Working Report: Projected Technological Requirements for Remote Sensing of Terrain Variables

Prepared by
Charles F. Hutchinson, Director
Applied Remote Sensing Program
Office of Arid Lands Studies
College of Agriculture
University of Arizona
Tucson

for
Multispectral Imaging Science Working Group
Geographic Science Workshop
San Antonio, Texas
April 28-30, 1982

Sponsored by
Earth and Planetary Exploration Division
National Aeronautics and Space Administration

April 1982

Working Report: Projected Technological Requirements for Remote Sensing of Terrain Variables

PREFACE

To my knowledge, there are few, if any, references that comprehensively describe landform or drainage characteristics in terms of their spatial or spectral properties. To compensate for the gaps in my own experience in this area, I consulted with colleagues at the University of Arizona in the departments of Geography and Regional Development; Geosciences; Soils, Water, and Engineering; and Electrical Engineering. Except for direct contributions by Victor Baker, I received considerable encouragement and sympathy from this group but no resounding consensus on recommendations. This, I feel, says much about the difficulty of the problem.

INTRODUCTION

There have been two basic approaches to the study of landforms and drainage, and both have relied heavily on remote sensing. One, represented by the collected work of Baker and

Holz, has focused on water and the organization of drainage patterns. The primary goal of this hydrogeomorphic approach has been to achieve a basic understanding of fluvial processes with the hope of developing the ability to predict stream behavior.

The second major approach to the study of landform and drainage has been in terrain analysis. This subject deals with "land" as an assemblage of linked attributes, e.g. soil and vegetation. Terrain analysis is commonly performed to assess land capability for agricultural or engineering purposes.

This working paper reviews some of the contributions of remote sensing to both of these areas with the intention of identifying characteristics that should receive future support in system and sensor configuration planning.

HYDROGEOMORPHOLOGY

Remote sensing applications to the field of hydrogeomorphology during the past 10 years have occurred in three areas: fluvial morphological studies, peak discharge modeling, and hydrogeomorphic floodplain mapping. The data sources for these investigations range from large-scale (1:12,000) to small-scale (1:750,000) orbital photography.

Fluvial Morphological Studies

The recent availability of orbital photography and imagery has provided coverage of hydrological systems formerly inaccessible or unmapped. The Apollo-Soyuz Test Project (ASTP) has provided coverage of the central Amazon basin of South America, affording a first view of many of the smaller rivers and streams within this drainage system. The photography from this joint project allowed the identification of floodplain limits, abandoned channels, changes in land use and vegetation, and settlements, all of which are important in assessing variability and change in hydrological systems (Holz et al, 1979). Another study of drainage system characteristics used ASTP products to measure channel patterns, width, meandering, sinuosity, and relative age of channel features (Holz and Baker, 1979). A problem encountered with this data source is the difficulty in obtaining accurate measurements of sinuosity since the imagery is oblique.

Modeling Peak Discharge

Morphometry involves the measurement and quantification of morphological features of the earth's surface. An important and comparatively recent application of morphometry to the subfield of hydrogeomorphology involves the measurement of landforms related to drainage with an objective of predicting peak discharge and, indirectly, the extent of flooding for an area.

The "upstream" approach to hydrogeomorphology, in large part, is based on the relationship of discharge to both transient and permanent controls, the latter of which include hydromorphic features of the landscape (Baker, 1976). Parametric modeling of these features has revealed the importance of two fundamental parameters -- drainage density and basin magnitude -- in the relationship.

Both of these parameters can be derived directly from photography using automated digitizing and computer processing techniques to translate them into usable form. While the orbital photography provides less information on low-order streams, it is still useful for evaluating the magnitude of the basin and for identifying higher-order stream segments (Baker, Holz and Patton, 1975).

Despite the demonstrated power of morphometric measurements in predicting discharge, the application has been given relatively little use, owing in large part to:

1. The tedious task of measuring parameters such as drainage density, bifurcation ratio, and stream order;
2. Difficulties of data acquisition and variable resolution of data sources such as maps, photographs, and imagery; and,
3. Subjective errors of judgment resulting from manual

interpretation (Baker, Holz and Hulke, 1974).

Peak discharge modeling of watersheds involves the collection and derivation of relationships between streamflow and characteristics of the drainage system such as channel density, order, drainage basin area, and relief. One study identified 995 first-order streams, gullies, and segments within a 3.4-square-mile area using conventional large-scale (1:13,000) black-and-white aerial photography (Patton and Baker, 1976). A more detailed investigation compared both medium- and large-scale black-and-white and color infrared photography (1:48,000 and 1:123,000, respectively) for drainage parameters including presence of standing water, land use change, alluvial surfaces, erosion and soil change, bedrock exposures, and first-order stream frequency (Baker, Holz and Hulke, 1974). The results of this study indicate that the scale is less critical than the use of color infrared rather than black-and-white photography. The investigators identify only one less first-order stream on the small-scale (95) than on the medium-scale color infrared photography (96), but can discern only 84 first-order channels on the medium-scale black-and-white photography.

A more intensive comparative investigation used conventional large-scale photography (1:20,000), with Skylab EREP 190A/B imagery (1:750,000 and 1:500,000, respectively), to determine drainage area, Strahler stream order, Shreve magnitude, and number of segments by order (Baker, 1976). This investigation reveals that resolution is more critical between the orbital photographs in identifying stream parameters, since the investigators identify only 14 first order streams on the smaller-scale photography in contrast to 44 on the larger-scale photography. The latter is nearly as effective a data source as conventional topographic maps. A major problem encountered with orbital photography is the determination of relief, a critical parameter in the discharge model (Baker, Holz and Patton, 1975).

Flood Hazard Mapping

Remote sensing data also have been used for "down-stream" evaluation of flood hazard by mapping abandoned river features and vegetation indicative of terrain that is rarely flooded (Baker and Holz, 1978). The utility of geomorphic mapping of flood hazard zones lies in its potential use for statewide or regional planning activities to provide interim flood hazard information before detailed hydrological studies at a local scale. The immediate deficiencies of these techniques include improved spatial resolution of imagery, increased coverage frequency for flood-effect assessment, and evaluation of morphometric measurements and their relationship to discharge in climatic and physiographic realms outside of those already tested.

One study used small-scale (1:116,000) color infrared photography to define a flood hazard area based on the identification of channel forms, regional flood lines, and texture of sediments (Baker, 1976). This same study also revealed the observable extent of flooding from pre- and post-event image comparison using 1:123,000 high-altitude photography and 1:750,000 Skylab photography. This method of multitemporal analysis also has been used to estimate recurrence intervals of flooding (Baker, Holz, and Patton, 1975).

Other surface features have been used to evaluate flood-prone areas on aerial photography. One study, using high altitude color infrared photography, identified vegetation that is typically found in floodplains (Baker and Holz, 1978). This method, which requires extensive field support for data verification, is valuable primarily in arid areas having comparatively sparse vegetation.

TERRAIN ANALYSIS

Terrain analysis (also variously known as land classification and integrated survey) and remote sensing have been closely linked since the concept first was applied extensively in Australia. Major publications on terrain analysis (Stewart, 1968; Mitchell, 1973; and Thie and Ironside, 1976) have dealt extensively with remote sensing techniques.

Recently, a book was published dealing specifically with remote sensing and terrain analysis (Townshend, 1981).

A number of projects covering a large part of the earth's surface have been done (for example, Perrin and Mitchell, 1970). However, techniques for mapping terrain have been and are criticized for the subjective ways in which units are sometimes recognized (Hutchinson, 1981). As a result, a recognized sub-branch of terrain analysis has focused on the development of quantative landform parameters (Mabbut, 1968). Quantitative criteria for describing landforms, developed for use with aerial photography, range from very detailed (Parry, Heginbottom and Cowan, 1968; scale of 1:5,000) to very gross (USAWES, 1959; scales of 1:400,000 to 1:5 million). Generally, these criteria were developed for rural development planning or military applications and thus have had a limited distribution.

Quantative assessment of terrain variables for specific applications use many of the same features identified for hydrogeomorphological studies. One application used remote sensing to assess trafficability in remote areas for off-road vehicles. The parameters used include surficial geology, percent of area permanently waterlogged, tree density, and micro-relief. Conventional aerial photography at 1:31,680 provided data for the first three parameters, while 1:6,000 scale was needed for accurate assessment of the last two parameters (Schreier and Lavkulich, 1978).

A secondary data input to this system was from Landsat 1 digital data. Bands 4 and 7 are used to contrast vegetation and water cover, improving the overall mapping of trafficability (Schreier and Lavkulich, 1979).

Land classification in the broadest sense involves delineating areas in which a recurring pattern of topography, soils, and vegetation occurs. Remote sensing is demonstrated as a data source for structural characteristics of the topographical factor by aiding to identify stream frequency and various "ecological" factors, including vegetative cover (King, 1970). Both relief:frequency (R:F) and relief:density (R:D) curves were employed in defining land systems in a subsequent study, with frequency and density characteristics obtained from 1:125,000 photo mosaics. The relief was determined stereoscopically from 1:60,000 stereopairs (King, 1972).

Land classification also has involved modeling of terrain features such as structural characteristics of diastrophic forms (fault systems and their orientation), drainage frequency, and channel patterns of width, length, variability, and sinuosity (Speight, 1977). These parameters were successfully derived from 1:40,000 aerial photography over a remote area of Papua, New Guinea. The author cites a 20-meter limit of resolution, considered to be adequate for the scale of the study of an area of 5,000 square kilometers.

Because of the limited applications, restricted distribution, and various scales employed in most of these studies, no summaries of criteria have been prepared. Although there is increasing contact between groups involved in terrain analysis (witnessed by the international meetings held in Bratislava, Czecholslovakia, in 1979 and Veldhoven, The Netherlands, in 1981), it is unrealistic to expect a consensus on landform parameters.

RECOMMENDATIONS

The recurring theme presented here is that there is little consensus on or guidance for the measurement of landform parameters and, as a result, that it is difficult to recommend specific spatial and spectral resolutions without extensive background research that attempts 1) to synthesize work done on quantitative descriptions of landforms, and 2) to determine regional variation in selected quantitative parameters.

The Committee on Earth Sciences of the Space Science Board, National Research Council, has struggled recently with a set of similar problems in developing recommendations for acquiring of orbital imagery for use in monitoring geomorphic processes. The Committee's conclusions were as follows:

1. The program of future research must achieve a balance between existing, proven sources of data and the development of of space-measurement systems employing

techniques proven useful in the laboratory.

2. Digital topographic data must be acquired for all land surfaces as a primary means to determine the morphology of the continental crust.

3. The determination of morphology can best be achieved with a combination of this topographic data and digital imagery in the visible and near-infrared wavelengths. Digital radar imagery also can provide considerable primary information on landforms.

4. A global program of orbital observations is needed for comparing hydrological systems.

5. Orbital sensors must obtain a ground resolution of 30 meters or less, and a frequency of coverage of two days to one week to provide detail for process mapping.

6. On scientific and strategic grounds, a coordination of space, airborne, and ground investigation measurements is indispensable for a global program.

7. NASA must continue to periodically review the development of instruments and measurement techniques to insure that current applications needs are being met (National Research Council, Space Science Board, Committee on Earth Sciences, 1982).

Clearly, these recommendations are intended to guide policy and the general direction of research and program development, rather than to serve as a basis for system design. Without additional groundwork, it is unlikely that we can do much better.

General Recommendations for Further Work

Both approaches to the study of landform and drainage would benefit by improvements beyond the 30-meter resolving capability of Landsat D. Optimal resolution values for 1) detecting low-order streams, 2) monitoring erosion, and 3) identifying vegetative cover are likely to vary from region to region. To determine these values, it is recommended that:

1. An exhaustive literature search be performed in the general and restricted publications describing specific parametric terrain analyses;
2. Field studies of selected watersheds be conducted in several different climatic regions to estimate optimal resolution for different environments; and,
3. An effort of international scope be made to define those attributes of landforms and vegetation that may be evaluated by photointerpretation, and a formal descriptive technique adopted to facilitate systematic improvement in techniques of mapping or extrapolation (Speight,1977).

References

Baker, Victor R. 1976. "Hydrogeomorphic methods for the regional evaluation of flood hazards." Environmental Geology 1: (1976), pp. 261-281.

Baker, Victor R., and Robert K. Holz. 1978. Remote Sensing of Flood Hazards in Central Texas. Austin, Texas: Texas Natural Resources Information System (TNRIS-003). 19 pp.

Baker, Victor R., Robert K. Holz, and Steven D. Hulke. 1974. "A hydrogeomorphic approach to evaluating flood potential in central Texas from orbital and suborbital remote sensing imagery." Environmental Research Institute of Michigan, Proceedings of the Ninth International Symposium on Remote Sensing of the Environment (15-19 April, 1974). pp. 629-645.

Baker, Victor R., Robert K. Holz, and Peter C. Patton. 1975. "Flood hazard studies in central Texas using orbital and suborbital remote sensing imagery." Proceedings of the NASA Earth Resources Survey Symposium, Houston, Texas (June, 1975). pp. 2253-2294.

Holz, Robert K. and Victor R. Baker. 1979. "An examination of fluvial morphological characteristics of western Amazon streams from Apollo-Soyuz photographs." American Water Resources Association, Satellite Hydrology (June 1979), n.p.

Holz, R.K., V.R. Baker, S.M. Sutton Jr., and M.M. Penteado-Orellana. 1979. "South American river morphology and hydrology." Apollo-Soyuz Test Project, Summary Science Report (Vol. II), NASA Special Publication 412, pp. 545-594.

Hutchinson, Charles F. 1981. "Use of digital Landsat data for integrated survey." Arid Lands Resource Inventories: Developing Cost-Efficient Methods (La Paz, Mexico - Nov. 30-Dec. 6, 1980), U.S. Department of Agriculture, Forest Service, General Technical Report WO-28. pp. 240-249.

King, R. Bruce. 1970. "A parametric approach to land system classification." Geoderma, 4:(1970), pp. 37-46.

___________. 1972. "Relief-stream frequency (R-F) diagram: method of displaying physiographic regions." Journal of Geology 80:6(Nov. 1972), pp. 740-743.

___________. 1975. "A comparison of information theory interdependence and product-moment correlation analyses as applied to geomorphic and soils data." Zeitschrift fur Geomorphologie, 19:4(Dec. 1975), pp. 393-404.

Mabbutt, J.A. 1968. "Review of concepts of land classification," in G.A. Stewart, ed., Land Evaluation. Melbourne: Macmillan of Australia.

Mitchell, Colin. 1973. Terrain Evaluation: The World's Landscapes. London: Longman Group Ltd. 221 pp.

National Research Council, Space Science Board, Committee on Earth Sciences. 1982. A Strategy for Earth Science from Space in the 1980's. (Part I: Solid Earth and Oceans). Washington, D.C.: National Academy Press. 99 pp.

Parry, J.T., J.A. Heginbottom, and W.R. Cowan. 1968. "Terrain analysis in mobility studies for military vehicles." in G.A. Stewart, ed., Land Evaluation. Melbourne: Macmillan of Australia.

Patton, Peter C., and Victor R. Baker. 1976. "Morphometry and floods in small drainage basins subject to diverse hydrogeomorphic controls." Water Resources Research, 12:5 (October 1976), pp. 941-952.

Perrin, R.M.S., and C.W. Mitchell. 1970. "An appraisal of physiographic units for predicting site conditions in arid areas." Military Engineering Experimental Establishment Report No. 1111 (2 vols).

Schreier, H., and L.M. Lavkulich. 1978. "A numerical terrain classification scheme for off-road terrain trafficability assessments." Geoforum, 9:(1978), pp. 225:234.

___________. 1979. "A numerical approach to terrain analysis for off-road trafficability." Photogrammetric Engineering and Remote Sensing, 45:4 (May 1979), pp. 635-642.

Speight, J. Garry. 1977. "Landform pattern description from aerial photographs." Photogrammetria, 32: (1977), pp. 161-182.

Stewart, G.A. (ed.) 1968. Land Evaluation. Melbourne: Macmillan of Australia.

Thie, J., and G. Ironside. 1976. Ecological (Biophysical) Land Classification in Canada. Proceedings of the First Meeting, Canada Committee on Ecological (Biophysical) Land Classification (25-28 May, 1976, Ontario). 269 pp.

Townshend, J.R.G., ed. 1981. Terrain Analysis and Remote Sensing. London: Allen Unwin. 240 pp.

United States Army Engineer Waterways Experiment Station (USAWES). 1959. Handbook: A Technique for Preparing Desert Terrain Analogs. Technical Report No. 3-506.