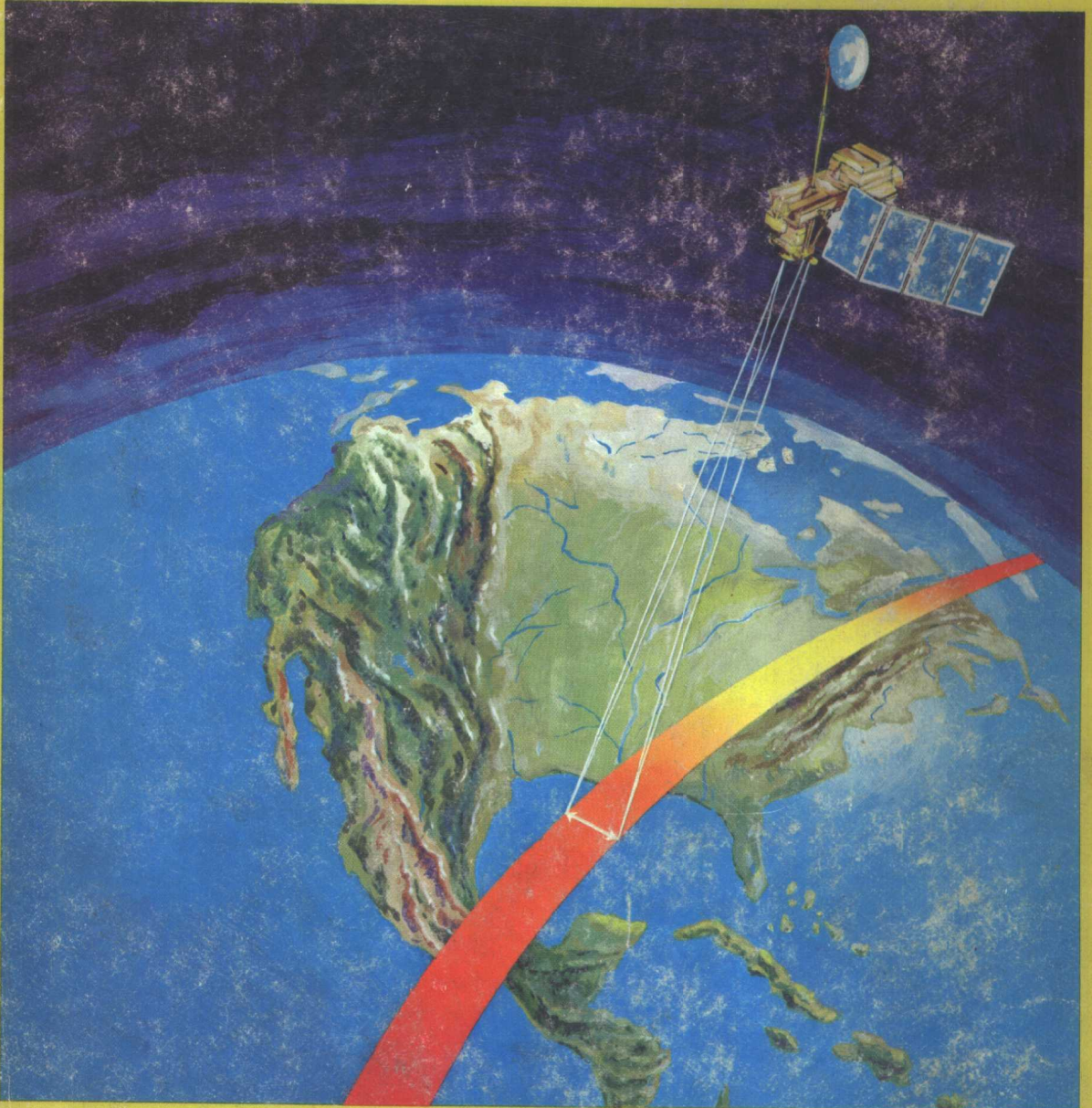


# MANUAL OF REMOTE SENSING



Second Edition

Volume I



American Society of Photogrammetry

# **MANUAL OF REMOTE SENSING**

## **Second Edition**

**In two volumes**

**Volume I  
Theory, Instruments and Techniques**



**Editor-in-Chief  
Robert N. Colwell**

**Volume I Editor : David S. Simonett  
Associate Editor : Fawwaz T. Ulaby**

**Volume II Editor : John E. Estes  
Associate Editor : Gene A. Thorley**

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PHOTOGRAMMETRY**

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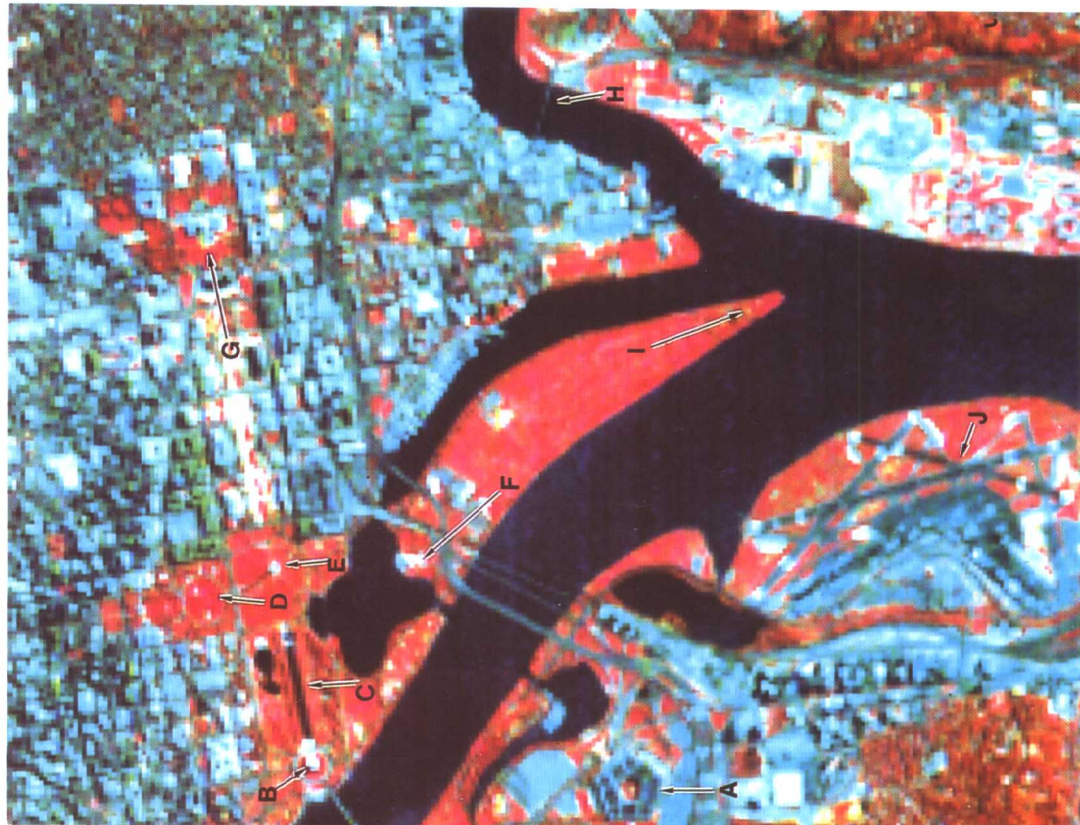
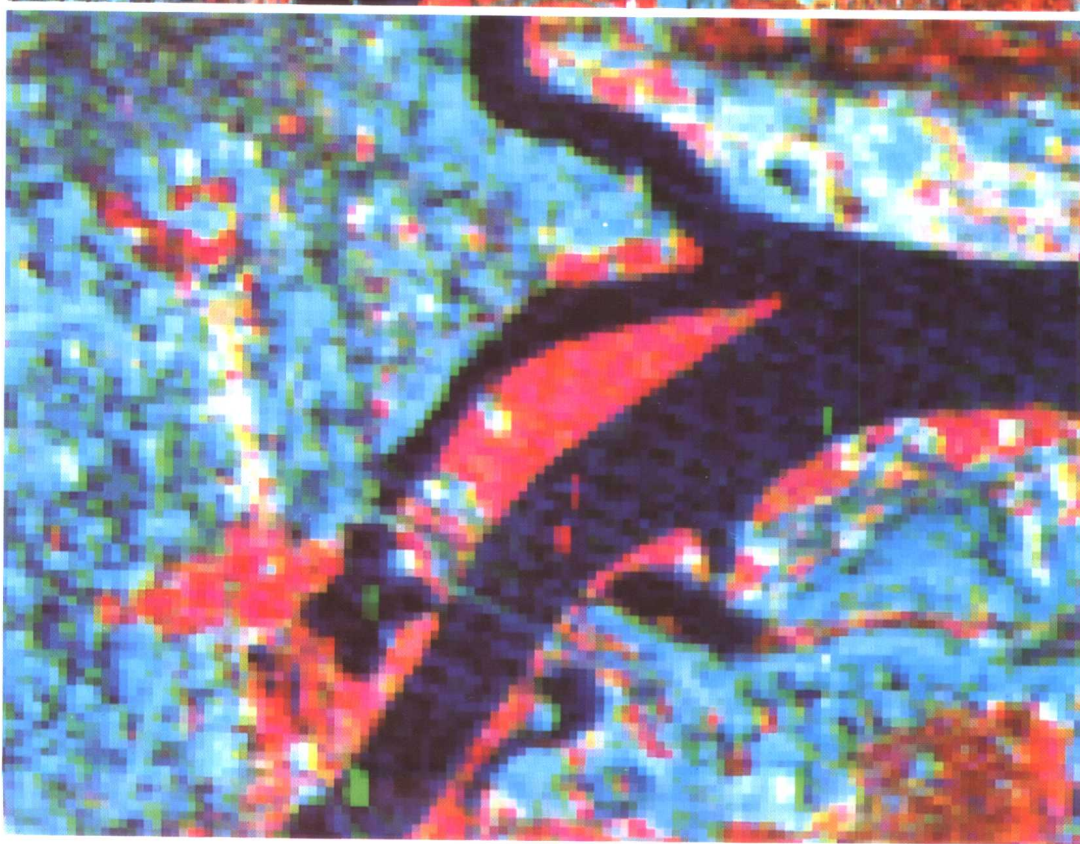
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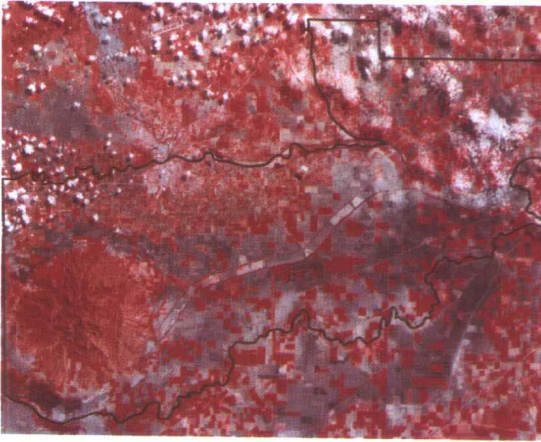
Two color renditions, scale 1/250,000, made from the same scene of Landsat Thematic Mapper imagery acquired on July 20, 1982. This subscene is centered over the Detroit/Windsor area on the boundary between the United States and Canada. *Top:* False color composite image formed by using TM bands 2 (green), 3 (red) and 4 (near infrared) printing them in blue, green and red, respectively. *Bottom:* Natural color composite image formed by printing bands 1 (blue), 2 (green) and (3) red, in blue, green, and red, respectively. Nominally, both color composites have the same spatial resolution, viz. approximately 30 meters. Various kinds of features differ, however, in their multiband spectral signatures. Therefore, the color contrasts among such features usually differ on these two image types. Consequently, the top figure is superior for detecting row patterns at (A), riparian vegetation along stream channels at (C); water channels at (E); vegetated islands at (G); differences in soil and vegetative conditions at (I), and the distinction between ponds, such as (J) (near the Detroit Airport) and cloud shadows, such as (K). The natural color photo is better, however, for detecting sediment plumes at (B); primary and secondary roads at (D); runways and walls at (F) and areas of bare soil at (H). (Imagery courtesy of NASA and Earth Satellite Corporation).





Simultaneously acquired Landsat 4 MSS imagery (left) and TM imagery of the Washington D.C. area, shown here in the form of simulated color infrared enhancements at a scale of approximately 1/50,000. Note the much greater spatial resolution of the TM imagery as evidenced by the appearance of the Pentagon at A; Lincoln Memorial at B; reflecting pool at C; grass-covered ellipse at D; Washington Monument at E (note its shadow); Jefferson Memorial at F; the Capitol at G; Anacostia Bridge at H; Hains Point at I; and National Airport at J. (Courtesy of NASA and the EROS Data Center.)

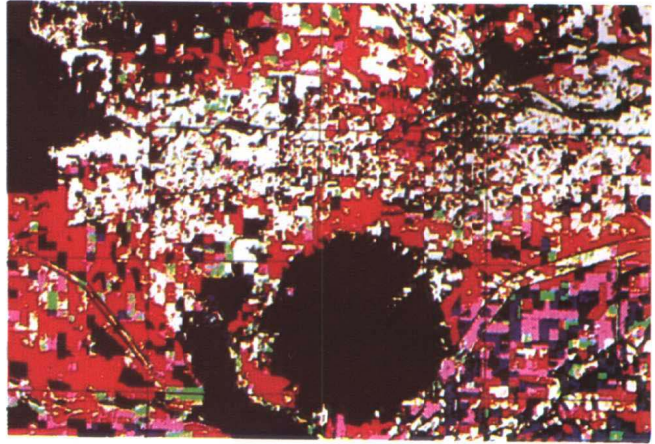




For some resource inventory purposes, one of Landsat's most important capabilities is that of obtaining multitemporal data of the same geographic area. One example is in the inventory and monitoring of agricultural crops in a vast area throughout each growing season. Illustrated in the above three Landsat images is a representative area of the state of California (total area of 100 million acres) in which the objective is to determine the location and acreage of all irrigated lands, each year, the better to manage critical supplies of water. (A), above, was acquired in midsummer, by which time all crops except those being irrigated had matured. Hence on this false color infrared enhancement the red areas are under irrigation and all other areas are not. (B) was acquired in spring so that additional irrigated areas, (mainly early-maturing small grains) that would be missed in (A) are included. Finally (C) was acquired in fall to identify additional irrigated areas that are cropped more than once during the growing season. Some of these areas might have been in a fallow state (between crops) on the earlier coverages. This 3-date direct visual interpretation, when combined with a stratified sample of "ground truth" data, provides estimates of irrigated acreage, year after year, to the required accuracy standard, viz. accurate to within three percent at the 99% probability level. A digital analysis system by means of which a computer can provide estimates of irrigated land using multitemporal Landsat data has also been developed. This system uses the three dates of Landsat described above. The digital data are registered to a 7½ minute USGS quadrangle base. Through use of a simple and inexpensive computer program, the MSS band 7-to-MSS band 5 ratio is used as a vegetation indicator. As a result, irrigated land is classified by actively selecting threshold values above which land is designated as irrigated and below which it is designated as not irrigated. Figure (D) shows for the entire Sacramento Valley (including the area shown in A, B and C), all land that was irrigated. The sequence of irrigation is color coded as follows:

Black — not irrigated	Purple — irrigated fall only	Red — irrigated summer
Blue — irrigated spring only	Green — irrigated spring & summer	and fall
Pink — irrigated summer only	Tan — irrigated spring & fall	White — irrigated spring
		summer & fall

The results of this classification are also combined with a stratified sample of ground data to provide estimates of irrigated land. Map-like products are also derivable from this classification. With the current interest and development of geo-based information systems, the value of Landsat digital data becomes increasingly significant. (Photos courtesy of NASA and Remote Sensing Research Program, University of California, Berkeley).



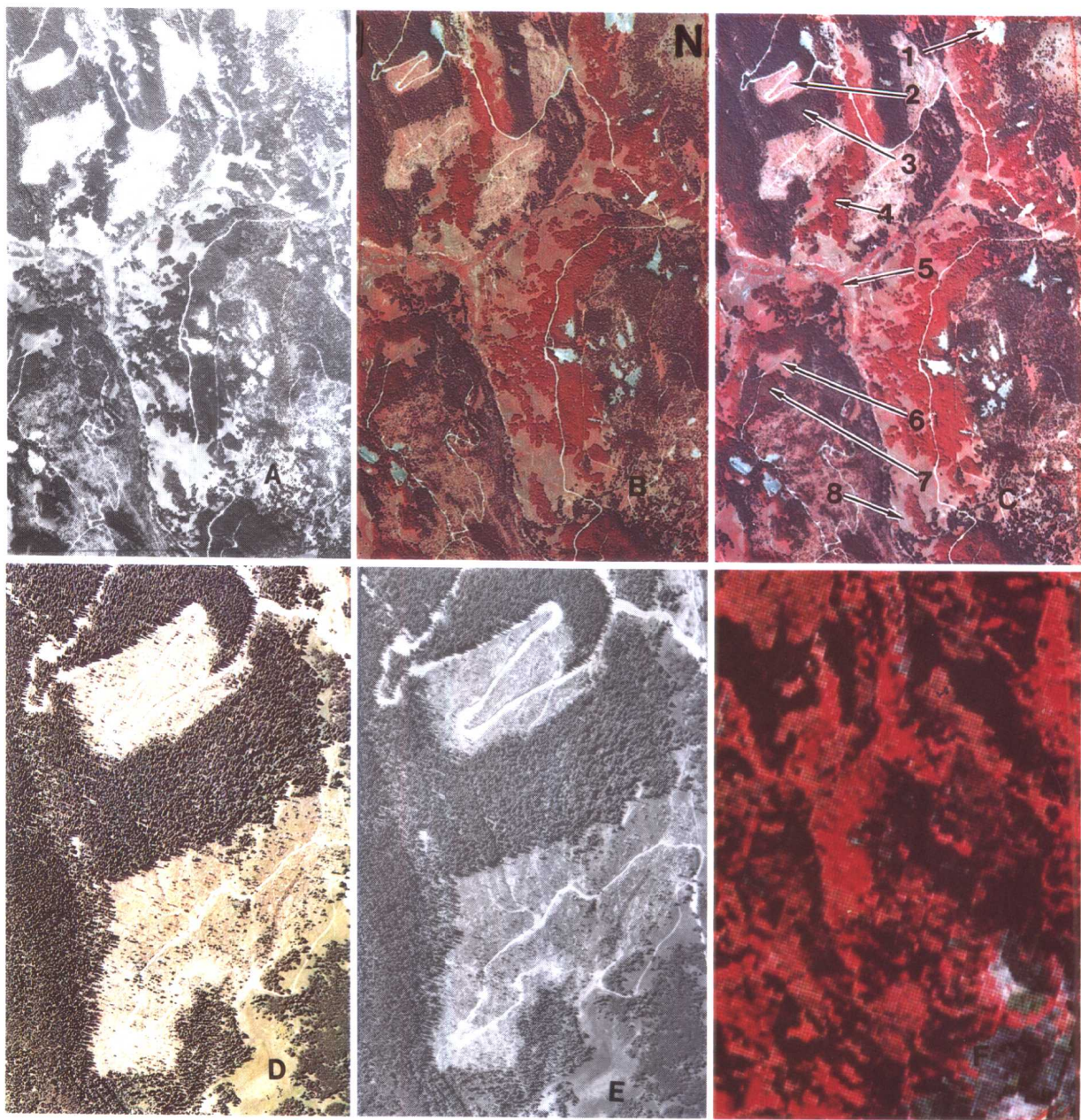




To an increasing extent, remote sensing from within the earth's atmosphere is being accomplished through the use of either the U-2 aircraft, shown here, or a greatly improved version of it, the ER-2, specifically designed for the remote sensing of Earth Resources. For any given U-2 or ER-2 mission, a choice can be made from among a great many types of cameras and other remote sensing devices, including those shown here, which have been letter-coded as follows:

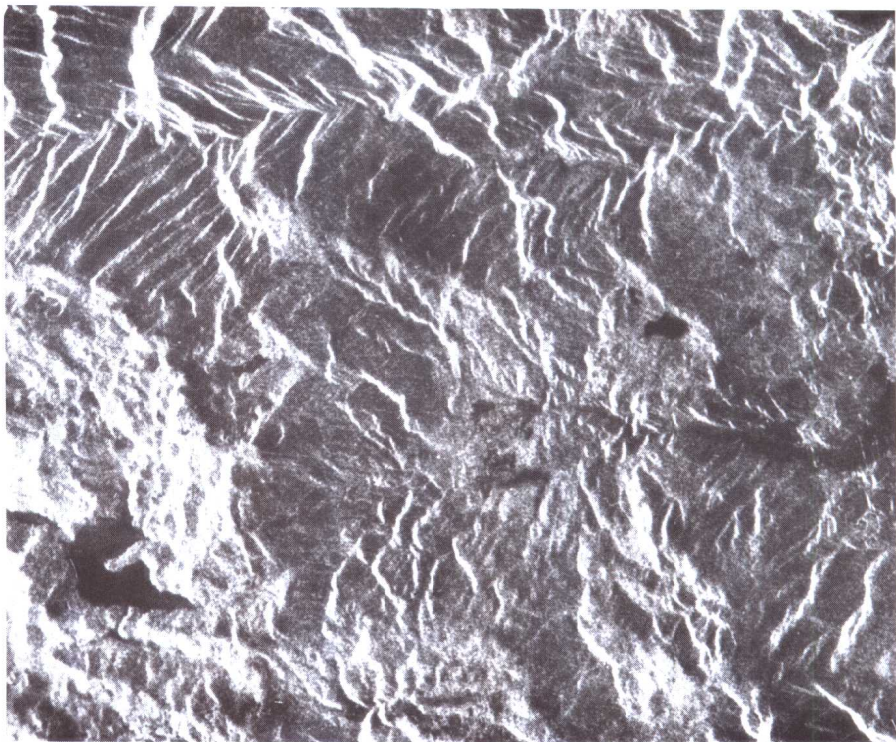
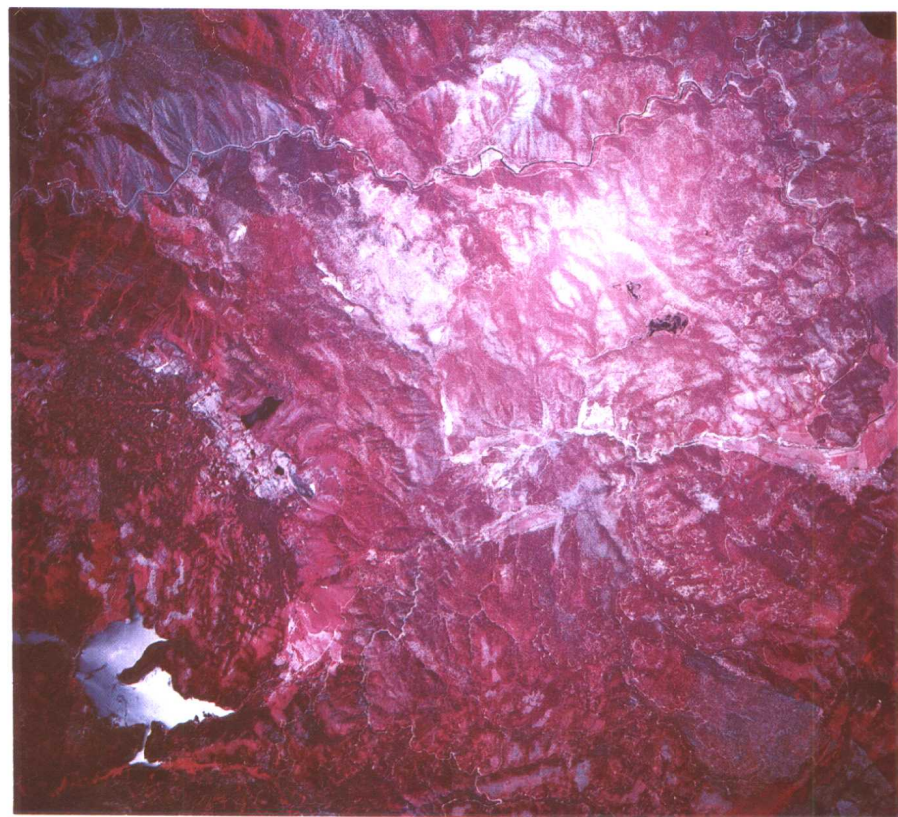
- |   |  |
|---|--|
| A TIRS (Thermal Infrared Scanner)                 | M KA-80A Optical Bar Panoramic Camera        |
| B IRR (Infrared Radiometer)                       | N Dual RC-10 Camera System                   |
| C & D HCMR (Heat Capacity Mapping Radiometer)     | O RC-10/Vinten Multispectral Camera System   |
| E Filter Sampler                                  | P FLO (Infrared Spectrometer)                |
| F OCS (Ocean Color Scanner)                       | Q REFLEX (Resonance Fluorescence Experiment) |
| G ASISGS (Ames Stratospheric In-Situ Gas Sampler) | R SEMIS (Solar Energy Measurements in Space) |
| H Aether Drift Radiometer                         | S CO <sub>2</sub> Collector                  |
| I SCS (Stratospheric Cryogenic Sampler)           | T H <sub>2</sub> O Vapor Radiometer          |
| J HR-73B Camera                                   | U HSI (High Speed Interferometer)            |
| K RC-10/HR-732 Camera System                      | V APS (Aerosol Particulate Sampler)          |
| L HR-732 Tri-Vertical Cameras                     |  |





Some kinds of multiband, multistage imagery are proving to be more useful than others for the making of resource inventories, as evidenced by the above image examples from a test site on the San Juan National Forest, Colorado. Images A, B, and C were all acquired simultaneously from an altitude of 60,000 feet. A is panchromatic minus-blue photography from an AMPS Hasselblad camera; B is Color Infrared photography from a second Hasselblad camera; C is Color Infrared photography from a Wild RC-10 camera. All three are reproduced here at a scale of approximately 1/60,000. In D and E are matching color and black-and-white images, both made from the same frame of aeroneg imagery at a scale of 1/24,000 taken with a Zeiss precision mapping camera. Image F is a Geopac-enhanced Landsat MSS color composite image, scale 1/100,000. As reported on page 1967 of this manual, nearly 40,000 individual photo-interpreter responses were obtained in determining the interpretability of these image types with respect to the resource categories that are labelled in the upper right photo above, viz. 1 = rock, 2 = cut-over (spruce-fir), 3 = spruce-fir, 4 = aspen, 5 = willow, 6 = mesic meadow, 7 = spruce-fir/aspen, and 8 = xeric meadow. (Photos courtesy of NASA and the Nationwide Forestry Applications Program of the U.S. Forest Service.)





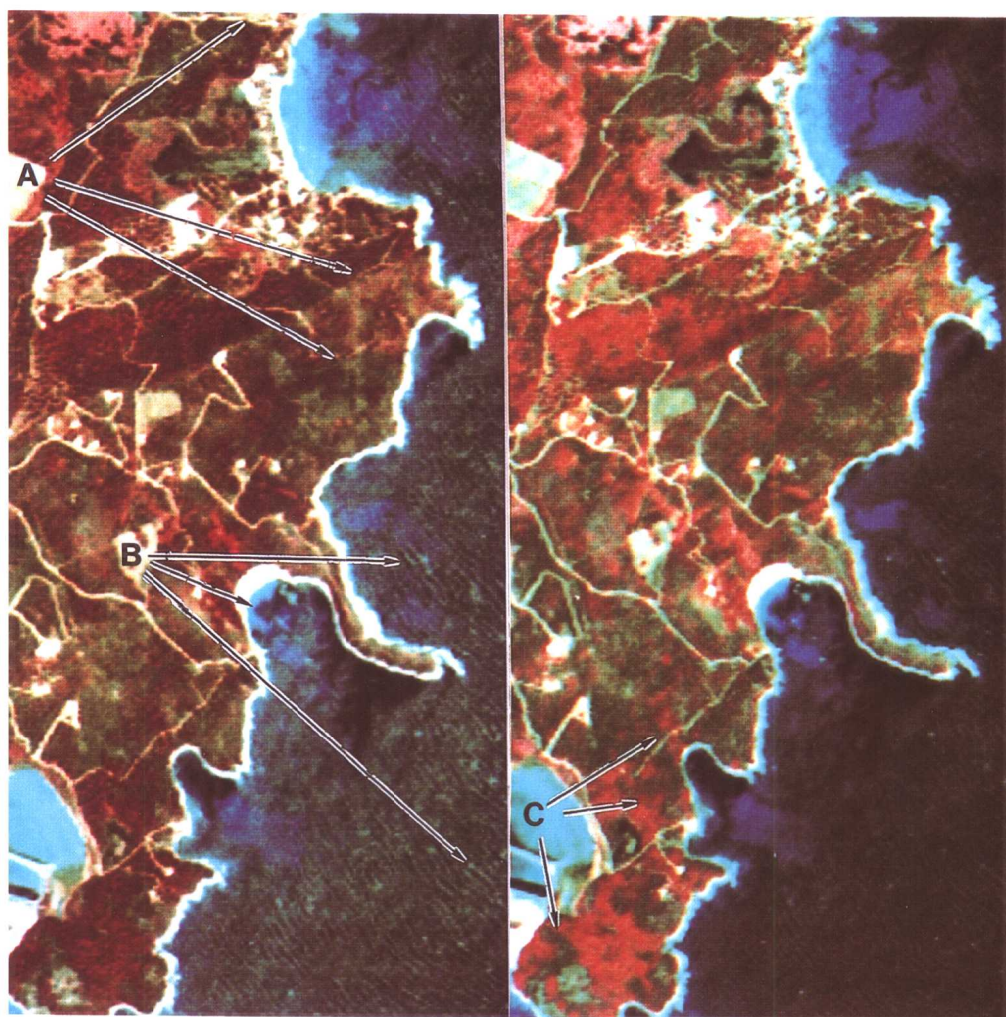
*Left:* Color infrared photography acquired by an RB 57 aircraft from an altitude of 65,000 feet of the NASA Bucks Lake Test Site, California through the use of a Zeiss 6-inch-focal-length metric mapping camera. *Right:* Seasat SAR (synthetic aperture radar) imagery of the same area acquired from an altitude of approximately 850 km (570 mi.) Both images are reproduced here at a scale of about 1/200,000. Note that the SAR imagery not only accentuates topographic features but also exhibits high spatial resolution for many features including lakes and moist areas. If this figure is rotated 180 degrees, radar shadows are made to fall away from the observer and the terrain appears to be reversed in that high features appear low and low features appear high.





*Top:* Radar imagery of the Enos Lake Quadrangle and environs of Idaho's Payette National Forest, acquired from an altitude of 60,000 feet with the AN/APQ 97 side-looking airborne radar (SLAR) system. Note the accentuation of terrain features in this highly glaciated topography. *Bottom:* A low-altitude aerial oblique stereogram that was taken (as indicated by matching arrows on the top and bottom figures) while looking through the notch between North Loon Mountain and South Loon Mountain. Note that while some features are better seen on this low-altitude stereogram, others are better seen on the very high altitude radar imagery. (Courtesy of NASA and the Nationwide Forestry Applications Program of the U.S. Forest Service).





The potential value of applying multi-enhancement techniques to space-acquired imagery is well illustrated by these two simulated SPOT images. The area shown is on the island of Corsica in the Mediterranean Sea. These two enhancements were prepared by applying different degrees of color stretching to Bands 1, 2 and 3 of Daedalus scanner data. The imagery was acquired at 10 meter resolution and preprocessed by the French Space Center, CNES. It was then resampled to obtain the 20 meter resolution used in producing the two color renditions shown above. The *left* image is superior for showing roads at A as well as the details of various water surface and subsurface features, as at B. The *right* image is superior, however, for showing significant vegetation boundaries at C. A comparison of this "subsample" figure with Color Figure 31-261 of Volume II demonstrates the feasibility of extrapolating these detailed interpretations to imagery that is of much smaller scale but covering a much larger geographic area. The original scale of the above figure was 1/62,500. (Imagery courtesy of CNES). See also the excellent simulated SPOT imagery on Frontispiece page viii of Volume II.

**ALL OF THE REMAINING 4-COLOR FIGURES FOR THIS VOLUME APPEAR IN A SINGLE 32-PAGE COLOR SIGNATURE. IN THE TEXT EACH SUCH FIGURE IS REFERRED TO AS A "COLOR FIGURE" AND IS DESIGNATED BY BOTH THE NUMBER OF THE CHAPTER TO WHICH IT PERTAINS AND THE FIGURE NUMBER WITHIN THE CHAPTER. THE COLOR PLATES BEGIN FOLLOWING PAGE 590 AND APPEAR IN SEQUENCE BY CHAPTER AND FIG. NO.**



# FOREWORD

With the publication of the *Manual of Remote Sensing, Second Edition*, the American Society of Photogrammetry completes the ninth in a series of book projects aimed at advancing the science of photogrammetry and remote sensing. Since 1944, the Society has produced this series at an average rate of one major book every five years, each new book bringing forth a text that reflects the most modern aspects of the art. Considering that these landmark publications are produced entirely with volunteer authors and editors, the American Society of Photogrammetry can justifiably take pride in this remarkable series of achievements by its members. The list of major publications includes:

- Manual of Photogrammetry, First Edition, 1944
- Manual of Photogrammetry, Second Edition, 1952
- Manual of Photographic Interpretation, 1960
- Manual of Photogrammetry, Third Edition, 1966
- Manual of Color Aerial Photography, 1968
- Manual of Remote Sensing, First Edition, 1975
- Handbook of Non-Topographic Photogrammetry, 1979
- Manual of Photogrammetry, Fourth Edition, 1980
- Manual of Remote Sensing, Second Edition, 1983

The publication of the second Edition of the *Manual of Remote Sensing* is especially gratifying because it represents a triumph over unfortunate circumstances that beset the project in its early stages. The formidable task of overseeing the preparation of the Second Edition, as Editor-in-Chief, was assigned originally to Professor Leonard Bowden of the University of California at Riverside. The talented Professor Bowden promptly proceeded to the appointment of editors and associate editors for the two volumes of the manual. The organization of the manual, chapter-by-chapter, was developed, a production time table was worked out and an author-editor was selected for each chapter. Then, in May 1979, came a sad and untimely event: Professor Bowden's sudden death of a heart attack. Although he died before the task had gained full momentum, Professor Bowden laid the groundwork for the project and his successor was able to build on that foundation. For the work that Professor Bowden accomplished in initiating the project, the American Society of Photogrammetry acknowledges a profound debt of gratitude and recognizes that the publication of this manual is, in considerable measure, a tribute to his initiative.

Following Professor Bowden's death, careful consideration was given to the selection of a successor with the competence and willingness to assume the formidable task of carrying on a major project initiated by someone else. Fortunately, a man with ideal qualifications and outlook was active in the society, and more fortunately still, he accepted the position when it was offered to him. Professor Robert N. Colwell of the University of California, Berkeley, brought to the position of Editor-in-Chief a distinguished technical background in photogrammetry and remote sensing plus a brilliant record as a writer and editor. As Editor-in-Chief of the society's *Manual of Photographic Interpretation*, published in 1960, he had acquired valuable experience in successfully managing the publication of that popular book. Above all, he had the talent and ability to adjust his outlook to prevailing conditions; this was a paramount consideration in maintaining the continuity and momentum that already existed within the team of some 300 people who were involved in preparing the Manual. Timely grants provided by the U.S. Geological Survey helped to defray certain editorial costs and also some of the costs entailed in preparing the chapter on Geological Applications. The



## MANUAL OF REMOTE SENSING

American Society of Photogrammetry hereby expresses its sincere thanks to the U.S.G.S. for this valuable assistance.

The extent of the trials and tribulations that Bob Colwell endured and conquered during the preparation of this Manual are completely known only to himself. Perhaps Executive Director Bill French and Publications Consultant Morris Thompson, who managed the business and production aspects of the project, have a substantial awareness of the problems that had to be solved. But that is all now history and the *Second Edition of the Manual of Remote Sensing* is now a reality. For this we, the presidents of the American Society of Photogrammetry during development of the Manual of Remote Sensing, Second Edition, congratulate and thank the Editor-in-Chief, the Volume Editors, the Associate Editors, the Author-Editors and all the contributors to this outstanding publication.

Francis H. Moffitt, 1979

Rex R. McHail, 1980

George J. M. Zarzycki, 1981

Allan C. Bock, 1982

William G. Hemple, 1983



## *PREFACE TO THE SECOND EDITION*

As defined in Webster's dictionary, a "Manual" is "a book containing, in concise form, the principles, rules and directions needed for the mastery of an art, science or skill". That definition describes exactly what this 2-volume publication purports to be with respect to the art, science and skill known as "remote sensing". The term "concise" as used in the above definition connotes "the cutting out of all superficialities and the avoidance of elaboration". Nevertheless, Webster asserts that a Manual should be "only as summary as is compatible with an adequate statement of the available information". The authors of this Manual have attempted to be both concise and summary. The fact that, in so doing, they have produced a document of nearly 2700 pages indicates that the multifaceted field of remote sensing has truly come of age.

This maturing process has been due in no small measure to a perception by successive governing boards of the American Society of Photogrammetry over the years that progressively greater recognition should be given to various aspects of a fast-growing field that is now encompassed by the term "remote sensing—the progenitor of which was" photographic interpretation". Briefly stated: (1) in 1952 the Society added greatly to the prestige of this field by devoting an entire chapter in its Manual of Photogrammetry—Second Edition to the subject of "photographic interpretation; (2) in 1960 the Society gave this field another quantum jump in prestige by devoting an entire Manual to the subject of photographic interpretation; (3) by 1975 the Society acknowledged, through publication of its "Manual of Remote Sensing", that the advent of space age platforms, multispectral scanners, and computer-assisted analysis techniques was bringing about a far more encompassing science than had been dealt with in its comprehensive Manual of Photographic Interpretation; and (4) in 1978 the Society formally adopted the recommendation of several of its most visionary remote sensing scientists, including the late Professor Bowden, that work should begin immediately on the preparation of this, the definitive Second Edition of the Manual of Remote Sensing—an effort that was to require four more years to complete after Professor Bowden's untimely death. His initiative and the organizational ability that he demonstrated in getting this second edition underway are hereby gratefully acknowledged. In keeping with the previously mentioned tradition of high level support, two officials at Society headquarters who have greatly facilitated the preparation of this Manual are Morris M. Thompson and William D. French who have served, respectively, as Production Editor and Publications Director.

Throughout much of the time that was spent in producing this Manual the Editor-in-Chief had almost daily dealings with the highly competent Editors of Volumes I and II, Professors David Simonett and John Estes, respectively. In so doing, he gained great respect for their editorial abilities, their maturity of judgment and the great team spirit that they demonstrated in their dealings both with him and with the author-editors of the 36 chapters. Their jobs, in turn, were greatly facilitated by yet another pair of very competent and dedicated individuals, Professor Fawwaz Ulaby and Dr. Gene Thorley, who served as Associate Editors for Volumes I and II, respectively and whose valuable roles in producing this Manual are likewise gratefully acknowledged. Furthermore, our collective tasks were facilitated and the Manual's quality was significantly improved through the editorial reviews, chapter-by-chapter, that were made by members of the Society's Remote Sensing Applications Division. The uniformly high quality that will be found in the figures, tables and page layout throughout this Manual is due very substantially to the dedication and effectiveness of Jane Schott, the printer's representative and Accounts Director for The Sheridan Press.

But in the hierarchy that is required to produce a Manual such as this, the primary people in the trenches are the author-editors and contributing authors for the individual chapters. In a very major sense the high quality that will be found throughout this Manual is a tribute to the professional expertise and dedication of these individuals. We all are greatly indebted to them.



The potential usefulness of an index tends to increase with the size and comprehensiveness of the book to which it applies. It is especially gratifying to know, therefore, that this voluminous Manual contains an index of unusually high quality and thoroughness, thanks to the efforts of one dedicated individual, G. Carper Tewinkel.—a former president of the Society and an indefatigable indexer of its many publications.

There were many other friendly faces that I encountered in the trenches on a daily basis during the chapter-by-chapter editorial skirmishes. I refer to several coworkers of mine in the University's Space Sciences Laboratory, including James Hardin, Kevin Dummer and Betsy Ross. Their professional response to my many requests also is gratefully acknowledged.

When compared with the First Edition, this Second Edition will be found to have major parts that are entirely new, including the comprehensive chapter dealing with Geological Applications—a field in which very substantial advances have been made in recent years. Special thanks are hereby extended to Dr. Richie Williams and his team of more than fifty contributors for preparing the Geology Chapter under difficult circumstances. Most other parts of the Manual are very substantially new. There are some parts however, including those dealing with remote-sensing-related theory, instruments and techniques, which draw extensively on the text and illustrations that appeared in the First Edition of the Manual or even in its predecessor by 15 years—the Manual of Photographic Interpretation. In those limited cases in which the earlier material seemed to be the best, there obviously was little point in replacing it with something that was only second best, however novel it might be.

An overview of some of the most important recent advances in remote sensing technology is provided by the illustrations that appear on the dust jackets and in a preface of color photos for each of the two volumes. It has been possible to greatly increase the number of color photos throughout this Manual through cost savings achieved by placing them in "signatures". Within each chapter, the color figures have been numbered serially with all other figures, even though separated from them. Throughout the text, use of the term "Color Figure" is made where necessary to direct the reader to the nearest color signature.

Now that this tome finally has been completed, a glance at its table of contents will show even the uninitiated person that remote sensing, in its non-military aspects, is primarily useful in the discovery, evaluation, and development of the earth's natural resources and in the intelligent planning for human occupancy of the earth's surface. In the book of Genesis we learn that it was God's plan to give man "dominion over all the Earth . . . and to subdue it". This Manual presents an effort to describe one of the most valuable means to that end that man has yet devised. But quite probably more than a mere search of the Scriptures would be needed to convince the average contributor to this Manual, frustrated as he/she has been by tight deadlines and perplexed by rigid requirements imposed by an uncompromising editor, that preparation of The Second Edition of the Manual of Remote Sensing was in response to a Divine calling. Nevertheless, it is hoped that this, the published product, will convince both the contributors and the readers that the effort was eminently worthwhile.

Among the primary aims, slightly paraphrased, of the American Society of Photogrammetry are these: to advance knowledge concerning and stimulate interest in the science and art of photogrammetry and remote sensing; to provide means for the dissemination of new knowledge and information and thus to encourage the free exchange of ideas and intercourse among those contributing to the advancement of the art; to stimulate student interest in the fields of photogrammetry and remote sensing; and to foster a spirit of understanding and cooperation among the users of aerospace photography in the United States and throughout the world. It is hoped that those using this Manual will share the conviction of those who produced it, that it represents a furthering of all of these aims and that it is an excellent example of cooperative accomplishment that could only have been achieved under the sponsorship of the American Society of Photogrammetry.

Robert N. Colwell  
Editor-in-Chief

Berkeley, California  
January, 1983



## *PREFACE TO VOLUME I*

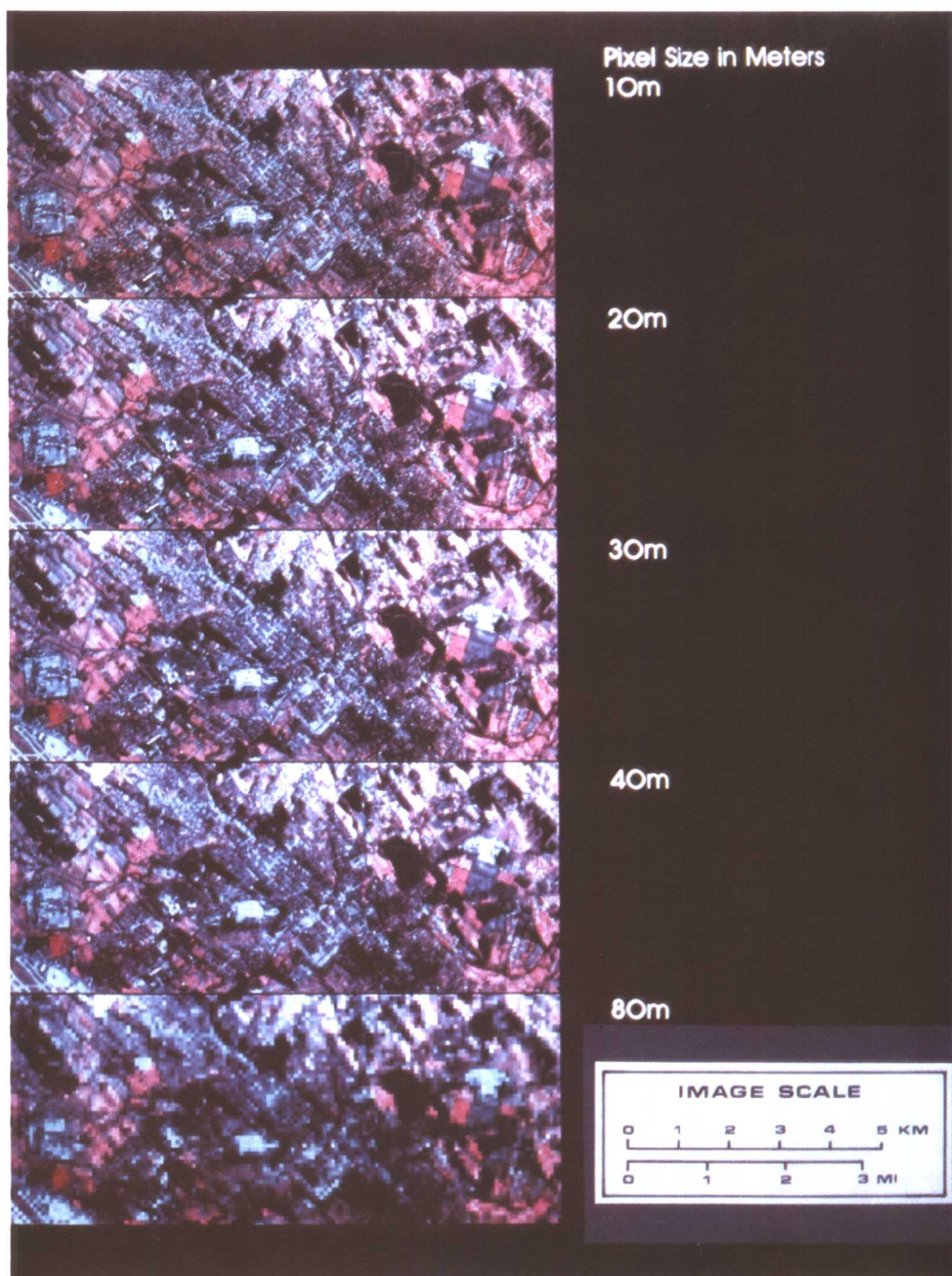
Volume I of the Second Edition of the Manual of Remote Sensing differs from the first edition in the following respects:

- 1) To make the volume more readable and accessible to students we decided to keep the length of each chapter to between 20 and 60 final printed pages (the mean length is 45 pages).
- 2) We start—in some cases finish—most chapters with a list of nomenclature.
- 3) MKS units are employed throughout insofar as feasible.
- 4) We eliminated most of the possible overlaps between chapters except in a few instances. In these we deliberately retained overlap (e.g. between Chapters 17 and 21), because of differences in viewpoint and treatment of the same material.
- 5) The number of chapters has approximately been doubled to 25 and each new chapter has been halved in length and has a narrower focus.
- 6) The material in three chapters has no counterpart in the First Edition: Chapter 16 on Orbital Mechanics; Chapter 19 on Remote Sensing Software Systems; and Chapter 20 on Digital Hardware.
- 7) Eight chapters are so completely revised as to be essentially new: Chapter 1 on the Development and Principles of Remote Sensing; Chapter 12 on Landsat satellites; Chapter 13 on Microwave and Infrared Satellite Remote Sensors; Chapter 14 on Meteorological Satellites; Chapter 17 on Data Processing and Reprocessing; Chapter 18 on Pattern Recognition and Classification; Chapter 21 on Image Geometry and Rectification; and Chapter 22 on Geographic Information Systems and Remote Sensing.
- 8) All the material in the remaining chapters (2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 15, 23, 24 and 25) has undergone substantial revision and updating, and much new material has been added. However, these chapters also incorporate considerable material from the first edition, where that material has not become outdated.

We wish to thank the author-editors and contributors to each chapter. It was a privilege to work with such an outstanding group of professionals, and to learn from them in our editing chores. We also thank Lee Blackledge and Robert E. Davis for their able assistance in editing.

David S. Simonett  
Editor, Volume I

Fawwaz T. Ulaby  
Associate Editor, Volume I



*Fig. 1-7.* Simulation of varying spatial resolutions for an urban test site at Marysville, Tennessee. By using the airport runway located in the lower left corner in each of the images, one can see how changes in spatial resolution can affect interpretability.