fast shutter to reduce image movement.

2) The camera must have a recycle rate of up to 5 frames/ second to assure the minimum of 60% overlap in the flight direction that is required to permit full stereo coverage.

3) Film emulsions must be fast enough to allow fast exposures.[110]

Much of the literature that deals with the problem of scale and resolution in stress detection is couched in terms of forest-tree epidemics. For such studies it may be required that individual tree crowns are detectable. On the basis of several examples encountered in the literature it appears that determination of the appropriate scale for a given forest-tree stress detection study depends on at least two factors:

1) Whether acceptable identification accuracies are such that single stressed individuals must be recognized or whether it is only necessary to detect groups of diseased trees.

2) Whether the forest is a single species stand or a mixed stand or several co-dominant species.

The economic significance of a plant community may also influence the scale at which stress detection is carried out. When foliage discolors over large forested areas color or color infrared aerial photography is considered an efficient sensor at medium (1:5,000 to 1:8,000) scales. When, however, early detection of disease is essential to protect a valuable crop, such as citrus, large-scale aerial photography may be required.

Where the prime concern of a stress detection study is merely to assess plant vigor it is generally only necessary to obtain remote imagery on one date. If, however, the study objective is to determine the nature of the damaging agent several alternative approaches may be used:

1) Verify the cause by ground sampling.

2) Utilize sequential imagery to determine causative agent through pattern and rate of spread.

3) Employ multiband imagery on a multi-date basis.

If sequential photographs are used, the selection of specific dates on which the photos are obtained should be related both to the phenology of the species and to the nature and rate at which the disease spreads. In their study of spruce budworm-induced mortality in Balsam fir Aldrich and Heller found that photos taken at 2-year intervals were adequate to detect change to monitor a rapidly-spreading disease such as southern corn leaf blight, on the other hand, would require sequential imagery at very closely-spaced intervals.

Another aspect of stress detection and monitoring that merits consideration is the impact of stress on crop yields. If crop vigor and the particular damaging agent can be determined it is possible to "calibrate" the photographic image of a crop in terms of yield. Yield estimates are made more complex by the fact that yield reduction varies in severity with the stage of maturity of the given crop relative to the onset of the specific stress-producing agent. Here too, sequential photos are considered useful.

At their present level of development infrared scanning systems are not sufficiently advanced to be classed as operational for most earth resource survey problems. There is, however, one major exception -- forest fire surveillance.

For some time after initial ignition, forest fires spread quite slowly and during this period they are easily extinguished. It is therefore highly desirable to achieve early detection. Traditional forest fire surveillance systems rely upon visual observation of smoke from lookout towers or aircraft. These systems are only efficient during daylight hours when a smoke plume is well developed and rises above the trees. In addition, fire detection is also limited by poor visibility. Another factor that may preclude early detection is that commonly after an initial high output of smoke and/or flame, a fire may remain dormant for long periods that are only occasionally interrupted by bursts of flame and puffs of smoke or both.

The technical and economic utility of airborne infrared scanners for forest fire detection has been investigated by the USDA Forest Service. According to Hirsch these studies conclude:

> "An IR system scanning 120^{o} at 15,000 feet at ground speeds in excess of 200 knots could economically compete with an airborne visual detection system which costs approximately 6¢ per sq. mile".[111]

The most suitable wavelength for forest fire detection is in the 3 to 6 μ range where radiant energy emitted is maximum. If a target fills less than 2×10^{-2} field of view of the scanner, the target's signal to background ratio will be insufficient to distinguish the fire from background thermal anomalies.

During July and August, 1970 the IR system described by Hirsch was used to patrol an 8,000 square-mile tract in Montana. Many fires were detected with this system before they were spotted by the present visual system of 59 towers and seven aircraft. However many fires were spotted visually but were missed by the IR system. Hirsch concludes that:

> "Until we learn more about the relationship between heat output and smoke output from latent fires we cannot determine the relative effectiveness of visual and IR systems. The...1970 tests convinced us that IR used in combination with visual detection will result in a more efficient system than visual alone. Even with our limited knowledge of the relative effectiveness of the two systems we can begin operational use of a combined system and substantially reduce total fire-fighting costs (detection plus suppression)".[112]

3(b). The Biosphere - Fauna

Studies dealing with animal populations utilize remote sensing techniques in one of two ways: to obtain basic census information such as the number and distribution of a given species and to gather data on animal behavior. While these two approaches may be complimentary, the major emphasis has been on the former.

Perhaps the most obvious application of remote sensing to the study of animal populations is the use of aerial photographs for census-taking. Aerial surveys are regularly made by governmental agencies to inventory waterfowl and various other species. For example:

> "When large concentrations of ducks and geese are involved, aerial photographs are often taken to enable biologists to determine more accurately than possible through visual estimates from an airplane and helicopter alone, the number of birds and species involved per unit of area. To identify birds or other wildlife by species, sex, or age, color photographs have obvious advantages over black and white photographs".[113]

A major difficulty with photographic censusing of wildlife, apart from problems of resolution, is that many large wild animals are primarily nocturnal. The use of thermal scanners flown at night when many animals are most active has distinct advantages. A number of interesting comments regarding the feasibility of animal censusing by thermal mapping are made by McCullough, et. al..[114] Some of their most significant conclusions are listed below:

1) Although some workers had previously demonstrated the capacity of infrared scanners to detect animals, the first

successful thermal censusing was reported in 1968. Subsequent work by McCullough and others confirms that deer can be inventoried by this technique under ideal conditions.

2) A typical scanner has an instantaneous field of view (IFV) of about 3 milliradians -- i.e., 3 feet across for each 1000 feet of altitude. Only a large animal can increase the average "temperature" of the IFV to a level that permits discrimination between the animal and its surroundings. For this reason with presently available equipment only large animals such as deer, elk, and cattle can be detected efficiently.

3) Because equipment sensitivity now approaches its theoretical limit, little hope exists that small animals will ever be censused by this technique.

4) The best range of wavelengths for animal inventory is the far infrared region of 8 to 14 μ.

5) Because infrared radiation does not penetrate green foliage, animal inventories utilizing available thermal sensors are most applicable to open range, tundra, low brushy areas, or defoliated forests.

6) Another major problem is that the apparent temperatures of both animals and their background are variable over space and through time and depend on such factors as surface characteristics and weather. Optimal conditions for animal inventories occur when a maximum temperature differential exists between

the animal and its background. These conditions are best obtained when there is little or no wind, high overcast sky, snow covered ground and daylight.

7) Although there are many situations where a single animal species is the only one likely to be recorded, the probability of encountering mixed species is often higher. Because of the characteristics of their coats, among other factors, animals tend to have similar apparent temperatures under a given set of environmental conditions. It is therefore unlikely that most species of birds or mammals can be distinguished on the basis of apparent temperature with infrared imagery.

The factors influencing animal surface temperatures are discussed in more detail by Gates who develops a model of animal heat transfer.[115] He notes that the heat differential between an animal's body temperature and radiant surface temperature depends upon the insulative quality of its fat and fur or feathers as well as upon its metabolic rate and moisture loss rate. By manipulating several of these factors a warm-blooded animal can maintain a nearly constant body temperature.

Both McCullough, et. al., and Gates describe studies of animal surface temperatures. On the one hand this work indicates different species in the same environment often exhibit very similar apparent temperatures. For example, nearly identical temperatures have been reported in one case between white-tailed deer, red fox, and red squirrel; in another case, between two deer species, antelope, and bison; and in a third case, between deer, wild turkeys, and a man's wool coat. On the other hand, appreciable variation in daytime surface temperatures of animals have been reported for the same species and even between different portions of the same animal. For example, in direct sunlight the surface temperature of a black dog ranged from 45° to $53^{\circ}C$ while an adjacent white dog registered from 30° to $42^{\circ}C$.

McCullough, _et_. _al_., suggest one possible method to selectively monitor certain larger species. They note that the area an animal occupies within the IFV is related to its probability of detection. Thus by manipulating the aircraft altitude it may be possible to detect a large animal such as a deer while smaller animals of fox- or raccoon-size would go undetected even though all animals have similar surface temperatures. According to McCullough, _et_. _al_.:

> "A certain amount of tailoring of equipment and flight altitude to distinguish animal species may be possible with large animals; but the constraint of resolution versus sensitivity is such that the prospects are poor for small animals. Presumably a bison, which completely filled a three milliradian IFV, could produce a hotter "spot" on the imagery than a deer, which would fill only about one-half of the field. However, differences in size of young and adult animals may prove to be an insurmountable problem. A bison calf may be closer in size to deer than to bison. Also, individual variation in apparent temperature between animals may be due to microhabitat and other factors which would severely complicate detection.
>
> Another difficulty is that many small animals such as a group of roosting birds could produce an image similar to that of a single large animal. Such cases appear to be relatively uncommon in nature, for most species maintain an individual distance, or living space, great enough to provide separable images with a 3 milliradian IFV".[116]

With presently available thermal scanners there is little prospect for discrimination of species. In studies where the requirements of the method are met however, infrared imagery will give a better count of animals over large areas than any other method presently available.

Habitat Evaluation

Another approach to faunal monitoring offering alternative or supplemental information to direct censusing of individual animals involves the assessment of habitat. Wildlife managers, range managers, and ecologists utilize ground and aerial surveys in conjunction with knowledge of the behavior and food and cover requirements of animals to determine the size and makeup of a faunal population that a given tract can support. Obviously a survey of this sort necessitates the inclusion of a great number of environmental factors-among them: the composition, density, and distribution of vegetative cover; the frequency and magnitude of meteorological events; the depth and quality of water in lakes and streams; the effects of man's use and manipulation of the environment; and the impact of various governmental policies that are related directly or indirectly to the animals or their habitat.[117] On the basis of such factors rangeland habitats, in particular, are often evaluated and described in terms of domestic animal carrying capacity in such terms as "animal months per unit area per year".

According to Poulton, et. al., space and high altitude aerial photos are only useful in delimiting groups of individual ecosystems. To achieve more detailed discrimination of specific plant communities large-scale photos from low altitude aircraft underflights are required. Even with these, however, determination of the actual makeup of a plant community is limited mainly to the identification of "larger and perhaps most characteristic species" of the community.

With a photographic base it may be possible to stratify rangeland into yield categories on the basis of the total amount of healthy vegetation present at the peak of the growing season. Forage yield is considered to be directly proportional to the amount of healthy vegetation at the growing season peak. However, the relationship between yield and healthy vegetation is made less useful, according to Colwell, because the proportion of unpalatable or noxious species cannot be taken into consideration. This suggests the need to calibrate aerial survey data with ground truth in order to make habitat evaluation an effective means of faunal monitoring. This, in turn, points to the utilization of the multistage sampling approach described in the section on monitoring of vegetation.

An example in which habitat information is currently being used to manage wildlife is in the determination of U.S. and Canadian migratory waterfowl hunting regulations. The U.S. Bureau of Sport Fisheries and Wildlife and the Canadian Wildlife Service in conjunction with appropriate state and provincial agencies base these regulations on aerial surveys and ground data sampling of habitat and breeding populations. Nelson, et. al., describe the necessity for accurate waterfowl monitoring:

> "Efficient management of this renewable resource depends upon annual adjustment of hunting regulations to insure that a sufficient number of birds remain after the hunting season to provide for production the following year. An estimate of the size of the fall flight must be available at the time hunting regulations are set. This estimate must be reasonably accurate since, for a number of species, hunting is the largest cause of mortality once the young have attained flight age. Regulations based on faulty estimates of current waterfowl numbers could

result in loss of hunting opportunity or reduction of the breeding population to undesirably low levels".[118]

The waterfowl inventorying system now in use is described below:

"Aerial surveys conducted in May and July are used to provide indices of habitat conditions and waterfowl breeding, populations and production. (An areally) stratified sampling plan is (used) ... Sample ground surveys are also made to provide correction factors for the aerial data, and the corrected data are then used to make predictions".[119]

Although these surveys are generally successful in providing the data base necessary for sound management policy-making, the techniques utilized need further improvement. The following are some of the most significant problems:

1) Hunting season recommendations... must be prepared in early August, but the last aerial surveys are not completed until the end of July. Administrators, therefore, are often pressed to evaluate the data and develop recommendations in time....

2) Populations... fluctuate with changes in weather and water conditions on the breeding grounds.... A large important portion of the North American waterfowl breeding range is located in the prairies of north central United States and south central Canada, an area subject to extreme variability in surface water conditions. Repeated observations are needed seasonally and annually to monitor changes in surface water and other environmental conditions.

3) Some portions of the migratory bird breeding grounds, especially in northern Canada and Alaska, are inaccessible to ground surveys and pose problems for surveys from small aircraft.

4) (Additional) indices of water conditions and waterfowl production would be helpful in meeting the inflexible time schedule required for the establishment of annual hunting regulations.[120]

In an attempt to find a solution to these problems, the potential of the airborne multispectral line-scanner in conjunction with computer-implemented automatic recognition techniques has been investigated by Nelson. The major premise on which this evaluation is based is that a reliable index of reproductive success can be derived from "habitat quantity and quality, particularly surface water conditions in ponds and small lakes".

The test site chosen for the study is a 15.5 km^2 portion of stagnation moraine along the eastern edge of the Missouri Coteau in North Dakota. This terrain is characterized by numerous closed depressions with an average of nearly 40 ponds and lakes per square km. As such it is well suited as waterfowl habitat and in the four years prior to the study, the breeding population of ducks in the area has ranged from 27 - 43 pairs per km^2.

The study utilized the University of Michigan 17 channel multispectral scanner and four aerial cameras. Thirteen runs were made over the target area at altitudes of 610 m and 3,050 m in late May of 1968. The purpose of the experiment was to determine "what characteristics of wetland habitats and adjacent uplands could be detected multispectrally and processed automatically with special computer equipment...".[121] The kinds of information sought were:

1. Number of ponds containing water.
2. Number of dry ponds.
3. Number of ponds by size class and wetland type.
4. Identification of major land use types.
5. Distribution of ponds within different land use types.
6. Identification of major associations of marsh plants.
7. Measurement of pond depth, area and shoreline perimeter.
8. Area and distribution of cultural features.
9. Effects of increased flight altitude on accuracy of measurements.

After the data were collected both analog and digital procedures were tested for success in identification of materials and digital techniques were used to measure the perimeter and area of ponds.

> "Several analog processing experiments were conducted with the 610 m imagery using six data channels in the visible and near infrared region. Materials tested for automatic recognition included open water, marsh vegetation, croplands, pastures, idle areas, hayland and cultural features. In some instances, attempts were made to identify components within these broad categories such as standing marsh vegetation, matted marsh vegetation, or a given species such as cattail. At other times materials were combined to identify a broader group, e.g., open water and marsh vegetation were combined to delineate entire pond basins. Spectral signatures were established by the analog computer for each test site and the signatures were then used to recognize similar materials within the recorded field of view.
>
> The 3,050 m data were not completely analyzed. The objective was to determine in a general way some of the advantages and disadvantages of sensing from higher altitudes and to simulate results obtainable from similar sensors aboard space craft".[122]

In general, the results are promising for analog processing of low altitude (610 m.) imagery. Nelson, et. al., conclude that the spectral characteristics of landscape components of waterfowl habitat can be detected with an airborne multispectral scanner and with the use of automatic processing techniques these components can be mapped. At their present stage of development, however, these techniques are not yet considered operational. It is necessary to (1) increase accuracy, (2) reduce retrieval and processing time, and (3) decrease costs.

Telemetric Observation of Animal Behavior

As was mentioned previously, monitoring of faunal populations either through the use of direct censusing techniques or through habitat evaluation requires data on animal behavior.

"A fundamental problem in the study of large wild vertebrates in their natural environment is locating the animals and obtaining information about them without significantly altering their behavior. For many years scientists have avoided the problem and serious study has often been limited to smaller animals which can be more easily studied under field or laboratory conditions. Vast amounts of good information have been obtained in this manner but it is becoming very apparent that it is necessary to conduct field studies to gain valid insight into the complexities of the natural ecology and behavior of many species. Many writers in recent years have emphasized the limitations or misrepresentations of data derived solely from laboratory experiments".[123]

Marchinton describes the use of transistorized radio transmitters as a means to obtain behavioral data on deer. Although this technique was introduced in the late 1950's, progress in its development has been slow. In part this is due to technical problems but also many researchers have failed to fully understand the limitations and requirements of the technique.

In his study Marchinton shows that not only is it possible to locate a tagged animal at intervals in time but also to determine the nature of the animal's activity. This is accomplished by relating variations in the telemetered signal to visual observation of types of activity such as feeding, bedding, and rapid movement. Analysis of data for each individual involves the compilation of all locations, movement patterns, and related information obtained during the period of observation. Where sufficient data is available this data is then used to establish and quantify a number of movement and home range descriptors including (1) the animal's minimum home range; (2) its core area; and (3) the minimum total distance moved in a given period of time.

With the present level of instrument sophistication many kinds of ethological and ecological information cannot be obtained solely by remote sensing. The problem of feeding habits of mammals is an example:

> "The most commonly used method of studying the food habits of mammals... has been the examination of food remains in the digestive tract or feces. Such studies were adequate to estimate gross food intake but were difficult to correlate with food availability because the investigator usually lacked detailed knowledge of foods available at the time and place the animal fed. Ideally, knowledge of food preferences and many other aspects of behavior can be best obtained by direct observation of the animal at close range".[124]

Marchinton has developed a technique to gather data on certain aspects of deer behavior including feeding habits that cannot be obtained solely by telemetry. He introduces into wild deer populations young transmitter-tagged animals that have been raised in the presence of man. These animals are not tame but have been conditioned to tolerate the close proximity of an observer. To obtain data, radio telemetry is used to locate an animal and then the observer walks toward it until visual contact is made. The observer records the nature of material consumed and other behavioral information including defecation rate, rumination cycles, bedding and movement patterns, activity cycles, social behavior, and behavioral interaction with other species.

Although these techniques are probably not suited for monitoring faunal populations over large areas, they undoubtedly provide valuable inputs to such studies. Marchinton notes that to the wildlife manager it is important to understand the activity cycles of economically important species and how they change with season, weather, and the impact of man and other predators. He concludes that:

"Radio telemetry seems to provide many opportunities for study of the intricate ecological, evolutionary, and genetic questions involved in the formation of movement and activity patterns. By quantifying the movement parameters of individual deer ecological patterns became evident which could be related to their sex, age, reproductive condition and social interactions, as well as, to the habitat, and population of which they were a part, and to meteorological variables in their environment".[125]

Conclusion

Remote sensing, particularly that from airborne or satellite platforms, provides the capability to quickly and, in some respects, accurately, assess environmental characteristics. It is particularly useful where a large geographical coverage is required and where sequential data collection is necessary. However, the technology is presently fraught with severe limitations. Some of these have to do with the spatial resolution or detail at which data may be collected. Other limitations have to do with the inability to interpret the correct meaning of sensed data. Perhaps the most restrictive limitations relate to our inability to decide or indeed objectively state, what are the most important environmental variables to be sensed and to know their significance to other environmental elements.

Nevertheless, remote sensing of various environmental elements will undoubtedly become an important means of basic environmental data collection in the future and therefore, a component of environmental monitoring systems. Already remote sensing is being used in the forecasting and prediction of events such as hurricanes or typhoons. This function will probably expand to other events in the future. In basic data collection and forecasting or warning functions, remote sensing will provide a powerful tool for identifying areas of stress or areas deserving more detailed analysis. This is a role similar to that played in the multistage sampling procedures described earlier; a role of collecting of information on which to base further action. But the question of what to measure remains and the next chapter reviews what environmental variables have been measured by any means and what variables are thought to be important.

References

1. P. L. Johnson (ed.), 1969, Remote Sensing in Ecology, Athens, University of Georgia Press; R. H. Alexander, 1967, "Man's New Views of the Earth: The Potential of Remote Sensing", in Problems and Trends in American Geography, S. B. Cohen (ed.), New York, Basic Books, p. 239-250; C. J. Rabinove, 1967, "Remote Sensing Potential in Basic Data Acquisition", Water Resources Bulletin, 3(3): 32-45; H. Aschmann, 1970, "Prolegomena to the Remote Sensing of Environmental Quality", Commission on Geographic Applications of Remote Sensing, Association of American Geographers, Technical Report 70-3.

2. G. W. North, 1971, "Remote Sensing of Environmental Pollution", in International Workshop on Earth Resources Survey System, Washington, NASA, Vol. II, p. 291-301; D. S. Simonett, 1968, "Land Evaluation Studies with Remote Sensors in the Infrared and Radar Regions", Technical Letter, NASA-126, Houston, Manned Spacecraft Center, 31 pp.

3. H. W. Smedes, 1971, "Automatic Computer Mapping of Terrain", in International Workshop on Earth Resources Survey System, Washington, NASA, Vol. II, p. 345-406.

4. H. W. Smedes, ibid., p. 370.

5. R. D. Leighty, 1968, "Remote Sensing for Engineering Investigation of Terrain-Radar Systems", in Proceedings of the 5th Symposium on Remote Sensing of the Environment, Ann Arbor, Willow Run Lab., University of Michigan, p. 669-686.

6. P. L. Johnson, 1969, op. cit.; D. S. Simonett, 1968, op. cit., D. G. Parker, 1968, "Remote Sensing for Engineering Investigations of Terrain-Infrared Systems", in Proceedings of the 5th Symposium on Remote Sensing of the Environment, Ann Arbor, Willow Run Lab., University of Michigan, p. 701-709.

7. R. D. Leighty, 1968, op. cit.

8. D. S. Simonett, 1968, op. cit., p. 2.

9. M. G. Tanguay, R. M. Hoffer and R. D. Miles, 1969, "Multispectral Imagery and Automatic Clarification of Spectral Response for Detailed Engineering Soils Mapping", in Proceedings 6th International Symposium on the Remote Sensing of the Environment, Ann Arbor, Willow Run Lab., University of Michigan, V. I., p. 33-63.

10. H. W. Smedes, 1971, op. cit., p. 371.

11. R. C. Heller, 1971, "Detection and Characterization of Stress Symptoms in Forest Vegetation", in International Workshop on Earth Resources Survey Systems, Washington, NASA, V. II., p. 109-152.

12. R. J. P. Lyon and J. Patterson, 1969, "Airborne Geological Mapping Using Infrared Emission Spectra", in Proceedings 6th International Symposium on Remote Sensing of the Environment, Ann Arbor, Willow Run Labs., University of Michigan, Vol. I, p. 527-552.

13. K. Watson, 1971, "Geophysical Aspects of Remote Sensing", in International Workshop on Earth Resources Survey System, Washington, NASA, Vol. II, p. 409-428.

14. D. G. Parker, 1968, op. cit., p. 702.

15. D. R. McCullough, C. E. Olson and L. M. Queal, 1969, "Progress in Large Animal Census by Thermal Mapping", in Remote Sensing in Ecology, P. L. Johnson (ed.), Athens, University of Georgia Press, p. 138-147.

16. D. G. Parker, 1968, op. cit., p. 702.

17. D. R. McCullough, et. al., 1969, op. cit., p. 140.

18. D. S. Simonett, 1968, op. cit., p. 5.

19. R. F. Pascucci, 1971, "Comparative Contribution of Three Remote Sensors to Geological Mapping", Technical Papers 37th Annual Meeting American Soc. Photogram., Falls Church, Virginia, p. 219-225.

20. D. S. Simonett, 1968, op. cit., p. 7.

21. L. F. Dellwig, H. C. MacDonald and J. N. Kirk, 1968, "The Potential of Radar in Geological Exploration", in Proceedings of 5th Symposium on Remote Sensing of the Environment, Ann Arbor, Willow Run Labs., University of Michigan, p. 747-763.

22. D. S. Simonett, 1968, op. cit.

23. D. S. Simonett, 1968, ibid., p. 16.

24. D. E. Schwarz and F. Caspall, 1968, "The Use of Radar in the Discrimination and Identification of Agricultural Land Use", in Proceedings of 5th Symposium on Remote Sensing of the Environment, Ann Arbor, Willow Run Lab., University of Michigan, p. 233-248.

25. A. T. Edgerton, 1968, "Engineering Applications of Microwave Radiometry", in Proceedings of 5th Symposium on Remote Sensing of the Environment, Ann Arbor, Willow Run Labs., University of Michigan, pp. 711-724.

26. R. F. Pascucci, 1971, op. cit., p. 223-224.

27. R. F. Pascucci, 1971, ibid., p. 224.

28. A. T. Edgerton, 1968, op. cit.

29. G. W. North, 1971, op. cit.

30. O. W. Mintzer, 1968a, "Remote Sensing for Engineering Investigations of Terrain-Photographic Systems", in Proceedings of 5th Symposium on Remote Sensing of the Environment, Ann Arbor, Willow Run Lab., University of Michigan, p. 687-699; see also: D. J. Belcher, et. al., 1960, "Photo Interpretation in Engineering"; R. E. Frost, et. al., 1960, "Photo Interpretation of Soils"; and B. A. Tator, et. al., 1960, "Photo Interpretation in Geology", Manual of Photographic Interpretation, Washington, American Society of Photogrammetry; R. G. Ray, 1960, "Aerial Photography in Geologic Interpretation and Mapping", U. S. Geological Survey Professional Paper 373, 230 pp; Soil Survey Staff, 1951, Soil Survey Manual, U. S. Department of Agriculture Handbook, #18, Soil Conservation Service, 503 pp.

31. Soil Survey Staff, 1951, ibid., p. 44.

32. See for example: W. T. Pryor, 1968, "Photographic Interpretation for Highway Engineering", in Manual of Color Aerial Photography, J. T. Smith (ed.), Falls Church, Virginia, American Society of Photogrammetry, Sec. 1011, p. 402-403.

33. R. G. Ray, 1960, op. cit., p. 5.

34. O. W. Mintzer, 1968b, "Soils", in Manual of Color Aerial Photography, J. R. Smith (ed.), Falls Church, Virginia, American Society of Photogrammetry, Sec. 1022, p. 425-430.

35. O. W. Mintzer, 1968b, ibid., p. 427.

36. R. G. Ray, 1960, op. cit., p. 8.

37. O. W. Mintzer, 1968b, op. cit., p. 427.

38. O. W. Mintzer, 1968b, op. cit., p. 428.

39. R. G. Ray, 1960, op. cit., p. 8.

40. O. W. Mintzer, 1968b, op. cit.

41. W. T. Pryor, 1968, op. cit.

42. L. F. Dellwig, et. al., 1968, op. cit., p. 748.

43. L. F. Dellwig, et. al., 1968, op. cit.

44. R. F. Pascucci, 1971, op. cit., p. 221.

45. R. D. Leighty, 1968, op. cit., p. 673.

46. R. D. Leighty, 1968, op. cit., p. 672.

47. D. S. Simonett, 1968, op. cit.

48. R. F. Pascucci, 1971, op. cit., p. 25.

49. D. S. Simonett, 1968, op. cit.

50. A. J. Lewis and W. P. Waite, 1971, "Cumulative Frequency Curves of Terrain Slopes from Radar Shadow Frequency" in Technical Papers from the 37th Annual Meeting of the American Society of Photogrammetry Falls Church, Virginia, American Society of Photogrammetry, p. 228-244.

51. A. J. Lewis and W. P. Waite, 1971, ibid., p. 240.

52. R. D. Leighty, 1968, op. cit.

53. R. D. Leighty, 1968, op. cit., p. 678.

54. D. G. Parker, 1968, op. cit., p. 703.

55. D. G. Parker, 1968, op. cit., p. 703.

56. D. G. Parker, 1968, op. cit., p. 704.

57. L. D. Miller and C. F. Cooper, 1969, "Analysis of Environmental and Vegetative Gradients in Yellowstone National Park from Remote Multispectral Sensing", in Remote Sensing in Ecology, P. L. Johnson (ed.), Athens, University of Georgia Press, p. 108-131; S. N. Hirsch, 1971, "Application of Infrared Scanners to Forest Fire Detection", in International Workshop on Earth Resources Survey Systems, Washington, NASA, V. II, p. 153-169.

58. K. Watson, 1971, "Geophysical Aspects of Remote Sensing", in International Workshop on Earth Resources Survey Systems, Washington, NASA, V. II, p. 409-428.

59. K. Watson, 1971, ibid., p. 413.

60. R. F. Pascucci, 1971, op. cit.

61. R. F. Pascucci, 1971, op. cit., p. 222-223.

62. R. F. Pascucci, 1971, op. cit., p. 223.

63. R. F. Pascucci, 1971, op. cit., p. 223

64. A. T. Edgerton, 1968, op. cit.

65. A. T. Edgerton, 1968, op. cit., p. 715.

66. J. P. Scherz and A. R. Stevens, 1970, "An Introduction to Remote Sensing for Environmental Monitoring", Madison, University of Wisconsin, Remote Sensing Program, Report No. 1, 80 pp. pp. 59-61.

67. R. G. Reeves, et. al., 1968, Introduction to Electromagnetic Remote Sensing, Short Course Lecture Notes, Houston, Texas, American Geological Institute, Washington, p. 3-48.

68. R. F. Pascucci, 1971, op. cit., p. 223-224.

69. See H. W. Smedes, 1971, op. cit., and M. G. Languay, R. M. Hoffer, and R. D. Mills, 1969, op. cit.

70. M. G. Languay, et. al., 1969, op. cit., p. 36.

71. M. G. Languay, et. al., 1969, op. cit., p. 42.

72. H. W. Smedes, 1971, op. cit., p. 348.

73. H. W. Smedes, 1971, op. cit., p. 367.

74. Lusignan, B. and J. Kiely, (eds.), (1970), Global Weather Prediction, the Coming Revolution, New York, Holt, Rinehart, and Winston, 307 pp.

75. C. J. Rabinove, 1968, "The Status of Remote Sensing in Hydrology", in Proceedings of 5th Symposium on Remote Sensing of The Environment, Ann Arbor, Willow Run Lab., University of Michigan, p. 827-831.

76. The following papers are examples of the trend: F. B. Silvestro, 1970, "Remote Sensing Analysis of Water Quality", Journal of Water Pollution Control Federation, 42(4): 553-561; C. T. Wasternak and F. C. Poleyn, 1970, "Pollution Surveillance and Data Acquisition Using Multispectral Remote Sensing", Water Resources Bulletin, 6(6): 920-934; D. Randerson, 1968, "A Study of Air Pollution Sources as Viewed from Earth Satellites", Journal of The Air Pollution Control Association, 18(4): 249-253; R. N. Larsh, et. al., 1970, "Aerial Photography to Detect and Evaluate Air Pollution Damaged Ponderosa Pine", Journal of the Air Pollution ControlAssociation, 20(5): 289-292; P. G. White, 1971, "Remote Sensing in Water Pollution", in International Workshop on Earth Resources Survey System, Washington, NASA, V. II, p. 303-321; C. B. Ludwig, et. al., 1969, Study of Air Pollution Detection by Remote Sensors, Washington, NASA, 160 pp.

77. M. G. Kelly and A. Conrad, 1969, "Aerial Photographic Studies of Shallow Water Ecology", in Remote Sensing in Ecology, P. L. Johnson (ed.), Athens, University of Georgia Press, p. 173-184.

78. See: D. R. Baker, 1971, "Remote Sensing of Snowfields from Earth Satellites"; E. P. McClain, 1971, "Remote Sensing of Sea Ice from Earth Satellites"; G. A. Rabchevsky, 1971, "Hydrologic Conditions Viewed by Nimbus Meteorological Satellites"; and V. V. Salomonson, 1971, "Nimbus 3 and 4 Observations of Snow Cover and other Hydrologic Features in the Western Himalayas"; all in International Workshop on Earth Resources Survey Systems, Washington, NASA, V. II, p. 431-440; 581-593; 469-511; 443-447.

Rados, R. M., (1969), "Atmospheric Measurements from Satellites", American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, Paper #69-158, New York. Whitehead, V. S., et. al., (1969), "Cloud Height Contouring from Apollo 6 Photography", American Meteorological Soc. Bulletin, 50(July): 522-528.

81. B. J. Conrath, 1965, "On the Estimation of Relative Humidity Profiles from Medium Resolution Infrared Spectra Obtained from a Satellite", J. Geophysical Research, 74: 3342-3361; C. Prabhakara, 1969, "The Feasibility of Determining Atmospheric Ozone from Outgoing Infrared Energy", Monthly Weather Review, 97: 307-314.

82. W. M. Wendland and R. A. Bryson, 1969, "Surface Temperature Patterns of Hudson Bay from Aerial Infrared Surveys" in Remote Sensing in Ecology, P. L. Johnson (ed.), Athens, University of Georgia Press, p. 185-193.

83. P. V. Rao, 1971, "Remote Sensing of Sea Surface Temperature from Earth Satellites", in International Workshop on Earth Resources Survey Systems, Washington, NASA, V. II, p. 595-606.

84. W. M. Wendland and R. A. Bryson, 1969, op. cit., p. 186.

85. W. M. Wendland and R. A. Bryson, 1969, op. cit., p. 186.

86. R. K. Rao, 1971, op. cit.

87. C. R. Wood, 1971, "Evidences of Ground-Water Flow into the Lehigh River, Pa.", in Technical Papers from 37th Annual Meeting of American Association of Photogrammetry, Falls Church, Virginia, p. 245-257.

88. C. E. Poulton, R. S. Driscoll and B. J. Schrumpf, 1969, "Range Resource Inventory from Space and Supporting Aircraft", in Second Annual Earth Resources Aircraft Program Status Review, Houston, NASA, Manned Spacecraft Center, V. II, Sec. 20, p. 1-28.

89. R. C. Heller, 1971, "Detection and Characterization of Stress Symptoms in Forest Vegetation", in International Workshop on Earth Resources Survey Systems, Washington, NASA, V. II, p. 109-152.

90. P. L. Johnson, 1969, op. cit.

91. L. R. Pettinger, 1969, "Multiple Resource Inventory on Space and High-Altitude Photography", in Second Annual Earth Resources Aircraft Program Status Review, Houston, Manned Spacecraft Center, NASA, V. II, p. 1-19.

92. C. E. Poulton, et. al., 1969, op. cit., p. 3.

93. D. T. Lauer, 1971, "Testing Multiband and Multidate Photography for Crop Identification", in International Workshop on Earth Resources Survey Systems, Washington, NASA, V. II, p. 33-46.

94. R. N. Colwell, 1969, "The Inventory of Vegetation Resources-User Requirements vs. Remote Sensing Capabilities", in Second Annual Earth Resources Aircraft Program Status Review, Houston, NASA, Manned Spacecraft Center, V. II, p. 18-1: 18-71.

95. D. E. Schwarz and F. Caspall, 1968, op. cit., p. 234-235.

96. W. C. Draeger, 1971, "The Use of Small Scale Aerial Photography in a Regional Agricultural Survey", in International Workshop on Earth Resources Survey Systems, Washington, NASA, V. II., p. 3-14.

97. P. G. Langley, R. C. Aldrich and R. C. Heller, 1969, "Multistage Sampling of Forest Resources by Using Space Photography", in Second Annual Earth Resources Aircraft Program Status Review, Houston, NASA Manned Spacecraft Center, V. II, Sec. 19: p. 1-21.

98. P. G. Langley, et. al., 1969, ibid., p. 3-9.

99. C. E. Poulton, et. al., 1969, op. cit., p. 2.

100. L. R. Pettinger, 1969, op. cit., p. 5.

101. W. C. Draeger, 1971, op. cit.

102. W. C. Draeger, 1971, op. cit., p. 9.

103. R. C. Aldrich and R. C. Heller, 1969, "Large-Scale Color Photography Reflects Changes in a Forest Community During a Spruce Budworm Epidemic", in Remote Sensing in Ecology, P. L. Johnson (ed.), Athens, University of Georgia Press, p. 30-45.

104. R. C. Aldrich and R. C. Heller, 1969, ibid., p. 34-35.

105. D. S. Simonett, 1968, op. cit.

106. D. K. Weaver, W. E. Butler, and C. E. Olson, 1969, "Observations on Interpretation of Vegetation from Infrared Imagery", in P. L. Johnson (ed.), Remote Sensing in Ecology, Athens, University of Georgia Press, p. 132-137.

107. E. B. Knipling, 1969, "Leaf Reflectance and Image Formation on Color Infrared Film", in Remote Sensing in Ecology, P. L. Johnson (ed.), Athens, University of Georgia Press, p. 17-29.

108. R. N. Colwell, 1969, op. cit., p. 20.

109. H. W. Gausman, 1971, "Photographic Remote Sensing of 'Sick' Citrus Tress", in International Workshop on Earth Resources Survey Systems, Washington, NASA, Vol. II, p. 15-30.

110. R. C. Aldrich and R. C. Heller, 1969, op. cit., p. 32.

111. S. N. Hirsch, 1971, op. cit., p. 154.

112. S. N. Hirsch, 1971, op. cit., p. 157-158.

113. D. L. Leedy, 1968, "The Inventorying of Wildlife" in Manual of Color Aerial Photography, J. T. Smith (ed.), Falls Church, Virginia, American Society of Photogrammetry, Sec. 10:21, p. 422-423.

114. D. R. McCullough, et. al., 1969, op. cit.

115. D. M. Gates, 1969, "Infrared Measurement of Plant and Animal Surface Temperature and Their Interpretation", in Remote Sensing in Ecology, Athens, University of Georgia Press, p. 95-107.

116. D. R. McCullough, et. al., 1969, op. cit., p. 144.

117. See: H. K. Nelson, A. T. Klett and J. E. Johnston, 1971, "Application of Remote Sensing Techniques for Appraising Changes in Wildlife Habitat", in International Workshop on Earth Resources Survey Systems, Washington, NASA, Vol. II, p. 263-288.

118. H. K. Nelson, et. al., 1971, ibid., p. 264.

119. H. K. Nelson, et. al., 1971, ibid., p. 264.

120. H. K. Nelson, et. al., 1971, ibid., p. 264-265.

121. H. K. Nelson, *et. al.*, 1971, *ibid.*, p. 266.

122. H. K. Nelson, *et. al.*, 1971, *ibid.*, p. 268.

123. R. L. Marchinton, 1969, "Portable Radios in Determination of Ecological Parameters of Large Vertebrates with Reference to Fur", in *Remote Sensing in Ecology*, P. L. Johnson (ed.), Athens, University of Georgia Press, p. 148-163.

124. R. L. Marchinton, 1969, *ibid.*, p. 158.

125. R. L. Marchinton, 1969, *ibid.*, p. 161.

CHAPTER IV

ENVIRONMENTAL DESCRIPTION - THE VARIABLES

Introduction

In this chapter, environmental description is reviewed with the objective of outlining those variables that best describe the status of an environmental element. The type of variables specified has considerable bearing on the methodology and techniques of data collection. For the purpose of the study, the environment has been defined as a composite of: lithosphere, atmosphere, biosphere and hydrosphere. The land use element has been added to or superimposed on this composite. Characterizing the environment in this way is somewhat arbitrary and artificial, even though it is necessary. The various elements are interdependent and related through the variables. This becomes quite apparent when one examines the variables that characterize the elements. For example, is groundwater to be considered part of the lithosphere or hydrosphere? Are soil microorganisms to be considered part of the biosphere or lithosphere? Although these questions are academic, they are raised here to illustrate the problems that may arise when the environment is viewed as a series of elements or compartments. The latter procedure is an essential step if one wishes to order and store environmental information.

In reviewing the methodology of environmental description, we have come to recognize two basically different types of variables. Primary variables are measured directly in the environment. Secondary variables are derivatives of one or more primary variables. In some respects, indices described in Chapter II could be viewed as secondary variables. This classification may be facile in that some variables, slope angle or humidity for example, may be measured directly in the environment or may be derived from other information. In addition to primary and secondary variables, there are surrogates or substitute variables. As our understanding of functional relationships between environmental variables increases, so will the use of surrogates. Some data are easier to collect than others and will provide almost as much information. If a good surrogate is available and the collection of data to describe it is simple and inexpensive, monitoring the surrogate would be the most efficient practice. An example of the use of a surrogate is the remote sensing of animal habitats as an indicator of animal population as discussed in Chapter III. In addition, as the understanding of environmental relationships increases, so will the ability to use certain key indicators as monitors for a complex of numerous other variables. There have been attempts to do this in the past using specific animals and/or plants. This might be termed the "miner's canary" approach to environmental monitoring. However, if this is to be used in a preventative or curative function, we must understand what the conditions of these indicators mean in terms of ecological processes. The flows of energy and matter in a system must be understood so as to trace the meaning of a given indication back to the source. This becomes particularly difficult if a synergism is involved because one must then understand what combinations of conditions produce a given effect greater than the sum of the combinations.

Much of this is in the future of environmental monitoring. At the present time a large number of variables must be considered so as to be sure that all "right" ones are included. Although this may be construed as a "shotgun" approach, it is probably necessary in the context of the present understanding of functional relationships between environmental variables. Efficiency in data collection is dependent on the understanding of ecological relationships but at present understanding of relationships is dependent on data collection.

Associated with the choice of variables to be measured are the methodology and techniques of data collection. Some very promising techniques of data collection were reviewed in Chapter III. Remote sensing circumvents some of the sampling constraints placed on ground surveys in both the temporal and spatial dimensions. Sampling procedures are well-developed[1] and in themselves do not present a problem. Sometimes the best procedures from the accuracy or representation viewpoint are physically impossible in the type of environment this report is considering. Moreover, serious problems of data compatibility arise when a large number of variables that differ greatly in their spatial and temporal characteristics are rectified into a unified data and information system.

In considering environmental variables or attributes, the following are examples of questions that should be posed:

1. To what extent does the attribute vary spatially and temporally?

2. Is the distribution of the attribute continuous in time and space?

3. Is the distribution made up of discrete objects or events (points) in time and space?

4. Is the distribution areally discrete? i.e., although the attribute has a spatial dimension, it may be defined by distinct boundaries or limits.

5. Is the distribution best characterized as a volume rather than a surface?

6. If the attribute is made up of discrete objects, are the objects mobile or stationary?

All these questions and numerous others of the same nature, bear directly on modes of data collection and storage and modes of information retrieval.

In the following sections the various ways major environmental elements have been characterized are reviewed. There is an attempt to be comprehensive. But lacking interdisciplinary expertise, the case has probably been understated and overgeneralized in several cases. Such will remain the case until interdisciplinary efforts are able to integrate environmental description and monitoring.

A. The Lithosphere

Within the lithosphere are considered three sub-elements: topography, geology and soils. Much of the recent literature dealing with the nature of the lithosphere as an element of man's environment is oriented towards providing basic topographic, geologic and pedologic information to planners and others involved in resource development and administration, particularly at the local level. The essence of this so-called "environmental geology"[2] is the packaging of information from several areas of traditional earth science into a simplified and integrated form readily comprehensible to a variety of users. This is essentially the same task as that of this report.

Areas of overlap with other environmental elements and within the three sub-elements as here defined are unavoidable. Some notable areas of overlap are: the groundwater-hydrosphere area, the soil organisms-biosphere area and the surficial geology-soils area.

I. Topography

In the scheme of environmental change, topography is generally regarded as a passive element. The extent to which this is valid depends on the spatial and temporal scales at which topography is viewed.

Geomorphologists have long questioned how to best represent or describe topography. Points that have arisen in this discussion may be summarized by the following questions:

1. Is it possible or proper to describe and classify topography without reference to its genesis?

2. What variables of the topography should be described in order to give a complete and accurate representation of reality?

3. How can these variables be most efficiently measured?

4. Is it realistic and appropriate to describe continuous variables on the basis of data from discrete points?

5. Over what kind of an areal unit, natural or arbitrary, should this generalization be made?

6. How should descriptive areal units be delimited?

7. If arbitrary units are used, how large should they be and should they be of uniform size and shape?

8. By what design and at what intensity should data be collected within the areal unit?

9. How should the data be presented and analyzed once it is collected?

Many of the terrain descriptors that have been discussed in the literature are suited to a narrow range of landform types such as: fluvial, glacial or karst. In the context of environmental monitoring and "initial state" description, any terrain descriptor must be viewed with respect to its suitability for describing topography of differing origin, as well as the ease with which it can be interpreted and yields results that are replicable.

The amount of information carried by a terrain descriptor is partly a function of the areal unit it represents. Those measures that describe topography at a single point are few and give very little information. Such measures may be considered primary measures or variables. If a number of primary variables are measured over an area, a wide range of sensitive secondary variables or measures may be derived to describe the topography of that area.

Areal Units

The importance of areal units of definition was recognized in early attempts to develop measures of integrated topography. Among several papers illustrating innovative approaches was a study by A. Penck in 1894 who suggested that average slope be obtained "by weighting the inclinations of various parts of the area in proportion to the respective percentages of the region they covered".[4] It was also suggested that to measure average slope, one should select a "typical" area.

Various geometric or natural areal units have been used. In a relative relief map of Ohio, rectangular quadrats of 25 square miles defined by latitude and longitude were used.[5] The characterization of New England topography first utilized five-foot rectangular quadrats then irregular areas of unequal size and shape.[6] The size was delimited by visually-defined uniform contour densities, making this one of the early attempts to use natural rather than arbitrary or geometric areal units. The trend to natural area units logically led to the drainage basin unit.[7] The major attraction of the drainage basin was the hierarchial nature which allowed units to be aggregated or disaggregated into larger or smaller units. Unfortunately, not all topography is characterized by integrated drainage basins. It has been pointed out that the use of the drainage basin as a unit of study ignores "large portions of the earth's surface where no good continuous divides exist --- in sand hills, Karst plains, swamps, deserts, tundra and glaciated regions ..."[8] A second disadvantage is that the technique for the delineation of divides between finger-tip tributaries is both slow and rather subjective.[9] In addition, as map accuracy decreases, subjectivity in divide delimiation increases. The drainage basin as a delimiter of a topographic environment is not universally applicable which gives ample justification for reviewing some geometric units in detail. However, some of the topographic descriptors derived from the drainage basin unit may have potential applicability outside that framework and are listed in a later section.

Although the geometric unit most frequently used is the rectangular quadrat, other units have been used and deserve brief mention.

1. Grain Circle

The grain circle is one of the more common non-rectangular areal units used in morphometric descriptions.[10] As used by Zakrzewska, the grain circle was placed on a systematic grid across the study area with the spacing between circle centers being twice the circle diameter. Hence the circles are not tangent to one another, but are separated by considerable distances. The distances have varied betweeen studies. In establishing the circle radius that is appropriate for a given study area, the steps were as follows:

(a) concentric circles with radii of equal increments were drawn on a representative area of the map;

(b) local relief within each circle was determined and plotted arithmetically against the circle radius;

(c) the appropriate radius for the study area in question was identified as that plotted point at which an inflection in the curve (local relief-radius) is first encountered.

The radius was said to be appropriate for the given study area because the resulting circle "will encompass the natural high and low of the selected area".[11]

The grain circle obviously has both advantages and disadvantages. The chief advantage is that it is a more compact unit than a rectangular quadrat of the same area. One major disadvantage of the grain circle is that the size of the unit is determined by one specific topographic variable, local relief. Secondly, it is impossible to cover and therefore describe an entire study area without overlapping circles. This overlapping could prove to be a useful quality in situations where "moving averages" or "trend" over an area is desired.

2. Terrain Polygon or Terrain Unit

Alternative areal units, the terrain polygon and the terrain unit,[12] have been suggested. However, they have both been rejected on the basis of being too subjective and too slow to derive.[13] The name "terrain polygon" is at least intuitively appealing in that one polygon, the hexagon, while approaching the compactness of a circle, avoids the problem of overlap encountered with the grain circle.

3. Rectangular Quadrats

Although rectangular quadrats are the most frequently used geometric areal units in morphometric analysis, optimum size and shape remain as problems. The determination of appropriate quadrat characteristics should be considered in terms of objectivity, practicality and comparability.[14]

In practice, the precise size of the quadrat depends on two factors: the overall size of the study area and the quality of data sources. Where latitude and longitude are used to define quadrats a systematic variation in quadrat size and shape will result if the study area covers a wide latitudinal range.[15] Compensation is then accomplished by overlapping quadrats. Studies that have used small quadrats have come to the conclusion that:

> "...in a situation requiring reliance upon secondary information (i.e. topographic maps) such as ... the relationship of mean slope, relief and drainage texture with lithology...quadrats of one square mile seem most satisfactory."[16]

The Terrain Characteristics and Their Descriptors

The literature reviewed has revealed a long list of terrain descriptors. Most, however, are modifications of rather basic concepts, operationalized in such a manner as to suit a specific set of conditions. These measures deal with five major aspects of terrain: slope, relief, elevation, texture and roughness, and pattern.

1. Slope

Most quantitative studies of slope are concerned with three problems:

(i) characterizing the actual, predominant, or average inclination at a point or in an area

(ii) determining the percentage of an area in different slope classes

(iii) ascertaining information regarding consistency or dispersion of slope orientations.

(a) Mean Slope

Of researchers who chose to utilize some measure of slope, many pick a technique that gives a mean or representative slope angle for a unit area. The methodology employed varies considerably in complexity. Hoy and Taylor use mean slope intensity (operationalized as contour density) measured along only two two-mile traverses within a grid area.[17] Wentworth bases his technique on the mean number of contour crossings per miles of traverse (based on a minimum of three random traverses each with not less than 100 to 200 contour intersections).[18] A more recent method to determine mean slope avoids problems associated with traverses by measuring slope along 200-foot orthogonals, centered on a series of randomly selected points, within the study area.[19]

While mean slope can be a useful and meaningful measure, attention should be given to the comments made by Calef and Newcomb:

> "The notion of the average slope of an area is a highly abstract concept...Average slope figures for an area do not necessarily reveal anything about the angle of real slopes (or their relative proportion) in an area, nor do they indicate that any particular part of an average slope area has average slopes that fall within the slope class limits indicated for that area...One of the greatest dangers in the use of statistical maps of terrain lies in the tendency to read things into the maps and then assume that they can be read from the maps."[20]

(b) Upland Slope

A slight modification of the average slope concept is "mean upland slope" of Dennis.[21] This measure is calculated in a manner similar to mean slope methods, but Dennis defines upland slope as:

> the slope beginning 40 feet above the drainage channel and ending either at the foot of a scarp or at a drainage divide if a scarp is not present.

By using this definition Dennis is apparently trying to avoid some of the problems associated with mean slope, i.e., the averaging of the individual slope facets that, together, form the valley-side slope. By the same token, he may also be eliminating from evaluation those basal slope elements that will most strongly reflect differences in aspect (microclimatic effect). An additional modification of Dennis' basic idea, the use of a basal slope measure, may be more revealing than upland slope, especially with regard to microclimate.

(c) Slope Classes

An alternative approach to areal description of slope through measures of central tendency involves the use of percent of total area in each of several pre-defined slope classes, i.e., a slope-class histogram.[22] This technique has been used mainly as a descriptive tool to classify extensive areas of continental size[23] or broad subregions, thereof. While such information might well be useful with smaller unit areas, two practical problems limit this potential. Difficulty first arises in defining class limits in any objective manner. Secondly, it seems unwise to aggregate detailed slope inclinations in such a way as to loose the very detail that might be useful in establishing interrelations with other variables.

(d) Slope Orientation

Perhaps the aspect of slope morphometry that is least explored and offers the greatest potential for significant contributions is slope orientation. Geomorphic literature often mentions the importance of this element but, with a few exceptions, measurement and analysis is couched in terms of generalizations--"north- versus south-facing slope," for example. In the literature encountered thus far only two papers attempt to deal with this problem.

(e) Slope Orientation classes

Dennis calculates mean inclination for slopes about selected weather stations both as the grand mean for all slopes and as separate means for groups of slopes, where groups are arbitrarily delimited for each 45-degree compass sector.[24] Zakrzewska uses a similar technique to visually determine preferential orientation of tributary stream channels (see discussion of "pattern").[25]

(f) Statistical Slope Orientation Diagram

Chapman's statistical slope orientation diagram (S.S.O.) is a technique that, with slight modification and with suitable analytical tools, may have considerable potential.[26] The S.S.O. is the common petrofabric diagram of the geologist applied to slope elements instead of mineral crystals. Essentially each slope facet is represented by a "pole"--a line constructed normal to the slope facet. Each slope in an assemblage is then plotted as a point on an equal area projection of a hemisphere (the Schmidt net may be used for this purpose). The "point" represents the intersection of the "pole" of the slope element and the hemisphere. The distance between a given point and the center of the projection represents the inclination of the slope element, while the azimuth of the (imaginary) line from the point to the projection center indicates the direction of "dip". (It should be noted that Chapman suggests the S.S.O. diagram be plotted in the lower hemisphere--as is standard procedure in petrofabric diagrams. The description above implies plotting in the upper hemisphere. In this way the azimuth is the same as dip direction, rather than 180° from dip direction, as Chapman recommends.) This is the significant part of Chapman's paper. His suggestions for analysis of the S.S.O. diagram center around semi-quantitative description of patterns derived by a rather laborious contouring method.

Recent developments in statistical methods for circular distributions offer a number of promising alternatives for analysis of S.S.O. diagram. In the two-dimensional case (where azimuth of poles is considered only) the analytical techniques are readily available. Results from such analyses should include a measure of dispersion, i.e., indicate preferential directions, that might be correlated with geologic structure, for example.

In the three-dimensional case (azimuth and inclination are considered) the potential for information is even more exciting than in the two-dimensional case. If suitable methods can be found, it should be possible to describe the slopes of an area in terms of measures of central tendency and dispersion of slopes about such measures. Even more interesting, it may be possible to analyze S.S.O. diagrams in terms of various grouping techniques that would identify "clusters" of slopes.

(g) Slope and Surrogate Measures

As a final comment regarding slope, both Salisbury and Peltier have discussed the high correlations between mean slope and local relief.[27] The possibility of utilizing the latter as a surrogate for the former should be investigated. It does not seem possible that there is any surrogate for slope orientation that would be applicable in all environments.

2. Relief

In practical terms, relief is more simply defined than is slope. As is indicated in the final paragraph of the slope discussion, however, the two elements are not unrelated. For example, the first English-speaking worker to use relief as a morphometric measure--G.H. Smith--considered his results as a surrogate for a slope map.[28]

(a) Local Relief

"Most studies on local relief that have appeared in American literature since 1935 are based on the sample method proposed by Smith".[29] This method merely determines the maximum altitude difference within a unit area. As Zakrzewska implies, all papers encountered to this point, use local relief as defined by Smith.

(b) Available Relief

Two papers also introduce the concept of available relief (although Nir uses the term "absolute altitude").[30] Both papers introduce this concept in order to improve certain weaknesses inherent in the local relief concept.

Dury visualizes available relief as:

> "that part of the landscape which, standing higher than the floors of the main valleys, may be looked on as available for destruction by the agents of erosion working with reference to existing base-levels..."[31]

Local relief, Dury states, takes "no account of the form of the interfluves" because only relative height is measured. Thus, using local relief alone, two landscapes, one with wide valleys and the other with deep, narrow valleys, would conceivably have the same local relief.

To improve sensitivity to such situations, Dury proposes a rather complex method that defines (through planimetry of the present surface and of a lower hypothetical "streamlined surface") the volume of the interfluves. Interfluve volume is, in turn, converted to mean available relief.

(c) Dissection Index

Dov Nir proposes a method that is conceptually similar to Dury's but much more tractable.[32] Nir suggests that for each quadrat, the ratio between maximum relative altitude and the maximum absolute altitude be determined. In the terminology used thus far, a ratio of local to available relief is suggested.

This ratio, Nir believes, is superior to local relief as an expression of relief energy.

> "Equal relative altitudes are not always of equal importance, since their absolute altitudes may differ. The picture gained from relative altitudes is only static, for it fails to take into account the vertical distance from the erosion base--that is, the dynamic potential of the area studied."[33]

The radio, termed the "dissection index" or "the degree to which dissection has advanced," will never exceed "1" nor, under normal conditions, be less than "0". (An exception will exist if a depression below sea level is encountered. This will produce negative values.)

The dissection index is an improvement over the standard local relief measure. It is probably superior to local relief in most situations but its applicability in regions of non-integrated terrain, with numerous undrained depressions, must first be evaluated.

(d) Cumulative Relief Frequency Curve

Tanner offers an alternative method of relief description.[34] First, he comments that sample data on relief (or elevation) over area generally is not normally distributed nor can it be normalized by the standard transformations. The data are not normal because distributions represent three variable components--upland, slope, and lowland. These components may be combined in distinctive ways and thus produce different distributions. Tanner's basic idea is that relief of an area can be meaningfully described in terms of skewness and kurtosis of a cumulative frequency curve of these values.

While this idea has merit, two questions should be raised. First, is Tanner correct when he states that relief and elevation data cannot be normalized by standard transformations? Both measures appear frequently in the literature where they are most often treated as log-normal. Secondly, if skewness and/or kurtosis are used to characterize relief, can these measures be considered normal or can they be normalized? If normality is not established, relationships with other terrain variables, derived through parametric statistics, are subject to question.

3. Elevation

Papers concerned with elevation as a morphometric measure often treat the subject either in terms of a generalized profile or as a cumulative frequency curve plotted against area.

(a) Characteristic Profile

Hammond is a leading proponent of the first approach. He attempts to develop a simple index that is capable of "indicating where in the profile, most 'flat' (8% slope) land lies".[35] The "characteristic profile" is operationalized as the percentage of gently inclined land that falls in the upper versus the lower hall of the elevation range. In his 1958 study, Hammond recognized three classes of gentle slope over area: 1) 2/3 in upper half of elevation range, 2) 2/3 in lower half of elevation range, 3) a more or less even distribution whether neither half has 2/3 of gentle slopes.[36]

Although this seems to be a highly subjective criterion on which to describe elevation, it should be recalled that Hammond is mainly concerned with problems related to small-scale mapping of terrain.

(b) Hypsometric Curve

A more refined measure that indicates the distribution of the proportion of areas within the elevation range is Strahler's Hypsometric Curve.[37] Although this measure was originally conceived for use within a drainage basin framework, there is no reason why is cannot be adopted for quadrat studies. The chief difficulty with the method, as outlined by Strahler, is that operationally, it is extremely slow to determine.

Haan and Johnson have described a method to obtain the hypsometric curve with a great reduction in time expended.[38] The method is based on a random sampling of elevations which is then converted to a cumulative frequency curve using predetermined class intervals. With small Iowa basins as a test, they have found the the hypsometric curves derived by planimetry and by sampling do not differ significantly from each other as judged by the Kolmogorov-Smirnov test.

Regarding data collection, Haan and Johnson have found that with 1:24,000 USGS topographic maps having contour intervals of 10 feet, 30 random points per square mile adequately define the curve. Since there exists a "contiguity effect" for elevations in reasonable close proximity to each other, it is probable that doubling the size of an area to be sampled will not require a doubling of the number of samples.

No change in methodology should be necessitated by a shift from a basin to a quadrat format. It may be preferable to eliminate the use of class intervals, especially if a study area encompasses greatly different terrain types.

> "Any terrain classification system should include a distribution of elevations factor.... such a factor should be capable of numerical expression by a technique that processes information quickly and where data collection is also rapid."[39]

While the hypsometric curve derived from random sampling methods does fulfill Woodruff's requirement for rapid data collection, the information is not in a form suitable for immediate numerical expression. Strahler suggests that for comparative purposes, the following dimensionless attributes may be used:

(i) The integral or relative area under the curve

(ii) The slope of the curve at its point of inflection

(iii) The degree of sinuosity of the curve[40]

(c) Elevation-Relief Ratio

Lastly, it should be noted that Wood and Snell, according to Zakrzewska, have proposed the elevation-relief ratio that measures the relative proportions of upland and lowland.[41] The ratio, that has the range $0 < ER < 1$, is determined by the following formula:

$$ER = (E - L) / R$$

where: E is mean elevation computed from random points
L is the lowest elevation
R is the relief of the area

A value of the ER ratio that is close to "0" indicates broad lowlands whereas a value near "1" is indicative of broad divides and narrow lowlands.

4. Texture and Roughness

The terms "texture" and "roughness" are sometimes incorrectly considered synonymous. Douglas Johnson defined "texture" as "the average size of the units composing a given topography".[42] Some later workers, including Smith, have tended to restrict the meaning of the term to refer only to fluvially dissected topography and, thereby, equate it to Horton's "stream frequency". According to Zakrzewska this is not appropriate in that texture analysis is "concerned with the size of the individual features or the distance between them".[43]

The term "roughness" or "ruggedness" normally refers to an index representing a combination of expressions of relief, texture, and slope steepness.

(a) Terrain Texture

There are relatively few papers in the literature dealing with texture. Among the earliest is work by Meyerhoff which mentions that a certain consistency appears to exist in the spacing of depressions and "mogotes" (topographic residuals) in the karst terrain of Puerto Rice.[44] Because topographic maps were not available, he did not attempt to perform any analysis to substantiate these observations.

In a more recent study of karst, LaValle has suggested a number of terrain parameters that reflect one or more specific aspects of terrain texture including:

"Depression density" - defined as the number of depressions per unit area

"Mean solution depression area" - defined as the mean depression area delimited by the upper-most closed contour.

"Composite terrain texture" - defined as the relative horizontal density of topographic slope reversals and measured as the number of contour reversals encountered per unit length in a series of random traverses cutting through a unit area.[45]

Peltier has suggested the number of discrete hilltops or summits per square mile a measure of "roughness" sic.[46]

Several workers, among them, Peltier and Lustig, have suggested the spacing between ridge crests has utility in characterizing "terrain texture", although neither of them uses the term.[47]

(b) Roughness

Only two means of establishing a roughness index have been encountered in the literature. The first of these, devised by Hamilton for sociological research, is based upon the number of contour lines crossed by a series of traverses run at right angles to each other.[48] The same technique was later used by Hook who correlated roughness with various agricultural phenomena.[49] Zakrzewska expressed "total terrain roughness" as the number of crossing of 100 foot contour lines by the circumference of a 3-mile diameter circle.[50] For analysis, data were grouped.

5. Pattern

In her review article, Zakrzewska indicates that characterization of horizontal pattern (as well as vertical profile) is among the most difficult tasks in morphometric analysis. A few semi-quantitative measures of pattern have, however, been developed. Perhaps the best examples are LaValle's two descriptors of preferential karst elongation: solution depression axial orientation and solution depression elongation ratio.[51] The former expresses the azimuth of the long axis of a depression. The latter is a variation on the glacial geomorphologist's length-width ratio that is often applied to drumlins and other streamlined forms.[52] A descriptor similar to LaValle's solution depression axial orientation is used by Zakrzewska to determine the "predominant orientation of tributary streams" within a unit area.[53]

The Drainage Basin Context

If one is fortunate enough to be examining terrain where an integrated drainage network is present, a much wider range of sensitive terrain discriptors is available. The problem that not all topography may be considered in this context limits the applicability of the drainage basin descriptors. The following listing summarizes some the measures based on integrated fluvial topography.[54]

Group I -- measures derived from channel network

1. Stream Length -- miles of stream channel in unit of study.

2. Length of overland flow, or slope length (in a sense, a measure of texture)

3. Stream azimuth

Group II -- measures requiring well-defined areal component.

4. Drainage density -- miles of channel of all orders per square mile

5. Constant of channel maintenance -- operationalized as 1/drainage density or sq. ft. / ft. ... tells the number of square feet required to sustain one foot of linear channel .... another texture measure

6. Stream frequency -- Number of streams / sq. mile ... may conceivably be independent of drainage density....

7. Texture ratio -- Number of streams / perimeter of basin ... while not directly suited for non-basin framework ... if for any reason, our areal units vary, this approach may be of use.

Group III -- Properties involving elevation differences -- relief

8. Stream channel slope -- expressed as percent, degrees, feet/mile

9. Ground slope -- measured orthogonal to contour ... suited to point measure

10. Ground slope (max. angle of valley-side slope)

11. Ratio of Channel slope to ground slope

12. Relief (max. in areal unit)

13. Hypsometric integral -- an area-elevation (cumulative curve... most practicable measure of curve's character appears to be "relative basin area"

    i.e. -- percent of total area under curve

14. Ruggedness number -- (relief)/(Drainage density) ... said to vary widely in value

Conclusion -- Topography

From two primary variables, elevation and slope angle, measured at discrete points, a large number of the foregoing terrain descriptors may be derived when the point data is aggregated for areas. Elevation data alone will yield the following information for areas:

1) Average elevation

Operationalized: Mean elevation from the number of random points.

2) Hypsometric integral

Operationalized: Cumulative frequency curve derived by random sampling of elevation

Described: By (1) calculated area under curve, (2) skewness, and (3) kurtosis of curve.

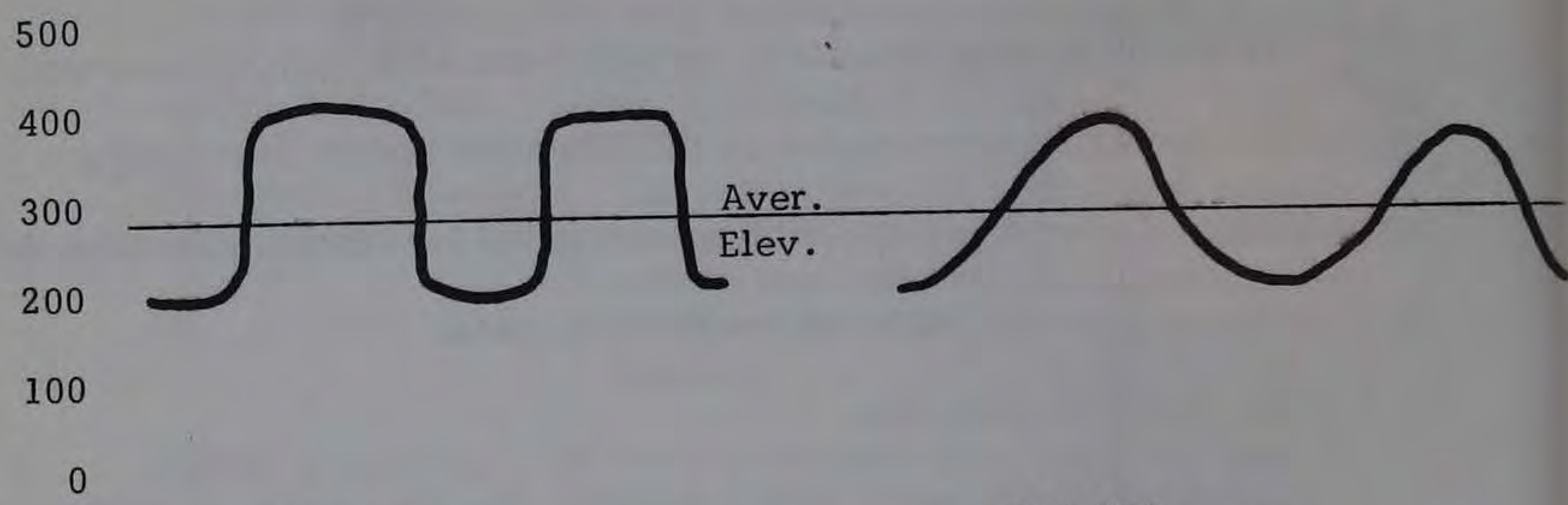
3) Local relief

Operationalized: May be approximated by calculating maximum difference between sample elevations or preferably by scanning area for max. & min. elevations (the latter seems best for #4 below).

4) Elevation - Relief ratio

Operationalization: ER = E - L / R where E is mean elevation (#1 above), L = lowest point (required for #3), R = local relief (#3 above).

The elevation - relief ratio is perhaps the most useful of the five measures because it provides an easily - interpreted index of the proportion of upland to lowland. (Range: O (broad lowlands) to 1 (broad uplands)) as Carr and VanLopik point out, however, two similar ER - values may have very different profiles as is illustrated below:[55]



$$ER = \frac{300-200}{200} = .5 \qquad ER = \frac{300-200}{200} = .5$$

This weakness in the ER - ratio can be overcome, however, by incorporating the hypsometric integral - a measure that distinguishes differences in the distribution of elevations over area (i.e., profile).

Slope angle data will also yield a variety of descriptors when aggregated for an area. The most obvious of these is the mean topographic slope. Various frequency distributions in some ways similar to the hypsometric integral may be derived for slopes in an area as well.

Regardless of what topographic measures are used for environmental description, this aspect of the environment must be considered relatively static in comparison to vegetation, atmosphere and soils. Thus in the context of monitoring, topography does not receive a high priority as a sensitive area of concern. Topographic description, however accomplished, provides valuable baseline or initial state information. This is so because the nature of the terrain influences the character, magnitude and frequency of numerous environmental processes, especially when intervening factors, such as natural vegetation, are removed or altered which is the case in many human activities.

II. Geology

Description of the geological element in the environment should include basic information of the following nature:

1. "Engineering properties"--particularly with reference to the stability of near-surface non-lithified deposits, their suitability as foundation materials and their potential for contributing to natural hazards.

2. Structures and lithology of consolidated units--of particular interest here should be the three-dimensional attitudes of rock units, the location and attitudes of discontinuities and the appropriate attributes of the petrographic characteristics.

3. Economic geology--the presence of potentially valuable mineral resources including building materials.

In some respects the geological factors of the environment are unique and this must be taken into consideration. Unlike topography and to a lesser degree, vegetation, surface hydrology and soils, geological description must emphasize the vertical and stratigraphic dimension as well as the spatial dimension. As the size of the basic areal unit of observation is decreased (to a point), geological description tends to become, in effect, the description of the column of strata beneath that area. The same may be said for ground water and the atmosphere. Geology and groundwater, unlike atmosphere are often characterized by abrupt rather than transitional changes in character. Although one must be cognizant of the vertical dimension in geological description, in most respects the significance of geological factors to man decreases with depth from the surface. In this respect geology is similar to ground water.[56] There are several important reasons for this concern with surficial geology:

1. Surficial deposits are often the most variable, areally and spatially.

2. Surficial deposits or material has the ability to sustain or limit human activities and influences the hazard potential from natural causes.

3. Activity related to extractible resources is concentrated near the surface and hence strongly influences the "quality of the environment".

It has been pointed out by several authors[57] that the nature of environmental geological description for even small areas must present only a broad overview. This is again related to the characteristics of the user's of this geological information. Most user's will not be geologists. For example, they will be planners concerned with the most appropriate land uses for a given area.

Because of the nature of the material, the following outline of geological description treats lithified and unconsolidated materials separately.

<u>Lithified Material</u>

1. Structural Characteristics

Perusal of standard references on methods of field geology suggests the most basic characteristics necessary to describe structural attributes of the geologic units.[58] These are:

(a) Three-dimensional attitude of geologic units:

(i) Dip azimuth (strike azimuth is thereby defined)

(ii) Dip angle

(b) Presence and measurement of discontinuities - this includes joints, faults, solution cavities, and mine workings. Because all discontinuities (but especially joints and solution cavities) may be developed in sets in two (or, less frequently, more) directions a provision should be made to record multiple observations. The mechanics of recording such multiple observations will require additional thought. Of main interest are the following:

(i) Azimuth of discontinuity

(ii) Dip of discontinuity

(iii) Proximity to known fault zone in miles

2. Lithological Characteristics

Consideration of lithological characteristics in any detail introduces more complexity into geologic description. Carried to the extreme, geologic description should be tailored to the major types of rocks encountered in the field. This results in an unreasonable proliferation of measures. Description of sedimentary rocks, for example, should include measures of:

a) Bedding thickness

b) Modal sediment size (or a similar measure of most frequent particle size)

c) Range in sediment size

d) Grain shape

e) Grain mineralogy

f) Grain compaction

g) Chemical composition of cementing agent

Obviously the above list is only partially complete and perusal of basic references on sedimentary rocks would suggest still more variables.

Similarily, a description of igneous rocks might include:

(a) Crystal size of matrix (ground mass)

(b) Crystal size of phenocrysts

(c) Percentage (by optical estimate) of principal rock-forming minerals such as:

1) quartz
2) potassium feldspar (Plagioclase)
3) sodic-calcic feldspars (Albite-Anorthite)
4) ferro-magnesian minerals (Augite, Pyroxene, etc.).

Description of metamorphic rocks might well include, in addition to the enumeration of mineralogical and grain-size attributes, such specifics as:

(a) Presence of minerals indicative of the degree of alteration (staurolite, talc, etc.)

(b) Dip angle of planes of foliation.

As mentioned previously, such detailed description while it may be complete, renders geologic description intractable and cumbersome in the context of comprehensive environmental description. An alternative approach would involve identifying a single characteristic (perhaps a behavioral characteristic) that would provide an overall estimate of the character of a given lithologic unit. Thus far, the most appropriate attribute of this type encountered is the bearing capacity expressed in some measure of weight per unit area.[59] The use of this attribute in environmental geology studies is not particularly common.[60] If a measure like bearing capacity proved adequate, the description of a lithologic unit would require only:

(a) dip azimuth and angle

(b) various measures of discontinuities

(c) bearing capacity

(d) unit thickness

(e) depth to upper surface of unit.

3. Resource Potential

The economic aspects of geologic materials should also be considered as an important aspect of geologic description. For simplicity, only the general and stratigraphic position of potential resources need be defined. This might be most easily accomplished by incorporating a series of dichotomous measures as follows:

a) Presence of building materials (0-1)

b) Depth

c) Presence of metallic/non-metallic minerals (0-1)

d) Depth

e) Presence of fossil fuels (0-1)

f) Depth

Unconsolidated Material

Many studies have noted the desirability of including "basic soil mechanics" information in descriptions of the geology and geomorphology of unconsolidated earth materials.[61] "Soil mechanics information" used here conforms with the engineer's usage of "soil" which includes all non-lithified materials as opposed to the pedologist's "soil" which is somewhat more restrictive. Despite numerous calls for the inclusion of basic soil mechanics data there have been relatively few examples of their application. This has been attributed to a lack of a rapid and inexpensive soil mechanics field test.[62] Perusal of Procedures for Testing Soils bears this out -- tests are complex and require specialized equipment.[63]

1. Grain-Size Distribution

One of the most common characteristics of soils measured in both geologic and pedologic work is the grain-size or texural analysis. Like many primary variables or attributes, texture may be used to make inferences about such properties as degree of compaction and permeability of the aggregate.[64]

Certain problems arise in the recording and evaluation of grain-size data in that sizes are commonly expressed as classes. The delimitation of classes varies somewhat between systems. Two alternatives may be offered to standardize or at least incorporate different classifications in a single information system:

(a) conversion of all data to some selected classification system such as the Wentworth scale;

(b) report data as collected and indicate by code which classification system it relates to.

Operationally, it is probably adequate to report only the percentages in four grain-size classes: clay, silt, sand and gravel.

2. Atterberg Limits

From an engineering standpoint the study of unconsolidated materials and prediction of their behavior in response to stress is greatly facilitated by a knowledge of the character of the silt and clay fractions. Developed by the Swedish soil scientist Atterberg in 1911 and subsequently modified and expanded by Casagrande and others, the Atterberg Plasticity Limits" define the change in strength of a fine-grained soil with changes in water content.

The purpose of these tests is, according to the Committee on Landslide Investigations:

> "... to identify the soil and to assign to the soil a quantitative designation that will aid the engineer in estimating its probable behavior in the field ... The strength of a soil is dependent on many variables including density, moisture content, structure, texture, geologic history, and many others. Generalizations are difficult, at best, regarding the interrelationship of these variables. Identification alone will not take into account all these variables, but will yield data which will be most helpful."[65]

Although the specific tests outlined below seem both arbitrary and simple "they have been found to be highly significant and readily repeatable with accuracy by different operators."[66] A number of recent papers in "environmental geology" also include Atterberg limit data.[67]

Some pertinent Atterberg limits are:

(a) Liquid Limit:

The liquid limit is defined as "the water content expressed in percentage of dry weight at which a remolded soil is just capable of resisting a measurable static shearing stress"[68] or in simpler terms, as "the water content at which soil cohesion approaches zero".[69] Factors controlling the liquid limit (although inadequately known) are thought to depend mainly on the mineralogic composition and attributes of individual particles such as grain size and sorting - in particular, the types and percentages of clay minerals, the percentage of organic matter, and the percentage of silt and coarser material in the soil.

(b) Plastic Limit

Plastic limit refers to the water content expressed as a percentage of dry weight at which a soil becomes plastic. This percentage is determined by rolling a mass of soil into a 1/8" diameter thread and ascertaining the water content of the soil at that point when the thread crumbles. As with liquid limit, the plastic limit is influenced by mineralogy and grain-size.

(c) Plasticity Index

An important secondary variable is the plasticity index. It is defined as the difference between the liquid and plastic limits and is a measure of the range in moisture content over which the soil remains in a plastic state. Casagrande used the plasticity index in conjunction with the liquid limit for a classification of clay soils.[70]

(d) Activity Index

Another derived property is the activity index. This is the ratio of the plasticity index to the amount of clay present in the soil and is "an attempt to express quantitatively the contributions of the clay minerals in aggregate to such properties as strength of cohesion and plasticity".[71]

(e) Shrinkage Limit

The shrinkage limit measure gives the water content of a soil below which that soil ceases to shrink on drying. This test, while conceivably significant for soils with a high expandable clay content, seems, on an intuitive level, to be of less potential use than the other Atterberg limits. For the purposes of this study it can probably be placed on a lower level of priority.

3. Natural Water Content

In studies "..of fine-grained soils, the water associated with soil solids will always be of significance". Operationally natural water content is the ratio of weight loss "sustained by a sample in drying at 105°C to the weight of the dried sample".

Unlike the Atterberg limits the natural water content is a property of a soil that depends upon the structure (grain to grain relationships, size and configuration of voids) of an undisturbed soil sample. Therefore both initial depositional conditions and subsequent loading history influence the values obtained.

Natural water content is "relatively independent" of the position of the water table because water is held in the voids of the soil by capillary and molecular forces.[72] It appears that natural water content is quite similar to the pedologist's "field capacity" or "moisture equivalent".[73]

(a) Ratio of Liquid Limit to Natural Water Content

A simple ratio of natural water content to liquid limit thus may be a significant secondary variable for environmental description. In glaciated areas fine-grained soils are sometimes encountered where the natural water content exceeds the liquid limit. An example of such a "sensitive clay" or "quick clay" is the Leda Clay of the St. Lawrence valley which, while apparently stable and capable of bearing considerable loads, may suddenly release excess water in response to a shock or to erosion at the toe of a slope.[74]

(b) Relative Water Content

This is another derived measure relating natural water content to Atterberg limits, i.e., the ratio of the difference between natural water content and plastic limit to the plasticity index. The relative water content may be used to reflect the variation in the loading history of the sediment.

4. Permeability

The rate at which soil is able to transmit water or air can be measured quantitatively in terms of the rate of flow of water through a unit cross-section of saturated soil, under specified temperature and hydraulic conditions. As mentioned previously, permeability like a number of other variables may be estimated on the basis of textural data. In addition, it is of interest that soil permeability and internal soil drainage are often reported in Soil Conservation Service county reports on an ordinal measurement scale, i.e., very slow to very rapid.[75]

5. Thickness

A measure of the thickness of the stratigraphic units under consideration, especially the surface unit, would be useful as a primary geologic description as well.

6. Additional Attributes

Several other attributes of unconsolidated materials are mentioned in the literature.[76] Some are listed below but are considered to be of a secondary nature within the context of this study either because:

(a) they yield information that is too specific for a general description of geologic conditions

(b) the effects of their variation is also measured in one of the previously considered variables. The additional attritubes are:

1) dry density
2) specific gravity of grains
3) grain shape
4) consolidation characteristics
5) pre-consolidation stress
6) free $CaCO_3$
7) pH
8) electrical resistivity
9) air intrusion values
10) mineralogical characteristics via
    (a) x-ray defraction
    (b) differential thermal analysis
    (c) optical mineralogy.

7. Shear Strength

The previously outlined measures may be considered as routine identification tests and as such contrast with another category of tests -- shear tests.[77] The shear strength of a soil or rock is the capacity of that material to resist sliding along internal surface in response to a stress. Shear strength may be expressed by the empirically derived equation:

$$s = c + n \tan \varnothing,$$

where s is the shear strength (the shear stress at which failure will occur in units such as pounds per square inch), n is the normal force on the failure plane, and $\varnothing$ is the angle of internal friction.[78] The shearing resistance of soils may be obtained in the laboratory by three tests: direct shear, triaxial compression or unconfined compression types. The newer triaxial test is considered more versatile than the direct shear test. Field testing devices are also available. Obviously shear strength is closely related to soil texture and moisture conditions. Articulation of the latter variables could provide useful bases for inferences about shear strength if tests and/or equipment to determine the latter were not available.

Concluding Comments - Geology

A problem that will undoubtedly be encountered in data gathering is that at any given site, information may be available only for a portion of the entire geologic column. The retrieval of information for a given point or site might require therefore, correlation and/or generalization with respect to nearby sites so as to provide a complete column. For subsurface geologic units a simpler approach might be to assign a "typical" geologic column for all sites within a geological region, province or entity. Any site selected within a coordinate location defined by that geologic entity could then be assigned the appropriate geologic column.

While the added emphasis on the vertical dimension complicates data collection and storage, this is counteracted by the relative temporal stability characteristic of most geological attributes. Exceptions are those associated with moisture conditions in the surficial material, a factor closely tied to climatic and landuse conditions which may be extremely variable. Thus the necessity for repeated surveys is diminished greatly.

III. Soils

The use of specific soil descriptors has depended on how and by whom the information was to be used. In the previous section on unconsolidated materials two general areas of interest were mentioned: that of the engineer who is primarily concerned with physical and structural properties and that of the pedologist (agriculturist) who has an added interest in fertility. A number and various combinations of variables have been used as a basis for soil classification. Soil classification, in turn, has been the basis for soil surveys and mapping, the form in which most soil information is presently stored.

In this section the primary emphasis will be on soil from the pedologist's point of view. Some of the variables of interest were articulated in the previous discussion of unconsolidated material. The reader will be referred to that section for discussions of the variables.

The pedologist's view of soil emphasizes the unique position of this environmental element. Soil manifests the interactions between virtually all environmental elements. Its character is an indicator of environmental conditions, past and present. The definition of soil used in the "Seventh Approximation" soil classification illustrates this position:

> "...the collection of natural bodies on the earth's surface, containing living matter, and supporting or capable of supporting plants. Soil includes all horizons differing from the underlying rock material as a result of interactions between climate, living organisms, parent materials and relief".[79]

The same idea is portrayed in Jenny's statement: $s = f(cl, o, r, p, t)$, which says soil is a function of climate, organic material, relief, parent material and time. Crocker modified the statement to: $s = f(cl, o, r, w, p)t$, to introduce the notion that soil is a dynamic rather than static entity.[80] This statement says soil is the integral against time of a function of the previous four factors plus the water table. Even this statement may be modified to take account of the present dynamism of soil which is principally the result of landuse activities (lu). Thus we have:

$s = f(cl, o, r, w, p, lu)t.$

All these elements contribute to the formation and modification of soil. Some, such as: parent material, relief or topography and time, may be considered as passive. Climate may be thought of as the most active element in the role of supplying moisture and controlling temperature. Moisture is an important factor since most chemical activities and transportation of materials in the soil rely on it. When the water table was listed above as an element in itself, the importance of it as a supplier of moisture and controller of other processes was meant to be emphasized. Temperature, an indicator of heat content, plays a similar role as a governor on the rate of activity in the soil. Other climatic variables play lesser roles. Changes in barometric pressure induce gaseous exchange between soil and atmosphere. Winds affect rates of evaporation, decreasing moisture content, and physically disturb the soil.

Biological organisms both live off and contribute to the soil. This is especially true of the flora that withdraw nutrients from the soil and add the same when they die. The same may be said for the fauna, although they may have a somewhat greater physical impact by burrowing, trampling and overturning.

Finally, man and landuse is an active element especially through the impact on the other elements. For example, changes in the soil's surface cover, whether by agriculture or urbanization, affect the organic element directly and alter the influence of climatic or atmospheric variables indirectly. Cultivation directly alters the physical structure and fertilization alters the chemical composition.

All the interactions between environmental elements that produce and alter soil may be summarized in a number of processes ranging from lateritization to podzolization.[81] The soil characteristics or pedological variables will reflect the processes and the influence of passive elements like parent material. As such, they will reflect environmental conditions and therefore must be included as key indicators in monitoring and description of the environment. Another way of saying this is that soil contains a maximum of environmental information. The way to extract the information is by examination of variables, the most important of which are described in the following paragraphs.

1. Color

Soil color is oftimes used as a surrogate for a number of other variables and soil history. Color has been used as a standard means for distinguishing between soil types and the horizons within a type. This procedure has been institutionalized and standardized in the Munsell Color Chart. The major difficulty in the use of color is that it may be extremely variable with moisture content changes. This necessitates analysis of wet and dry samples, something that may be a tedious and cumbersome process for the amount of information gained.

2. Texture

The first aspect of texture, particle size distributions, was discussed in the section on unconsolidated materials.[82] Another aspect of texture is particle shape. Shape is usually observed qualitatively and characterized by nominal adjectives like: platelike, rodlike, bladed, cuboid, etc. For particles of equal mass and density, shape will determine the particle surface area. Related to particle surface area is another aspect of texture, an aggregate measure termed "specific surface".[83] Specific surface is the aggregate surface area of a given material as a ratio of the unit mass (cm^2/gm). For a given material, the aggregate specific surface area decreases as particle size increases.

3. Structure

Related to texture is the soil structure. This is primarily a descriptive measure based on the nature of the soil aggregates, the pore spaces and the binding material. Again this variable is operationalized through classifications that use terms such as: blocklike, prismlike, platy, etc.[84]

The soil profile is related to structure and is also characterized by a standardized set of terms that are essentially qualitative.

4. Density

Although not discussed in the section on unconsolidated material, density and its derivatives and related variables describe the physical character of the soil. Density determinations are carried out on a dried soil sample. From them may be derived a large number of secondary variables that are of use for specific purposes. Included here are:

(a) Bulk density - mass/unit volume of undisturbed sample;
(b) Particle density - voids are excluded in the volume;
(c) Void ratio (e) - volume of voids/volume of particles;
(d) Porosity (n) - volume of voids/total volume;
(e) Unit dry weight - weight of dry particles/unit of soil volume;

(f) Unit wet weight - weight of wet particles/unit of soil volume;
(g) Specific gravity (g) - unit weight of particles/unit weight of water.

5. Moisture Content

Considerations of the mositure content of a soil include hygroscopic, capillary and gravitational categories. Although moisture content was briefly discussed in the section dealing with unconsolidated materials a number of more specialized secondary variables and indices are worthy of mention:

(a) Water content (dry) (w) - weight of water/weight of solids;
(b) Water content (wet) (m) - weight of water/total weight of sample;
(c) Degree of saturation (s) - volume of water/volume of voids;
(d) Unit wet weight (wet) - total weight of total volume

6. Moisture Availability

There are several methods by which the availability of moisture is portrayed. Of course, availability is a relative term and the availability for what must be specified. In pedology, availability is applied with reference to plants. Variables that provide information on water availability in a given soil include: field capacity, permanent wilting point and incipient wilting point.

7. Consistency

The consistency of a soil refers to its workability or firmness with variations in moisture content, degree of saturation and the nature of the moisture. The Atterberg system, discussed in the previous section, provides indices of consistency based on a rigid set of laboratory procedures (see section on unconsolidated material).

8. Soil Atmosphere

The atmosphere of the soil is a variable not often treated in descriptions of soil. Yet it is extremely important from the biological and agricultural points of view. As the soil becomes more porous, the soil atmosphere will make up a greater proportion of the volume. Variables of interest here include: the chemical composition of the soil atmosphere, the barometric pressure of the soil atmosphere and the air permeability of the soil.

9. Permeability

Permeability was discussed in the section on unconsolidated materials where the major emphasis was on permeability to moisture. There permeability was defined as the rate of discharge of water through a cross-sectional area of soil under unit hydraulic gradient and standard temperature conditions. Related to this is the air permeability of the soil which is governed by such variables as barometric pressure, temperature and moisture content. The air to moisture permeability ratio is the ratio between air permeability and moisture permeability and is used as an index of the stability of the soil structure where it reflects the magnitude of structural breakdown and the decrease in open pore passages due to wetting.

10. Infiltration Capacity

The infiltration capacity of a soil is dependent on many of the physical characteristics of the soil noted previously as well as on the prior moisture conditions. This is an extremely useful variable in hydrological studies in that it characterizes the soil's ability to take in water from the surface at a given time and place. The moisture that doesn't infiltrate and/or remain stored at the surface will runoff.

11. Thermal Characteristics

Soil temperature is a variable often included in standard meteorological observations. A primary concern is whether or not the soil is frozen and if so, to what depth. A secondary concern is the definition of thermal gradients in the soil. Related thermal characteristics include: heat capacity, specific heat, heat transfer, thermal conductivity, thermal diffusivity and freezing point.

12. Shearing Strength

(see section on unconsolidated material)

13. Bearing Capacity

(see section on unconsolidated material)[85]

14. Mineralogical Composition

This variable or group of variables is useful for distinguishing between soil types and/or distinguishing between parent materials from which the soil is derived. It is simply a mineralogical content (frequency) analysis of a soil sample. It may have implications for the type of uses or stresses to which the soil may be subjected.

15. Chemical Composition

The principal concern here is the pH or hydrogen-ion concentration in the soil. Other key substances usually considered is the concentration of soluble salts, sesqui-oxides and toxins. The latter have become especially relevant of late and include harmful (at certain concentrations) chemicals and substances such as lead, mercury, arsenic, herbicides, insecticides, nitrogen, etc.[86]

16. Biological Composition

Again this requires a content analysis of a given sample to determine organisms, their species and species population. Not only are the living organisms of concern in this characteristic but the organic content including humus is as well.

17. Fertility

Fertility is a relative variable depending on what one wishes to grow in the soil. It is dependent on a large number of the preceeding soil characteristics, particularly the last three. It is a vaguely defined and complex entity that may be measured best by its results, i.e., productivity.

Concluding Remarks - Soils

Many of the variables listed in this section are interrelated, particularly the last four. Apart from soil erosion and the structural alteration due to cultivation and construction, the impact of man's activities on soil have been greatest in the chemical and biological composition. From the point of view of monitoring, the latter probably are the most pertinent variables to key on, at least once the initial state of the soil is described in the "baseline" type of survey.

Numerous base-line soil surveys have been completed in this country and elsewhere. Various classifactory schemes have been devised to facilitate this type of survey and the derived information is often stored in soil survey reports with their accompanying maps. In the United States the primary soil surveying organization is the Soil Survey Staff of the Soil Conservation Service. Their work is conducted on two levels: field-work identifying and mapping soil units, and classification of soils applicable to the global scale. In an attempt to fit the described units into a classification scheme, it was found to be impossible without restructuring of the classification. Thus began the effort toward a unified and comprehensive soil classification scheme, the 7th Approximation.[87] The impact of the new classification on the field reports does not appear to have been very great. The latter remain as the primary sources of soil information in this country.

Those concerned with engineering properties of soil have devised somewhat different classification schemes keying on different variables. Four such systems have come to our attention. All of them incorporate rigid testing procedures with specified groupings according to the results. Included here are the following systems and the criteria for classification in each:

1. ASTM Standard Method: (a) particle size, (b) liquid limit, (c) plasticity index;

2. Highway Research Board: (a) particle size (sieve), (b) liquid limit, (c) plastic limit, (d) desirability as subgrade material;

3. Civil Aeronautic Authority: same as above with special considerations for drainage and frost conditions;

4. Unified System - U. S. Army Corps of Engineers: (a) particle size; (b) dilatancy (reaction to shaking), (c) dry strength (crushing characteristics), (d) toughness (consistency near plastic limit), (e) ratings in construction conditions, frost action, compressibility, expansion, drainage, compaction, unit dry weight, etc.

For the characterization of soil for engineering and trafficability purposes very detailed surveying and analyses are required. By the same token monitoring of chemical and biological characteristics will require a similar level of detail. The spatial coverage of information of this detail will be limited therefore. Thus the systematic and generalized collection of information of this nature is unlikely and will probably be restricted to small areas where specific types of operations are planned. In hierarchical environmental monitoring the collection of these types of data will occur at a lower level than the collection of data necessary for generalized classifications such as the 7th Approximation.

B. The Atmosphere

Of the environmental elements being considered in this review, the character of the atmosphere is probably the most variable in most respects. Much of this variation is of a predictable nature in that it is cyclical in diurnal and seasonal contexts. In addition, the atmosphere close to the ground surface has had a long history of being measured and monitored. It is one of the most systematically and completely monitored environmental elements at both the global and national scales.[88] The definition of pertinent atmospheric variables for the description of both the physical and chemical character of the atmosphere is well-developed. Several important groups of variables may be identified, including: temperature, pressure, motion, radiation, humidity, precipitation, and composition.[89]

1. Composition

Atmospheric composition was thought to be relatively stable until the recent attention to air pollution. In the major constituents, composition is probably still relatively stable at the global scale.[90] This may not be the case at regional or local levels.

The major atmospheric constituents under all natural conditions are: nitrogen, oxygen, argon, carbon dioxide. Secondary naturally occurring constituents include: water vapor, helium, krypton, xenon, neon, methane, ammonia, ozone, carbon monoxide. Several of these substances are toxic at certain levels. In addition, a variety of particulates are always present in the atmosphere.

The following and a variety of combinations of them have become of particular concern and may be referred to as air contaminants.

A. Organic gases:
   1. Hydrocarbons
      (a) Paraffins
      (b) Olefins
      (c) Aromatics
      (d) Oxygenated hydrocarbons
      (e) Hologenated hydrocarbons

B. Inorganic gases:
   1. Oxides of nitrogen
   2. Oxides of sulfur
   3. Carbon monoxide

C. Aerosols:
   1. Solid Particulates
      (a) Carbon and soot
      (b) Metal oxides
      (c) Salt
      (d) Silicates
      (e) Mineral dusts and organic particles
      (f) Metallic fumes
   2. Liquid Particles
      (a) Acids
      (b) Oil and tar
      (c) Paints[91]

From the air pollution point of view, several of these substances have been identified as especially crucial, including: particulates of all types, sulphur oxides, nitrogen oxides, oxidants, hydrocarbons and carbon monoxide.[92]

2. Radiation

Within the context of radiation are included: (a) insolation, (b) albedo and (c) outgoing longwave radiation. Various crude substitutes for direct measurement of radiation have been standard variables for atmospheric description in the past. Estimates of cloud cover and the recording of sunshine at a place are examples. Instrumentation of a variety of types is now available to measure incoming solar radiation directly.[93] The reflectivity or albedo of the earth's surface is important in determining the energy balance in a given area. In addition to incoming short-wave radiation and reflected short-wave radiation, outgoing long-wave radiation should be monitored. Remote sensing from satellite platforms is especially applicable to the measurement of the latter two variables.[94]

3. Atmospheric Pressure

For the purposes of weather forecasting, atmospheric pressure is the most important atmospheric variable. Specifically, it is the barometric tendency or day-by-day trends in atmospheric pressure that is of importance in weather forecasting. Because of its importance, pressure is carefully and continuously monitored in many locations. It is an important independent environmental variable, at least in the short run. Its value in long-term data storage schemes may be questionable apart from its role as an independent variable that may influence the behavior of other seemingly unrelated environmental variables.

4. Temperature

Air temperature is an important variable in understanding the behavior of any ecological system. It is easily measured and has been measured for some time at a variety of locations, at least at the earth's surface. There is considerable value in temperature data from positions above the earth's surface, but this introduces information storage problems by adding a third dimension much as some geological information does.

Although temperature may be recorded continuously, temperature data is usually stored in a time specific form. Daily maximum and minimum, mean daily temperature, mean monthly temperature, mean annual temperature and the standard deviations from these are examples.

5. Humidity

Humidity, or the amount of moisture present in the atmosphere, is another basic variable. It is usually measured through comparing wet- and dry-bulb temperatures at a given time and place. Like most other atmospheric variables it may be recorded continuously but the data are normally stored in a time specific framework. A number of variables have been developed to describe atmospheric humidity. The most commonly used and one of the least useful is relative humidity which is the ratio between the water vapor present and that present at the saturation condition for that temperature. It is expressed as a percentage. Other humidity measures include: mixing ratio, saturation mixing ratio, absolute humidity and specific humidity. Absolute humidity is a measure of the mass of water vapor per unit volume of air. Specific humidity is a comparative measure of the mass of water vapor present per mass of moist air of which the water vapor is part. Regardless of what measure of humidity is used, it is an important derived or measured variable in environmental description.

6. Precipitation

Precipitation is an extremely important environmental variable and like most of those associated with the atmosphere and weather has been observed systematically for a long time. The major components of precipitation are rain and snow. Significant contributions may be made by hail, rime, sleet, freezing rain and dew as well. Regardless of its form, precipitation is usually recorded in the form of water equivalent expressed as some depth of water. It is prudent to point out that although precipitation has a long histor of measurement, the technology of recording it and the methodology for converting solid forms to water equivalent is subject to large errors. Measurement is usually carried out by trapping the precipitation in some form of guage. This can prove difficult and inaccurate in windy conditions.

Recording rain guages gives an approximation of a continuous precipitation record. However, most precipitation data are time specific, being collected every four hours, six hours, 12 hours or 24 hours. Mean monthly precipitation is probably the most commonly used form of presentation. An additional measure that has received increasing attention because of its value in runoff and erosion studies is precipitation intensity. This is simply a measure that portrays precipitation amounts per unit time period.

7. Atmospheric Motion

Most atmospheric motion is a vector of two components -- horizontal and vertical motion. Wind is an expression of the horizontal component and is important as a environmental variable in its own right. Wind also is important in the influence it exerts over the spatial distribution of characteristics of other atmospheric phenomena like composition, humidity, pressure, etc. Vertical motion is most often associated with convection and orography.

Measurements at the earth's surface emphasize wind. Normally wind direction and speed are recorded. Speed, of course, is a measure of distance over time and is therefore, time period specific.

Increasing attention has been directed to wind conditions above the ground surface, especially in the upper parts of the troposphere. This will be discussed briefly in a following section on upper atmosphere meteorology.

As with most other atmospheric variables, wind data are recorded as mean velocity per day, month and year. Wind direction is recorded as the prevailing direction over a given time period or as percentage of time blowing from each of the principal compass directions.

8. Special Variables

The foregoing variables are more or less standard requirements for adequate atmospheric description. At the microclimatic scale and for the purposes of ecological studies, especially those associated with plants, other important variables should be considered. Light intensity, although associated with radiation, is important. Three phenomena: the spectral distribution of solar energy, the relative spectral luminosity curve for photopic vision and the maximum attainable luminous efficiency, are listed by Platt and Griffiths as important.[95]

Evapotranspiration is a variable of the same nature. It is an expression of the combined process of evaporation of moisture from exposed surfaces and the transpiration of moisture by growing plants. Various means are available for measuring evaporation and transpiration directly or estimating the potential and actual amounts of both from other parameters.[96]

Radiation, pressure, temperature, humidity, precipitation and wind are basic atmospheric variables for the description of environmental conditions and for the understanding of ecological processes. Atmospheric composition has become a crucial variable set through the increasing impact of human activities on the quality of the atmosphere. These man-induced changes are having a secondary influence on the basic atmospheric characteristics, principally radiation, temperature and precipitation at the earth's surface.

For descriptive purposes, these atmospheric characteristics must be summarized in terms of certain standard measures. The following list has been presented as the most important data necessary for climatic description.[97] Most of the items in the list may be derived from the systematic collection of data for the basic variables discussed here.

Basic summary statistics for climatic description at point locations:

Mean monthly temperature
Mean annual temperature
Mean annual range in temperature
Mean daily maximum temperature
Mean daily minimum temperature
Mean daily range in temperature
Highest temperature of record
Lowest temperature of record
Average number of days with maximum $> 90^\circ$ F; $> 100^\circ$ F
Average number of days with temperature $< 32^\circ$ F; $< 0^\circ$ F
Mean monthly relative humidity
Mean annual relative humidity
Mean monthly precipitation
Mean annual precipitation
Greatest precipitation in 24 hours
Mean monthly snowfall

Average number of days with: rain, snow, hail, fog, thunder
Mean cloudiness
Mean monthly percent of sunshine
Mean monthly wind velocity
Prevailing wind direction by months
Wind frequency by direction
Mean frequency of gales
Mean frequency for air mass types
Mean and extreme dates for first and last killing frost

Concluding Remarks -- Atmosphere

Most of the variables and measures discussed have referred to the atmosphere in contact with the earth's surface. From the point of view of environmental monitoring this is probably the most significant part of the atmosphere. However, there are exceptions. For weather forecasting purposes upper atmospheric observations are extremely important. In some instances observations above the ground are important from the viewpoint of monitoring environmental quality. At least two examples come to mind. First, the definition of environmental lapse rates or the profile of temperature change with height above the ground is important in forecasting conditions of atmospheric stability or instability. This is important in determing air pollution potential at the surface. Secondly, the sampling of atmospheric composition at various levels is important in understanding the amount and character of solar radiation reaching the earth's surface and the amount of terrestrial radiation passing through the atmosphere into space. Of crucial importance here is the ozone content in the upper atmosphere and the lower boundary of ozone concentration in the atmosphere. The former is important because ozone provides a shield against excess short-wave radiation reaching the earth's surface.

The second is important because ozone is toxic in small amounts and provides a hazard in the lower atmosphere.

Upper atmospheric conditions will become more important as our understanding of the influence they exert on conditions at the earth's surface becomes more complete. The importance of the upper atmosphere has become more apparent as the technology for making meaningful observations there has developed. With increasing use of high altitude aircraft and earth satellites as observational platforms, the trend will continue.

C. The Hydrosphere

A vast number of variables have been used to describe the state of the hydrosphere. This study addresses itself only to that part of the hydrosphere associated with the continental land masses. In so doing, we ignore the major part, by volume, of the hydrosphere: the oceans. This is an arbitrary decision based on the availability of time and resources. It is not meant to imply that the oceans are not important, indeed there is increasing concern about the status of the oceans.[98]

Two major aspects of the hydrosphere are discussed in this section. First, is a concern with the physical characteristics of water in a variety of contexts and states. The contexts include channels, lakes and overland flow, while the states include liquid and solid in the form of snow, glacier ice, lake ice, river ice and ground ice. Secondly, a review of the most important aspects of water quality is made. Finally a section outlining ground water variables is appended.

Physical Characteristics

1. Surface Water

(a) Area Covered

The amount of land surface covered by water is an important descriptive measure. Of course the major portion of surface water area is usually in the form of lakes. One will recognize that the amount (or percentage) of land surface covered by water must be based on a given area or region. Thus, it is distinctly different than the more usual point measures. In the context of lakes, a variety of secondary variables may be derived from measurements of surface area. These include such things as: shoreline length, circularity or shape, orientation of major axes, etc. If the subsurface contours or a sampling of depths are known, some estimate of volume may be derived. All these measures are important in the study of lake morphometry and morphology.[99] Apart from area covered by water, these variables are of secondary interest.

(b) Volume

The volume of water contained in streams, lakes and swamps at a given time in a given area is of interest for planning and water resource purposes. Volume of surface water in a given area is calculated from some estimate of subsurface configuration of lakes, channel geometry (especially cross-section) in the streams and surface area in both.

(c) Discharge

Closely related to volume is discharge or the amount of water passing a given point in a stream channel per unit of time (cubic feet per second). Discharge is usually calculated by multiplying the known cross-sectional area of the stream at a given time by the velocity of moving water. Discharge is one of the most useful hydrological variables. It is useful in determining both water quantity and some aspects of water quality and is thus a key variable in environmental monitoring.

There are various means for measuring and estimating discharge. Once a "station's" (a point on a stream) rating curve is known, discharge may be estimated from guage height or stage. The rating curve is empirically based and relates guage height to discharge. Several chemical dilution methods of estimating discharge have been developed for use in specific contexts.[100]

A considerable amount of valuable information may be generated from discharge data collected over a long period of time. Most important is the information on excessive or unusual discharge, or floods if the volume of water exceeds the confines of the channel. Recurrence intervals for various discharges may be calculated and the probability of given flood levels may be estimated. A record of discharge provides information for the establishment of maximum allowable effluent discharge into a stream. Careful monitoring of discharge permits inferences to be made about the impact of changing ecological conditions, especially land use changes, in the drainage basin.

(d) Drainage Net Characteristics

These have been discussed in the section on topography. The major value of data on drainage basin characteristics is as a descriptive tool. The most important variables are: drainage area, stream orders, length of overland flow, bifurcation ratio, drainage density, length of overland flow, etc.[101] Some value of this type of data lies in the fact that the character of the stream hydrograph may be estimated and more fully understood on their basis.

(e) Overland Flow

The overland flow component of surface water has received relatively less attention. This is partly a result of the fact that it tends to be periodic and is generally slight in vegetated conditions. It takes two morphological forms: rills and sheetwash. Overland flow may be conveniently expressed as discharge per unit contour length which is calculated as the difference between rainfall intensity and soil infiltration rate, times the area drained per unit contour length.[102]

(f) Water Temperature

Water temperature at the surface and at a variety of depths is an important variable both in streams and lakes. It influences the rate at which chemical and biological processes take place. In the extreme, temperature determines whether or not certain processes take place at all. The vertical distribution of water temperature is important to know as this influences the degree of vertical mixing, as the same distribution does in the atmosphere. Changes in water temperature have important implications for many aquatic processes and as such temperature must be considered an important variable for consideration in environmental monitoring. The methodology and technology for the measurement of water temperature is well-developed and, to some degree, standardized.[103]

2. <u>Snow</u>

(a) Area Covered

Area covered by snow is important in estimating the consequences of snow melt. It is also an important descriptive variable, especially as it is used in defining a seasonal and/or permanent snow line. Increasingly the area covered by snow is being estimated with the use of satellite sensing platforms. As a result, data on snow coverage is becoming available on something approaching a "real time" basis, rather than on a monthly and seasonal basis as is the case where ground surveys and reporting are used. From the hydrological viewpoint, area of snow cover is only of use in conjunction with additional measurements of the character of the snow cover itself.[104]

(b) Depth

(c) Densities

(d) Water Equivalent

The water equivalent of the snow cover may be estimated from depth and density measurements at a point. The water equivalent for an area of snow cover may be estimated by sampling depth and densities at a number of points.

(e) Additional Variables

A variety of other physical variables are of use, though of secondary importance, in estimating the hydrological impact of snow. Included are: crystal size and type, cohesion, wetness, hardness, temperature, compressive yield strength, tensile strength, shear strength, surface conditions, etc.[105] Most of these physical characteristics of the snow cover must be measured on the ground. Usually this has been accomplished through "snow courses" and time profile sites that are periodically visited throughout the snow cover period. Increasingly, remote gauging is being implemented through the use of pneumatic snow pillows and radio isotopes.

3. Glacier Ice

(a) Areal Extent

As with snow cover, the main reason glacier ice is of interest in environmental monitoring is through its contribution to the hydrological resources of a given area. In addition, a statistic on the area covered by glacier ice is of descriptive interest. However, the measurement of the areal extent of glacier ice in a region is not as simple as might be supposed. Definition of boundaries is made difficult using remote imagery by seasonal and semi-permanent snow cover and permant debris or morainic cover.[106]

(b) Depth and Subsurface Configuration

Accurate assessment of ice volumes for hydrological purposes requires some estimate of glacier depth and/or the subglacial configuration. The methodology and technology for collecting these data are not well-developed. The result is that most estimates of glacier ice amount are approximate. The usual means of collecting these data are by various seismic sounding techniques carried out from the ice surface--an expensive and cumbersome proposition in remote regions. Recently, airborne radio sounding techniques have been used for the same purpose with some success.

(c) Velocity

Careful monitoring of glacier behavior has proven to be useful.

The glacier behavior of most interest is velocity. Recent events have focussed attention on rapid changes in velocity, particularly surges.[107] Glacier surges and floods and icefalls resulting from both are important environmental hazards in inhabited mountain regions.

(d) Other Variables and Characteristics

Numerous other glacier ice attributes are important in glaciology. Their importance in general environmental description and monitoring may be limited however. Such variables are: accumulation, ablation, mass budget, ice temperature and glacier morphology. It is of significance that glacier ice traps various materials extant in the atmosphere with the result that the analysis of particulates contained within the ice is providing information on atmospheric conditions of the recent past.

4. Lake, River and Sea Ice

As the use of lakes, rivers, and those parts of the oceans subject to ice cover has increased, so has the importance of monitoring the ice cover on these features. As usual, the primary variables are depth (thickness) and areal extant. Ice thickness is important in predicting the likely time of break-up in a continuous ice cover. Of secondary importance in this regard are: the nature of the ice, the amount of white ice and black ice, and the depth of snow on the ice.[108] Both the estimate of break-up in a continuous ice cover and the areal extent of a non-continuous cover constitute important information for carrying out most activities in a cold region. In addition, careful monitoring of river ice is important in the forecasting and prevention of ice-jam flooding, a common hazard in cold regions.

5. Ground Ice

Permafrost need not involve ice. However, most permafrost does contain a measure of ice. The amount of ice in the ground, whether it be permanent or seasonal is extremely important in planning activities in an area. This point has been especially well illustrated in the controversy surrounding the construction of the Trans Alaska Pipeline. Ground ice generally takes two forms: interstitial or segregated. It is important to know which is present. Very high soil or ground water contents are usually present where segregated ground ice forms. Of course, small changes in ground surface cover may radically alter the heat balance causing ground ice to melt. In arctic conditions this usually means that the terrain is made impassable.[109] Characteristics of relevance are permafrost thickness, areal extent, spatial distribution, depth below the ground surface of the permafrost table and the water content.

The purpose is not to discuss the phenomenon of permafrost and ground ice in detail. Rather, it is to point out that permafrost is a very important environmental factor when operations are being considered in a cold region.

6. Ground Water

Ground water, like ground ice, could be included in the section on the lithosphere. The fact that it isn't results from an arbitrary decision. From the viewpoint of human activities, ground water table level, yield estimates and chemical characteristics of the ground water are the most important variables. Recent monitoring of all three variables have indicated marked changes in the status of ground water at a variety of locations in the United States and elsewhere.[110]

In the process of collecting data on the basic characteristics of ground water, a considerable amount of basic geological information may be gathered as well. Well-logs have proven to be valuable sources of this type of information. Automated information systems for the storage and retrieval of the data associated with ground water are operational and standardized in the United States and several other countries.[111]

The following are some of the basic well data recorded in the U. S. Geological Survey and Canadian ground water data information systems.[112]

1. Location: (a) township and range,
   (b) longitude and latitude,
   (c) local agency field office code.
2. Ownership:
   (a) owner,
   (b) well-use (e.g., withdraw, test, recharge),
   (c) water use (e.g., public, industry, stock, waste).
3. Basic Well Description:
   (a) drill method,
   (b) drill date,
   (c) depth,
   (d) casing length,
   (e) pump setting,
   (f) water level and yield,
   (g) drawdown.
4. Hydrogeologic Environment:
   (a) physiographic region or province,
   (b) drainage basin,
   (c) topographic setting,
   (d) thickness of surficial material and infiltration capacity,
   (e) general description of major and minor aquifers including: system, series, lithology, thickness, depth to top of unit, coefficient of transmissibility, coefficient of storage.
5. Water Quality:
   (a) color
   (b) odor
   (c) turbidity
   (d) hardness
   (e) SO_4, Cl, NO_2, NO_3, HCO_3, CO_3, Fe, etc.,
   (f) Spectographic analysis.

Depending on the system, various other data are recorded. The Canadian system lists the characteristics of each lithological unit encountered in drilling a well. The U. S. Geological Survey system may include data derived from tests on rock samples, such as: permeability, specific yield, capillarity, Atterburg limits, particle size analysis, etc.

Although information on ground water is important in and of itself for environmental monitoring and description, the act of collecting these data often permits the collection of important data on other lithosphere characteristics.

Water Quality Characteristics

Water quality is an environmental characteristic of long standing concern. However, systematic collection of water quality data is, at best, a recent phenomenon.[113] The variables of interest and the methods of measuring them are relatively well-standardized.[114] The following are the basic variables for the assessment and understanding of water quality: temperature, specific conductance, turbidity, color, odor, pH (field), pH (lab.), EH, suspended solids, chloride, nutrients (nitrogen), nutrients (phosphorus), common ions, hardness, radiochemical characteristics, dissolved oxygen, other gases, pesticides, detergents, biochemical oxygen demand, carbon, coliforms, other microorganisms, other biological data, suspended sediment concentration, particle size of suspended sediment and particle size of bed load.[115]

Among the more common and useful water quality variables are: dissolved oxygen, dissolved solids, biochemical oxygen demand, suspended sediment, pH, and temperature. The usefulness of these variables lies mainly in the information they give regarding processes that are operating within the water body. That is, they provide good first approximations of the presence or increase in critical substances. For example, increasing BOD could be an indication of an increased amount of organic material present in the water which in turn could be the result of increasing amounts of nitrates and phosphates in the water. This, in turn, could be a reflection of changing land use activities. By the same token, increased amounts of suspended sediment may reflect such things as construction or changing agricultural practices.

D. The Biosphere

The condition of the biosphere has been of central concern in the present "environmental crisis". It is of concern because of the marked changes that have occurred in the "natural" condition as the result of human activities. Changes have occurred in the number of species of plants and animals, the populations of individual species, the mix and diversity of species in a given area, etc. It would seem these basic characteristics are those to receive attention in monitoring and description of plant and animal conditions.

The traditional approach to organizing information about the biosphere is through classifications of one sort or another. Basic to much of the classification is the Linnean taxonomy. Beyond this, plant and animal communities are normally studied as quite distinct entities. For both, there are numerous ways of organizing (classifying) the information or describing the phenomena.

1. Flora

A floristic description can be simply a comprehensive listing of the plant species present in an area. Each species is identified with its Linnean name which places it in a well-defined niche in the classical taxonomic classification of the botanist. This classification is something of a genealogy of the species identifying its relatives in the plant kingdom.

A physiognomic description is an attempt to duplicate the structural appearance of the vegetation. The elements of the structure are the physical components of the plants: the stems, roots, branches, leaves, etc. A purely physiognomic description would be concerned with only what is there at a point in time, but since vegetation changes in time, a more informative description would include notation of how the plants will change. Apparently the time sequence is usually limited to a single year, enough to note seasonal changes, but not enough to introduce the concepts of vegetation dynamics or plant succession.

Again this sort of description is of limited value. The product is a presentation of the physical structure, but no consideration is given to the relationships of plants to plants, or plants to other environmental elements. Likewise no regard is given to variations in space and time of the sampled area and its relationship to other areas.

A description incorporating ecological and phytosociological information will remedy the forementioned problems. Plant ecology is concerned with the reaction of plants to their immediate environment. Phytosociology is "the detailed study of proportions and interrelations of individuals of one or more species that partake of the same resources."[116] Such a description would include quantitative and qualitative descriptors of plant communities. The variables assessed are essentially physical characteristics which indicate social and ecological relationships.

A comprehensive description of the vegetation of an area would answer these questions: What species are present? What do the individuals and what does the vegetation of the whole area look like? How does the stand relate to its environment and how does the stand relate to the past and future vegetation in the area? Unfortunately such a description would be so long and so complex as to make the cost prohibitive and the product indigestible. But such is the case, apparently, with all other elements of the environment. The task then is the selection of variables most valuable to the user.

There are a large number of ways that vegetation groups, whatever their size, scale or character, have been organized.[117] The characteristics or criteria for grouping, both qualitative and quantitative, are summarized in the following listing.[118]

A. Features of Plant Communities
   I. Physiognomic Criteria
      a. Life forms
         1. The dominant life form(s)
         2. The combination of life forms
      b. Structure
         1. Layers of different life forms and their height
         2. Density within layers
      c. Seasonal periodicity

   II. Floristic Criteria
      a. An individual taxon (rarely 2-3 taxa)
         1. The dominant taxon (or taxa)
         2. The most frequent taxon (or taxa)
      b. Groups of taxa
         1. Statistically established groups
            i. Constant taxa
            ii. Differential taxa
            iii. Character taxa
         2. Groups that are independent of statistics
            i. Taxa of similar ecological constitution
            ii. Taxa of similar geographical distribution
            iii. Taxa of similar dynamic significance

III. Numerical Relations (commonly coefficients)
 a. Between different taxa
 b. Between different stands

B. Features Outside the Present Plant Communities
 I. Final State of Vegetation Evolution (climax)
  a. As a physiognomic unit
  b. As a floristic unit

 II. The Site
  a. Geographical location of the site
  b. Individual site factors
   1. Physical factors
   2. Chemical factors
   3. The water factor
   4. The human factor
  c. The site as a whole

To this list may be added several refinements especially with respects to structure. Structure is important because it plays an important role in influencing other physical environmental processes, runoff and flooding for example. Special attention might be directed to the vertical arrangement of the vegetation and the coverage which is the amount of plan space occupied by all the individuals in a given area. Other characteristics of this sort include:

1. Abundance--The total number of individuals of a species present in an area;
2. Frequency--The percentage of occurrence of a species in a set of samples;
3. Fidelity--The relative exclusiveness of a species to a particular association or community;
4. Sociability--The spacing or aggregation of individuals of a species.

Much of the recent literature on the description and analysis of vegetation emphasizes quantification. Out of this have arisen some basic differences with respect to how vegetation information ought to be organized. On the one hand are those advocating classification. On the other are those advocating ordination.[119]

Ordination maintains that the ecology of the plants within a community are best expressed in terms of multi-dimensional abstract space. Specific communities would be located in this space and some clustering of communities would be expected. However, these clusters should not be placed in a definite group. Ordination regards vegetational variation as being continuous in space and time.

Classification would take those clusters and identify them as classes while discarding the intermediate stands. The criteria chosen to establish these groups would determine which stands are to be ignored. In short, classification maintains that vegetation may be classified, that is organized into discrete groups.

While the debate is of primary concern to those associated with plant ecology and taxonomy, it could have implications for those concerned only with having vegetation information at hand for other uses. Some of the grouping procedures of ordination are not unlike numerical taxonomy procedures suggested for ordination of land use data to be discussed in the following chapter.

2. Fauna

The fact that animals, especially large mammals, are mobile and discrete sets this environmental component apart from other components discussed here. Information gathering for the larger animals has been conducted through "wildlife surveys". Population and diversity surveys may be done at any scale from a sample of soil to a litre of water to a subcontinent. The information sought is usually the same, namely the population of a species, the number of species, some measure of the state of health of the species, the sex distribution of the species, etc.

Population measurement may be direct or indirect. That is, census may be a count or sample of members, or a determination of the parameters of the population by investigating a variety of indicators. Inherent in either approach are errors of systematic omission, inability to determine age and other species characteristics accurately and inadequate or non-representative sampling.

A number of techniques have been employed to estimate directly the population characteristics of larger animals in an area.[120] Individuals, flocks or coveys are counted when driven from cover. Migrating water fowl are counted in the flyways as they pass overhead. Quadrats and grids are set over an area of given size and observers walk transects counting species as they go. This methodology may be applied at smaller quadrat scales as well.

There are at least six basic methods for the indirect estimation of animal populations.[121]

(a) The population in a universe is estimated by using the ratio of marked (previously released) to unmarked species in a sample. The rationale is that this ratio should be the same as the ratio in the universe.

(b) The second method uses as its base the catch-per-unit effort. Each catch is noted and the total catch-per-unit effort is determined. To prevent the effects of being caught on the chances of being caught again, the individuals are withdrawn from the population. The population figures derived will be relative measures. Examples include:

number of fish per hour of fishing,
animals per trap-night, per hour
number seen per hour,
coveys per dog per day,
coveys per man-hour.

(c) This method is based on the fact that for many exploited populations, one is harvested more intensively than others, e.g., males.

N_1 is the total population prior to hunting
F_1 is the female population prior to hunting
M_2 is the male population after hunting
M_H is the number of males killed by hunting
f_1 is the number of females in sample prior to hunting
m_1 is the number of males in sample prior to hunting

Ignoring other forms of mortality:

$$\frac{f_1}{m_1} = \frac{F_1}{M_2}, \quad \frac{f_z}{m_z} = \frac{F_2}{M_2}$$

$$r = \text{ratio of males to females}, \; r_1 = \frac{m_1}{f_1}, \; r_2 = \frac{m_2}{f_2}$$

Where only males are hunted:

$$\frac{M_1}{r_1} = \frac{M_H}{r_1 - r_2} \quad \text{or} \quad M_1 = \frac{r_1 M_H}{r_1 - r_2}$$

$$F_1 = \frac{f_1}{m_1}\left(\frac{r_1 M_H}{r_1 - r_2}\right) = \frac{M_H}{r_1 - r_2}$$

(d) This method is based on the idea that animals leave various signs behind them. If the number of signs per animal per unit area is known from a control area, a count can be made and the population can be computed. This method is of questionable accuracy, but is frequently employed as a check on another method. The following is a list of such signs: pellet counts, den trees or nests for squirrels, houses for muskrats or beavers, abundance of tracks, beds for deer, rabbit forms, crowing grounds for pheasants, dancing and booming grounds for sharp-tailed grouse or prairie chickens.

(e) An absolute minimum population can be attained with the "virtual" population technique. The basic idea is that the minimum number of individuals of a species that could have been present is the total number of animals of that age group ever caught and killed.

(f) The final method is an extension of the catch-per-unit-effort method. For a sequence of pairs of years, a series of ratios is determined.

$$\frac{\text{catch/unit effort of 6-year-olds in year "y+1"}}{\text{catch/unit effort of 5-year-olds in year "y"}}$$

Then a regression of these ratios on the effort in the first of these pairs of years is established.

The following array of variables would be pertinent to the description of the fauna of an area. In addition to these that refer to an individual species, such variables that describe the diversity of species in an area might be considered as well.[122]

Physical descriptors of the individual or species
- Size
- Weight
- Color
- Anatomy--unique or distinguishing characteristics
- Status of life processes--e.g., temperature, blood pressure, how the body performs various life processes, and in general, status of health.
- Growth rate (all of the above should be correlated to age).

Population characteristics
- Natality rates } potential and realized
- Mortality rates } potential and realized
  - vital index--100 $\frac{\text{no. of births}}{\text{no. of deaths}}$
  - biotic potential--increase with maximum natality and minimum mortality

Age distribution or structure
Sex ratio
Growth curve
Migrations--in and out, seasonal and permanent
Population density--minimum, optimum, maximum

Space requirements
- Home range--area within which an animal tends to stay
- Territory--that which is actively defended
  - Vertical boundaries
  - Horizontal boundaries
- Geographic locations
  - Characteristic area

Living habits
- Feeding--what, where, when, how?
  - Food-chain relationship (eats and is eaten)
    - Forageratio--$\frac{\text{\% of A in B's food}}{\text{\% of A in environment}}$
- Reproduction--sexual or asexual
  - Mating procedures and rituals
  - Family bond (?), young bound to parent (?)
  - Gestation period
- Life stages--where, when, and how? of birth, mating, death, metamorphoses
- Relations within species
  - Division of labor
  - Groups--numbers, reasons
- Relations between species
  - According to frame on I-3
  - Nature of benefits or harm

Of the information that may be gathered on the fauna of a given area, it is that on population and diversity of species that would be of the most value in a general environmental monitoring sense.

Biological information is important in an environmental monitoring and information for reasons in addition to assessing the flora and fauna for their own sake. Both are extremely sensitive to the condition and character of most of the environmental elements discussed in this chapter. Hence, information on biota of an area provides through inference an initial approximation of what the climate, geology, soil and hydrology are like.

E. Sampling

In reviewing the literature on flora and fauna, it quickly becomes apparent that quantitative description is closely tied to sampling procedures. Plant ecologists, in particular, have been at the forefront in developing spatial sampling methodologies.[123] Sampling and the descriptions that result are important in the collection of primary data for all the variables discussed. This applies to both spatial and temporal sampling.

There is little point in going into a detailed assessment of sampling methodologies, especially those for the spatial dimension. They are well discussed in textbooks on statistics and in a previous ETL report.[124] It is pertinent to briefly outline the major points brought out in that report.

1. Spatial sampling techniques are more effective for areal distribution than for line or point distributions.
2. For sampling of areal data, point samples are consistently more efficient than traverse samples.
3. Simple random samples are consistently the least efficient methods for sampling of areal and line data.
4. Sampling intensities of 1 point per 0.75 square inch...yield generally good estimates for areal data. Intensities beyond this level show diminishing returns for the time and effort expended.
5. Appropriate quadrat size is crucial to the efficient sampling of line and point data. More specifically, quadrat size may affect both accuracy and the time required for performing the sample.[125]

While these points are very pertinent in the case where one is establishing a data collection scheme, this is not always possible and one must rely on second-hand data collected by someone else. This will be the case with most environmental data, apart from that associated with small scale and specific studies. This will also be the case where the data are expensive to collect. A good example would be atmospheric meteorological data. In some cases, it is necessary to extend or interpolate from the available data into areas for which data does not exist. This has been done frequently with precipitation data in the study of drainage basins.[126]

Temporal sampling presents special problems. Some temporal data may be collected continuously. However, very often the accuracy of the continuous recording device severely constraints the accuracy of the data. Considerable attention to temporal sampling has accompanied the recent concern for environmental conditions, particularly air and water quality. For a discussion of sampling procedures and criteria in this context, one need only review some recent air pollution literature.[127]

Conclusion

The elements and variables discussed in this chapter represent only a portion of those that have been used to describe environmental conditions. The section describing lithospheric variables is relatively complete. The discussions of the atmosphere and hydrosphere only pay lip-service to the huge variety of secondary variables and descriptors that may be derived, especially at the microlevel. Most are based on the same primary measures however. The biosphere is superficially treated, but it is felt that the most pertinent variables for general environmental description are included. Again, more emphasis could be placed on the microlevel and microorganisms.

The chapter is meant to present the basic framework in which to organize environmental information. The information organized in this fashion and systematically up-dated and stored will perform two functions. First, it will allow one to gain a comprehensive description of the physical-natural environment for a given time and place. Secondly, it will allow one to trace or monitor changes in this environment at a given place over a period of time. These two functions relate directly to the environment as viewed, controlled and used by man. Therefore, it is appropriate that the next chapter discusses the characterization of human activities, land use.

References:

1. See: G. Olsson, 1971, "Spatial Sampling: A Technique for Acquisition of Geographic Data from Aerial Photographs and Maps", Final Report, U. S. Army Engineering Topographic Labs, Fort Belvoir.

2. P. T. Flawn, 1970, Environmental Geology, New York, Harper and Row, 313 pp.; R. E. Bergstrom, 1970, "Geology for Planning at Crescent City, Illinois", Illinois Geological Survey, Environmental Geology Notes, No. 36, 15 pp.; D. F. Hewitt, 1968, "Some Aspects of Environmental Geology", Ontario Department of Mines, Industrial Minerals Report, No. 26, 19 pp.; P. L. Hilpman, et. al., 1968, "A Pilot Study of Land-use Planning and Environmental Geology", State Geological Survey of Kansas, Geological Survey Study Committee, 63 pp.

3. See for Example: T. R. DeSatwyler, 1971, Man's Impact on Environment New York, McGraw-Hill, 731 pp.

4. C. K. Wentworth, 1930, "A Simplified Method of Determining the Average Slope of Land Surfaces", American Journal of Science, 20: pp. 184-194.

5. G. H. Smith, 1935, "The Relative Relief of Ohio", Geographical Review, 25:272-284.

6. E. Raisz and J. Henry, 1937, "An Average Slope Map of Southern New England", Geographical Review, 27:467-472.

7. R. E. Horton, 1945, "Erosional Development of Streams and Their Drainage Basins: Hydrophysical Approach to Quantitative Morphology", Bulletin Geological Society of America, 56:275-370.

8. W. F. Tanner, 1960, "Numerical Comparison of Geomorphic Samples", Science, 131 (3412): pp. 1525-1526.

9. H. W. Dennis, 1967, "Slope Development in East-Central Colorado", Oriental Geographer, 7(1): pp. 38-54.

10. B. Zakrzewska, 1963, "An Analysis of Landforms in a Part of the Central Great Plains", Annals Association of American Geographers, 53(4): pp. 536-568.

11. H. W. Dennis, 1967, op. cit., p. 46.

12. C. R. Kolb and J. R. VanLopik, 1958, "Semiquantitative Classification of Landscapes in Desert Regions", Bulletin Geological Society of America, 69: p. 1598.

13. H. W. Dennis, 1967, op. cit.

14. E. H. Hammond, 1954, "Small Scale Continental Landform Maps", Annals Association of American Geographers, 44: pp. 33-42.

15. L. C. Peltier, 1962, "Area Sampling for Terrain Analysis", Professional Geographer, 14(2): pp. 24-28.

16. L. C. Peltier, 1962, ibid., p. 25.

17. D. R. Hoy and J. A. Taylor, 1963, "A Descriptive Classification of Terrain", (abs.), Annals Association of American Geographers, 53(4); p. 598.

18. C. K. Wentworth, 1930, op. cit.

19. N. E. Salisbury, 1957, "A General Classification of Landforms of Minnesota", Unpublished Ph.D. Dissertation, University of Minnesota; P. D. Lavalle, 1965, "Areal Variation of Karst Topography in South-central Kentucky", Unpublished Ph.D. Dissertation, University of Iowa, 204 pp.

20. W. Calef and R. Newcomb, 1953, "An Average Slope Map of Illinois", Annals Association of American Geographers, 43: p. 311.

21. H. W. Dennis, 1967, op. cit.

22. A. N. Stahler, 1956, "Quantitative Slope Analysis", Bulletin Geological Society of America, 67: pp. 571-596.

23. E. H. Hammond, 1964, "Analysis of Properties in Landform Geography...", Annals Association of American Geographers, 54(1): pp. 11-19.

24. H. W. Dennis, 1967, op. cit.

25. B. Zakrzewska, 1963, op. cit.

26. C. A. Chapman, 1951, "Applications of the Statistical Slope Orientation Diagram", Trans. Illinois Academy of Sciences, 44: pp. 129-136; ______________, 1952, "A New Quantitative Method of Topographic Analysis", American Journal of Science, 250: pp.428-452.

27. N. E. Salisbury, 1962, "Relief-Slope Relationships in Glaciated Terrain", (abs.), Annals Association of American Geographers, 52(3): pp. 358-359; L. C. Peltier, 1955, "Landform Analysis in Operational Research", Bulletin Geological Society of America, 66: pp.1716-1717.

28. B. Zakrzewska, 1967, "Trends and Methods in Landform Description", Annals Association of American Geographers, 57(1): pp. 128-165.

29. B. Zakrzewska, 1967, ibid., p. 141.

30. G. H. Dury, 1951, "Quantitative Measurements of Available Relief and Depth of Dissection", Geological Magazine, 88: pp. 339-343; Dov Nir, 1957, "The Ratio of Relative and Absolute Altitudes of Mt. Carmel: A Contribution to the Problem of Relief Analysis and Relief Classification", Geographical Review, 47: pp. 564-569.

31. G. H. Dury, 1951, op. cit., p. 339.

32. Dov Nir, 1957, op. cit.

33. Dov Nir, 1957, op. cit., p. 568.

34. W. F. Tanner, 1960, op. cit.

35. E. H. Hammond, 1954, op. cit., pp. 35-36.

36. B. Zakrzewska, 1967, op. cit., p. 150.

37. A. N. Strahler, 1952, "Hypsometric (area-altitude) Analysis of Erosional Topography", Bulletin Geological Society of America, 63: pp. 1117-1142.

38. C. T. Haan and H. P. Johnson, 1966, "Rapid Determination of Hypsometric Curves", Bulletin Geological Society of America, 77(1): pp. 123-125.

39. J. F. Woodruff, 1965, "Frequency Distribution of Elevations as an Index to Terrain Classification", (abs.), Annals Association of American Geographers, 55(4): p. 658.

40. A. N. Strahler, 1964, "Quantitative Geomorphology of Drainage Basins and Channel Networks" in Handbook of Applied Hydrology, V. T. Chow (ed.), New York, McGraw-Hill, pp. 4.39-4.76.

41. B. Zakrzewska, 1967, op. cit.

42. D. W. Johnson, 1933, "Available Relief and Texture of Topography: A Discussion", Journal of Geology, 41: pp. 293-305.

43. B. Zakrzewska, 1967, op. cit., p. 145.

44. H. A. Meyerhoff, 1938, "The Texture of Karst Topography in Cuba and Puerto Rico", Journal of Geomorphology, 6: pp. 279-295.

45. P. D. Lavalle, 1965, op. cit.

46. L. C. Peltier, 1955, op. cit.

47. L. C. Peltier, 1955, op. cit.; L. K. Lustig, 1966, "Topographic Analysis of the Basin and Ranges Province", (abs.) Geological Society of America, Special Paper 87, pp. 99-100.

48. C. H. Hamilton, 1930, "A Statistical Index of Topography", Social Forces, 9: p. 204.

49. J. C. Hook, 1955, "The Relationship Between Roughness of Terrain and Phenomena Related to Agriculture in the Northeastern U. S.", Unpublished Ph.D. Thesis, University of Iowa.

50. B. Zakrzewska, 1963, op. cit.

51. P. D. Lavalle, 1965, op. cit.

52. C. Heidenreich, 1964, "Some Observations of the Shape of Drumlins", Canadian Geographer, 8: pp. 101-107.

53. B. Zakrzewska, 1963, op. cit., p. 545.

54. This type of material is well explained and illustrated in the many papers of A. N. Strahler including: A. N. Strahler, 1954, "Statistical Analysis in Geomorphic Research", Journal of Geology, 62: pp. 1-25; __________, 1958, "Dimensional Analysis Applied to Fluvially Eroded Landforms", Bulletin Geological Society of America, 69; pp. 279-300; and __________, 1964, op. cit.

55. D. Carr and J. VanLopik, 1962, "Terrain Quantification-Phase I. Surface Geometry Measurement", Dallas, Texas Instr., Inc. Final Report, Contribution AF19(628)-481, Project 7628.

56. J. C. Frye, 1967, "Geological Information for Managing the Environment", Illinois Geological Survey, Environmental Geology Notes, No. 18, 12 pp.

57. R. P. Blanc and G. B. Cleveland, 1968, "Natural Slope Stability as Related to Geology, San Clemente Area, Orange and San Diego Counties, California", California Division of Mines and Geology, San Francisco, Special Report 98, 19 pp.; W. C. Smith, 1968, "Geology and Engineering Characteristics of Some Surface Materials in McHenry County, Illinois", Illinois Geological Survey, Environmental Geology Notes, No. 19, 23 pp.

58. F. H. Lahee, 1961, Field Geology, 6th Ed., New York, McGraw-Hill, 926 pp.; R. R. Compton, 1961, Manual of Field Geology, New York, Wiley & Sons, 378 pp.

59. P. T. Flawn, 1970, op. cit., p. 75, Table 5.

60. Examples of studies that have made use of it include: J. E. Hackett, 1968, "Geologic Factors in Community Development at Naperville, Illinois", Illinois Geological Survey, Environmental Geology Notes, No. 22, 16 pp.; W. C. Smith, 1966, "Geologic Factors in Dam and Reservoir Planning", Illinois Geological Survey, Environmental Geology Notes, No. 13, 10 pp.

61. See for example: R. F. Legget, 1967, "Soil--Its Geology and Use", Bulletin Geological Society of America, 78(12): pp. 1433-1459.

62. R. A. Lohnes, 1969, "Soil Mechanics and Natural Slopes", in 33rd Tri-State Field Conference, Iowa State University, Department of Earth Science, Publication No. 22, pp. 40-49.

63. American Society for Testing and Materials, 1964, Procedures for Testing Soils, 4th Ed., Philadelphia, ASTM, 535 pp.

64. P. T. Flawn, 1970, op. cit., p. 1440.

65. Committee on Landslide Investigations, 1958, Landslides and Engineering Practices, (Washington) National Research Council, Highway Research Board, Special Report 29, 232 pp.

66. R. F. Legget, 1967, op. cit., p. 1440.

67. P. F. Kerr and I. M. Drew, 1969, "Clay Mobility, Portuguese Bend, California", in Short Contributions to California Geology, San Francisco, Division of Mines and Geology, Special Report 100, pp. 3-16; W. A. White and M. K. Kyriazis, 1968, "Effects of Waste Effluents on the Plasticity of Earth Materials", Illinois Geological Survey, Environmental Geology Notes, No. 23, 23 pp.

68. J. F. Rominger and P. E. Rutledge, 1952, "Use of Soil Mechanics Data in Correlation and Interpretation of Lake Agassiz Sediments", Journal of Geology, 60(2): pp. 160-180.

69. P. T. Flawn, 1970, op. cit., p. 70.

70. J. F. Rominger and P. C. Rutledge, 1952, op. cit.

71. P. T. Flawn, 1970, op. cit., p. 70.

72. J. F. Rominger and P. C. Rutledge, 1952, op. cit.

73. See: C. A. Black, 1957, Soil-Plant Relationships, New York, Wiley & Sons, 322 pp., pp. 47-50.

74. R. F. Legget, 1967, op. cit., p. 1443.

75. Soil Survey Staff, 1951, Soil Survey Manual, U. S. Department of Agriculture, Handbook 18, 503 pp.

76. P. T. Flawn, 1970, op. cit.; Committee on Landslide Investigation, 1958, op. cit.

77. Committee on Landslide Investigation, 1958, op. cit., p. 107.

78. R. A. Lohnes, 1969, op. cit.

79. Soil Survey Staff, 1960, Soil Classification: A Comprehensive System, Seventh Approximation, U. S. Department of Agriculture, Soil Conservation Service.

80. See: B. T. Bunting, 1965. The Geography of Soil, Chicago, Aldine, 213 pp.

81. A comprehensive treatment of pedological processes and the terminology of the same is presented in: I. P. Gerasimov and M. A. Glazowskaya, 1960, Fundamentals of Soil Science and Soil Geography, Moscow, Translated and Published by Israeli Program for Scientific Translations, 382 pp.

82. For an additional discussion of methods for determining grain size distributions see: L. D. Baves, 1956, Soil Physics, 3rd Edition, New York, J. Wiley, 398 pp.; American Society for Testing and Materials, 1962, Field Testing of Soils, ASTM Special Publication No. 32.

83. See: C. A. Black (ed.), 1965, Methods of Soil Analysis: Part I, Physical and Mineralogical Properties, Madison, Wisconsin, American Society of Agronomy.

84. For discussions of structure see: Soil Survey Staff, 1951, Soil Survey Manual, U. S. Department of Agriculture, Handbook 18, 503 pp.; and G. W. Robinson, 1949, Soils: Their Origin, Constitution and Classification, London, Murly, 573 pp.

85. For complete discussions on shearing strength and bearing capacity, see: American Society for Testing Materials, 1970, Special Procedures for Testing Soil and Rock for Engineering Purposes, 5th Edition, ASTM Special Publication No. 479.

86. See: W. R. McCaskill, B. H. Phillips and C. A. Thomas, 1970, "Residues of Chlorinated Hydrocarbons in Soybean Seed and Surface Soils from Selected Counties in South Carolina", Pesticides Monitoring Journal, 4(2):42-46; S. Voerman and A. F. H. Basemer, 1970, "Residues of Dieldrin, Lindone, DDT, and Parathion in a Light Sandy Soil after Application throughout a Period of 15 Years", Journal of Agriculture and Food Chemistry, 18(4): pp. 717-719; A. L. Page and T. J. Ganje, 1970, "Accumulation of Lead in Soils for Regions of High and Low Motor Vehicle Traffic Density", Environmental Science and Technology, 4(2): pp. 140-142.

87. Soil Survey Staff, 1960, op. cit.

88. This is illustrated in Chapters II and III where World Weather Watch and the use of remote sensing in atmospheric observation are discussed.

89. R.B. Platt and J.F. Griffiths, 1964, Environmental Measurement and Interpretation, New York, Rheinhold.

90. H.E. Landsberg, 1970, "Man-Made Climatic Changes", Science, 170(3964): 1265-1274.

91. J.A. Danielson, 1967, Air Pollution Engineering Manual, Air Pollution Control District, County of Los Angeles Public Health Service, Publ. No. 999-AP-40.

92. L.R. Babcock, 1970, "A Combined Pollution Index for the Measurement of Total Air Pollution", Journal of the Air Pollution Control Association, 20: 653-659.

93. See: L.C. Wadsworth, 1968, Measurement of Environmental Factors in Terrestrial Ecology, Oxford, Blackwells.

94. S.I. Rasool, 1967, "Satellite Meteorology", Encyclopedia of Atmospheric Science and Astrology, New York, Rheinhold, pp. 847-851.

95. R.B. Platt and J.F. Griffiths, 1964, op. cit.

96. See: C.W. Thornthwaite, 1948, "An Approach Toward a Rational Classification of Climate", Geographical Review, 38: 55-94; C.W. Thornthwaite and J.R. Mather, 1957, "Instrumentation and Tables for Computing Potential Evapotranspiration and the Water Balance", Johns Hopkins University Laboratory of Climatology, Publ. in Climatology, 10(3): 185-311.

97. T.A. Blair and R.C. Fite, 1965, Weather Elements, 5th ed. Englewood-Cliffs, Prentice-Hall.

98. In fact a monitoring scheme to keep a close watch on the physical, biological and chemical state of ocean waters is tentatively outlined and discussed in: SCEP, 1970, Man's Impact on the Global Environment, Report of the Study of Critical Environmental Problems, Cambridge, Mass., Massachusetts Institute of Technology, 319 pp.

99. J.H. Zumberge and J.C. Ayers, 1964, "Hydrology of Lakes and Swamps", in Handbook of Applied Hydrology, V.T. Chow (ed.), New York, McGraw-Hill, p. 23-1 to 23-33.

100. For examples see: J. Aastad and R. Søgnen, 1954, "Discharge Measurements by Means of a Sutt Solution, The Relative Salt Dilution Method", Proceedings, International Association Scientific Hydrology, Rome, p. 289-292; W.P. Adams, 1966, "The Sodium Dichromate Dilution Method of Measuring Stream Discharge", Hydrological Studies in Labrador-Ungava, McGill Subarctic Research Papers, No. 22, p. 141-153; H. Dumas, 1953, "La Methode Chimique pour la Measure du Debit des Cours d'Eau", La Houille Blanche, 3: 360-373.

101. For full discussions of these variables see: A.N. Strahler, 1954, op. cit.; R.E. Horton, 1945, op. cit.; L.B. Leopold, M.G. Wolman and J.P. Miller, 1964, Fluvial Processes in Geomorphology, San Francisco, Freeman.

102. M.J. Kirkby, 1969, "Erosion by Water on Hillslopes", in Water, Earth and Man, R.J. Chorley (ed.), London, Metheun, p. 229-238.

103. ASTM, 1969, Manual on Water, American Society for Testing and Materials, Euston, Maryland.

104. V.J. Schaefer, G.J. Klein and M.R. de Quervain, 1954, "The International Classification of Snow - With Special Reference to Snow on the Ground", International Association of Scientific Hydrology, Ottawa, National Research Council, Association Committee on Soil and Snow Mechanics, Technical Memo. 1.

105. V.J. Schaefer, et. al., 1954, ibid.

106. As part of the Internation Hydrological Decade considerable effort is being put into glacier inventory, for example see: C.S.L. Ommanney, 1968, An Assessment of the Ice Masses of Axel Heiberg Island, N.W.T.: A Study in Glacier Inventory, Unpublished M.Sc. Thesis, Montreal, McGill University, 183 pp.

107. See for example: L.E. Neilson, 1968, "Some Hypotheses on Surging Glaciers", Bulletin Geological Society of America, 79(9): 1195-1201.

108. A considerable literature is available on the nature of lake, river and sea ice, and the prediction of break-up, etc.. For further study, one is referred to the bibliographies that appear regularly in the Journal of Glaciology. Examples of specific references are: J.T. Andrews, 1962, "Variability of Lake Ice Growth and Quality in the Schefferville Region, Central Labrador-Ungava", Journal of Glaciology, 4(33): 337-347; J.B. Shaw, 1965, "Growth and Decay of Lake Ice in the Vicinity of Schefferville, Quebec", Arctic, 18(2): 123-132.

109. Again, a vast amount of literature is available on permafrost, its influence on everything from trafficability to vegetation, and its measurement. For further reference see: Army Corps of Engineers, 1956, Engineering Problems and Construction in Permafrost Regions, The Dynamic North, Vol. II, U.S. Navy; S.W. Muller, 1947, Permafrost or Permanently Frozen Ground and Related Engineering Problems, Ann Arbor, 231 pp.

110. See for example: P.H. McGauhey, 1968, "Man-made contamination hazards to ground-water", Groundwater, 6(3): 10-13; B.A. Stewart, F.G. Viets and G.L. Hutchinson, 1968, "Agriculture's Effect on Nitrate Pollution of Ground Water", Journal of Soil and Water Conservation, 23(1): 13-15; J.F. Poland and G.H. Davis, 1969, "Land Subsidence Due to Withdrawal of Fluids", Reviews in Engineering Geology, 2: 187-269.

111. L.G. Moore, 1970, "Experience with Storage and Retrieval of Ground Water Data", Symposium Data and Instrumentation in Water Quality Management, J.E. Kerrigan (ed.), Madison, Water Research Center, University of Wisconsin, p. 208-213; J.A. Gilliland, 1968, "Digitizing, Storing and Recovering Observation Well-Hydrographs", Journal of Hydrology, 6: 143-167; J.E. Price, 1967, A Comparison of Traditional and Automatic Methods for Retrieval of Geologic Well Data, Unpublished M.Sc. Thesis, Department of Geology, University of Iowa.

112. See: U.S.G.S., 1964, "Punched Card System for the Storage and Retrieval of Groundwater Data", Department of Interior, U.S. Geological Survey, Washington, D.C., 52 pp.; S.C. Robinson, 1966, "Storage and Retrieval of Geological Data in Canada", Geological Survey of Canada, G.S.C. 66-43, 98 pp.; S.M. Lang and J.H. Irwin, 1965, "Punch Card System for the Storage and Retrieval of Ground-Water Data", International Association of Scientific Hydrology, Quebec, Extract of Publ. No. 68, pp. 800-805; W.R. Turner, 1967, Instructions for using the HYDRODAT Computer-Oriented System for The Storage and Retrieval of Ground Water Data, Research Council of Alberta, Unpublished Report, 56 pp.; J.A. Gilliland, 1966, Proposal for Integrating Hydrological Data Storage Systems, Geological Survey of Canada, Unpublished Report, 5 pp.

113. M.G. Wolman, 1971, "The Nation's Rivers", Science, 174: 905-918; W.C. Ackerman, R.H. Harmeson and R.A. Sinclair, 1970, "Some Long-Term Trends in Water Quality of Rivers and Lakes", Transactions American Geophysical Union, 51(6): 516-522.

114. See ASTM, 1969, op. cit.

115. U.S. Geological Survey, 1970 ed., Index to Water Quality Section, Catalogue of Information on Water Data, Dept. of Interior, U.S.G.S., Office of Water Data Co-ordination.

116. P.M. Dansereau, 1957, Biogeography: An Ecological Perspective, New York, Ronald Press, p. 331.

117. A.W. Küchler, 1967, Vegetation Mapping, New York, Ronald Press, 472 pp.

118. A.W. Küchler, 1967, ibid., p. 35.

119. The following discuss the status of this issue: D.J. Anderson, 1965, "Classification and Ordination in Vegetation Science: Controversy Over a Non-Existent Problem?" Journal of Ecology, 53(2): 521-526; C.M. Harrison, 1971, "Recent Approaches to the Description and Analysis of Vegetation", Transactions, Institute of British Geographers, 52: 113-128; N.V. Peers, 1968, "Some Recent Trends in Classification and Description of Vegetation", Geografiska Annaler, 50A: 163-172.

120. There are numerous sources discussing wildlife management and the estimate of populations. See for example: I.N. Gabrielson, 1959, Wildlife Conservation, New York, McMillan, 244 pp.; ____________, 1951, Wildlife Management, New York, McMillan, 274 pp.

121. K.E.F. Watt, 1968, Ecology and Resource Management, New York, McGraw-Hill, 450 pp.

122. See: C.B. Williams, 1964, Patterns in the Balance of Nature, New York, Academic Press.

123. P. Greig-Smith, 1964, Quantitative Plant Ecology, London, Butterworth, 256 pp.

124. G. Olsson, 1971, op. cit.

125. G. Olsson, 1971, op. cit., p. F67-68.

126. D.J. Unwin, 1969, "The Areal Extension of Rainfall Records: An Alternative Model", Journal of Hydrology, 7: 404-414; J.O. Ayoade, 1970, "Rainfall Networks and the Areal Extension of Rainfall Records", Department of Geography, University College, London, Occasional Papers, No. 10, 16 pp.

127. A.S.T.M., 1962, ASTM Standards on Methods of Atmospheric Sampling and Analysis, Philadelphia, American Society for Testing & Materials, D-22; R.D. Cadle, et. al., 1956, Sampling Procedures in Air Pollution Handbook, New York, McGraw-Hill; B.E. Saltzman, 1970, "Significance of Sampling Time in Air Monitoring", Journal of Air Pollution Control Association, 20(10): 660-665; R.E. Munn, 1970, Biometeorological Methods, New York, Academic, 336 pp.

Introduction

The concept "land use" is a convenient way of thinking about human activities. In this context, the human activities always have some physical manifestation on the surface of the earth. It is by the physical manifestation that one is able to identify the land use activity. In addition, it is through the physical manifestation that human activities have a major impact on the physical environment and the processes operating therein.

Environmental monitoring implies that change is occurring in environmental condition. We know that environmental conditions change naturally. However, as was noted in Chapter I, we know that environmental change is occurring much more rapidly than it should under natural conditions. We ascribe this accelerated environmental change to the changing character, intensity and ubiquity of human activities. Of course, the fact that much of the change is perceived to be bad has stimulated the search for environmental monitoring systems.

Since we may assume that most change measured in physical (natural) environmental variables is the result of human activity, it is desirable that any monitoring should address itself to this stimulus. This will be important in explaining the change that is monitored. In turn, it will be important in forecasting and predicting environmental change through the impact of changing human activity on the earth's surface. For these reasons, and the fact that land use is an adequate manifestation of human activity, we have explored the possibility of including a land use element in an environmental monitoring system.

Land Use Classification

Current practice and understanding dictates that land use information or data must be dealt with on a nominal, or perhaps ordinal, scale of measurement. It is not inconceivable that with a specific purpose in mind, such as environmental impact, criteria for the establishment of an index or quantitative (interval scale) characterization of land use could be developed. One can immediately imagine an index based on ground surface cover characteristics such as permeability, specific heat and albedo. For the moment that is in the future.

With respect to land classification two problems arise. The concept of the individual (object, entity) generally accepted in taxonomy requires clarification, and the basis of classification or principle of division needs to be articulated. Classification may take place by grouping or division on the basis of common characteristics or relationships. While common properties or similarities form the basis for grouping in classification, in division an initial class is taken as the universe and this class divided into subclasses on the basis of some principle. Each produce the same result, a classification system with a hierarchy of orders.[1]

A confusion of concepts relating to classification in general and land use groups in particular, has received attention in recent years.[2]

The major aspects of land which have relevance to classification include: location, activity on the land, natural characteristics, improvements to the land, intensity of use, form of tenure or ownership, relationship to other areas and interrelationships among activities on the land.

The most common ground for many different interests in land appears to be the activity on the land, thereby explaining the great interest in land use classifications. But activity is generally not measured without regard to other factors. For example, 'single family residence' and 'multi-family residence' are variations of the activity 'residing' but the distinction in classification seems necessary since it differentiates between structure types (i.e., improvements on the land). Also, the intensity of land use is often of interest. Residences on acre lots and twenty story apartments reflect differing residential environments which cannot be easily depicted by surrogate measures such as population density.

Interrelationships of different kinds of data, for the same area, are frequently desirable. When each type of data is separately identified and locationally recorded, then it may be interrelated in the analysis stage for any desired area or purpose. Thus, it is generally considered unwise to code "high", "medium", or "low-density residential" since this would be a derived concept rather than a basic one; structure type has been excluded and is unrecoverable.

What constitutes a best land classification or land use classification depends on a number of factors, not the least of which is the use to which it is to be put. In this regard, the question of the entity or individual to be classified must be approached. Although the entity will be a parcel of land of some given size, the choice of size is quite arbitrary in most instances. Consider the following statement:

> "A parcel is the smallest unit or tract of land identifiable with the techniques used in a particular study. Separately-owned tracts within a single activity group, such as individual home owners in a residential neighborhood, would ordinarily be parcels. But different activities within a single ownership, such as fields with different crops within one farm, would also ordinarily be parcels. The parking lot, office headquarters, tank storage area, and actual refinery structures might well be shown as separate parcels for a petroleum refinery. The detail, or "grain," of a particular study would largely determine how small a difference would be considered sufficient to distinguish one parcel from another."[3]

To assure usefulness for more than a single study, parcelling should be of the smallest possible size, thereby permitting whatever aggregation is necessary for a given circumstance. But, then the "techniques" of the classification system take on new meaning. Contrast a "grain" of one sq. kilometer parcels and one sq. meter parcels, the former being 1,000,000 times larger than the latter. How is the activity (land use) within each cell to be determined? If high altitude photography or satellite imagery is to be employed the fine grid overemphasizes the true precision of the techniques. Without very detailed checking of each grid cell, confidence in the system must be low. Using square kilometers as reporting units allows more confidence in tying the classification to the land, but suffers from an increase in the generality of the classes. There is no satisfactory solution to the parcel size question except in very well defined situations.

Assume for the moment a constant grid cell size. If a majority of the grid squares contain only one element (land use type) then the information capability of the system would be near optimal. But if most of the cells of one particular size contain more than one element, the information must be a composite or given as percentages of recognized land uses. In the first instance the result is a class not representative of any single element, and in the latter instance, characterization and retrieval become less precise and more complex.

Suppose one wished to record improvements on land (buildings) in an area where most buildings are 100 ft. on a side. The cell size would have to be less than 100 ft. sq. since the probability of a cell exactly this size falling directly on any building would be low. To alleviate this problem two approaches are common. First, the parcel size is allowed to vary, in fact being completely flexible. This produces difficult storage and retrieval questions and hinders upward compatibility, aggregation and analysis. The second approach involves the acceptance of non-singular (more than one element) classes. For example, the classification of large segments of urban land as "residential" may include streets, lawns, gardens, houses, apartments, and perhaps small commercial and industrial space all within a broad category. While acceptable for some purposes, the end product of such procedures is of very limited utility. The probability of innovative use of the data would seem to be an inverse function of the generality of the classification system.

Each of the approaches discussed is defended in practice by economic and time constraints, with theoretical issues ignored. The criticisms are futile because, given sufficient resources, a system of almost any desired capability, with respect to the issues stated above, could be designed and operationalized. Likewise, it is claimed, and justly so perhaps, that a general use system cannot be expected to fit all needs.

The two accepted bases for classification of land use:

a) categorize by pure-line (single element) elements only; and

b) record in as much detail as possible,

are invulnerable.

Thus, while a system proposed for general use (and acceptable costs) can be criticized for being general little is gained in the process. A specific system cannot be devised until the purpose and scale of the proposed project are known. Criticisms of general purpose systems are not difficult from the advantageous position of a pre-defined set of goals.

Under such circumstances it seems reasonable to expect that a set of decision rules would exist to very narrowly define the acceptable parameters of a classification system intended for a given purpose. Ken Dueker, of the University of Iowa, has recently initiated discussion about this topic. His emphasis is on the technological constraints, especially in the area of remote sensing as applied to land use classification, but he is attempting to outline the basics of a rational approach. To this writer's knowledge his will be the first attempt to provide such a schema, the lack of which goes unrecognized in the literature.

In the United States land data have developed piecemeal as various specialized data series, usually by different agencies, to meet specific operational needs. Such development means that a comprehensive approach to land data using basic concepts and consistent definitions would be difficult to implement. However, a more unified approach has been discussed because of the great need for timely and adequate data in a dynamic society. Technological and efficiency constraints encourage the implementation of systems from the top rather than independent development throughout many agencies at various levels. The two sections which follow discuss existing classifications and the direction of current research efforts.

Common Existing Classifications

Perhaps the most widely known classification is that contained in the Standard Land Use Coding Manual.[5] This is an attempt to develop a system for identifying and coding, rather than mapping, urban land use activities. The report is based on the premise that the most useful and effective approach to classification is one that will permit standardization in coding land use activity data and flexibility in the use of the data once it is coded. This requires identification and coding at a very detailed level (a four digit level system is suggested in the Manual). Once coded at the very detailed level suggested, the data can then be regrouped into a variety of different classification patterns to fit the needs of special studies and analyses.

TABLE I

A COMPARISON OF SELECTED LAND USE CLASSIFICATION SCHEMES

Scheme from Study by Association of American Geographers

I. Resource Production and Extraction

- A. Agricultural
  - 1. Crop production (cropland)
  - 2. Fruit (orchards, groves, & vineyards)
- B. Grazing
  - 1. Rangeland grazing (rangeland)
  - 2. Livestock pasturing (pasture)
- C. Forestry
  - 1. Commercial
  - 2. Non-commercial
- D. Mining
- E. Quarrying

II. Transportation, Communication, and Utilities

- A. Transportation
  - 1. Motoring (highways, parking, terminals, etc.)
  - 2. Railroading (rights-of-way, yards, terminals, etc.)
  - 3. Flying (airports)

Canada Land Inventory

I. Urban

- 1. Built-up area
- 2. Mines, quarries, sand & gravel pits
- 3. Outdoor recreation

II. Agricultural Lands

- 1. Horticultural, poultry, & fur operations
- 2. Orchards & vineyards
- 3. Cropland
- 4. Improved pasture & forage crops
- 5. Rough grazing & rangeland
  - a. Areas of natural grasslands, sedges, herbaceous plants, & abandoned farmland whether used for grazing or not
  - b. Woodland grazing

III. Woodland

- 1. Productive woodland
- 2. Non-productive woodland

Standard Land Use Coding Manual (One- and Two-Digit Levels Only)

1. Residential

- 11. Household units
- 12. Group quarters
- 13. Residential hotels
- 14. Mobile home parks or courts
- 15. Transient lodgings
- 19. Other residential, NEC[1/]

2. Manufacturing

- 21. Food & kindred products-manufacturing
- 22. Textile mill products-manufacturing
- 23. Apparel & other finished products made from fabrics, leather, & similar materials-manufacturing
- 24. Lumber & wood products (except furniture)-manufacturing
- 25. Furniture & fixtures-manufacturing
- 26. Paper & allied products-manufacturing
- 27. Printing, publishing, & allied industries
- 28. Chemicals & allied products-manufacturing
- 29. Petroleum refining & related industries

New York State Inventory

A. Agriculture

Areas:

- Ao Orchards
- Av Vineyards
- Ah Horticulture, floriculture
- Ay Specialty farms
- At High-intensity cropland
- Ac Cropland & cropland pasture
- Ap Permanent pasture
- Ai Inactive agricultural land
- Ui Other inactive lands
- Uc Lands under construction

Point Data:

- Ay Specialty farms
  - y-1 Mink
  - y-2 Pheasant & game
  - y-5 Aquatic agriculture
  - y-6 Horse farms
  - d Dairy farms: number
  - e Poultry operation: number
  - f Active farmsteads: number

4. Shipping (inland waterway & marine docks & related facilities)

B. Communications
1. Telephone lines and facilities
2. Telegraph lines and facilities
3. Radio stations and facilities
4. Television stations and facilities

C. Utilities
1. Electric
2. Gas
3. Water (including irrigation)
4. Sewage disposal
5. Solid waste disposal

III. Urban Activities

A. Urbanized livelihood areas (urbanized areas defined by the Bureau of the Census)

1. Industrial
2. Commercial
3. Services
4. Residential
5. Recreational

IV. Wetland (swamp, marsh or bog)

V. Unproductive Land (land which does not, and will not, support vegetation)

1. Sand
2. Rock & other unvegetated surfaces

VI. Water

3.
31. Rubber & miscellaneous plastic products - manufacturing
32. Stone, clay & glass products - manufacturing
33. Primary metal industries
34. Fabricated metal products - manufacturing
35. Professional, scientific, & controlling instruments; photographic & optical goods; watches & clocks-manufacturing
39. Miscellaneous manufacturing - NEC

4. Transportation, communication, and utilities
41. Railroad, rapid rail transit, & street railway transportation
42. Motor vehicle transportation
43. Aircraft transportation
44. Marine craft transportation
45. Highway & street right-of-way
46. Automobile parking
47. Communication
48. Utilities

F. Forest Land

<u>Areas</u>:
Fc Forest brushland
Fn Forest land
Fp Plantations

W. Water Resources

<u>Areas</u>:
Wn Natural ponds & lakes (1 acre +)
Wc Artificial ponds & reservoirs (1 acre +)
Ws Streams & rivers (100' ±)
Wh Hudson River
Wm Marine lakes, rivers & seas
Wb Shrub wetlands, bogs, marshes
Ww Wooded wetlands

<u>Point data</u>:
n Natural ponds & lakes: number
c Articifial ponds & reservoirs: number
p Ponds less than 1 acre in size: number
l Lake shoreline: miles
s Streams & rivers: miles

N. Nonproductive land

Ns Sand (unstabilized)

B. Other urban livelihood (places of more than 2,500 population but not including urbanized areas)

1. Industrial
2. Commercial
3. Services
4. Residential
5. Recreational

IV. Towns and Other Built-Up Livelihood Areas

A. Industrial

B. Commercial

C. Services

D. Residential

E. Recreational

V. Recreational Activities (other than those in urban areas and towns)

A. Mountain oriented

B. Water Oriented

C. Desert Oriented

D. Forest Oriented

E. Other (including combinations of above)

49. Other Transportation, communication, and utilities, NEC

5. Trade
   51. Wholesale trade
   52. Retail trade - building materials, hardware, and farm equipment
   53. Retail trade-general merchandise
   54. Retail trade-food
   55. Retail trade - automotive, marine craft, aircraft, & accessories
   56. Retail trade-apparel & accessories
   57. Retail trade-furniture, home furnishings, & equipment
   58. Retail trade-eating & drinking
   59. Other retail trade, NEC

6. Services
   61. Finance, insurance, & real estate services
   62. Personal services
   63. Business services
   64. Repair services
   65. Professional services
   66. Contract construction services
   67. Governmental services

Nr Rock (exposed)

R. Residential Land Use

<u>Areas</u>:
- Rh High density (50' frontage)
- Rm Medium density (50-100' frontage)
- Rl Low density (100' + frontage)
- Re Residential estates (5 acres +)
- Rs Strip development
- Rr Rural hamlet
- Rc Farm labor camp
- Rk Shoreline cottage development

<u>Point data</u>:
- k Shoreline developed in cottages: miles
- z High-rise apartment buildings: number
- v Trailer parks: number
- x Rural non-farm residences never a farm residence: number
- o Rural non-farm residences once a farm residence: number

C. Commercial Areas

<u>Areas</u>:
- Cu Central business district
- Cc Shopping center
- Cs Strip development
- Cr Resorts

I. Industrial Areas

<u>Areas</u>:
- Ii Light manufacturing
- Ih Heavy manufacturing

VI. Low-Activity Areas

A. Marshland oriented

B. Tundra oriented

C. Barren land oriented (including lava flows, dunes, salt flats, mountain peaks above timber line, etc.)

VII. Water-Using Activities

A. Lakes

B. Reservoirs

C. Streams

D. Ponds

68. Educational services
69. Miscellaneous services

7. Cultural, Entertainment, and Recreational
   71. Cultural activities
   72. Public assembly
   73. Amusements
   74. Recreational activities
   75. Resorts & group camps
   76. Parks
   79. Other cultural, entertainment, recreation, & NEC

8. Resource Production and Extraction
   81. Agriculture
   82. Agricultural related activities
   83. Forestry activities & related services
   84. Fishing activities & related services
   85. Mining activities & related services
   89. Other resource production & extraction, NEC

E. Extractive Industry

Areas:
- Es Stone quarries
- Eg Sand and gravel pits
- Em Metalic mineral extraction
- Eu Underground mining

Point data:
- Eu Underground mining: types present
- u-1 Oil and gas
- u-2 Salt
- u-3 Other
- u-4 Abandoned

OR. Outdoor Recreation

Areas:
- OR All outdoor recreation facilities

Point data:
- OR Outdoor recreation facilities: types present
- OR-1 Golf courses
- OR-2 Ski areas, other winter sports
- OR-3 Beaches and pools
- OR-4 Marinas, boat launching sites
- OR-5 Campgrounds
- OR-6 Drive-in theaters, race tracks, amusement parks
- OR-8 Fairgrounds
- OR-9 Public parks
- OR-13 Shooting, archery
- OR-16 Private company facilities, community areas

9. Undeveloped Land and Water Areas
   91. Undeveloped & unused land area (excluding non-commercial forest development)
   92. Noncommercial forest development
   93. Water areas
   94. Vacant floor area
   95. Under construction
   99. Other undeveloped land and water areas, NEC

1/ NEC - Not elsewhere classified

P. Public and Semi-Public Land Uses

Areas:

P All public & semi-public areas

Point data:

P Public & semi-public areas - types present
P-1 Educational institutions
P-2 Religious institutions
P-3 Health institutions
P-4 Military bases & armories
P-5 Solid waste disposal
P-6 Cemeteries
P-7 Water supply treatment
P-8 Sewage treatment plants
P-9 Flood control structures
P-11 Correctional institutions
P-12 Road equipment centers
P-16 Welfare centers, county farms

T. Transportation

Areas:

Th Highway interchanges, limited access right-of-way, etc.
Tr Railway facilities
Ta Airport facilities
Tp Marine port and dock facilities
Ts Shipyards
Tl Marine locks
Tt Communication and utility facilities

Point data:

h Highway category: highest present
h-o None

h-3 Unimproved, gravel, town roads
h-4 Two-three land highway
h-5 Four-line highway
h-6 Divided highway
h-7 Limited access highway
h-8 Limited access interchange

Tr Railway facilities: type present
r-1 Abandoned right-of-way
r-2 Active track
r-3 Switching yards
r-4 Stations and structures
r-5 Spur

Ta Airport facilities: type present
a-1 Personal
a-2 Non-commercial
a-3 Commercial
a-4 Airline
a-5 Military
a-6 Heliport
a-7 Seaplane base

Tb Barge canal facilities: types present
b-1 Channel
b-2 Lock
b-3 Abandoned channel

Tt Communications & utilities: types present
t-1 TV-radio tower
t-2 Microwave station
t-3 Gas & oil-long distance transmission
t-4 Electric power-long distance transmission

t-5 Water- long-distance transmission
t-6 Telephone - long-distance transmission

The Standard System is presented at the two digit level with three other important land use classification schemes in Table I.[6] The Standard System was developed for use in urban and adjacent situations. The Canadian Land Inventory System is a two-digit or two-level scheme developed for use throughout the settled part of Canada. Using this scheme, maps of present land use are being compiled at a scale of 1:50,000. The New York Land Use and Natural Resources Inventory was developed for use with 1:24,000 scale aerial photography. The categorization was developed to accommodate both spatial (areal) and point data, eg., farmsteads and cropland. The fourth system developed out of a study by the Commission on Geographic Applications of Remote Sensing of the Association of American Geographers. This system is for use with satellite imagery supplemented by ground observation and enumeration.

Although the Standard System is the most detailed of the four presented, it is strictly not an activity classification. Other information, such as structure type, is provided. A system for identifying ownership is suggested as well and there is the ever-present footnote that: "if it becomes necessary to further subdivide a category into a finer breakdown of --- (anything)---, this can be done by adding digits to the right".

The difference in classification is in detail rather than structure. Each must be evaluated in terms of its ability to do effectively those things for which it was designed. None of the systems were designed to fill a role in an environmental monitoring system. If some meaning in terms of environmental impact can be attached to the various classes of land use in any of the systems than they will be of use. It is reasonable to expect that utilization of either of the systems will provide valuable information. However, it is also reasonable to suggest that for the purposes of monitoring, forecasting and predicting environmental impact and change, some system based on the physical characteristics and qualities (eg., permeability, specific heat, etc.) of the material exposed at the surface and the activities carried on at the surface will provide more valuable information. Such a system does not yet exist but the discussion in the following section proposes some new directions that should be explored in this regard.

New Considerations for Land Use Classification

The need for some quantitative descriptive measure of land use for environmental monitoring, the methodologies of taxonomy and new means of land use data collection via remote sensing, all suggest possible directions in the development of land use classifications. The following concepts propounded by Sokal and Sneath[7] provide a good starting point:

> "We would stress the fact that, from the time of Linnaeus to our own, a weak point in biological science has been the absence of any quantitative meaning in our classificatory terms. What is a Class, and does Class A differ from Class B as much as Class C differs from Class D? The question can be put for the other classificatory grades, such as Order, Family, Genus, and Species. In no case can it be answered fully, and in most cases it cannot be answered at all...... Until some adequate reply can be given to such questions as

these, our classificatory schemes can never be satisfactory or "natural." They can be little better than mnemonics-mere skeletons or frames on which we hang somewhat disconnected fragments of knowledge. Evolutionary doctrine, which has been at the back of all classificatory systems of the last century, has provided no real answer to these difficulties. Geology has given a fragmentary answer here and there. But to sketch the manner in which the various groups of living things arose is a very different thing from ascribing any quantitative value to those groups."[8]

Drawing on analogy between the biological taxa and land use classes, the above notion suggests that the principles of numerical taxonomy would be relevant to land use classification. Numerical taxonomy is the quantitative expression of the affinity between taxa and their ordering on this basis. The following axioms apply to the procedure:

1. The ideal taxonomy is that in which the taxa have the greatest content of information and is based on as many characters as possible.

2. A priori, every character is of equal weight in creating natural taxa.

3. Overall similarity (or affinity) between any two entities is a function of the similarity of the many characters in which they are being compared.

4. Distinct taxa can be constructed because of diverse character correlations in the groups under study.

5. Taxonomy as thus conceived is therefore a strictly empirical science.

6. Affinity is estimated independently of phylogenetic (historical) considerations.

In the context of land use classification, the following example could apply. Where are the greatest differences in terms of land use between: (a) high-rise apartments, (b) suburban single family homes, (c) mobile home park, (d) an outlying unplanned commercial (retail) center, and (e) a landscaped suburban park (industrial)? Most classificatory systems would initially group a, b, and c into one class, with d and e as separate classes. However, this is emphasizing the political-functional aspects over all other characteristics of the entities and is contrary to axiom (2). If many characteristics, say 100, were recorded, measured and reduced to fundamental dimensions through multivariate techniques, a clustering of the entities might show (a) and (b) more dissimilar than (b) and (e). The detection of this and other such affinities may prove more useful than existing classifications for analytical purposes.

For such a procedure to be of use for environmental monitoring purposes the groupings must have some rational meaning in terms of environmental impact and change. This emphasis could be built into the classification system at the earliest stage--the choice of characteristics to be recorded and measured. Careful study of land use characteristics that have the most meaning in terms of environmental change would ensure some relevance in the final taxa.

Some recent work in remote sensing technology has direct relevancy to some of the points discussed here. This work suggests that the concepts of classification of land use could be readjusted to be more in line with the concepts of numerical taxonomy. In Chapter III the quasi-automated classification of terrain from multispectral data was discussed. Most of this work has been completed by H. W. Smedes and his associates, using Yellowstone National Park as a test site.[9]

One approach is for target areas in the scene to be selected for training the computer. Statistical parameters of radiance such as mean, standard deviation, divergence, and covariance are computed for each category of material. These data are used in the computer program to determine which channels are most useful for recognition of all object categories studied, and to actually classify all the unknown data points into the known categories. An alternative approach is to utilize the available wavelength bands to group data points according to their similarity without comparison to test or target areas. The resulting groupings can be mapped and examined, and with the help of other aids identified as distinct terrain classes. This schema is equivalent to a numerical taxonomic classification with subsequent naming of the categories.

These studies also indicate that, for a broad range of terrain categories, many combinations of three or four channels of data would be satisfactory. Careful selection of specific wavelength bands is necessary only if there is a specific category being sought.

In his more recent work Smedes[10] has demonstrated the possibility of the second approach with the use of color film. Color and color-infrared photography can be used as the basis for extracting characteristics of the ground surface, thereby making it unnecessary to align multiple exposure imagery.

Many studies and reports have been made of computer classification and mapping of terrain from multispectral scanner and multiband photographic data. Although most of the scanner data have high spectral resolution, they generally have low spatial resolution. Scanners also have serious handicaps owing to various kinds of inherent geometric distortion. Precise registry of the different spectral bands from separate frames of multiband photography is difficult; the degree of misregistration limits the accuracy of terrain classification. The present technique obviates this problem because the three emulsion layers are all on the same base. All three color film layers are sampled simultaneously by means of beam-splitters and filters. Traids of density values obtained from each area element on the transparency are recorded on magnetic tape. Characteristic spectral signatures inherent in the data -- presumably representing terrain classes -- are identified by the application of clustering techniques in three-color space. Each datum point is assigned, on the basis of its spectral signature, to one of these classes; and each class is then identified by external means. Smedes reports an accuracy of classification of 86% using this technique. At the present time, systematic studies of this approach do not exist and its full potential have yet to be determined. However, as many as 13 terrain classes have been identified using these techniques in preliminary research.

It is reasonable to expect that similar or extended groupings could be derived in other diverse areas. Urban areas should be particularly amenable to this technique which is apparently able to work with 20-30 feet-square cells. However, interpretation or naming of classes might require additional processing since land use as currently conceptualized has point, line, and area components which may separately or in combination constitute a given category. For example, areas of single family homes, if such a category is to be defined, will be made up of grass, roads, and buildings, similar in many respects to a landscaped suburban manufacturing park. If it is deemed desirable to maintain these classes then a systematic investigation is necessary to evaluate alternative methodologies. A change in scale of the imagery may require alternative techniques or algorithms for analysis purposes.

Very small cells would have reasonably "pure" spectral signatures ("fingerprints") but as the cell size increased the spatial resolution would decrease and the spectral purity would decrease. Figure 1 illustrates this problem. In (a) the element types would give off pure spectral signatures (a reflectance attributable to a single source) given the fine resolution. In (b) the spectral signature would be a complex response to perhaps several elements each having its own characteristic signature.

The distinction is of interest because a sophisticated pattern recognition schema would be necessary if a type (a) methodology were in use. Conversely, type (b) methodology would require an elaborate storage bank of land use signatures. While the methodologies are not totally different there is a shift of emphasis at the interpretation and analysis stage, especially if current land use classification systems are to be serviced.

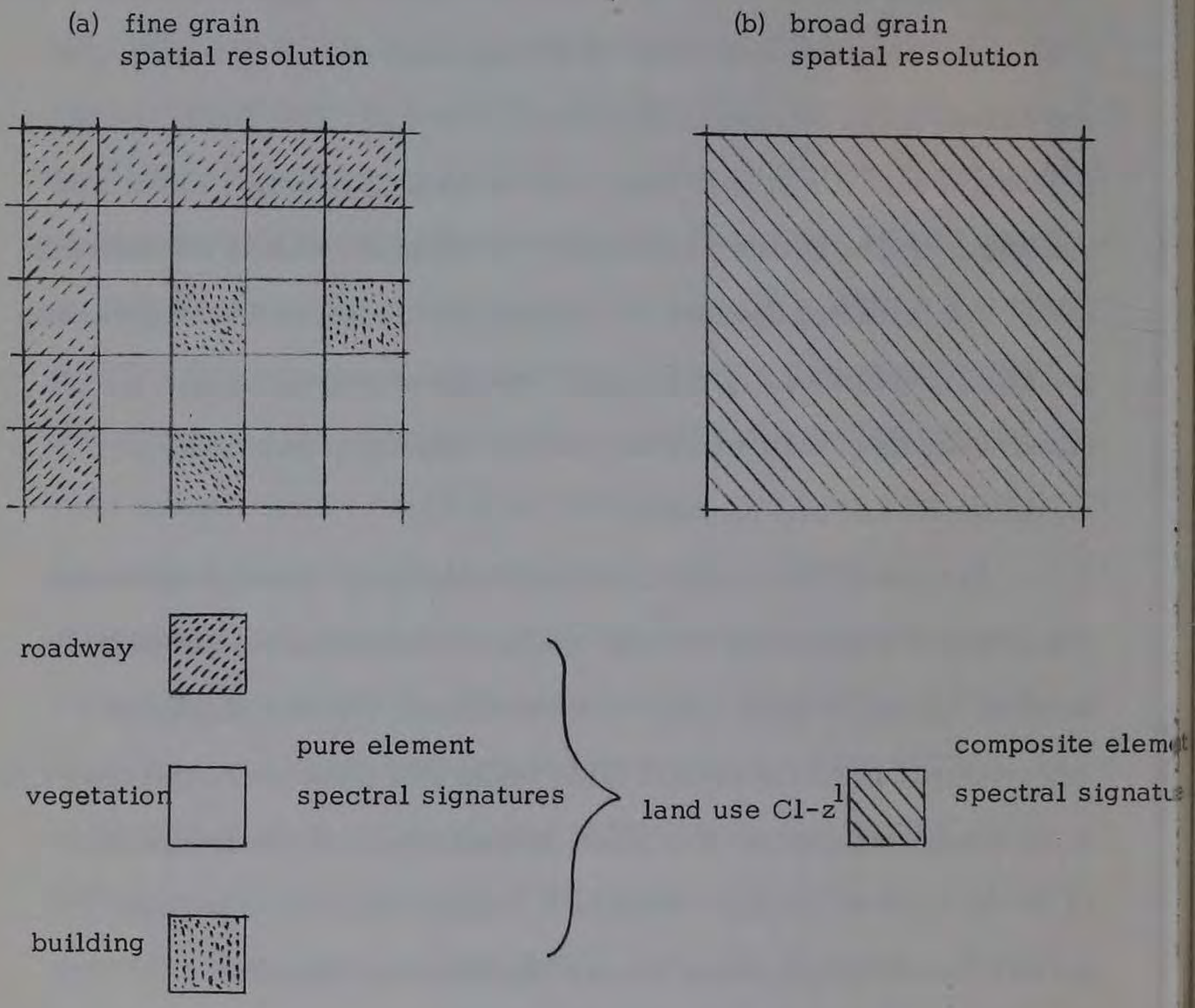


Figure 1: Spatial Resolution

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[1] The composite element spectral signature "Cl-z" may be characterized by 'small regularly spaced buildings, smooth surface linear rectangular pattern, in a mesh (matrix) of mixed vegetation', and this may be interpreted as 'single family residential'. Until systematic research is completed this diagram is conjectural; there is no assurance that such a class can be distinguished from other composite surfaces.

Based primarily on remote sensing inputs and the principles of numerical taxonomy, a new system might conceivably require a more throughly systematic investigation of signatures and processing methods before consistently useful results are possible.

One aspect of current technology which promises advances in classificatory methodology is the ability, through essentially simulation-like investigations, to characterize an unknown entity through photographic analysis. One example of this is the description of lunar "rolling stones" and adjacent terrain through analysis of photometric patterns.[11] Since rocks sighted did not give signatures expected of them laboratory models were constructed, photographed, and compared by isodensitometer analysis. The nature of the rocks is thus believed to be determined when a close correspondence exists between the patterns returned from a given model and the actual rocks of interest. Such procedures would be adapted for the purpose of revealing the nature of earth surfaces where the spectral signature was not previously known.

The essence of the above argument is not to stress the current capabilities but rather to indicate the potential of remote sensing and concomitant analysis systems. Clearly, current research in the field demonstrates that advances are possible. It is perhaps unfortunate that at this time the future directions and developments in the field are so unclear. The research endeavors are so new that the ultimate influence they might have on other fields, say classification systems, is as yet unknown.

In summary, land use classifications suffer from the fact that no entity (individual) to be classified is clearly defined. A perplexing consideration of scale must enter into any land use data coding system. Unless an order of magnitude can initially be assumed any land use data is questionable as to its relevance. Remote sensing threatens a technologically imposed scale criterion on land use data in terms of current classificatory schemas. If an innovative approach to the nature of classification of land use and developments in remote sensing is allowed, it is suggested that numerical taxonomic methods might appreciably alter the structure, and improve the usefulness of, land use information.

Conclusion

There is adequate justification for the inclusion of land use data or information in a comprehensive environmental monitoring system. The question that remains is the form these data should take. Several well established land use classification schemes are presently available but there is some concern about the applicability of these in environmental monitoring. Research into the significance of various land use characteristics in environmental change would be of value. These characteristics could then be used as the basis for classification, or perhaps schemes following the axioms of numerical taxonomy. Developing technology in remote sensing could provide the means for implementing the classification in an information gathering sense. Identification of the various taxa derived through numerical taxonomy with spectral signatures could prove to be very useful.

Regardless, careful attention to land use as a surrogate for aggregated human activity is of direct relevance to the monitoring of environmental change. Moreover, land use information may be used as a valuable indicator of environmental conditions, assuming the land use is not totally anomalous in its environmental context.

Closely associated with the development of various land use classification schemes has been the development of automated systems for storing the land use information. The Canadian Land Use Inventory would be a good example of this. Such automated information storage systems must be a major component of any environmental monitoring system. It is appropriate then, that we outline the structure of an environmental information system in the following chapter.

References:

1. D. Grigg, 1965, "The Logic of Regional Systems", Annals of the Association of American Geographers, 55(3): 465-491.

2. M. Clawson and C.L. Stewart, 1965, Land Use Information : A Critical Survey of U.S. Statistics Including Possibilities for Greater Uniformity, Baltimore, Resources for the Future, Johns Hopkins Press.

3. M. Clawson and C.L. Stewart, 1965, ibid., p. 32.

4. Kenneth J. Dueker, personal communication.

5. Department of Commerce, 1965, Standard Land Use Coding Manual, First Edition, Urban Renewal Administration, Housing and Home Finance Agency and Bureau of Public Roads, Washington.

6. See: "A Standard System for Identifying and Coding Land Use Activities," Standard Land Use Coding Manual, Washington, Urban Renewal Administration and Bureau of Public Roads, 111 pp.; "A Guide to the Classification of Land Use," 1970, The Canadian Land Inventory, Report No. 1, Dept. of Regional Economic Expansion, Ottawa, 61 pp.; "A Review of the New York State Land Use and Natural Resources Inventory," 1970, Center for Aerial Photographic Studies, Ithaca, Cornell University, 28 pp.; J.R. Anderson, 1971, "Land Use Classification Schemes," Photogrammetric Eng., 35(4): 379-387.

7. R.R. Sokal and H.A. Sneath, 1963, Principles of Numerical Taxonomy, San Francisco, Freeman.

8. C. Singer, 1959, A History of Biology, 3rd Ed., London, Abelard-Schuman, p. 200.

9. See: H.W. Smedes, 1969, "Digital Computer Terrain Mapping from Multispectral Data, and Evaluation of Proposed Earth Resources Technology Satellite (ERTS) Data Channels, Yellowstone National Park: Preliminary Report," NASA, Second Annual Earth Resources Aircraft Program Status Review, Vol. I, Geology and Geography, Houston, Manned Spacecraft Center; H.W. Smedes, M.M. Spencer and F.J. Thomson, 1971, "Preprocessing of Multispectral Data and Simulations of ERTS Data Channels to Make Computer Terrain Maps of a Yellowstone National Park Test Site," 7th International Symposium on Remote Sensing of the Environments, Ann Arbor, Willow Run Labs.

10. H.W. Smedes, et. al., 1971, "Digital Computer Mapping of Terrain by Clustering Techniques Using Color Film as a Three-Band Sensor," 7th International Symposium on Remote Sensing of the Environment, Ann Arbor, Willow Run Labs.

11. D.L. Spooner, 1969, "Analysis of Goniophotometric Properties of Lunar Rolling Stones," Proceedings of 6th International Symposium on Remote Sensing of the Environment, Vol. II, Ann Arbor, Willow Run Labs.

Introduction

Virtually all modern monitoring systems have some form of information storage and retrieval associated with them. In the simplest form, the information is stored as a single threshold or critical value which, if exceeded, initiates corrective action. The common thermostat and governor would be examples. All natural ecological systems have the same mechanism operative. This concept is basic to cybernetics and is commonly referred to as "feedback". In the development of environmental monitoring systems, what we desire is meaningful and accurate "feedback". The nature of the environment of concern in this report necessitates corrective action prior to the attainment of a critical value. Data collection and storage therefore must be of a continuing nature. Feedback (retrieval) may or may not be continuous depending on the behavior of the variables being monitored. Nevertheless, it is necessary that the system has an internal function continually assessing the incoming data defining and projecting trends and generating information of value to the user. This permits corrective action to be taken prior to critical levels being reached. In such a system the monitoring function is integrated with the information system. It is conceivable that the "action" or "reaction" function could be integrated as well. Human interaction in the process would be minimal. Monitoring of industrial activities and electric power generation provide numerous examples of this type of system. With the vast array of variables that describe the "environment", our limited knowledge of the relationships between them and the lack of understanding of environmental impact probably rule out this level of system for some time in environmental monitoring.

Regardless of the level of automation in the system and the amount of human interaction in the monitoring function, the information system must be multifaceted and flexible. The system should be comprehensive. It should be comprehensive in the phenomena (variables) it stores data for and monitors. It should be comprehensive in its structure. A comprehensive structure involves at least the following components: data acquisition, data transmission, data storage and processing and data usage.[1]

Data acquisition includes both the collection of primary data and the utilization of secondary data and information sources. The types of data that should be considered in this component have been discussed in Chapters IV and V. Chapter III reviews some of the developing technology for data acquisition. A brief discussion of the methodology (sampling) for primary data acquisition appears in Chapter IV. Therefore, this chapter comments only in a general sense on the data acquisition component.

A variety of activities may be considered in the data transmission component. Essentially they involve the movement of data from the collection site to the information storage system. Through the rapid developments in communications technology, especially the utilization of sophis-ticated telemetry and satellite systems, primary data is easily and rapidly transmitted. An associated element of data transmission has to do with dissemination. Agencies concerned with primary data collection have some responsibility for seeing that these data or information about it are transmitted to the most probable users of it. Most government agencies are very competent at this with the Weather Bureau being one of the best examples.

The component of primary concern in this chapter is data storage and processing, or the system to do this. There are numerous examples of information systems, operational and otherwise. In Chapter II a number of such systems specifically devoted to physical environmental variables are discussed. In general, the literature devoted to the development of information systems has expanded as the use of computers has expanded.[2] Some of the more notable advances in automated information storage and retrieval deal with socio-economic data rather than physical environmental data. An important research area in this regard has to do with urban regions.[3] Thus, there exists a large variety of precedents for the system outlined in the following pages.

Organizational Principles and Basic Elements

Organizational principles emphasize the system development and utilization. Development involves specification of data and data handling procedures including: input or geo-coding, transformations and storage. Emphasis in this section is on data handling procedures. Storage or the provision of data files ties development to utilization. The nature of the data files will obviously depend on the types of uses to which the system is likely to be put. System utilization means the processing of queries addressed to the system by users. No provision is made here as regards how best to deal with queries. The queries will have to be phrased in terms of variables included within the system and in locational and spatial configuration terms. The pertinent variable groups will be outlined in a following section. Examples of queries or phrasing in spatial terms are:

1. point-area: do persons with severe emphysema cases live or work (point) in an area of high air pollution?

2. area-line: will the proposed highway (line) cross the watershed (area) of the Scenic River?

3. point-line: what is the pollution index by stream segment (line) in the southeastern part of town and how does this correlate with the locations (point) of industrial plants?

4. point-line-area: will the location of the new power plant (point) affect any residential areas downwind (line) of it?

5. duplicate data definition: where do areas of industrial land use intersect with areas of high air pollution?[4]

In general, the components of the information system will include:

a) BASIC ELEMENTS, these are:

1. people,
2. computer and related packages,
3. data definition,
4. institutional procedures,
5. data collection methodology;

and

b) PRESCRIBED SYSTEM PATTERNS that will:

1. meet operational requirements,
2. facilitate summarizing and analytical techniques,
3. assist in the search for program goals,
4. assist in evaluation and control,
5. aid information exchange.

The basic elements include:

1. <u>People:</u>

Set policy and establish programs,
Develop and maintain information system hardware and software,
Provide input data,
Utilize the system to answer a broad range of questions;

2. <u>Computer and related packages</u>:

Hardware:
computer,
tape and disk drives,
graphic display,
remote input;

Software:
control system,
analytic program packages,
statistical routines,
query procedures,
file manipulation;

3. <u>Data Definition:</u>

Descriptional:
data items,
indicies and surrogates,
sensitivity analyses and relationships,
areal compatibility,
temporal requirements;

Contextual:
norms,
standards,
assumptions;

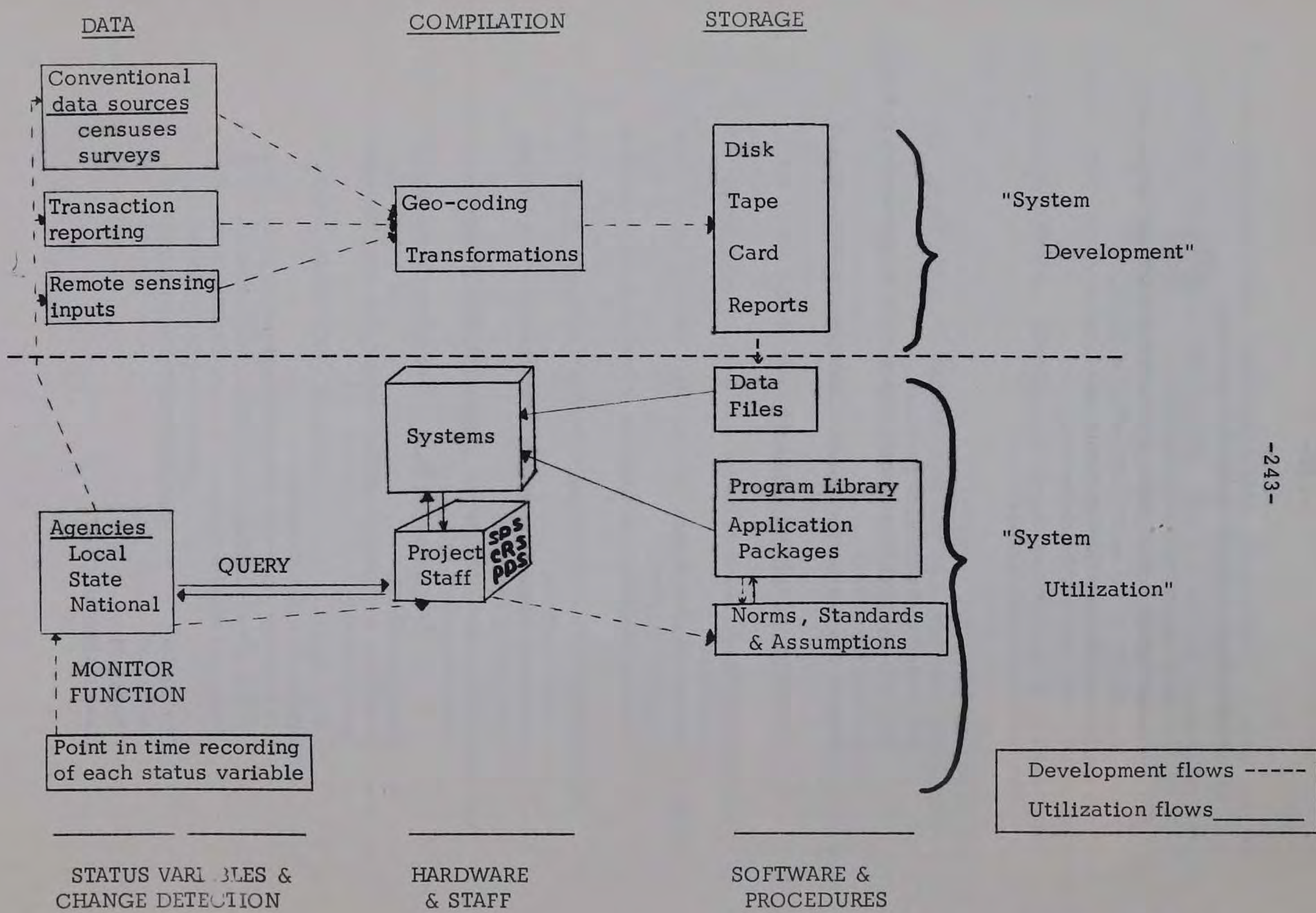


Figure 2: Schematic Representation: The Structure of an Information System for Environmental Monitoring

4. Institutional Procedures:

   Level of existing technology,
   Functional/Organizational responsibility;

5. Data Collection Methodology:

   Field Surveys,
   Automatic remote sensors,
   Geo-coding.

Figure 1 schematically represents the structure of the information system and the relative positions of the elements listed above.

The elements and structure outlined here are portrayed in a general sense. To place the discussion in a specific context, the major variable groups must be outlined.

Data Items

Chapters IV and V discuss and outline the major data items that are pertinent to description and monitoring of the physical environment. As suggested, there is plenty of room for the development of new data items that would be of more direct relevance to environmental description and monitoring. This was emphasized with respect to the development of indices to describe environmental quality (Chapter II). Within the standard areas of environmental science outlined in Chapter IV, experimentation with new measures and descriptors has been most emphasized in topographic analysis. In reviewing land use classifications, the need for land use descriptors of relevance to environmental monitoring is continually emphasized. Thus an obvious need exists for the continuing development of environmental descriptors. The elements and variables outlined here represent what is presently available but this should by no means imply that they are optimal.

An environmental monitoring and information system must have data for a given area describing:

1. The atmosphere
2. The hydrosphere
3. The lithosphere
    a. geology
    b. topography
    c. soils
4. The biosphere
    a. flora
    b. fauna
5. The land use activities.

Within each of these environmental elements there are a set of primary variables that must be measured directly in the environment. From these may be derived sets of secondary variables that may more accurately describe the condition of the environment. Some of the secondary variables may be measured directly in the environment -- a practice that is often more expedient than deriving them secondarily. Some variables, as measured, refer to points whereas others are phrased in terms of areas. This applies whether or not the variable describes continuous or discrete temporal and spatial distributions.

The following listing gives specific areas of information, in some cases specific variables, that would provide the basis of the information system. The composite refers to an area of any size. Some of the information should be regarded as "base line" data, or information that would not require updating regularly. The remainder are the "monitoring" variables or information areas that would require frequent if not continuous updating.

Both types of information are necessary for a composite image of the environment at any point in time.

ELEMENT	INFORMATION AREA OR VARIABLES	TYPE
Atmosphere	Temperature	Monitoring
	Humidity	Monitoring
	Radiation (incoming & outgoing)	Monitoring
	Wind speed and direction	Monitoring
	Precipitation	Monitoring
	Composition (physical & chemical)	Monitoring
Hydrosphere	Surface water cover	Baseline
	Water volume	Baseline
	Drainage characteristics (see Topography)	Baseline
	Discharge	Monitoring
	Surface water quality (physical & chemical)	Monitoring
	Snow coverage	Monitoring
	Snow cover depth	Monitoring
	Snow water equivalent	Monitoring
	Glacier ice extent and volume	Baseline
	Glacier behavior	Monitoring
	Lake, sea and river ice extent and thickness	Monitoring
	Ground ice extent and thickness	Baseline
	Ground ice water content	Baseline
	Ground water table (below surface)	Monitoring
	Ground water yield	Monitoring
	Ground water quality	Monitoring
Lithosphere	<u>Topography</u>	
	Hypsometric curve	Baseline
	Slope angle distribution	Baseline
	Slope orientation distribution	Baseline
	Drainage characteristics (see Hydrosphere)	Baseline
	Terrain roughness	Baseline
	<u>Geology</u>	
	Depth to bedrock	Baseline
	Lithology of bedrock	Baseline
	Areal distribution of surface bedrock	Baseline

ELEMENT	INFORMATION AREA OR VARIABLES	TYPE
	Attitude of geologic units	Baseline
	Bearing capacity	Baseline
	Thickness of surficial material (see depth)	Baseline
	Texture of surficial material	Baseline
	Permeability of surficial material	Baseline
	Infiltration capacity of surficial material	Baseline
	Atterberg limits of surficial material	Baseline
	Water content of surficial material	Monitoring
	<u>Soils</u>	
	(same as for surficial material plus:)	
	Color	Baseline
	Temperature	Monitoring
	Chemical characteristics and toxicity	Monitoring
	Biological characteristics	Monitoring
	Structure	Baseline
	Atmospheric characteristics	Monitoring
Biosphere	<u>Flora</u>	
	Vegetation type (by classification)	Baseline
	Dominant life form	Monitoring
	Vertical structure	Monitoring
	Density	Monitoring
	Frequency of individual species	Monitoring
	Number of species	Monitoring
	Dominant taxon	Monitoring
	Stage of evolution(climax)	Baseline
	<u>Fauna</u>	
	Population of individual species	Monitoring
	Age and sex structure of species	Monitoring
	Dominant species	Monitoring
	Status of life process of individual species	Monitoring
	Number of species	Monitoring
Land Use	A description of land use activities by some form of land use classification that portrays structure and function	Monitoring

Locational Identification (Geo-coding)

One of the most perplexing problems in the storage of real world data and information has to do with locational identification. The individual data items must be addressed in terms of their spatial and temporal contexts. The spatial context as it relates to a locational identifier is of concern here. The input of data, the data file structure, comparative analyses between data sets within the system and the output of data in any form are processes all dependent on the addressing of data by some identification code. In geographically-oriented information systems the address refers to geographic or spatial location. Two general types of locational identification for data storage are discussed here: grid storage and continuous image storage. The former mode and variations of it is the most frequently used and is probably the simplest and most easily implemented at this time for the system being discussed here. The continuous image mode is a growth area in this field of research and development, and therefore warrants careful attention for the future.

1. Grid Storage

The most frequent filing system is generalized storage by an arbitrary grid. Some systems allow multiple data entries, and some allow any size or shape and maintain the information by centroid and areas size. This makes it very difficult to relate areas to each other for the production of image output.

The generalized grid system results in a storage-retrieval problem which illustrates the difficulties presented by geographic referencing given current technology. Regardless of whether the data are stored on a tape or disc, it is possible to gain access to only a single record at any given point in time. The problem being that unless the next item of data required is physically "near", time is taken to retrieve it. In both cases, the times are proportional to the separation which exists in the file between successive data items being sought. The problem concerning the sequence in which such records should be filed arises from the fact that frequently there is a need to manipulate the file in order to extract information for a series of land areas which are adjacent to one another in the real world. This should require as little file manipulation as possible and a number of schemes have been developed for this purpose. One such two-dimensional storage structure is the Morton Matrix.[5] The purpose of the Morton Matrix file structure is to minimize (in a physical/statistical sense) the distance within the file between any two data elements which refer to adjacent locations in the real world. As can be seen from Figure 2 which illustrates the Morton Matrix structure, the individual elements are arranged in order to satisfy this requirement. The extent to which this requirement is met is not uniform but is satisfied better around the origin, and in many other local points, and less so in the center of the matrix. Also, the actual record address of a desired geographic location can be directly computed by manipulating the binary representation of

		85	87	93	95	117	119	125	127	213	215	221	223	245	247	253	255
		84	86	92	94	116	118	124	126	212	214	220	222	244	246	252	254
		81	83	89	91	113	115	121	123	209	211	217	219	241	243	249	251
		80	82	88	90	112	114	120	122	208	210	216	218	240	242	248	250
		69	71	77	79	101	103	109	111	197	199	205	207	229	231	237	239
		68	70	76	78	100	102	108	110	196	198	204	206	228	230	236	238
		65	67	73	75	97	99	105	107	193	195	201	203	225	227	233	235
		64	66	72	74	96	98	104	106	192	194	200	202	224	226	232	234
	111	21	23	29	31	53	55	61	63	149	151	157	159	181	183	189	191
	110	20	22	28	30	52	54	60	62	148	150	156	158	180	182	188	190
	101	17	19	25	27	49	51	57	59	145	147	153	155	177	179	185	187
Y	100	16	18	24	26	48	50	56	58	144	146	152	154	176	178	184	186
3	011	5 0101	7 0111	13 1101	15 1111	37	39	45	47	133	135	141	143	165	167	173	175
2	010	4 0100	6 0110	12 1100	14 1110	36	38	44	46	132	134	140	142	164	166	172	174
1	001	1 0001	3 0011	9 1001	11 1011	33	35	41	43	129	131	137	139	161	163	169	171
0	000	0 0000	2 0010	8 1000	10 1010	32	34	40	42	128	130	136	138	160	162	168	170
		000 0	001 1	010 2	011 3	100 X ⟶	101	110	111								

Figure 3: "Morton Matrix"*

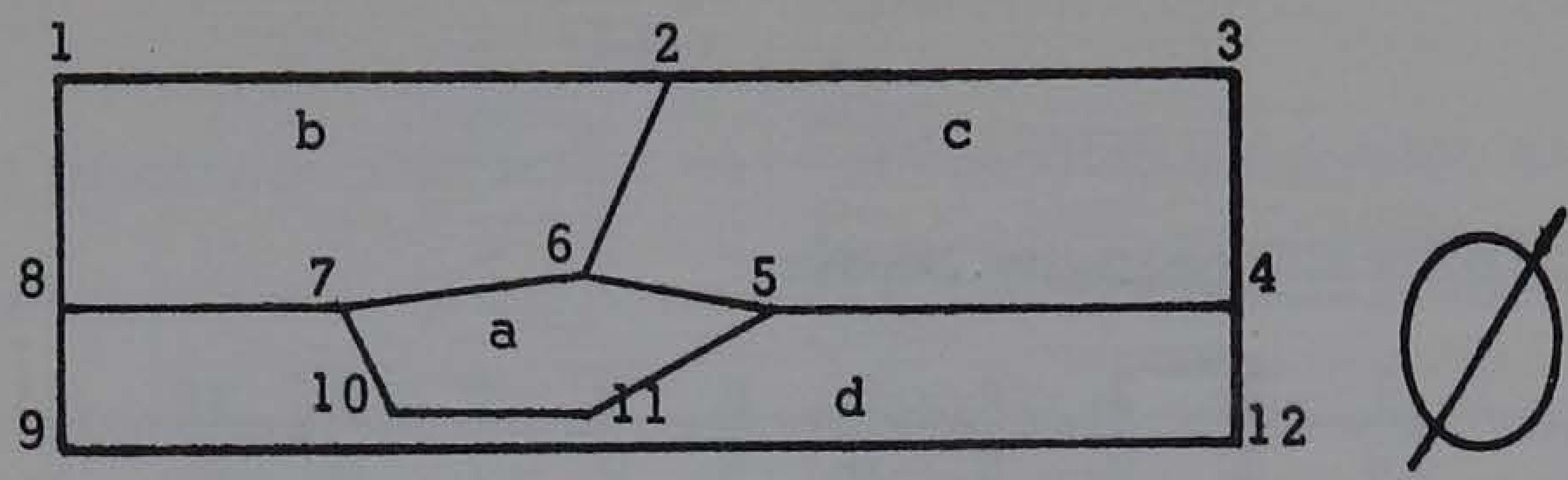
*Source: Tomlinson, p. 72.

the geographic X, Y co-ordinates as shown on the Morton Matrix diagram. The address is established by interleaving the binary representation of the X and Y co-ordinates in such a way as to combine the individual digits of each axis in sequence from high order to low order.

When stored in grid format, the cells are frequently used to derive values for larger areal units. Aggregating units in this manner results in an increase in generality, that is, some information is lost. For example, knowing that 50 percent of a particular square mile area is swamp land provides less information than replicating the image which indicates how it is distributed in the area and its proximity to the other types of land in the area. Storing data in this form limits the flexibility of the system and constrains the range of permissible problems, but, it greatly simplifies the geographic information system requirements. If in fact, however, this mode of operation is sufficient in terms of user needs it is preferred to undertaking the tremendous systems problems of replicating areas from imagery in digital form.

2. Continuous Image

While the most flexible storage mode is the continuous image, where the points, lines, or areas describing each phenomena are completely recorded, the practical problems are considerable. The approach to coding data under this concept can best be approached by developing a conceptual model for encoding geographic data in the general case.[6]



Possible Encodings

1. Areas encoded as polygons made up as a sequence of points
   E(a): A(6,5,11,10,7,6)*
   E(b): A(1,2,6,7,8,1)

2. Areas encoded as being contiguous to other areas (where Ø is the area outside the area system)
   E(b): A(c,a,d,Ø)
   E(a): A(c,d,b)

3. Line segments encoded in relationship to their end-points and their contiguity to areas
   E(1,2): A(b,Ø)
   E(1,8): A(Ø,b)
   E(2,3): A(c,Ø)
   E(2,6): A(b,c) } reverse encoding for redundancy edit
   E(6,2): A(c,b)

4. Points encoded as being connected to other points
   E(1): A(2,8)
   E(2): A(1,3,6)

5. Points encoded as being related to areas
   E(1): A(Ø,b)
   E(2): A(Ø,c,b)
   E(3): A(Ø,b)

Figure 3 Alternative Methods of Encoding Geographic Data

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*Read as the entity is area a and attributes are a sequence of point numbers 6,5,11,10,7, and 6.

6. Point Connectivity Matrix

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	1	0	0	0	0	0	1	0	0	0	0
2	1	0	1	0	0	1	0	0	0	0	0	0
3	0	1	0	1	0	0	0	0	0	0	0	0
4	0	0	1	0	1	0	0	0	0	0	0	1
5	0	0	0	1	0	1	0	0	0	0	1	0
6	0	1	0	0	1	0	1	0	0	0	0	0
7	0	0	0	0	0	1	0	1	0	1	0	0
8	1	0	0	0	0	0	1	0	1	0	0	0
9	0	0	0	0	0	0	0	1	0	0	0	1
10	0	0	0	0	0	0	1	0	0	0	1	0
11	0	0	0	0	1	0	0	0	0	1	0	0
12	0	0	0	1	0	0	0	0	1	0	0	0

7. Area Connectivity Matrix

	a	b	c	d
a	0	1	1	1
b	1	0	1	1
c	1	1	0	1
d	1	1	1	0

8. Coordinate definition of:

a) points

b) area bounds

c) area centroids

Figure 4: Alternative Methods of Encoding Geographic Data[8]

Figure 3 illustrates alternative ways of encoding geographic data.[7] Depending upon needs, and the hardware-software environment, any combination of one or more encoding schemes may suffice. More than one is usually needed, however, to provide error detection through redundant coding. Except for encoding procedures listed under No. 8 in Figure 3, the procedures illustrated provide a network theory basis for the geographic information system which in turn provides a framework for discussing input, storage, retrieval, and output problems associated with the design of the system. Each of the procedures listed have a variety of advantages and disadvantages associated with them when viewed in light of storage, comparison, retrieval, and output elements.

The input problem can be considered a problem of digitizing and coding a sequence of points that make up an area, or a line segment. Alternatively, the image could be scanned and encoded as small x-y cells which are a part of a line segment. It is clear that the input problem is not independent of data storage and that the overriding consideration as to which is preferable must relate to the purpose for which the image is needed in machine-readable form. It should also be noted that encoding methods provide the linkage between different elements of a geographic information system which enables evaluation of alternative forms of the system.

The data storage problem is one of selecting the appropriate encoding method to meet retrieval needs and at the same time be compatible with the medium upon which the data are stored. Pattern recognition type queries may require that contiguity characteristics about areas be stored in a direct access mode. Other queries might require comparison of two polygon sets, such as forest cover with rainfall patterns. Thus data must be encoded to make area description and area characteristics accessible and comparable.

Three different methods exist for encoding geographic data to machine-readable form from a two dimension medium. The patterns must be manually identified as points, lines or areas. The particular aspect of the problem discussed here is in the encoding of area data that exhaustively partitions the continuous image into areas represented as polygons. Essentially there are three ways of making area data machine readable:

1. point digitizing of polygon vertices
2. polygon trace with line follower digitizer, and
3. scanning for the presence and absence of lines making up polygon regions.

In all three cases the image must be partitioned into areas representing the phenomenon, such as land use, land capability or jurisdictional boundaries. When in machine readable form the system must provide for internal computation of intersections between phenomena or data sets and mapping of the original data or a derivative therefrom.

Point digitizing is the most straight-forward way of making area data machine readable and requires the least hardware and software capability. Operating in this mode all polygonal vertices are digitized and in a separate operation all the polygon vertice numbers are coded, and sometimes for edit check the line segment, i.e., connectivity between vertices are coded. The resultant entities from this encoding process are:

E(vertice number): A(x,y)*

E(polygon): A(sequence of vertice numbers bounding the polygon)

E(line segment: vertice i, vertice j): A(polygon code for left adjacent area, polygon code for right adjacent area).

This dual encoding allows editing to assess the consistency of the data by connecting line segments with common vertices and checking whether the right polygonal code number remains the same as an algorithm chains around the area in a clockwise direction.[9] This data structure can be used directly for storage and retrieval for most purposes. However, a connectivity matrix can also be easily created. A connectivity matrix is useful in mapping when it is desired to draw line segments that connect vertices and nodes.

Input from map or maplike imagery polygon trace with a line follower digitizer as used in the MAP/MODEL system[10] eases the input problem significantly. The only instruction necessary is that the digitizer stylus trace around each polygon. The resultant entity:

E(polygon code): A(x,y coordinates at regular intervals)

A computer algorithm must then be developed to identify junctions and points of inflection to create a polygonal file changing the attribute structure of a sequence of x, y coordinates to a sequence of line segments, thus simplifying the polygonal description to one developed by the point digitizer and manual coding. The edit employed by this method utilizes the characteristic

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*Read as: The entity is a vertice or node number and the attributes are a x-coordinate value and a y-coordinate value.

of the methods that encodes each line segment twice (because it is part of two polygons). The separately encoded line segments are compared and if they fall within a given tolerance are accepted; if not the records are rejected and a correction must be made. The resultant record for storage and retrieval is the same as the resultant records from point digitizing.

A flying spot scanner as used by the Canadian Land Inventory,[11] creates machine-readable records for each resolution cell of the image, consisting of whether a line is present or absent for that cell:

E(x,Y): A(presence or absence of a line segment for x,y)

An algorithm is necessary to connect contiguous cells having lines present to form line segments in order to proceed as above. For edit, a separately encoded polygon number and coordinate value falling within the polygon region must be digitized separately:

E(approximate polygon centroid): A(x,y).

Again the resultant data for storage and retrieval consists of a polygon description and/or line segment description with coordinates for the vertices of the polygon regions.

The choice of encoding method for imagery data is dependent upon a variety of factors. These are largely related to the magnitude of the data being encoded which is measured by the size of the area and the number of subareas into which it is divided. However, considering the scale of the image the density of lines or points becomes extremely important and the choice of whether to use a digitizer or a scanner is largely a function of the density of the points on each image and the number of images to be processed. An index of magnitude and density would be useful to jointly consider the size of the area and the density of line segments to be digitized.

Operating in the point digitizing mode the following costs are incurred:

Image Preparation c_{11}

Point Digitizing c_{12}

Polygon Encoding c_{13}

Line Segment Encoding c_{14}

Computer Processing c_{15}

In the point line follower mode the costs are:

Image Preparation c_{21}

Polygon Digitizing c_{22}

Computer Processing c_{23}

In the scanning mode the costs are:

Image Preparation c_{31}

Scanning c_{32}

Point Digitizing c_{33}

Computer Processing c_{34}

Operating in the point digitizing mode the costs for digitizing and polygon encoding, c_{12} and c_{13} respectively, are high whereas costs for computer processing are low because the encoded data are directed to storage without intervening processing. The line follower mode has a higher computer processing cost reflecting processing to determine points of inflection and junction. Operating in the scanner mode also has a high cost for image preparation and computer processing which is also related to the determination of line segments and points of inflection and junction.

Given that the scanning mode and the line follower mode have higher initial costs in terms of the development of algorithms to convert the data for storage and retrieval, but operate more efficiently at higher magnitude-density of imagery, they will be most appropriate as the demand for environmental information and detail increases.

The Organizational Structure

The environmental sciences present a vast array of data. With the development of remote sensing and other large-scale data collection programs there is reason to believe that the rate at which environmental information is generated will increase. The "environmental crisis" has emphasized the need for collecting data for new variables and for collecting these data more frequently. The result is that a coordinated description and continuing surveillance of a large area on the earth's surface could rapidly become unmanageable through the shear volume of data. Although the data items and information areas listed in this chapter will limit the data somewhat, collection over extended period of time will produce vast amounts of data. In a previous chapte the large number of already operational monitoring systems were noted. Their presence cannot be ignored. With these points in mind the following organizational structure for an environmental information system is suggested.

In the general system there are three major elements. These are:

1. the Standard Data System (SDS)
2. the Co-ordination and Resource System (CRS)
3. the Priority Data System (PDS)

This arrangement is not unlike an information system outlined for the Environmental Health Service by the Battelle Institute.[12]

The Standard Data System would contain geographically coded standard information. The coding procedure would follow the coding procedures discussed earlier in this chapter. Standard Information includes all the "baseline" and "monitoring" variables. The information for "monitoring" variables would be continually updated.

The Coordination and Resource System would consist of two subunits. One subunit would monitor data sources and research activities of related interest and store this information in an automated retrieval mode. Notice would be made to the SDS when a new data series is available meeting its requirements for inclusion. The second subunit of CRS would interface with secondary requests to determine when requests can be serviced through SDS. Referral to sources of original data would be made when the SDS does not offer necessary data series or when frequency or spatial detail is inappropriate.

The third element of the system, the Priority Data System, would have two roles. First, when routine processing of information files of the SDS indicate the appearance of parameter changes in data series, the PDS would investigate. Preliminary response would be to substantiate the findings of the SDS, and if appropriate, an in depth, on site surveillance would be initiated. Phenomena recorded and spatial detail could be much greater with the reduced scale of operation. The second role served by the PDS would be similar to the first in that local, in depth, studies would be undertaken. Initiation of such studies would not result from an indicated change in the "monitoring" variables. Rather, these studies might be undertaken as a result of a forecasted or predicted change, the field testing of new techniques and methodologies, or the anticipation of new operations in an area. This aspect of the Priority Data System would be the research and development segment of the total system.

A project team, having completed a research study, would institute new procedures both in CRS and SDS, not by report, but in person. A new data series would become available as standard procedure through the cooperative interaction of those that developed it, those that must maintain the system and those that must coordinate its utilization. Another example illustrates the integrated nature of the total system, suppose the CRS determined a critical needs for a data series as perceived by researchers requesting service. A project team might be organized from personnel of each section to evaluate this demand, determine the feasibility of meeting it, and finally collecting, processing, and making it available in standard format.

Organized in a manner consistent with the above description, the total system would have an inherent flexibility and should not develop a static content or a rigid structure. It is important that three factors be stressed in developing the system. First, it must remain flexible and encourage growth and refinement of data series and analyses capability. Second, it must emphasize change-detection, and third, the retrieval systems must have a strong geographic foundation. The first two requirements are less a part of the structure of an information system than they are its innovative use. The latter requirement is so important to the development of the system that it was considered in detail in a previous section.

Priorities for Development

The development of the total information system would obviously be a massive undertaking. Therefore it is pertinent to suggest priorities for development. First, the set of information areas for which data are to be collected must be carefully determined. The data items outlined in this chapter would provide a basis for this. At the same time some decision as regards the area (geographical) to be covered is in order. From the intelligence point of view this might be global in scale; from a logistical-operational point of view it might be national or regional in scale. Having made these decisions, the Co-ordination and Resource System must receive top priority. This statement is based on our findings in reviewing the status of environmental information (see Chapter II). A vast amount of information is already available or is rapidly becoming available.

This is not to say that all or any of this information will be of use for a given purpose but at the very least a systematic inventory of information available would define the most crucial areas of need. From this inventory of data and information sources, which would be a continuing effort, the bases for the Standard Data System and Priority Data System could be established. The information in the Co-ordination and Resource System would be stored by environmental element and variable, and geographic location.

Conclusion

Given that large amounts of data are involved in monitoring the environment, an extraordinary level of effort is necessary to develop appropriate operational geographic information systems useful in the storage and processing of such data. Automated interpretation of images and translation to digital form for data storage, automated pattern recognition and comparison, and automated report generation are possible though not fully operational. In the short run, it is necessary to develop a strategy which can incorporate improved automated methods as they become available. Similarly, the size and scope of the data acquisition program must be evaluated in order to determine the extent to which automated data extraction and processing is cost effective.

One cannot assume that automated information storage and retrieval systems will be sufficient to handle the volumes of environmental data that are already available or will be soon available. Some of the remote sensing and scanning devices presently being developed are capable of returning 10^{10} bits of information every few hours.[13] This would quickly overload most automated information systems and the hardware on which they are based. Storage capacity (except remote storage) is not keeping pace with information gathering technology. There is some evidence that the latter surpasses the significance of the data being collected. Thus, careful attention must be directed to the data being collected and its meaning.

The information system development must take place in a phased program. The first phase should involve the development of a Co-ordination and Resource Data System that continually monitors the general status of environmental data collection.

References:

1. R.P. Ouellette, D.M. Rosenbaum and R.F. Greeley, 1971, "Is There a System for Pollution Madness?", Datamation, 17(8): 30-33.

2. C. Meadow, 1967, The Analysis of Information Systems: An Introduction to Information Retrieval, New York, Wiley & Sons.

3. The following references provide examples of this emphasis: K.J. Dueker and F.E. Horton, 1970, "Urban Change Detection Systems in Urban and Regional Planning", Institute of Urban and Regional Research Working Paper Series, University of Iowa, Iowa City, No. 5, 17 pp.; T. Tamura, 1968, "Prospects in Municipal Information Systems: The Example of Los Angeles", Computers and Automation, 17: 15-18; O.E. Dial, 1968, Urban Information Systems: A Bibliographic Essay, Monograph for Summer Studies Group on Urban Information Systems; R.D. Johnson and J.F. Ruff, 1969, "GEOPLANS: A Subsystem of the Kansas City Regional Information System (KCRIS)", URISA Proceedings, p. 137-160; U.S. Department of Housing and Urban Development, 1968, Urban and Regional Information Systems: Support for Planning in Metropolitan Areas.

4. This was extracted from an unpublished paper by Nancy B. Hultquist, 1970, "ENVISU: A Proposal for Inclusion of Physical Environmental Data in Urban Information Systems", University of Iowa, 22 pp.

5. R.F. Tomlinson, (ed.) 1971, Environmental Information Systems, Proceedings of the UNESCO/IGU First Symposium on Geographical Information Systems, Sept. 1970, Ottawa, I.G.U. Commission on Geographical Data Sensing and Processing, 161 pp.

6. K.J. Dueker and F.E. Horton, 1970, op. cit.

7. These are taken from an unpublished paper: K.J. Dueker, 1970, "A Framework for Encoding Spatial Data", Institute of Urban and Regional Research, University of Iowa.

8. K.J. Dueker, 1970, ibid.

9. This type of edit is employed by the DIME system developed at the "New Haven Use Study": U.S. Bureau of Census, 1970, Census Use Study: The Dime Geocoding System, Washington, Report No. 4.

10. S. Arms, 1970, The MAP/MODEL System: System Description and User's Guide, Bureau of Governmental Research and Services, University of Oregon.

11. Spartan Air Services, Data for Decision Makers, Ottawa, Canada, See Chapter 4 in particular.

12. See: D.L. Morrison et. al., 1970, Technical, Intelligence and Project Information System for the Environmental Health Service, Vol. I, "Management Assistance and Planning", Battelle Memorial Institute, Columbus, 72 pp; R.L. Darby et. al., Technical, Intelligence and Project Information System for the Environmental Health Service, Vol. II, "EHS Information Network Analysis", Battelle Memorial Institute, Columbus, 100 pp; R.L. Darby, et. al., 1970, Technical, Intelligence and Project Information System for the Environmental Health Service, Vol. V, "Directory of EHS Information Facilities with Selected Supplementary Resources", Battelle Memorial Institute, Columbus, 44 pp.

13. T. Brewer, 1970, "Earth Resources", Datamation, (August 15), p. 25-28.

Conclusions

We can anticipate an enormous increase in the volume of environmental data. A need and desire to learn what has happened, is happening and is likely to happen to man's environment is the primary stimulus. Concurrently, there has been increased research and development in data collection technology. The increased application of remote sensing is an example. Automated data processing systems have allowed the systematic storage, processing and retrieval of the raw and processed data. However, there is some question of the ability of the data processing systems to keep pace with the data collection. There is also some question as to the value and meaning of some of the data being collected. Obviously a new effort to collect primary environmental data with no use specified would be irresponsible and possibly non-productive. The most apparent characteristic of the current environmental data collection thrust is that there is very little co-ordinated effort at any scale; local, regional, national or global. The best examples of co-ordinated systems development is probably at the international scale through agencies like The World Meteorological Organization, International Hydrological Decade and The International Biological Program. Moreover, much of the current effort is structured in the mold of traditional disciplinary science. Plans for comprehensive and interdisciplinary systems development are few. There are valid reasons for this; the major one being the complexity and volume of data to be collected, stored and manipulated.

The report has attempted to specify and outline a number of pertinent variables that could be used to describe a composite environment. A composite would require attention to four major elements: atmosphere, hydrosphere, biosphere and lithosphere, and the imposition of human activities or land use on these elements. Important emphasis should be placed on the identification and use of primary variables to describe these elements. From the primary variables a wide range of secondary variables may be developed for specific uses. In an automated information system the computation of secondary variables would be internalized in the processing function through the development of the appropriate software.

Monitoring changes in the environmental elements would simply involve the periodic or continuous input of new data into the system. This would only be meaningful if the baseline conditions of the elements and variables were carefully specified. The periodic and continuous input of new data is especially crucial for the atmospheric, biological and hydrological elements of the environment. It would not be so important for the standard descriptive variables used to describe topography and geology. This has to do with the inherent temporal variability of the variables.

Examination of the functional relationships between environmental variables indicates that a considerable amount of empirical research is necessary before these relationships can be incorporated into a monitoring system. One area where considerable effort has been devoted to the empirical study of functional relationships is hydrological response and behavior in the drainage basin context. Even here much uncertainty remains as to the character of relationships between vegetation cover and land use changes and the hydrological and erosional response. Research into functional relationships between environmental variables still follows disciplinary lines. The development of predictive and simulation models based on known functional relationships is probably most advanced in hydrology and the atmospheric sciences. A need to develop more comprehensive models has been recognized in regional studies. These models emphasize socio-economic variables with the physical environmental variables being expressed in very general terms.

Apart from expense considerations, it would appear that environmental data collection does not present serious obstacles. The methods and techniques of data collection are well developed and will continue to develop through increasing remote sensing research. Expense and available resources are large factors that must be considered. They determine the temporal and spatial configuration or resolution of the actual data collection. They constrain the sampling methodology. The most appropriate methodology from the point of view of representativeness may not be possible to implement as a result. The research indicates that sampling procedures for point, line and continuous populations are sufficiently well developed as to be functional.

The organizational structure of an environmental information system has been discussed. It is suggested that such a system be composed of three major components. The Standard Data System would collect, store and process data on the primary environmental variables. A Co-ordination and Resource Data System would monitor environmental data collection and research activities generally. The purpose of this would be to avoid duplication in data collection and bring the development of new data sets, techniques and systems to the attention of the system. The third component is a Priority Data System. This system would have two roles: (1) to investigate marked changes of variables or parameters in the data series being accumulated in the Standard Data System; (2) to develop localized in-depth studies on the basis of evidence coming from the other two systems.

The actual storage of information presents some problems. The major difficulties arise from the fact that a geographical information system would be the most pertinent for environmental data. By this is meant that data bits would be stored, addressed or indexed according to some index of relative or real location. The items would be cross-filed and accessible according to the environmental element they described as well. For data to be stored at a variety of scales and locations, considerable research and attention needs to be directed to these problems of geocoding.

In completing the review, it may be concluded that further development of an environmental monitoring and information system must rest on the specification of uses for the information. Some general uses and applications were outlined in Chapter I. However, these are not sufficient to provide a specific focus for systems development.

Environmental information of all types has been used in the past for planning activities in various regions. This information, though not in an automated format and thus time-consuming to come by, has been fully integrated into many planning processes. However, this information has been primarily descriptive of environmental conditions. Recently, increased emphasis has been placed on another type of environmental information.

This is information about the possible impact of the planned activities on the environmental conditions of a given area. Thus there has been a slight shift from a concern for environmental impact on human activities to a concern for human activities impact on environmental conditions. This shift has been fostered by policies that demand "environmental impact" statements prior to the utilization of space and resources in a region. An environmental information system should provide for both types of general use.

On the basis of the review and research of the status of environmental monitoring and information, the following recommendations are made.

Recommendations

1. The funding agency should not proceed immediately with the development of an environmental monitoring and information system involving the collection of primary data until specific uses of the data and information are carefully pre-defined. Of course the development of an automated information system, as opposed to the continuation of other less formal and systematic information collection and utilization, must be based on cost-effectiveness criteria.

2. A logical first step would be a careful and systematic inventory of all environmental data sources, information systems and monitoring systems. This would provide the information base for a Co-ordination and Resource Data System. The report provides a starting point for this recommended action. Similar procedures have been initiated for the Environmental Health Service and by the Smithsonian Center for Short-Lived Phenomena. The development of a Co-ordination and Resource Data System immediately gives

rise to further recommendations.

3. It is recommended that further research and development be devoted to the problems associated with geocoding and other schemes for the systematic storage and retrieval of information.

4. Continuing research and assessment of data collection technology, particularly remote sensing, from the viewpoint of providing environmental data on the variables and elements outlined in this report should be encouraged.

5. A specific effort should be devoted to the development of schemes and classifications for human activities that would be of use in assessing the environmental impact of these activities. Classifications incorporating structural and functional dimensions of land use would provide a good starting point.

6. It is recommended that attention be directed to the development and testing of a Standard Data System on a small experimental basis. By this is meant the collection, storage, processing and retrieval, for specific purposes, of data on some of the basic variables outlined in this report in a small well-documented test region. An attempt should be made to make the information as comprehensive as possible. All the steps from data collection, coding, input, storage, processing and retrieval in a variety of formats would be operationalized and tested.

7. Finally, it is recommended that the agency consider carefully the current policy and public opinion trends in the utilization of environmental information for assessing the impact of human activities on environmental conditions. The recommended Co-ordination and Resource Data System

development would provide access to this type of information and its utilization.

Priorities are implied in the recommendations but it is pertinent to repeat that a Co-ordination and Resource Data System be considered as a top priority item. This system and its development would have definite and immediate applications. Second priority might be given to the basic research areas of geocoding, remote sensing and land use classification. Third priority should be given to the development and testing of a Standard Data System on a small scale.

APPENDIX A

SELECTED BIBLIOGRAPHY

The following is not meant to be an exhaustive bibliography on environmental problems. The literature is replete with such things already. Included here are a number of general works that, in the course of our research, have appeared to be of primary importance to environmental monitoring and information systems. Some have appeared in the reference lists at the ends of the chapters.

AAAS (1965) Air Conservation, Report, Air Conservation Commission AAAS, Publication #80, Washington, D.C., 355 pp.

Ackermann, W.C. et. al. (1970) "Some Long-term Trends in Water Quality of Rivers and Lakes", EOS, 51(6): 516-522.

American Chemical Society (1969) Cleaning Our Environment: The Chemical Basis for Action, Washington, D.C.

American Institute of Biological Sciences (1962) Information Handling & Science Information: A Bibliography.

Anderson, H.W. (1966) "Watershed Modelling Approach to Evaluation of the Hydrological Potential of Unit Areas" in Int. Symposium on Forest Hydrology, W.E. Sopper & H.W. Lull (ed.), 737-748, Oxford, Pergamon.

Anderson, P.W. et. al. (1970) "Automated Stream Quality Sensing Network" in Symposium Data & Inst. Water Quality Management, J.E. Kerrigan (ed.): 261-281, Madison, Water Res. Center, University of Wisconsin.

Anon, "Environmental Monitoring Instruments on the Upswing", Oceanology International, 5(2): 41.

Anon (1966) Environmental Monitoring in Emergency Situations, Int. Atomic Energy Agency, Vienna, Safety Ser. #18, 128 pp.

Anon (1969) "Environmental Science Centers at Institutions of Higher Learning", prepared by The Environmental Policy Division of the Library of Congress for U.S. House Committee on Science & Astronautics, Dec. 1969.

Anon (1970) "A Global Network to Monitor the World's Environment", Civil Engineering, 40(11): 27.

Anstey, Robert L. (1960) Digitized Environmental Data Processing, Quartermaster Research & Engineering Center, U.S. Army Research Study Report RER-31, 38 pp., 2 appendix.

Arthur, D.R. (1969) Man and His Environment, New York, American Elsevier, 218pp.

Aschmann, H. (1970) Prolegomena to the Remote Sensing of Environmental Quality, Comm. Geog. Appl. of Remote Sensing A.A.G., Technical Report 70-3.

ASTM (1962) ASTM Standards on Methods of Atmospheric Sampling and Analysis, ASTM Comm-D-22, Philadelphia, Pa.

Babcock, L.R. (1970) "A Combined Pollution Index for Measurement of Total Air Pollution", Journal of Air Pollution Control, 20: 653-659.

Barlow, M.H. & R.G. Newton (1968) Patterns & Processes in Man's Physical Environment, Sydney, Angus & Robertson.

Bates, Marston (1969)"The Human Ecosystem," Resources & Man, Division of Earth Sciences, N.A.S., N.R.C., (W.H. Freeman & Co., San Francisco), pp. 21-30, 11 refs.

Bell, F.W. (1967) "An Econometric Forecasting Model for a Region", Journal of Regional Science, 7: 109-127.

Berkman, Herman G. (1965)"Game Theory of Land Use Determination," Land Economics 41: 11-19.

Berry, B.L.J. (1962) "Sampling, Coding and Storing Flood Plain Data", U.S. Dept. of Agriculture, Farm Economics Division, Agricultural Handbook, 237: 1-27.

Blakey, J.F. (1970) "Design of an Automatic Monitoring System" in Symposium Data & Inst. Water Quality Management, J.E. Kerrigan (ed.): 243-247, Madison, Water Research Center, University of Wisconsin.

Boughton, W.C. (1970) Effects of Land Management on Quantity and Quality of Available Water, Water Research Lab., University of New South Wales, Manly Vale, Australia, Report #120, 330 pp.

Boulding, K.E. (1968) "A Data-Collecting Network for the Sociosphere", Impact of Science on Society, XVIII(2): 97-101.

Bourliere, F. & M. Hadley (1970)"Analysis of Ecosystems: Combination of Qualitative and Quantitative Approaches", in Temperate Forest Ecosystems, D.E. Reichle (ed.), p. 1-7, Berlin, Springer-Verlag.

Brady, Nyle C. (ed.) (1967) Agriculture and the Quality of our Environment, AAAS Symposium Publication 85, Washington, D.C.

Brodovicz, B.A., V.H. Sussman & G.B. Murdock (1969) "Pennsylvania's Computerized Air Monitoring System", Journal of Air Pollution Control Association, 19(7): 484-

Bromberg, A.W. & M. Carames (1970) "Experiences with Operating an Automatic Water Quality Monitoring System in an Estuarine Environment", in Symposium Data & Inst. Water Quality Management, J.E. Kerrigan (ed.): 248-255, Madison, Water Research Center, University of Wisconsin.

Brown, R.M. et. al. (1970) "Water Quality Index - Do We Dare?" in Symposium Data & Inst. Water Quality Management, J.E. Kerrigan (ed.): 364-383, Madison, Water Research Center, University of Wisconsin.

Browne, N.E. (1969) "A Simulation Model for Air Pollution Over Connecticut", Journal of Air Pollution Control Association, 19(8): 570-574.

Burton, I. (1968) "The Quality of the Environment: A Review", Geographical Review, 58(3): 472-481.

Cairns, J. et. al. (1970) "A Preliminary Report on Rapid Biological Information Systems for Water Pollution Control", Journal of Water Pollution Control Federation, 42(5): 685-703.

Carnes, R.C. (1970) "Environmental Detection Systems", Water & Sewage Works, 117(12): 430-433.

Carpenter, R.A. (1970) "Information for Decisions in Environmental Policy", Science, 168(3937): 1316-1321.

Carter, R.W. & M.A. Benson (1971) "Nationwide Study of the Stream Flow Data Program", Water Res. Bulletin, 7: 383-385.

Carver, T.C. (1970) Estuarine Monitoring Program, Report of the Subcommittee on Pesticides of the Cabinet Committee on the Environment, Washington, D.C.

Chapman, R.N. (1928) "Quantitative analysis of environmental factors", Ecology, 9: 111-122.

Chisholm, M., A.E. Frey & P. Haggett (1971) (eds.) Regional Forecasting, Anchor Books, 467 pp.

Chorley, R.J. & P. Haggett (1965) "Trend Surface Mapping in Geographical Research", Inst. British Geographers Transactions, 37: 47-68.

Chorley, R.J. (ed.) (1969) Water, Earth and Man: A Synthesis of Hydrology, Geomorphology and Socio-economic Geography, Methuen, London.

Chow, Ven T. (ed.) (1964) Handbook of Applied Hydrology, New York, McGraw-Hill.

Ciriacy-Wantrup, S.V. & J.J. Parsons (eds.) (1967) Natural Resources - Quality and Quantity, Berkeley, U. of California Press.

Clarkson, J.D. (1970) "Ecology and Spatial Analysis", Annals, Association of American Geographers, 60(4): 700-716.

Colwell, Robert N. (1969)"The inventory of vegetation resources - user requirements vs. remote sensing capabilities" in Second Annual Earth Resources Aircraft Program Status Review, Vol. II, Agriculture/ Forestry, & Sensor Studies (Sept. 16 - 18, 1969); N.A.S.A., Manned Spacecraft Center, Houston, Texas, p18-1-18-71.

Commoner, B., M. Corr & P.J. Stamler (in press) Data on the United States Economy of Relevance to Environmental Problems, prepared for the Committee on Environmental Alterations AAAS, Washington.

Cooper, C.F. & W.C. Jolly (1969) Ecological Effects of Weather Modification: A Problem Analysis, Ann Arbor, Department of Resource Planning and Conservation, University of Michigan.

Cooper, C.F. (1969) "Ecosystem Models in Watershed Management", in The Ecosystem Concept in Natural Resources Management, Van Dyne (ed.) New York, Academic, pp. 309-325.

Coulthard, T.L. & J.R. Stein (1970) "Water Quality Survey", American Society of Agricultural Engineering Transactions, 13(4): 430-432.

Cox, G.W. (ed.) (1969) Readings in Conservation Ecology, New York, Appleton-Century-Crofts, 595 pp.

Crawford, N.H. & R.K. Linsley (1966) "Digital Simulation in Hydrology Stanford Watershed Model IV", Stanford University, Dept. of Civil Engineering, Technical Report #39, 210 pp.

Curlin, J.W. (1970) "Models of the hydrological cycle", in Temperate Forest Ecosystems, D.E. Reichle (ed.) Berlin, Springer-Verlag, pp. 268-285.

Curry, L. (1964) "Landscape as System", Geographical Review, 54, 121-124.

Dale, M.B. (1970)"Systems Analysis and Ecology," Ecology, 51(1), pp. 2-16, 101 refs.

Daniel, J.F. (1970) "Satellite (ERTS-A) Network of Ground Data Sensors: A User-Oriented Experiment", in Symposium Data & Inst. Water Quality Management, J.E. Kerrigan (ed.): 166-176, Madison, Wisconsin, Water Res. Center, University of Wisconsin.

Darby, R.L. et. al. (1970) "Technical Intelligence, and Project Information System for the Environmental Health Service, Vol. II, EHS Information Network Analysis", Battelle Institute, Columbus, National Technical Information Service, PB194411.

Darby, R.L. et. al. (1970) "Technical, Intelligence, and Project Information System for the Environmental Health Service, Vol. V, Directory of EHS Information Facilities with Selected Supplementary Resources", Battelle Institute, Columbus, PB194414, National Technical Information Service.

Darley, E.F. (1960) "The Use of Plants for Air Pollution Monitoring", Journal of Air Pollution Control Association, 10(3): 198-219.

Darling, F. Fraser (1964) "Conservation and Ecological Theory," Journal of Ecology and Journal of Animal Ecology, Jubilee Symposium Supplement, pp. 39-45, 14 refs.

Davis, D.R. & W.M. Dvoranchik (1971) "Evaluation of the Worth of Additional Data", Water Resources Bulletin, 7(4): 700-707.

Dellwig, L.F., H.C. MacDonald and J.N. Kirk (1968) "The Potential of Radar in Geological Exploration" in Proceedings of the 5th Symposium on Remote Sensing of Environment, (16-18 April, 1968), Willow Run Laboratories, University of Michigan, Ann Arbor, pp. 747-763.

Detwyler, T.R. (ed.) (1971) Man's Impact on Environment, New York, McGraw-Hill Co.

Dorfman, R. (1965) "Formal Models in the Design of Water Resource Systems", Water Resources Research, 1(3): 329-336.

DuMontelle, Paul B. (1970) "Geologic Investigation of the Site for an Environmental Pollution Study," Illinois Geologic Survey, Environmental Geol. notes, No. 31, 19p.

Dynes, V. & M. George, The Ecosystem Concept in Natural Resources Management, New York, Academic Press.

Eddy, Amos (1969) "A Meteorologically Oriented Computer Model of an Ecosystem," Transactions, New York Academy of Sciences, 31(6), pp. 618-628.

Edwards, Gordon (1969) Land, People and Policy: The Problems and Techniques of Assembling Land for the Urbanization of 100 Million New Americans, Chandler-Davis, West Trenton, N.J.

Eisendud, Merril (1963) Environmental Radioactivity, McGraw-Hill, New York.

Engman, E.T., et. al. (1971) "Scale Problems in Interdisciplinary Water Resources Investigation", Water Res. Bulletin, 7(3): 495-505.

Evan, F.C. (1956) "Ecosystem as the basic unit in ecology", Science, 123: 1127-1128.

Ewald, Jr. William R. (ed.) (1967) Environment for Man: The Next Fifty Years, Indiana University Press: Bloomington.

Ewald, W.R. (1968) Environment & Change, Bloomington, Indiana University Press.

Fair, D.H. et. al. (1968) Storage and Retrieval of Air Quality Data, System Description and Data Coding Manual, Environmental Health Series - Air Pollution, NAPCA.

Farvar, M.T. & J.P. Milton (eds.) (1971) Proceedings of the Conference on Ecological Aspects of International Development, New York, Natural History Press.

Federal Water Quality Federation (1969) Storet System Handbook, Division of Technical Support, Pollution Surveillance Branch.

Feltz, H.R. (1969) Monitoring Program for the Assessment of Pesticides in the Hydrologic Environment, Washington, Water Resources Division, U.S.G.S.

Field, N.C. (1968) "Environment Quality and Land Productivity: A Comparison of the Agricultural Land Base of the USSR and N. America," The Canadian Geographer, 12, 1-14.

Flack, E.J. & M. Shipley (ed.) (1968) Man the The Quality of His Environment, Western Res. Conference Papers, Boulder, University of Colorado Press.

Flawn, Peter T. (1970) Environmental Geology, Harper, New York.

Frye, John C. (1967) 'Geological Information for Managing the Environment, Illinois Geologic Survey," Environmental Geol. Notes, No. 18, 12p.

Garnsey, Morris E. & James R. Hibbs (eds.) (1967) Social Sciences and the Environment: Conference on Present and Potential Contribution of Social Sciences to Research and Policy Formulation in Quality of Physical Environment, University of Colorado Press, Boulder.

Gartrell, F.E. & J.C. Barber (1970) "Environmental Protection - TVA Experience", Journal San. Eng. DW. (ASCE), 96(SA6):

Gates, D.M. (1965) "Energy, Plants & Ecology," Ecology, 46(1, 2), pp. 1-13, 20 refs.

Geiger, Rudolph (1965) Climate Near the Ground, Harvard University Press, Cambridge.

Gibson, U.P. (1971) "Integrating Water Quality Management into Total Water Resources Management", Critical Review in Environmental Control, 2: 1-56.

Goodall, D.W. (1970) "Studying the Effects of Environmental Factors on Ecosystems", in Temperate Forest Ecosystems, D.E. Reichle (ed.) Berlin, Springer-Verlag, pp. 19-28.

Goodman, A.S. (1970) "Potential Benefits of Mathematical Models and Computers for Water Quality Management Programs", in Symposium Data & Inst. Water Quality Management, J.E. Kerrigan (ed.): 440-453, Madison, Water Res. Center, University of Wisconsin.

Goodman, G.T. et. al. (1965) Ecology and the Industrial Society, New York, Wiley.

Gould, S.W. (1968) Geo-Code, New Haven, Gould Fund.

Grabau, Warren E. & William N. Rushing (1968) A Computer-Compatible System for Quantitatively Describing the Physiognomy of Veg. Assemblages, Land Evaluation, Papers of a CSIRO Symposium organized in cooperation with UNESCO, 26-31 August, 1968, (ed.) G.A. Stewart, (MacMillan, Australia), pp. 263-275, 2 refs.

Greig-Smith, P. (1964) Quantitative Plant Ecology, 2nd ed. London, Butterworth, 256 pp.

Gysi, M. & D.P. Loucks (1969) A Selected Bibliography on the Analysis of Water Resources Systems, Cornell University, Water Resources and Marine Sciences Center, Ithaca, New York, Publication 25.

Hackett, James E. (1968) "Geologic Factors in Community Development at Naperville, Illinois," Illinois Geologic Survey, Environmental, Geol. Notes, No. 22, 16 p.

Hamilton, H.R. et. al. (1969) Systems Simulation for Regional Analysis an Application to River Basin Planning, Cambridge, Mass., M.I.T. Press, 407 pp.

Hann, R.W. & T.M. Sparr (1970) "A Water Quality Storage and Retrieval System for Regional Application", in Symposium Data & Inst. Water Quality Management, J.E. Kerrigan (ed.): 214-222, Madison, Water Res. Center, University of Wisconsin.

Harrington, J.J. (1966) "Operation Research-Relatively New Approach to Managing Man's Environment", New England Journal of Medicine, 275:

Harrison, C.M. (1971) "Recent Approaches to the Description and Analysis of Vegetation", Transactions, Institute of British Geographers, 52: 113-128.

Henderson, L.J. (1913) The Fitness of the Environment, New York, Mac-Millan.

Herfindahl, Orris C. & Allen V. Kneese (1965) Quality of the Environment: An Economic Approach to Some Problems in Using Land, Water, and Air, Johns Hopkins Press, Baltimore.

Herfindahl, O.C. (1969) Natural Resource Information For Economic Development, Resources for The Future, Baltimore, The Johns Hopkins Press, 212 pp.

Hilpman, Paul L. et. al. (1968) (The Kansas Geological Survey Study Committee) "A Pilot Study of Land-Use Planning and Environmental Geology," State Geological Survey of Kansas & The University of Kansas, 63 p.

Hoover, T.E. & R.A. Arnoldi (1970) "Computer Model of Connecticut River Pollution", Journal of Water Pollution Control Federation, 42(2): 67-76.

Hudson, H.E. & J.B. Stall (1952) "Getting the Facts Through Surveys and Investigations", Journal of Soil & Water Conservation, 7(1): 11-15.

Idso, Sherwood B. & Donald G. Baker (1968) "Naturally Varying Energy Environment and its Effects Upon Net Photosyntheses," Ecology 49, 311-316.

International Association of Scientific Hydrology (1965) Symposium on the Design of Hydrological Networks, Held at Quebec June 15-22, 1965, I.A.S.H., Gentbrugge, 816 pp.

Isherwood, W. C. (1970) "Use of Digital Computers in Processing, Publishing and Analyzing Hydrological Data", Nordic Hydrology, 1(1): 38-55.

James, I. C., et. al. (1969) "Relative Importance of Variables in Water Resources Planning", Water Resources Research, 5(6): 1165-1175.

Jarrett, H. (ed.) (1966) Environmental Quality in a Growing Economy, Johns Hopkins Press, Baltimore.

Jennings, B. H. and J. E. Murphy (ed.) (1966) Interactions of Man and His Environment, Proceedings of the Northwestern University Conference, Evanston.

Kerrigan, J. E. (ed.) (1970) Data and Instrumentation for Water Quality Management, Proceedings from Symposium held at Madison, Wisc., July 21-23, Joint Committee on Water Quality Management Data, Conference of State Sanitary Engineers, Water Resources Center, 534 pp.

Kershaw, K. A. (1964) Quantitative and Dynamic Ecology, Arnold, London, 183 pp.

Ketchum, B. H. (1969) "An Ecological View of Environmental Management", Oceanus, 15(2): 15-23.

Kneese, Allen V. (1962) Water Pollution: Economic Aspects and Research Needs, Johns Hopkins Press, Baltimore.

Kneese, Allen V. and Blair T. Bower (1968) Managing Water Quality: Economics, Technology, Institutions, Johns Hopkins Press, Baltimore.

Lambert, J. M. and W. T. Williams (1966) "Multivariate Methods in Plant Ecology. VI. Comparison of Information-analysis and Association-analysis", Journal of Ecology, 54(3), pp. 635-664, 16 refs.

Langbein, W. B. and W. G. Hoyt (1959) Water Facts for the Nation's Future: Uses and Benefits of Hydrological Data Programs, Conservation Foundation, Ronald, New York, 288 pp.

Langford, R. H. and G. H. Davis (1970) "National Systems for Water Data", Journal of Hydraulics Division, ASCE, 96(498): HY7 1391-1402.

Langley, P. G., R. C. Aldrich, and R. C. Heller (1969) "Multi-Stage Sampling of Forest Resources by Using Space Photography", in Second Annual Earth Resources Aircraft Program Status Review, Vol. II, Agriculture, Forestry, and Sensor Studies (September 16-18), NASA, Manned Spacecraft Center, Houston, Section 19, pp. 1-21.

Lanyon, R. and J. Kurland (1971) "Monitoring System Boosts Water Data Collection", Water and Wastes Engineering, 8: 20-23.

Larsh, R. N. et. al. (1970) "Aerial Photography to Detect and Evaluate Air Pollution Damaged Ponderosa Pine", Journal of Air Pollution Control Association, 20(5): 289-292.

Leinwand, G. (ed.) (1969) Air and Water Pollution, Washington Square, New York.

Leopold, L. B. and W. W. Emmett (1965) "Vigil Network Sites--A Sample of Data for Permanent Filing", International Association of Scientific Hydrology Bulletin, 10(3): 12-21.

Lewis, J. L., J. H. McDermott and P. L. Taylor (1971) "Making Information Out of Data", Journal of Water Pollution Control Federation, 43(9): 1902-1911.

Lieberman, A. and P. Schipma (1969) Air Pollution Monitoring Instrumentation, NASA, Office of Technology Utilization, 74 pp.

Liebman, H. (1969) Atlas of Water Quality: Methodik and Practical Condi-tionie", R. Oldenburg, Munich.

Litton, R. Burton, Jr. (1968) "Forest Landscape Description and Inventories--A Basis for Land Planning and Design", Forest Service Research Paper, PSW-49, Berkeley, California.

Livingstone, D. A. (1966) "Biological Aspects of Weather Modification", Ecological Society of America Bulletin (January), 47: 39-78.

Lyon, W. A. (1970) "Water Quality Information Systems--The Key to Cleaner Waters" in Symposium on Data and Institute for Water Quality Management, J. E. Kerrigan (ed.), Madison, Wisconsin, 2-7.

Maelzer, D. A. (1965) "Environment, Semantics and System Theory in Ecology", Journal of Theoretical Biology, 8: 395-402.

Magill, P. L. (ed.) (1956), Air Pollution Handbook, McGraw-Hill, New York.

Maise, G. (1970) "Concept and Utilities of Ecological Model", Journal of Sanitary Engineering Division (ASCE), 96(SA5):

Major, J. (1969) "Historical Development of the Ecosystem Concept" in The Ecosystem Concept in Natural Resource Management, Van Dyne (ed.), 9-22.

Margalef, D. R. (1958) "Information Theory in Ecology", General Systems, 3: 36-71.

Margalef, R. (1968) Perspectives in Ecological Theory, University of Chicago Press, Chicago.

Marsh, G. P. (1884) The Earth as Modified by Human Action, Scribners, New York, 629 pp.

Martin, E. (1965) Electronic Data Processing--An Introduction, Irwin, Inc., Homewood, Illinois.

Matalas, N. C. and E. J. Gilroy (1968) "Some Comments on the Regionalization in Hydrological Studies", Water Resources Research, 4(6): 1361-1370.

Matalas, N. C. (1970) "Systems Analysis in Water-Resources Investigations", in Computer Applications in the Earth Sciences, D. F. Merriam (ed.), Planum Press, New York, pp. 143-160.

Mayda, Jaro (1968) Environment and Resources, School of Law, University of Puerto Rico, Rio Piedas.

Maylath, R. E. (1970) "New York State Automatic Water Quality Monitoring System" in Symposium on Data and Instruction of Water Quality Management, J. E. Kerrigan (ed.), Water Resources Center, University of Wisconsin, Madison, Wisconsin, pp. 256-260.

Maytin, I. L. and P. B. Henderson (1970) "Hydrologic Data Acquisition and The Instrumentation", Water Resources Bulletin, 6(2): 178-188.

McCabe, L. C., et. al. (1964) "Evaluation of Air Pollution Data", Journal of Air Pollution Control Association, 14(4): 107-109.

McComos, M. R., K. C. Hinkley, and J. P. Kempton (1969) "Coordinated Mapping of Geology and Soils for Land-Use Planning", Illinois Geological Survey Environmental Geological Note 29, 11 pp.

Meadow, C. (1967) The Analysis of Information Systems: An Introduction to Information Retrieval, Wiley & Sons, New York.

Meetham, A. R. (1964) Atmospheric Pollution, 3rd Edition, Pergamon Press, New York.

Melin, R. (1970) "Hydrological Regions in Scandinavia and Finland", Nordic Hydrology, 1(1): 5-37.

Milford, S. N., G. C. McCoyd, L. Aronowitz, J. H. Scanlon, and C. Simon (1971) "Developing a Practical Dispersion Model for an Air Quality Region", Journal of Air Pollution Control Association, 21(9): 549-554.

Miller, L. D., and C. F. Cooper (1969) "Analysis of Environmental and Vegetative Gradients in Yellowstone National Park from Remote Multispectral Sensing" in P. L. Johnson (ed.), Remote Sensing in Ecology, University of Georgia Press, Athens, Georgia, pp. 108-131.

Molof, A. H. (1970) "Social Implications of Automation in Environmental Science", Technicon Quarterly, 2(1): 12-14.

Moody, D. W. (1970) "Organizing a Data Collection Program for Water Resources Planning, Development and Management" in Symposium on Data and Instruction of Water Quality Management, J. E. Kerrigan (ed.), Water Resources Center, University of Wisconsin, Madison, Wisconsin, pp. 325-335.

Mordy, W. A. and P. A. Sholtup (1970) "Directory of Organizations Concerned with Environmental Pollution", State University College, Fredonia, New York.

Morgan, P. V. (1970) "Basic Data Requirements to Evaluate Water Pollution in Quality Control Programs" in Symposium on Data and Instruction of Water Quality Management, J. D. Kerrigan (ed.), Water Resources Center, University of Wisconsin, Madison, Wisconsin, pp. 33-56.

Morrison, D. L., et. al. (1970) "Technical, Intelligence and Project Information System for the Environmental Health Service. Vol. I, Management Assistance and Planning", National Technical Information Service, Battelle, Institute, Columbus.

Mukammal, et. al. (1968) Air Pollutants, Meteorology, and Plant Injury, WMO, Technical Note No. 96.

Murdock, G. B. (1970) "A Systems Approach to Water Quality Data Management" in Symposium on Data and Instruction of Water Quality Management, J. E. Kerrigan (ed.), Water Resources Center, University of Wisconsin, Madison, Wisconsin, pp. 57-75.

NAPCA (1968) "Storage and Retrieval of Air Quality Data", U. S. Department of Health, Education, and Welfare, Public Health Service, Consumer Protection and Environmental Health Service.

National Academy of Sciences (1970) Institutions for Effective Management of the Environment, Report of the Environmental Study Group, Environmental Board, NAS, National Academy of Engineering, Washington, D. C.

Nebraska Department of Roads (Division of Materials and Tests) (1962) Application of Soil Survey Information in Nebraska, State of Nebraska.

Neiberger, M. (1970) Artificial Modification of Clouds and Precipitation, World Meteorological Organization, Technical Note No. 105, 33 pp.

Neilon, J. R. and E. Terauchi (1969) Standards and Procedures for the Presentation of Processed Data in Digital Form, World Weather Watch Planning Report No. 29, World Meterological Organization, 39 pp.

Nelson, D. J. (1970) "Measurement and Sampling of Outputs from Watersheds" in Temperate Forest Ecosystems, D. E. Reichle (ed.), Springer-Verlag, Berlin, pp. 257-267.

North, G. W.,(1971) "Remote Sensing of Environmental Pollution" in International Workshop on Earth Resources Survey System (May 3-14, 1971) Vol. II, NASA, Washington, D. C., pp. 291-301.

Oak Ridge National Laboratories (1970) "National Science Foundation Interdisciplinary Research Relevant to Problems of Our Society", Progress Report, Summer, 128 pp.

Odum, H. T. (1971) Environment Power and Society, Wiley, New York, 331 pp.

Olsson, G. W. (1964) "Application of Soil Survey to Problems of Health, Sanitation, and Engineering", Cornell University Agricultural Experimentation Station, Memoir 387, 77 pp.

Olsson, G. (1971) "Spatial Sampling: A Technique for Acquisition of Geographic Data from Aerial Photographs and Maps", Final Report for U. S. Army Topographic Laboratories, Fort Belvoir, Virginia.

O'Riordan, T. (1971) "Environmental Management", Progress in Geography, 3: 175-231.

Ouellette, R. P., D. M. Rosenbaum, and R. F. Greely (1971) "Is There a System for Pollution Madness?" Datamation, 17(8): 30-33.

Palmer, M. D. and J. B. Izatt (1970) "Water Quality Modelling with Submersible Recording Water Quality and Current Meters", in Symposium on Data and Instruction of Water Quàlity Management, J. E. Kerrigan (ed.), Water Resources Center, University of Wisconsin, Madison, Wisconsin, pp. 406-418.

Partain, L. E. (1970) "Land and Water Resources Management for Environmental Improvement", Water Resources Bulletin, 6(2): 229-234.

Perks, W. T. (1970) "Pollution Control and Abatement within the Planning Process" in Man and His Environment, Vol. I, M. A. Ward (ed.), Pergamon Press, Toronto: 185-196.

Pettinger, L. R. (1969) "Multiple Resource Inventory on Space and High-Altitude Photography" in Second Annual Earth Resources Aircraft Program Status Review, Vol. II, Agriculture, Forestry, and Sensor Studies (September 16-18), NASA, Manned Spacecraft Center, Houston, Section 21, pp. 1-19.

Platt, R. B. and J. F. Griffiths (1964) Environmental Measurement and Interpretation, Reinhold, New York.

Price, J. E. (1967) "A Comparison of Traditional and Automatic Methods for Retrieval of Geologic Well Data", M. S. Thesis, University of Iowa.

Prokayev, V. I. (1966) "Man-induced Differentiation of Natural Conditions as a Factor in Physical-Geographic Regionalization", Soviet Geography, Review and Translation, 7: 32-40.

Randerson, D. (1968) "A Study of Air Pollution Sources as Viewed from Earth Satellites", Journal of Air Pollution Control Association, 18(4): 249-253.

Rapp, R. R. and R. E. Huschke (1964) Weather Information: Its Uses, Actual Potential, Rand Corporation, Santa Monica, California.

Reinig, W. C. (ed.) (1970) Environmental Surveillance in the Vicinity of Nuclear Facilities, Thomas, Springfield.

Ridker, R. G. (1967) Economic Costs of Air Pollution, Praeger, New York, 214 pp.

Ringenoldus, J. C. (1970) "Water Resources and Regional Land-Use Plan" Journal of Sanitary Engineering Division (ASCE), 96(SAG):

Robinove, C. J. (1967) "Remote-Sensing Potential in Basic Data Acquisition" Water Resources Bulletin, 3(3): 32-45.

Robinove, C. J. (1968) "The Status of Remote Sensing in Hydrology" in Proceedings of the 5th Symposium on Remote Sensing of Environment (April 16-18, 1968), Willow Run Laboratories, University of Michigan, Ann Arbor, Michigan, pp. 827-831.

Roche, W. M. (1970) "Organizing a Data-Collection Program" in Symposium on Data and Instruction of Water Quality Management, J. E. Kerrigan (ed.), Water Resources Center, University of Wisconsin, Madison, pp. 183-191.

Rowe, S. M. (1969) National Aerometric Data System, Air Quality Section, Status Report, Division of Air Quality and Emission Data, NAPCA.

Rubinoff, M. (ed.) (1965) Toward a National Information System, Proceedings of the Second National Colloquium of Information Retrieval, Philadelphia, Pennsylvania, Spartan, Washington.

Russell, C. S. and H. H. Landsberg (1971) "International Environmental Problems--A Taxonomy", Science, 172: 1307-1314.

Saltzman, B. E. (1970) "Significance of Sampling Time in Air Monitoring" Journal of Air Pollution Control Association, 20(10): 660-665.

Sand, P. F. (1970) National Pesticide Monitoring Program, Report of Subcommittee on Pesticides of the Cabinet Committee on the Environment, Washington, D. C.

San Francisco (1968) "Combined Pollutant Indices for the San Francisco Bay Area", Information Bulletin No. 10-68, Bay Area Air Pollution Control District.

Scherz, J. P. and A. R. Stevens (1970) "An Introduction to Remote Sensing for Environmental Monitoring", Report No. 1, Remote Sensing Program, University of Wisconsin, Madison, Wisconsin, 80 pp.

Searle, V. C. et. al. (1966) Thesaurus of Air Pollution Terms, U. S. Public Health Service, Scientific Communications, Inc.

Sena, J. A. (1970) "The Water Management Information System (WAMIS)" in Symposium on Data and Instruction of Water Quality Management, J. E. Kerrigan (ed.), Water Resources Center, University of Wisconsin, Madison, Wisconsin, pp. 430-439.

Sewell, W. R. D. and H. D. Foster (1971) "Environmental Revival: Promise and Performance" Environment and Behavior, 3(2): 123-135.

Showen, C. R. (1970) "Fundamentals of Systems Design" in Symposium on Data and Instruction of Water Quality Management, J. E. Kerrigan (ed.), Water Resources Center, University of Wisconsin, Madison, Wisconsin, pp. 177-191.

Silvestro, F. B. (1970) "Remote Sensing Analysis of Water Quality", Journal of Water Pollution Control Federation, 42(4): 553-561.

Singer, S. F. (ed.) Global Effects of Atmospheric Pollution, Reidel Publishing Company, Dordrecht, Netherlands.

Smith, A. R. (1966) Air Pollution: A Survey Carried Out for the Society of Chemical Industry into the Causes, Incidence and Effects of Air Pollution, Permagon Press, New York, 203 pp.

Smith, E. B. (1970) "A Study of Water Resources Information Services", Water Resources Bulletin, 6(6): 907-919.

Smithsonian Institute (1970) National and International Environmental Monitoring Activities--A Directory, Center for Short-Lived Phenomena, 292 pp.

Smoot, G. F. and J. F. Blakey (1966) "Systems for Monitoring and Digitally Recording Water Quality Parameters", U.S.G.S., Open-file Report, 14 pp.

Spurr, S. H. (1969) "The Natural Resource Ecosystem" in The Ecosystem Concept in Natural Resource Management, Van Dyne (ed.), Academic, New York, pp. 3-7.

Stanley, W. J. and D. D. Cranshaw (1968) "Use of a Computer-Based Total Management System to Support an Air Resources Management Program", Journal of Air Pollution Control Association, 18(3): 158-159.

Steele, T. D. (1970) "Beneficial Uses and Pitfalls of Historical Water Quality Data" in Symposium on Data and Instruction of Water Quality Management, J. E. Kerrigan (ed.), Water Resources Center, University of Wisconsin, Madison, Wisconsin, pp. 346-363.

Steinitz, C. and P. Rogers (1969) A Study of Resource Use in Urbanizing Watersheds, Harvard Graduate School of Design, Harvard University.

Steinitz, C. and P. Rogers (1970) A Systems Analysis Model of Urbanization and Change, MIT Press, Cambridge, Mass., 78 pp.

Stockton, E. L. (1970) "Experience with a Computer Oriented Air Monitoring Program", Journal of Air Pollution Control Association, 20(7): 456-471.

Stoddart, D. R. (1965) "Geography and the Ecological Approach", Geography, 50: 242-251.

Strahler, A. N. (1956) "Quantitative Slope Analysis", Bulletin G.S.A. 67, pp. 571-596.

Strobel, G. and F. Silverstro (1970) "Application of Remote Sensing to Water Quality Management" in Symposium on Data and Instruction of Water Quality Management, J. E. Kerrigan (ed.), Water Resources Center, University of Wisconsin, Madison, Wisconsin, pp. 160-165.

Sukachev, V. N. (1960) "Relationship of Biogeocoenosis, Ecosystem and Facies", Soviet Soil Science (Eng.), 6: 579-584.

Taylor, P. L. (1970) "Experiences with a Water Pollution Control Storage and Retrieval System (STORET) in Symposium on Data and Instruction of Water Quality Management, J. E. Kerrigan (ed.), Water Resources Center, University of Wisconsin, Madison, Wisconsin, pp. 198-207.

Teller, A. (1967) "Air Pollution Abatement: Economic Rationality and Reality", Daedalus (fall), also in America's Changing Environment, R. Revelle and H. H. Landsberg (eds.) (1970), Houghton Mifflin, Boston, pp. 39-55.

Thomas, M. F. and G. W. Whittington (eds.) (1969) Environment and Land Use in Africa, Methuen, London.

Thomas, W. A. (1971) "Indicators of Environmental Quality", Science, 174: 437-438.

Thompson, M. M. (1970) "Mapping for Changing Environment", Journal of Survey and Mapping Division, ASCE, 96(8U2).

Tomlinson, R. F. (ed.) (1971) Environmental Information Systems, Proceedings of the UNESCO/IGU Symposium on Geographical Information Systems, Ottawa, October 1970.

Tri-State Transportation Commission (1970) "Managing the Natural Environment--A Regional Plan for Water, Sewage, Air and Refuse." Connecticut, New Jersey, New York.

U. S. President's Science Advisory Committee (1965) "Restoring the Quality of Our Environment", Washington, D. C.

United States Public Health Service (1966) Air Pollution, a National Sample, Publication No. 1562, 27 pp.

Van Dyne, G. (1969) The Ecosystem Concept in Natural Resources Management, Academic Press, New York.

Wadsworth, L. C. (1968) Measurement of Environmental Factors in Terrestrial Ecology, Blackwell, Oxford.

Ward, M. A. (ed.) (1970) Man and His Environment, Pergamon Press, Toronto, 196 pp.

Watt, Kenneth E. F. (1968) Ecology and Resource Management, a Quantitative Approach, McGraw-Hill, New York.

Weers, D. D. (1970) "An Economical Method of Continuous Collection of Air Pollution Data in Computer Compatible Form", Journal of Air Pollution Control Association, 20(6): 405-406.

Weisburd, M. (1971) "Ecology...The Start of Something Big", Datamation, 17(8): 22-25.

Wilkinson, H. R. (1963) Man and the Natural Environment, Hull, Department of Geography, University of Hull, 35 pp.

Williams, C. B. (1964) Patterns in the Balance of Nature, Academic Press, New York.

Wilson, B. (1968) Environmental Problems, Lippincott, Philadelphia.

Wilson, T. W. (1971) International Environmental Action: A Global Survey, Dunellen, Cambridge, Mass., 364 pp.

Wolozin, Harold (1966) Economics of Air Pollution, Norton, New York.

Woodwell, G. M. (1970) "Effects of Pollution on the Structure and Physiology of Ecosystems", Science, 168(3930): 429-435.

World Meteorological Organization (1970) Meteorological Aspects of Air Pollution, Technical Note No. 106, 69 pp.

Young, A. (1969) "Natural Resource Survey in Malawi: Some Considerations of the Regional Method of Environmental Description" in Environment and Land Use in Africa, M. F. Thomas and G. W. Whittington (eds.), Methuen, London, pp. 355-384.

Young, J. Y. (ed.) (1970) "A Survey of Environmental Science Organizations in the U. S. A." Ecology Center Press, San Francisco.

Youngberg, C. (1965) Forest-Soil Relationships in North America, Oregon State University Press, Corrallis.

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13. ABSTRACT

Environmental information has a variety of uses. The report emphasizes one such use: the monitoring and periodic description of environmental quality. Operational and planned schemes for environmental monitoring are briefly reviewed. The status of remote sensing or data collection is discussed in relation to pertinent environmental elements and variables. The attributes or variables by which the physical environment may be described are outlined along with a measure of human activities, land use. On the basis of the review, the organizational structure of an environmental information system is outlined and discussed.

It is very apparent that the amount of environmental information is enormous and promises to increase in volume at an increasing rate. This and the numerous efforts to monitor various aspects of the environment suggest priorities in the development of an environmental monitoring and information system. Top priority is given to the development of a Coordination and Resource Data System which would monitor data gathering and research activities related to environmental matters. The emphasis is placed on avoiding duplication, an essential prerequisite in a field as diverse and complex as environmental science.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Air Pollution						
Atmosphere						
Biosphere						
Data Collection						
Data Retrieval						
Data Storage						
Environment						
Environmental Impact						
Environmental Variables						
Geology						
Hydrology						
Indices						
Information Systems						
Land Use						
Monitoring						
Remote Sensing						
Soils						
Water Quality						