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Remote Sensing Evidence and Environmental Law*

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In this article the authors introduce to the legal profession a new but increasingly prominent source of environmental information: remote sensing technology. The first section of the Article provides a preliminary description of this technology and discusses the social and economic factors that underlie its predicted utility for environmental law. The Article then identifies a range of current and projected legal applications of remote sensing. Included in this section is a discussion of cases and administrative hearings which have already

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featured the submission of remote sensing evidence. The third section of the Article evaluates alternative remote sensing techniques and legal applications in the context of the formal rules of evidence as they pertain to the introduction of scientific information. The authors conclude that remote sensing is too diverse an activity to be treated in a reductionist manner. In each distinctive factual and legal setting, the specific characteristics of remote sensing evidence must be examined in terms of the qualifications of expert witnesses, the reliability of the scientific process employed, the conduct of that process in the given case, and compliance of the evidence with authentication and documentary original requirements.

CONTENTS

I

THE UTILITY OF REMOTE SENSING: AN OVERVIEW

Remote sensing is the generic label applied to a set of technologies designed to collect information about the physical properties of the earth. The typical remote sensing application employs some form of aerial or satellite reconnaissance to measure and record environmental phenomena from a distance. Remote sensing technologies have facilitated major advances in diverse scientific disciplines during the past decade, but only now are they on the verge of assuming great legal significance.[1] To date, no accessible judicial or administrative opinion

1. In more than 20 instances information derived from remote sensing has already played some role in litigation, yet few of these cases have reached a final determination on the merits and fewer still have undergone appellate review. These cases are identified and discussed throughout this Article. There are several reasons for the dearth of reported decisions. First, since the technology is of recent origin, some of

presents a comprehensive analysis of the utility and admissibility of remote sensing information, nor has one yet appeared in the legal literature. The principal justification for a treatment of the subject at this time lies in the probability that remote sensing will soon become a more prevalent and decisive feature in a variety of legal contexts.

Expanding technological capabilities are not, in and of themselves, the primary factor behind the predicted utility of remote sensing in legal settings. Rather, this development reflects changing national priorities, which have resulted in unprecedented demands for new knowledge. Popular expectations have increased dramatically in recent years with respect to two related but often conflicting goals: natural resources exploitation and environmental protection.[2] The perceived need for governmental intervention to accommodate these interests has manifested itself in the enactment of a wide range of legislation,[3] which in the aggregate requires the compilation of vast quantities of detailed information about our world, its resources, and its ecology. Remote sensing offers a set of flexible and efficient tools for obtain-

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the cases in which it initially appeared are still in progress. *See, e.g.*, City of Newark v. Natural Resource Couucil, Civil No. A-3311-72 (N.J. Super. Ct., App. Div., Bergen County, filed July 18, 1973); State v. County of San Mateo, Civil No. 144257 (Cal. Super. Ct., San Mateo County, filed Nov. 12, 1971). Second, the great majority of the cases have principally iuvolved environmental law issues; it is the norm rather than the exception for environmental cases to be settled prior to a final determination on the merits. *See* Sullivan & Roberts, *Expert Witnesses and Environmental Litigation*, 25 J. AIR POLL. CONTROL ASS'N 353 (1975). Third, remote sensing evidence can be quite graphic and persuasive; the more effective the evidence the more likely the case is to be settled. *See, e.g.*, Stipulation No. 17363, City of Cloquet v. Ruble & Assocs., (Minn. Dist. Ct., Carlton County, July 9, 1973); Stipulation of Settlement, filed Nov. 29, 1973, State v. Groveland Ranch Acres, Inc., No. GCG73-1495 (Fla. Cir. Ct., 10th Cir., Polk County).

2. *See, e.g.*, Carpenter, *Tensions Between Materials and Environmental Quality*, 191 SCIENCE, Feb. 20, 1976, at 665; North, *Remote Sensing of Environmental Quality*, in NASA INTERNATIONAL WORKSHOP ON EARTH RESOURCES SURVEY SYSTEMS 119 (May 14, 1972) (STAR acc. no. N73-16358) (workshop held at Ann Arbor, Mich.).

[Ed.] STAR, an acronym for Scientific and Technical Aerospace Reports, is an abstract and indexing service for technical papers in the aerospace field. Published monthly with biannual and annual compendiums, the STAR system has two main components: *indexes* (subject, author, corporate source, contract number, report accession number) that may be used to locate related publications in a given field; and *abstracts* of the papers themselves, organized by accession (or "N") number. The two digits immediately following the "N" in an accession number relate to the year in which the paper was listed with the service; for example, "N75-18400" is the accession number of a paper listed in 1975.

3. *See, e.g.*, National Environmental Policy Act of 1969, 42 U.S.C. §§ 4321-47 (1970); Miuing and Minerals Policy Act of 1970, 30 U.S.C. § 21a (1970); Federal Water Pollution Control Act Amendments of 1972, 33 U.S.C. §§ 1251-1376 (Supp. V, 1975); Clean Air Act Amendments of 1970, 42 U.S.C. §§ 1857-58a (1970), *as amended* 42 U.S.C. §§ 1857-1857*l* (Supp. V, 1975); Resource Recovery Act of 1970, 42 U.S.C. §§ 3253a, 3254a-f, *amending* 42 U.S.C. §§ 3251-53, 3258-59, *repealing* 42 U.S.C. § 3255 (1970).

ing much of that data. After first introducing the technology, that initial section of this Article explores and illustrates the proposition that remote sensing will be increasingly relevant to the law because it provides information necessary to implement the elaborate planning and regulatory mechanisms recently created to convert social aspirations into public policy and environmental law.

Remote sensing information may be valuable in every aspect of environmental decisionmaking and law enforcement—in the articulation of environmental goals, in the development of regulatory standards, in the identification of potential transgressors, and as formal evidence in litigation. The second section of this Article considers alternative requirements for particularity, certainty, and procedural regularity imposed on information introduced in these different legal contexts. In addition, the second section describes representative remote sensing applications in each area. The selection of representative applications was based on a survey of existing federal and state agency plans, on remote sensing feasibility studies reported in the technical literature, and on the experiences of public and private litigants in past remote sensing cases. The discussion is thus intended not only to indicate the manner in which remote sensing information might eventually become legally relevant, but also to identify current developments which suggest the kinds of environmental programs or cases that are most likely to feature remote sensing in the near future.

One may not, however, conclude that remote sensing information will necessarily be admissible as evidence in a judicial proceeding simply because it might prove useful. Since neither the various remote sensing techniques nor the interpretation of their output falls within the realm of general knowledge, the admissibility of remote sensing information must be examined within the context of the general requirements for admission of scientific evidence and expert opinion. The third and longest section of this Article provides an overview of those requirements and then considers them in the light of the particular characteristics of remote sensing technology. Although all aspects of the admission process are addressed, two difficult but essential issues receive more extended treatment: (1) the ability of the adversarial system to determine if an innovative technique is sufficiently reliable to justify admission; and (2) the adequacy of different remote sensing techniques when evaluated in terms of the documentary original and authentication provisions of the formal rules of evidence.

The admissibility of remote sensing information cannot be treated in a reductionistic manner. There are a variety of sensing techniques, a number of which are undergoing dynamic change in terms of cost and

capabilities. There is a much larger group of potential applications for which particular sensing techniques will be more or less suitable.[4] Moreover, the data may be introduced in a variety of legal settings—each with different criteria for the admission of scientific evidence. The question of the admissibility of remote sensing evidence will not be wholly resolved in a limited number of cases or in the foreseeable future. Rather the problem will arise recurrently as new techniques and applications are developed to meet the information needs of society. Frequent legal assessments of the admissibility and utility of remote sensing data will be a necessary and inevitable concomitant of our increasing desire to understand and control the world in which we live.

A. Remote Sensing Defined

At its most general remote sensing includes any systematic observation and recording of physical objects and phenomena at a distance.[5] In scientific parlance, however, the term denotes employing all or some of the following elements: technological recording devices called sensors; aerial, satellite, or, less often in practice, ground-based sensing platforms; computer and data processing equipment; and information theory and processing methodology.[6] The concept may be clarified by

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4. The utility of a given remote sensing technique in one situation does not mean that it will be useful in others. *See, e.g.*, Hamilton v. MacDonald, Civil No. 579 (D. Ariz., Oct. 14, 1972), which involved a dispute between the Hopi and Navajo Indian tribes over collective grazing rights on common tribal property. In order to locate excess grazing stock and unauthorized structures ("*hogans*") allegedly located on the joint property, the trial court ordered a survey of the 1 million acre joint reservation area. In its opinion the court specifically approved the use of aerial photography to survey the large area involved. *See* Order of Contempt at 11, Sekaquaptewa v. MacDonald, Civil No. 579 Pct. (JAW) (D. Ariz., May 29, 1974) (noncompliance with the judgment rendered in Hamilton v. MacDonald, *supra*). While high-altitude color infrared photographs obtained by the Bureau of Indian Affairs (BIA) from NASA were useful in determining the presence and quantity of vegetation, information related to the livestock carrying capacity of the land, the resolution of the high-altitude photography was insufficient to detect readily the *hogans*. Accordingly, the BIA found it necessary to commission a subsequent and more expensive low-level aerial survey (using ordinary black and white photography), which succeeded in locating the structures. Conversation with Lynn Montgomery, Acting Project Officer, BIA, Joint Use Administration Office, Flagstaff, Ariz., Oct. 9, 1975.

5. Holz, *Introduction* to THE SURVEILLANT SCIENCE: REMOTE SENSING OF THE ENVIRONMENT, at v (R. Holz ed. 1973) [this collection will hereinafter be cited as THE SURVEILLANT SCIENCE].

6. Luney & Dill, *Uses, Potentialities, and Needs in Agriculture and Forestry*, in COMM. ON REMOTE SENSING FOR AGRICULTURAL PURPOSES, AGRICULTURAL BOARD, NAT'L RESEARCH COUNCIL, REMOTE SENSING WITH SPECIAL REFERENCE TO AGRICULTURE AND FORESTRY 1 (Nat'l Academy of Sciences 1970) [this collection will hereinafter be cited as REMOTE SENSING IN AGRICULTURE]. As employed herein, the term "remote sensing" does not include wiretapping or any similar form of electronic surveillance.

noting that the most commonplace remote sensing device is the camera, which records energy in the visible light segment of the electromagnetic spectrum.[7] Figure 1, which depicts the relevant portions of the electromagnetic spectrum, identifies a number of other spectral bands utilized in remote sensing. Some of these, like the radar range, are already well known to the public.[8] For most spectral bands, including the visible light range, there are several potential sensing devices, each with associated advantages and costs.[9] Moreover, the familiar distinc-

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7. Although aerial photography in the visible light range definitely is included within the ambit of remote sensing, it is addressed in this Article only to the extent that it provides useful analogies in respect to the other spectral techniques. Conventional aerial photography is excluded from primary coverage here because there is little question of its admissibility as evidence and because visible light photography, unlike the other techniques, records information that can be directly and conveniently perceived by human beings. Indeed, photographs were initially admitted only as a pictorial representation of the testimony of a witness who had observed the matter depicted, and not as independent evidence. *See, e.g.*, Cowley v. People, 83 N.Y. 464, 478-79 (1881); Udderzook v. Commonwealth, 76 Pa. 340, 352-53 (1874); Barnes v. Ingalls, 39 Ala. 193, 199-201 (1863). Although the prevalent line of authority now holds photographs to be independent evidence, *see, e.g.*, People v. Bowley, 59 Cal. 2d 855, 860, 382 P.2d 591, 595, 31 Cal. Rptr. 471, 474-75 (1963); State v. Tatum, 58 Wash. 2d 73, 75, 360 P.2d 754, 756 (1961); State v. Goyet, 120 Vt. 12, 20-21, 132 A.2d 623, 630-31 (1951); 3 J. WIGMORE, EVIDENCE § 790 (Chadbourn rev. 1972) [hereinafter cited as WIGMORE (Chad. rev.)]; C. MCCORMICK, HANDBOOK OF THE LAW OF EVIDENCE § 214 (2d ed. E. Cleary 1972) [hereinafter cited as MCCORMICK]; Gardner, *The Camera Goes to Court*, 24 N.C.L. REV. 233 (1946), at least one jurisdiction, North Carolina, retains the original rationale. *See, e.g.*, State v. Johnson, 280 N.C. 281, 286, 185 S.E.2d 698, 700-01 (1972); State v. Atkinson, 278 N.C. 168, 175, 179 S.E.2d 410, 415 (1971); State v. Morris, 242 N.C. 47, 57-58, 86 S.E.2d 916, 923 (1955); C. SCOTT, PHOTOGRAPHIC EVIDENCE § 1022 (2d ed. 1969, Supp. 1974) [hereinafter cited as SCOTT]. *But see* Gardner, *supra*.

8. X-rays are not employed in long-distance monitoring and hence are not considered to fall within the category of remote sensing techniques. Since X-ray photography depends on the recording of information from a nonvisible spectral band, and since X-ray images are universally accepted as admissible evidence, they provide one of the most useful analogies for the introduction of remote sensing data.

9. The majority of sensors fall into one of two categories: cameras (including cameralike devices) and scanners. The camera employs filters to screen out unwanted wavelengths and a lens to focus the waves on the recording medium, which is a photographic emulsion or film. Camera systems reproduce a continuous tone image of varying light intensities on film, with resolution (the ability to discriminate between adjacent features) dependent upon the grain size of the film emulsion. Cameras using special film are often employed to record the ultraviolet and near infrared wavelengths. A particularly common technique is the use of false color infrared film (CIR); visible blue is filtered out and a modified emulsion is employed so that after development visible green appears as blue on the positive, visible red appears as green, and the near infrared appears as red. Plate 2 presents a simulated CIR image.

In contrast, scanners employ prisms or crystals instead of lenses and filters to select out the desired spectral bands. Rather than producing a continuous tone image, scanners "read" a line at a time. This scanning process may be understood by reference to a television tube where the image is created by successively reproducing a series of horizontal lines on the screen. Resolution for a scanner is dependent on the sensitivity

tions between photographs and X-ray plates should make clear to the reader that different kinds of information can be obtained from an inspection of different spectral bands.[10] Remote sensing subsumes the alternative recording methods, the various recording media, and the interpretation techniques necessary to extract meaningful information from these sources.

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of the prism or crystal and on the number of lines per inch of recorded image. The principal advantages of scanners are that they can select out a narrower spectral range than can a camera-filter combination, that they generate output which may be recorded directly on computer compatible tapes for subsequent manipulation, and that they can conveniently be designed to record several spectral bands simultaneously. For example, the first and second Landsat remote sensing satellites (formerly knowu as ERTS—Earth Resources Technology Satellites) possessed multispectral scanners with four bands. National Aeronautics and Space Adm'n Press Release No. 72-137 (ERTS-A), at 32, 40 (July 20, 1972); National Aeronautics and Space Adm'n Press Release No. 74-329 (ERTS-B), at 22 (Jan. 14, 1975); Arlanskas, *Multispectral Scanner (MSS), ERTS-1*, in NASA SIGNIFICANT ACCOMPLISHMENTS IN TECHNOLOGY 1972, at 60 (1973) (STAR acc. no. N73-27831) (symposium held at NASA Goddard Space Flight Center, Nov. 8, 1972). Landsat III, scheduled for launch in 1977, will add a fifth band iu the thermal infrared range. Conversation with Dr. Stan Fredan, Landsat Project Scientist, NASA Goddard Space Flight Center, July 31, 1975. An airborne multispectral scanner used in the Reserve Mining case, monitored 24 different ranges. Record at 2503, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974). *See generally* R. Nalepka & J. Erickson, Investigation Related to Multispectral Imaging Systems (1974) (STAR acc. no. N75-18670) (final report, Environmental Research Institute of Michigan).

10. Some systems, like sonar and seismography, employ sound waves rather than electromagnetic ones. *See, e.g.*, Spiridonov, Naumov, Rybalko, Alyavdin & Eykhgorm, *Geological Survey of the Littoral Shelf Using Side-Looking Sonar*, 219 DOKLADY AKAD. NAUK 462 (1974) (STAR acc. no. N75-18668) (Jt. Pub. Research Service, Arlington, Va., transl. 1975); Jurov & Efimkina, *Results of Correlation of Deep Seismic Sounding and Gravimetry Data*, in IZOSTAZIYA ISOSTASKY 53 (1973) (STAR acc. no. N74-29766) (Tech. Transl. Section, Defense Mapping Agency Aerospace Center, St. Louis, Mo., transl. 1974). These technologies, however, are less widely used and, from a legal perspective, are logically similar to those discussed.

ELECTROMAGNETIC SPECTRUM

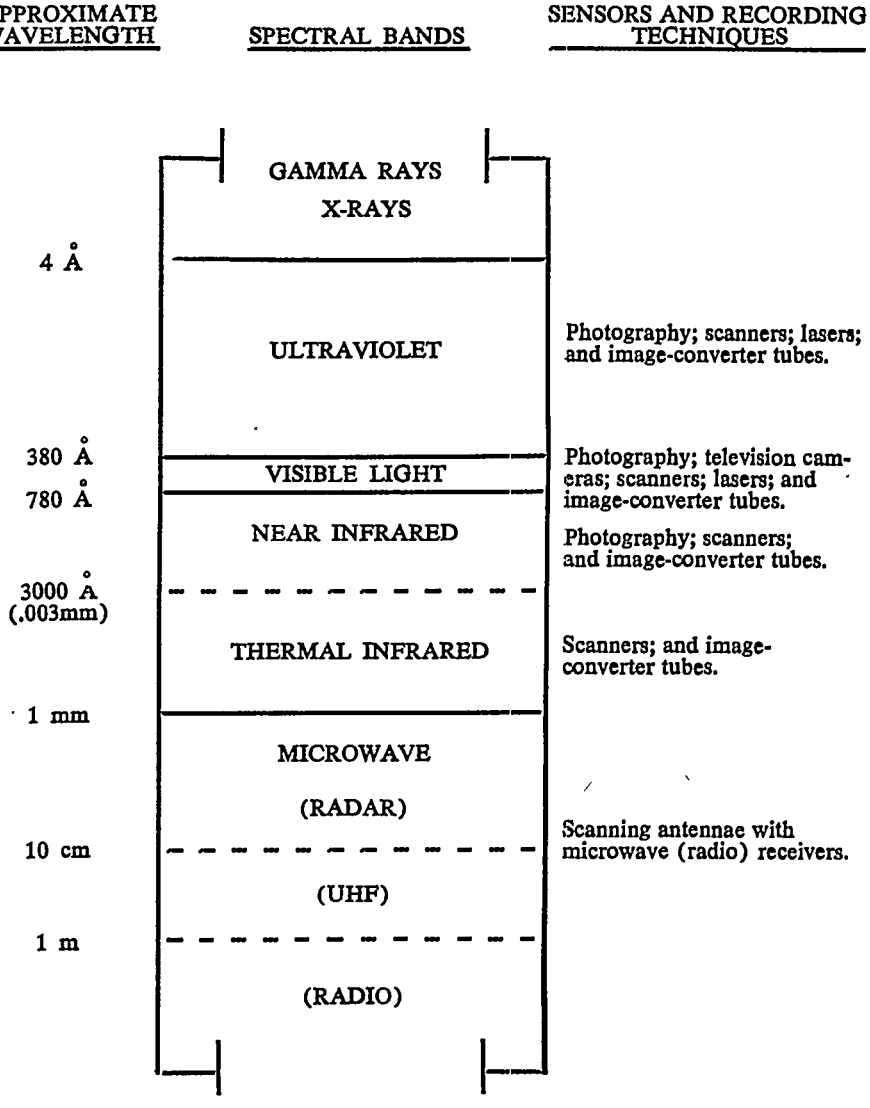
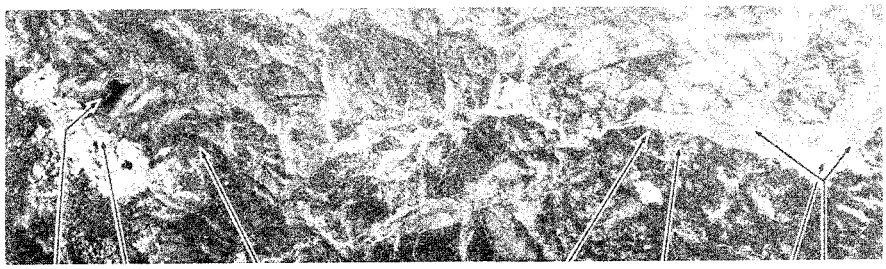
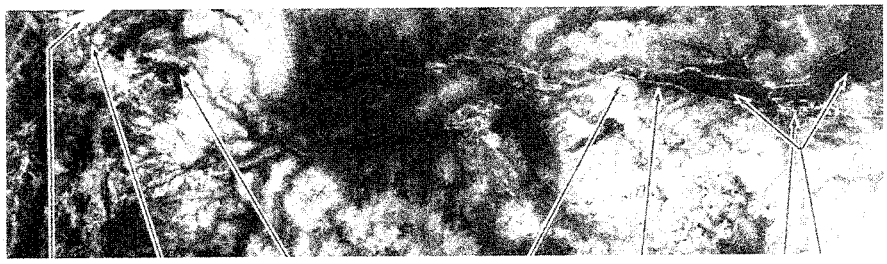


Figure 1



SILVER LAKE ROCK SHRUB CONIFER HARDWOOD QUINCY GRASS

PLATE 1a



SILVER LAKE ROCK SHRUB CONIFER HARDWOOD QUINCY GRASS

PLATE 1b

SILVER LAKE ROCK SHRUB CONIFER HARDWOOD QUINCY GRASS

PLATE 1c

PLATE 1:

Three views of the terrain around Silver Lake and Quincy, California. Plate 1a. used panchromatic black and white film exposed at 12:00 noon with a minus blue filter. Plate 1b. was produced by a thermal infrared scanner operated at 3:00 A.M. Plate 1c. was obtained by side-looking airborne radar (SLAR) at 2:00 P.M. The views are presented at a scale of approximately 1/120,000. In these images, the photograph is most successful at identifying vegetation features; the thermal scanner most clearly reveals the streets of Quincy and the SLAR is most useful to indicate the topography of the land.

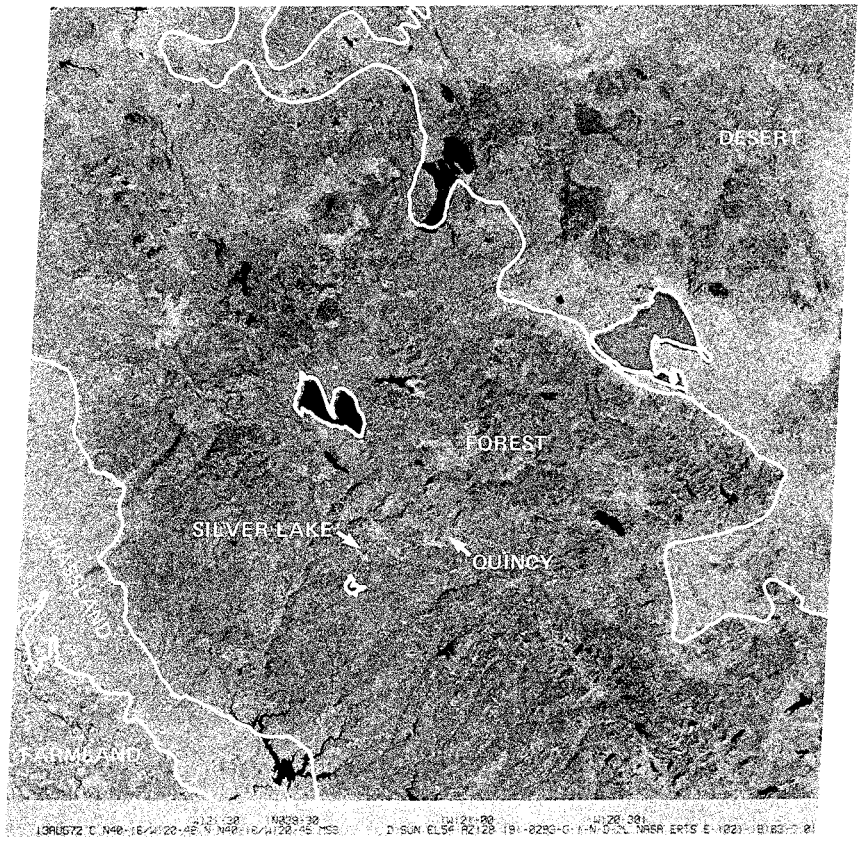


PLATE 2:
A NASA Landsat image of the Quincy area and surrounding territory. This image is a composite of the green, red, and one of the two infrared multi-spectral scanner bands on Landsat. Consequently, the image simulates false-color infrared photography although the actual sensor used to obtain the data was not a camera. Major terrain and vegetation types are designated as they appear at a scale of approximately 1/1,000,000. The ephemeris data at the bottom of the image indicate the date, the location, the spectral bands (4, 5 & 7), the sun angle, and other pertinent information.

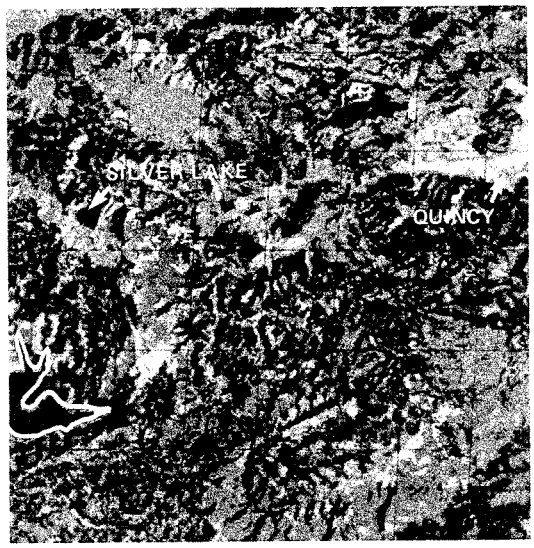


PLATE 3:
A computer-generated enlargement (scale 1/120,000) of the Silver Lake area revealed in Plate 2. NASA distributes Landsat output in several forms: as black and white reconstructions of individual spectral bands; as black and white or color composites of several bands (Plate 2); and directly in digital format on magnetic tapes. As the sensitive terrain and color gradations visible in Plate 3 indicate, more information is available to the image interpreter from digital processing than from the corresponding color composite.

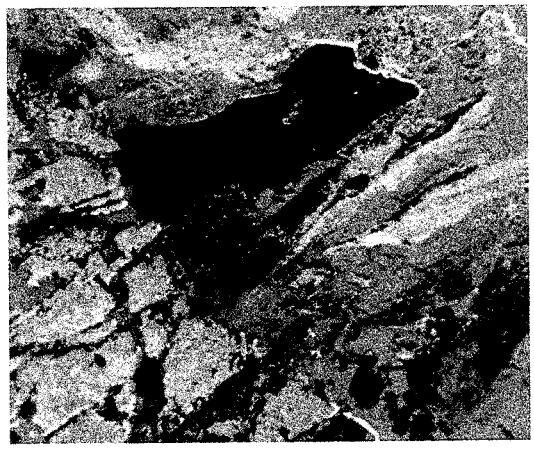
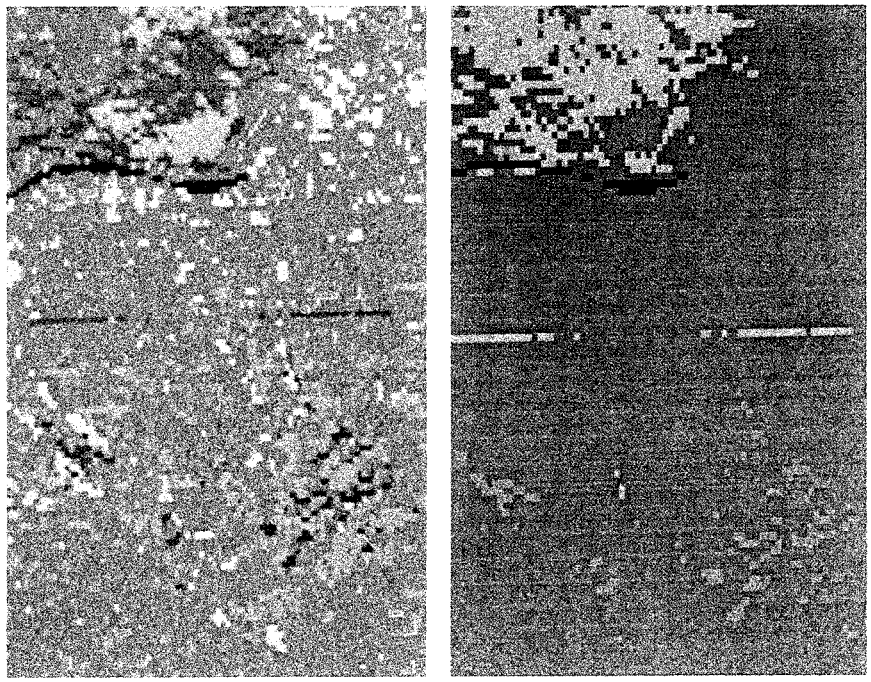


PLATE 4:
Color enhancement of Silver Lake area. Three separate optical spectral bands were assigned different colors and then focussed on a single screen as one overlapping image. The light intensities of certain of the colors were then increased in order to bring up particular features. In this image, the red colors are vegetation, the light and royal blue are rocks, and the dark blue is water.



(a) (b)

PLATE 5:
Two examples of computer classification of vegetation and terrain types using Landsat digital MSS data. Plate 5a is an overview of the area, in which different colors are assigned to each dominant type of feature: red = sage brush; brown, olive green and yellow = types of marshland; turquoise = bare ground; white = dry grass, lavender, blue and navy blue = hardwood tree species; and black = artificially inserted registration marks. Each small rectangular block represents slightly more than one acre on the ground. Plate 5b., an image of the same area constructed using the identical data as in Plate 5a., illustrates Sensitive Area Analysis. In this technique, only specific target features are identified and the rest of the features are suppressed by being assigned a single color. In the example, the image locates vegetation types of interest to range managers concerned with animal grazing. In Plate 5b., red = wet marsh; yellow = dry marsh; lavender = riparian or meadow hardwoods; black = artificially inserted registration marks; and other features are coded in gray. The broken horizontal lines that nearly bisect the images indicate lost data, probably attributable to Landsat scanner or transmission problems.

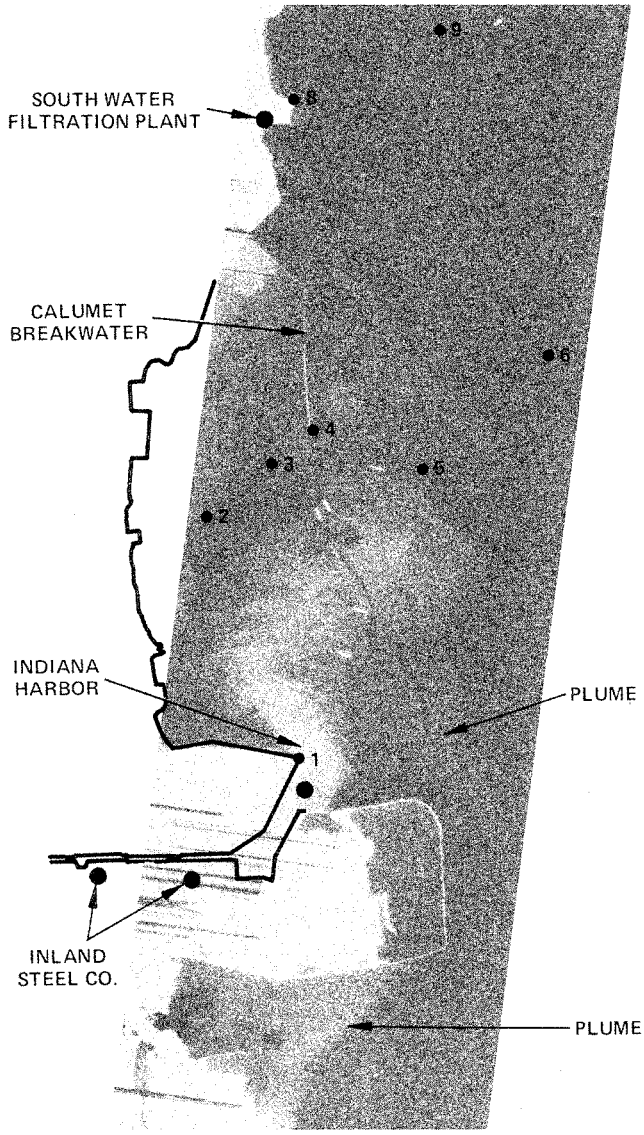


PLATE 6:
Thermal infrared scanner image introduced in State vs Inland Steel Co. When submitted, the image was accompanied by a plastic overlay on which the official National Ocean Survey map of the area was reproduced. Only the most important features have been superimposed in this Plate in order to maximize the clarity of the effluent plume visible in the imagery. The numbers mark the location of water-sampling stations. When this image was taken, around 3:00 P.M. on May 10, 1974, the plume was some distance south of the Calumet Harbor breakwater (marked at its end by station 4), and the wind was blowing from the southeast, or directly towards Chicago. The Indiana-Illinois state line is slightly to the north of the base of the breakwater.

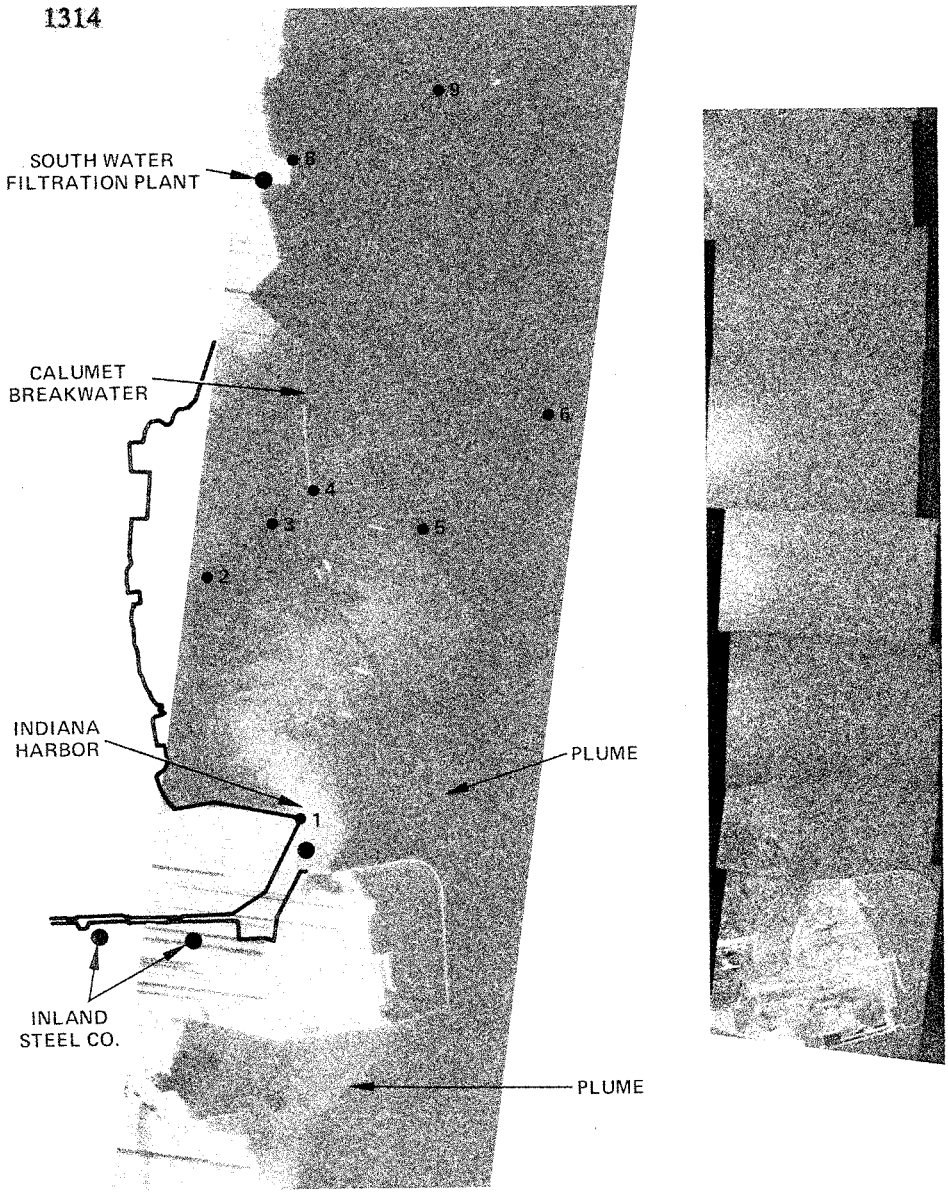


PLATE 7:
A side-by-side comparison of the thermal image in Plate 6 and a mosaic of aerial photographs taken simultaneously. In the photo-mosaic, some water turbidity is visible in the Indiana Ship Canal near the Inland Steel plant, but the effluent plume in Lake Michigan cannot be detected. The light area at the left center of the photographs was caused by sun glint, or reflection produced by the angle at which the sun's rays hit the water, rather than by any condition in the lake. The nearly horizontal, parallel lines partially obscuring the Inland Steel plant and the Canal in the thermal image were caused by scanner problems.

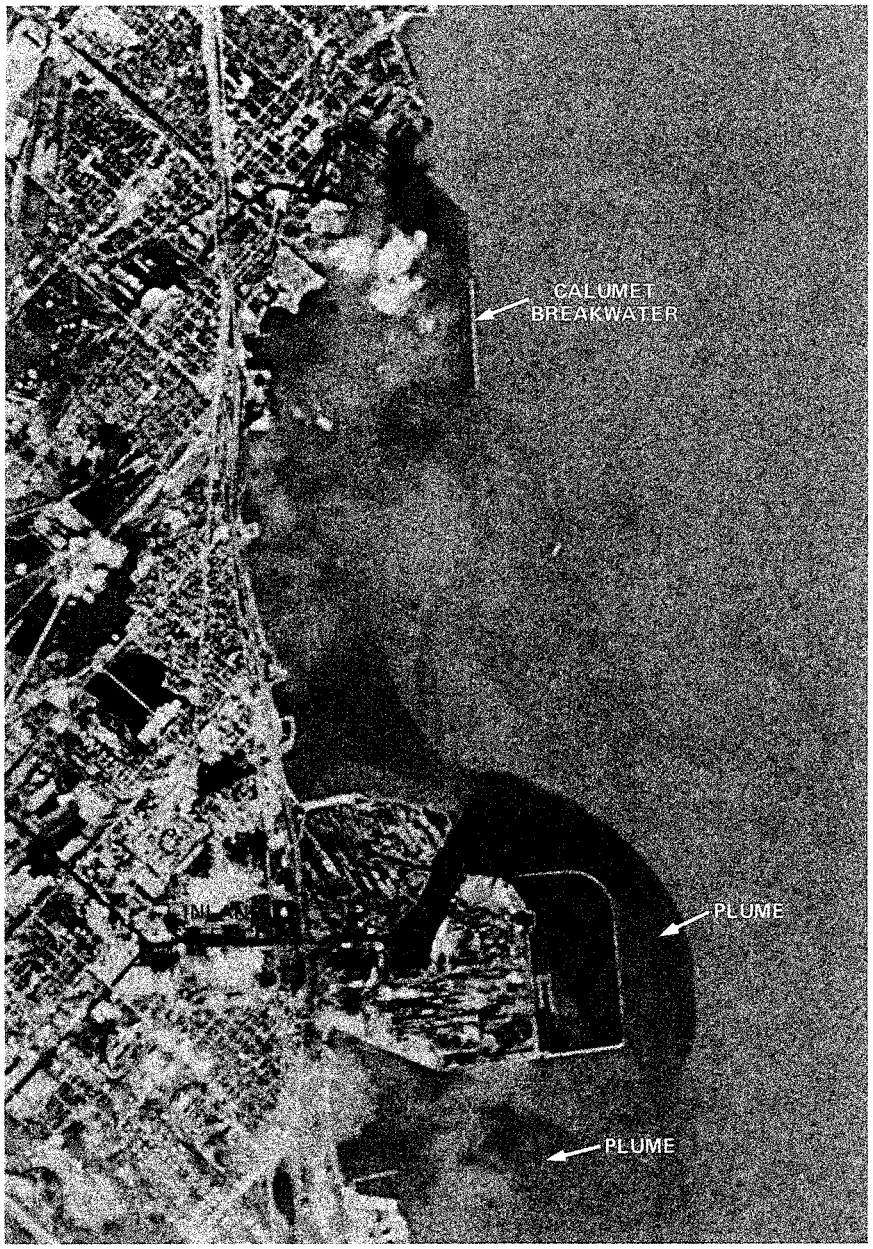


PLATE 8:
A Skylab color photograph taken on September 18, 1973, and submitted in Inland Steel to show the length that a pollution plume could attain. Since the wind was blowing from the northwest, the plume moved south from the mouth of the Canal, and then curled around in an eddy below the plant. The length of the plume was measured along the curve of its path rather than in mileage along the shore.

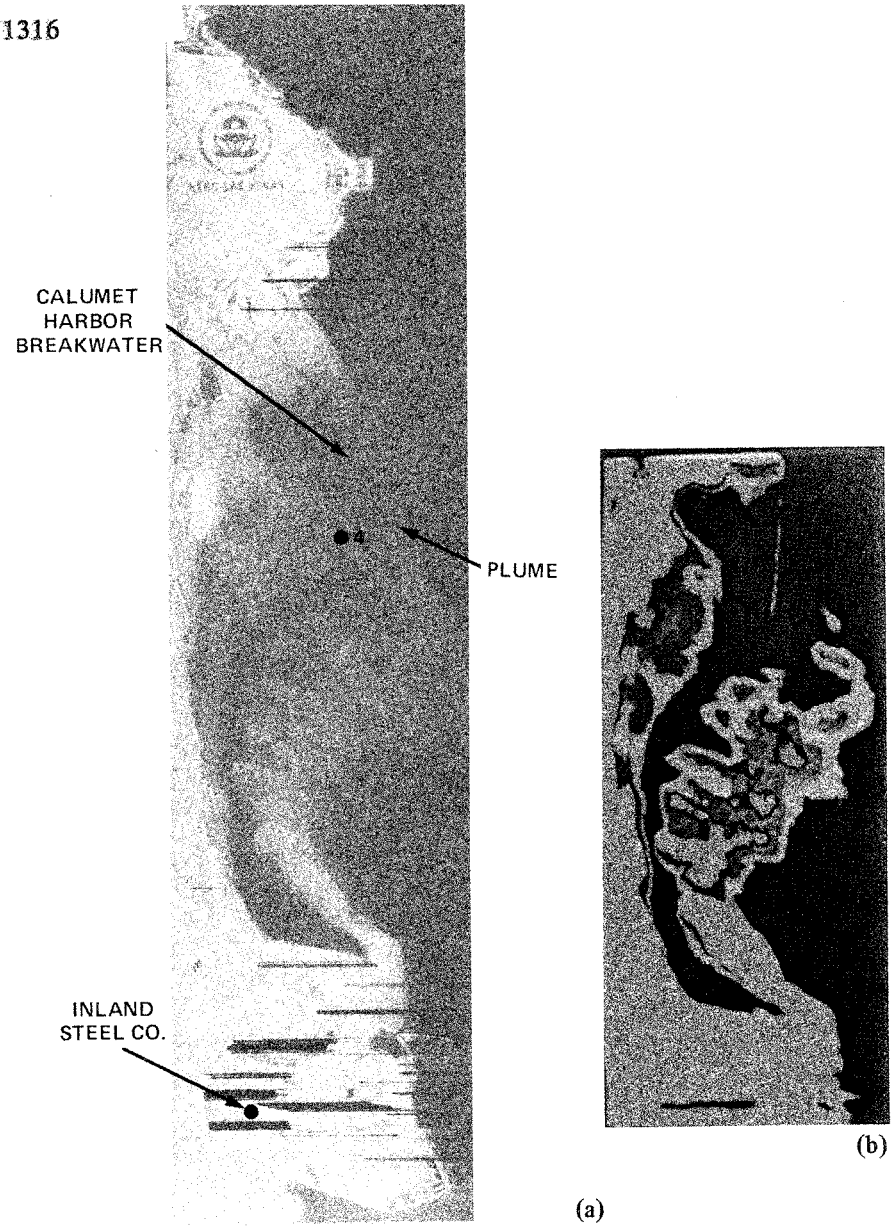


PLATE 9:
Thermal infrared image obtained at 6:20 P.M. on May 10, 1974, and introduced in Inland Steel (Plate 9a.), together with a density-sliced enhancement of that image (Plate 9b.). The conventional thermal image shows that three hours after the earlier thermal image (Plate 6) was taken, the plume had moved north until its leading point had passed the end of the Calumet breakwater. The enhancement was made by assigning a different color to each temperature range in the thermal image, as indicated by a different degree of exposure (or lightness and darkness) in the negative of the thermal image. The enhancement was not submitted because of its potential to confuse the trier of fact and because the temperature of the plume was not significant in the litigation.

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The principal remote sensing end products ("output") may be characterized in terms of decreasing familiarity to the law. The initial category, here denominated "photographic images," is produced by remote sensing techniques that record directly on photographic film as the sensor receives data.[11] The simplest illustration from a conceptual point of view is an image obtained by a camera and differing from a conventional photograph only in that a special film is used to capture a nonvisible spectral band. Only slightly more involved are color infrared photographs in which the film emulsion is modified to record the near infrared band along with the visible light range.[12] Next in progression is the immediate conversion of scanner output to optical radiation, which exposes photographic film in order to produce a permanent record.[13]

The second category of remote sensing output, "reconstructed images," requires computer processing or some other form of data manipulation as an intermediate step in the production of the final images. In the most direct case sensor data is initially recorded on computer-compatible magnetic tapes (CCT's); a computer is subsequently used to reconstruct images exactly as they were originally sensed. The processing of Landsat images, such as the one reproduced in Plate 2, is somewhat more complicated. Data is telecommunicated from the satellite to earth-receiving stations where it is recorded on CCT's; the data is then manipulated to correct for distortion in the sensing process introduced by rotation of the earth and by the fluctuating position (pitch, roll, and yaw) of the satellite.[14] The common denominator of reconstructed images is that the ultimate output is designed to be a complete and accurate representation of the phenomena originally sensed.

The most exotic category of remote sensing output from a legal perspeetive is that of "enhanced images." Computer or photographic

11. For example, all the remote sensing devices carried by the Coast Guard's Airborne Oil Surveillance System (AOSS) record on videotape. See text accompanying notes 128-32 *infra*. The AOSS system employs a combination of radar, thermal infrared scanner, microwave radiometer, and low-light-intensity television, which are used to assist the Coast Guard in its regulatory enforcement programs and for ocean rescue purposes.

12. See note 9 *supra*. Plate 1a is a black and white near infrared photograph produced using the same principle.

13. This process is often employed to record the output of thermal infrared scanners. *See, e.g.*, Crouch & Mower, An Application of Infrared Remote Sensing Techniques to Ecological Problems 6 (July 1974) (STAR acc. no. N75-13419); Brown and Scarpace, *Airborne Infrared Imaging System*, in ATMOSPHERIC TECH., Mar. 1973, at 43. For a description of thermal infrared scanning and its relation to photography, see SCOTT, *supra* note 7, at § 685. Plate 1b illustrates this kind of photographic image.

14. NASA, ERTS DATA USERS HANDBOOK F.1.3.1-F.1.3.1.2 (Sept. 15, 1971, as revised, July 18, 1972) [hereinafter cited as ERTS HANDBOOK].

processing techniques are utilized to locate features that would not be directly identifiable in standard photographic and reconstructed images,[15] or to emphasize desired relationships by accentuating certain features and suppressing others.[16] Information derived from enhancement techniques may be presented in the form of statistical tables or computer-generated charts; it may also be employed to construct graphic images, such as those illustrated in Plates 4, 5, and 9b, which bear a superficial resemblance to photographs but are logically quite distinguishable. Enhanced images, by definition, do not purport to be exact portrayals of conditions as they were originally recorded.

Remote sensing received its initial impetus during World War II with the development of radar and the discovery that aerial infrared photography provided an excellent tool for camouflage detection.[17] With the design of sophisticated sensor packages, satellites, and enhanced data processing capabilities, the number of remote sensing applications increased rapidly in the last decade. Yet the technology is by no means mature; if even a small proportion of the techniques

15. Illustrative is the technique of band ratioing, which involves comparing the intensity of a particular wavelength reflected from a given point on the earth with the intensity of a different wavelength reflected from the same point. The principal value of band ratioing lies in its suppression of sun-angle dependence, a key limitation of passive remote sensing systems. Vincent, *An ERTS Multispectral Scanner Experiment for Mapping Iron Compounds*, in PROCEEDINGS OF THE EIGHTH INTERNATIONAL SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT 1239 (Ann Arbor, Mich., Oct. 6, 1972). A research team at the University of Kansas has successfully used band ratios derived from Landsat multispectral scanner (MSS) computer tapes to identify, at levels approaching 900 parts per milliou, loads of solids suspended in water. Yarger, McCauley, James, Magnuson & Marzolf, *Quantitative Water Quality with ERTS-I*, in THIRD EARTH RESOURCES TECHNOLOGY SATELLITE SYMPOSIUM 1637 (Dec. 14, 1973) (NASA Sci. and Tech. Information Office, Washington, D.C.) [the SYMPOSIUM as a whole hereinafter cited as THIRD ERTS-1 SYMPOSIUM]. Band ratioing has also been employed, albeit with less success, to map the extent of flooding of the Mississippi River. Piech & Walker, *Thematic Mapping of Flooded Acreage*, 38 PHOTOGRAMMETRIC ENGINEERING 1081 (1972).

16. One such enhancement technique is density slicing. An image is scanned with a high quality black and white television camera, and the difference in film density (the amount of light which penetrates the exposed transparency) is converted into a voltage signal. This signal is digitally incremented into a series of discrete voltage levels, and a different color is assigued to each voltage level. C. WIER & F. WOBBER, APPLICATION OF ERTS-A IMAGERY TO FRACTURE RELATED MINE SAFETY HAZARDS IN THE COAL MINING INDUSTRY § 4, at 9 (Feb. 1975) (I.B.M. Corp., Gaithersburg, Md.) [hereinafter cited as WIER & WOBBER]. The enhanced image may then be used to delineate graphically minor variations within given features, such as isotherms. Plate 9b illustrates this type of application. In addition, variations of this technique have been employed in geological studies to produce a "pseudo-relief" effect emphasizing straight line features such as faults or fractures. *Id.* at 11.

17. V. HOOD, A GLOBAL SATELLITE OBSERVATION SYSTEM FOR EARTH RESOURCES: PROBLEMS AND PROSPECTS 4-5 (Am. Soc'y of Int'l Law July 1, 1975). Many of the more venerable experts in the field of remote sensing still refer to infrared film as "CD" film.

now undergoing laboratory development and testing prove fruitful, it appears certain that future growth will exceed that of the past.[18]

B. *Examples of Legal Relevance*

The central thesis of this discussion is that the predicted legal relevance of remote sensing derives from the attempt to translate current social aspirations into effective public policy and law. The recent implementation of a panoply of natural resources and environmental programs generated a need for increasingly precise and timely information about physical conditions in our country and the world. Given the multitude and variety of such programs, their cumulative data requirements amount to a demand for thorough and frequent monitoring of all ecological and many industrial phenomena in the United States. Because of its ability to obtain the "big picture"—in scientific terminology, a synoptic view[19]—aerial and satellite remote sensing can occasionally produce valuable information not formerly available at all.[20] In the great majority of instances, however, the utility of remote sensing lies in its capacity to collect needed data in a cost-effective[21]

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18. Fink, *Monitoring Earth's Resources from Space*, 75 TECHNOL. REV., June 1973, at 32, 41 [hereinafter cited as Fink]. *Cf.* Holter, *Research Needs: The Influence of Discrimination, Data Processing, and System Design*, in REMOTE SENSING IN AGRICULTURE, *supra* note 6, at 374-75, 408-20.

19. Synoptic view is the ability to capture a large area in a single image and is inversely proportional to resolution—that is, the ability to identify details decreases as the area covered is increased. The Landsat series obtains images from an altitude of approximately 900 km, which results in an image of an area 185 km-on-a-side with a resolution on the order of 80 meters (in other words, features smaller than 80 meters across cannot be detected reliably). A complete mosaic of the earth is obtained every 18 days. ERTS HANDBOOK, *supra* note 14, at 2.1, I.1-I.4; Fink, *supra* note 18, at 32-34. The choice of the Landsat scale and resolution criteria represents an intentional accommodation between those applications that benefit from synoptic view and those that require fine detail. It would be possible to mount higher resolution sensors on satellites; indeed, the resolution for the sensor package ou Landsat IV, planned for 1979-80, is expected to be in the range of 30 to 40 meters. Conversation with Dr. Stan Freden, Landsat Project Scientist, NASA Goddard Space Flight Center, July 31, 1975. *Cf.* Bylinsky, *ERTS Puts the Whole Earth Under a Microscope*, 91 FORTUNE, Feb. 1975, at 116, 118, where the author asserts that military satellite sensors can read automobile license plate numbers.

20. It is, for example, possible to detect large-scale geological formations from space that could not be readily identified on the ground, an ability that has proved extremely useful in the development of plate tectonics theories and that has practical ramifications for mineral exploration. *See, e.g.*, Molnar & Tapponnier, *Cenozoic Tectonics of Asia: Effects of a Continental Collision*, 189 SCIENCE, Aug. 8, 1975, at 419; Guild, *Discovery of Natural Resources*, 181 SCIENCE, Feb. 20, 1976, at 709, 710-11.

21. F. WOBBER, O. RUSSELL & D. DEELY, A SUMMARY OF MULTISCALE AERIAL AND ORBITAL TECHNIQUES FOR MANAGEMENT OF COAL MINED LANDS 8 (1974) [hereinafter cited as WOBBER *et al.*] describes a project demonstrating mined-lands management applications in the state of Indiana:

> Refuse banks from old underground mining operations were usually too small and too highly vegetated to be distinguished using ERTS [Earth Re-

and timely manner.[22] Two illustrations will serve to underscore the progression from social expectations to expanded information requirements to the utilization of remote sensing technology.

1. *Enforcement of Water Pollution Controls*

The principal tool in the federal effort to control the environmental effects of water pollution is the National Pollutant Discharge Elimination System (NPDES),[23] created by the Water Pollution Control Act Amendments of 1972.[24] The NPDES legislation and implementing regulations render unlawful any discharge of pollutants[25] from a point source[26] unless the discharge complies with effluent limitations and water quality standards incorporated in an NPDES permit;[27] the

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sources Technology Satellite] imagery. Detailed data provided by 1:120,000 scale color infrared aerial photography proved cost effective for this program. For a cost of approximately $2.00 a square mile, refuse sites were accurately located and a variety of cost of reclamation decisions were made.

22. *See, e.g.*, Land Use Maps & Space Pictures Help Louisiana Assess Floods, U.S. Geological Survey, Department of the Interior News Release (July 7, 1975).

23. 33 U.S.C. §§ 1342-45 (Supp. V, 1975); 40 C.F.R. §§ 125.1-.44 (1975).

24. 33 U.S.C. §§ 1251-1376 (Supp. V, 1975). *See generally* [1972] U.S. CODE CONG. & AD. NEWS 3668. As early as 1899, Congress has prohibited the discharge of any "refuse" into navigable waters without a permit from the Army Corps of Engineers. Act of Mar. 3, 1899, ch. 425, § 13, 30 Stat. 1152. A trend in this direction can be traced even earlier. *See* Act of Sept. 19, 1890, ch. 907, § 6, 26 Stat. 453; Act of Aug. 18, 1894, ch. 299, §§ 6-8, 28 Stat. 363. *See also* 33 U.S.C. § 407 (1970). That authority, however, remained dormant until 1971, [1972] U.S. CODE CONG. & AD. NEWS 3668, 3736, when an Executive Order of the President directed the Corps to promulgate regulations to implement the permit requirement. Exec. Order No. 11,574, 3 C.F.R. 986 (1970). In creating the NPDES, Congress transferred to the Environmental Protection Agency the permit-granting function for discharges other than dredged or fill material, 33 U.S.C. § 1344 (Supp. V, 1975), and expanded the scope of regulated activities to include municipal sewage discharges, 33 U.S.C. § 1345 (Supp. V, 1975), and ocean discharges, 33 U.S.C. § 1343 (Supp. V, 1975). Municipal sewage had been exempted from the definition of "refuse" under the 1899 Act, as construed. [1972] U.S. CODE CONG. & AD. NEWS 3668, 3736.

25. The term "discharge of pollutants" means (1) any addition of any pollutant to navigable waters other than the territorial sea, from any point source, or (2) any addition of any pollutants to the waters of the territorial sea, the contiguous zone or the ocean from any point source other than a vessel or other floating craft. 40 C.F.R. § 125.1(i) (1975).

26. The term "point source" means any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. 40 C.F.R. § 125.1(x) (1975).

27. 33 U.S.C. § 1342 (Supp. V, 1975); 40 C.F.R. §§ 125.3(b), 125.15(a) (1975). For authorized discharges the permit may specify average and maximum daily quantitative limitations, measured in terms of weight, pH, temperature, radiation, or other appropriate criteria, average and maximum concentration levels, and other conditions necessary to insure compliance with water quality standards. 40 C.F.R. §§ 125.24, 125.26 (1975).

discharger procures the permit from a Regional Administrator of the EPA, from an approved state official, or, in the case of dredged and fill material, from the U.S. Army Corps of Engineers.[28] The intent is that no permit shall be issued unless the relevant governmental authorities are satisfied that the discharge is lawful and that the resulting environmental degradation is minimized.

Consider the demand on institutional resources that enforcement of the permit systems places on the EPA, the Corps, and associated state agencies. Prior to the passage of the 1972 Amendments, at least 40,000 industrial sources of discharges had already been identified.[29] Yet at that time the Senate Report noted that "[t]he Federal water pollution control program suffers from a lack of information concerning dischargers, amounts and kinds of pollution, abatement measures taken, and compliance."[30] The permit systems are intended to control each of these items, but are not limited in scope only to industrial discharges.[31] To accomplish this objective the concerned agencies are now required periodically to monitor thousands of miles of navigable waters[32] in order to detect nonfilers and to assure that authorized dischargers comply with the provisions of their permits.[33]

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28. 33 U.S.C. § 1344 (Supp. V, 1975); 33 U.S.C. § 407 (1970).

29. [1972] U.S. CODE CONG. & AD. NEWS 3668, 3736.

30. *Id.* at 3673.

31. *See, e.g.*, 33 U.S.C. § 1316(b)(1)(A) (Supp. V, 1975).

32. Although "navigable waters" was once thought to include only those areas below the mean high tide line, the traditional limit of federal admiralty jurisdiction, the lower federal courts have recently given the term a more expansive definition. Examining both the legislative history and the historical background of the term "navigable waters" in the Federal Water Pollution Control Act Amendments of 1972, 33 U.S.C. §§ 1251-1376 (Supp. V, 1975), the court in United States v. Holland, 373 F. Supp. 665 (M.D. Fla. 1974), adopted a "navigability in fact" test on the strength of Waring v. Clarke, 46 U.S. (5 How.) 441 (1847). *See also* United States v. Ashland Oil & Transp. Co., 364 F. Supp. 349 (W.D. Ky. 1973), *aff'd*, 504 F.2d 1317 (6th Cir. 1974). A similar construction was recently given the venerable Rivers & Harbors Appropriations Act of 1899 by the Fifth Circuit, which, while adopting the mean high tide line as a base for federal jurisdiction, added to the term "navigable waters" such activities occurring above the line which *affect* navigation. *See* United States v. Sexton Cove Estates, Inc., 526 F.2d 1293 (5th Cir. 1976); Weiszmann v. Corps of Eng., 526 F.2d 1302 (5th Cir. 1976); United States v. Joseph G. Moretti, Inc., 526 F.2d 1306 (5th Cir. 1976).

33. 40 C.F.R. § 125.22(a) (1975) requires the Regional Administrators to insure that the terms and conditions of all issued permits provide:

> (1) That all discharges authorized by the permit shall be consistent with the terms and conditions of the permit; that facility expansions, production increases or process modifications which result in new or increased discharges must be reported by submission of a new application, or, if such discharge does not violate effluent limitations specified in the permit, by submission to the Regional Administrator of notice of such new or increased discharges or pollutants; that the discharge of any pollutant more frequently than or at a level in excess of that identified and authorized by the permit shall constitute a violation of the terms and conditions of the permit.

Even for known point sources, effective compliance monitoring is far from a trivial or

The 1972 Water Pollution Control Act Amendments specify that appropriate pollution monitoring devices, sampling procedures, and recordkeeping practices by the discharger may be required when necessary to carry out the objectives of the Act. Such requirements may be imposed as a condition for obtaining an NPDES permit.[34] The Act also provides that authorized officials shall have a right of entry to, upon, or through any premises in which an effluent source is located,[35] so that inspections may be undertaken where the enforcement authorities know of the existence of a pollution source. Consequently, the threshold problem for compliance enforcement is the detection of nonfilers and of unauthorized discharge outlets. Given the immense geographical area to be monitored, aerial and satellite reconnaissance in the visible spectrum offers important cost advantages to enforcement agencies because, through the identification of visible features like industrial construction, outfall pipes, or drainage ditches, they enable the agencies to allocate inspection resources to sites of possible violations.

Remote sensing in spectral bands other than the visible light range offers complementary and perhaps more significant benefits. It is, for example, a property of the near infrared wavelengths that they are largely absorbed by water but reflected by land.[36] The resulting clear differentiation between water and land areas makes near infrared sensing a valuable tool for the detection of unauthorized land fill operations. The Corps of Engineers, which has primary jurisdiction in that area, has already employed this technique in a number of cases,[37] and inter-

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inexpensive task. Discharges may be authorized for and may in fact take place only at infrequent intervals during the day, month, or year. Unauthorized outfall pipes are likely to be submerged and may not be visible from the ground or, using conventional photography, from the air. Abatement and control equipment satisfactory when installed may fall into disrepair, with consequent rises in the discharge rate or contamination level. Moreover, the concentrations of effluents may greatly exceed permissible levels and yet not be detectable by onsite observers without the assistance of laboratory tests. *Cf.* Lillesand, Scarpace & Clapp, Photographic Quantification of Water Quality in Mixing Zones 1 (1974) (STAR acc. no. N74-20016):

> Knowledge of the mechanisms by which pollutants are mixed and transported in natural courses is implicit in the rational control of water quality. Unfortunately, this knowledge is sparse due in great part to the practical problems inherent in employing conventional techniques to measure physical parameters in "mixing zones".

34. 33 U.S.C. § 1318(A) (Supp. V, 1975); 40 C.F.R. § 125.27 (1975).

35. 33 U.S.C. § 1318(B) (Supp. V, 1975); 40 C.F.R. §§ 125.13, 125.22(a)(3) (1975).

36. Lind, Environmental Study of ERTS-1 Imagery: Lake Champlain and Vermont 21 (1974) (STAR acc. no. N74-25842) (unpublished manuscript available at the University of Vermont); *see* Moore & North, *Flood Inundation in the Southeastern United States from Aircraft and Satellite Imagery*, 10 WATER RESOURCES BULL. 1082, 1087 (1974).

37. Where couventional and color-infrared imagery of the land in question before

est in its use appears to be spreading to additional Corps districts.[38]

The thermal infrared band, which encompasses radiation that humans perceive as heat, may be especially useful in compliance monitoring. Even in the absence of contaminants, discharges of hot water, a common feature of power plants and many industrial processes,[39] are themselves regulated activities for which a permit is required.[40] Moreover, since most effluents are discharged at a higher temperature than that of the ambient water,[41] an unexpected hot spot or thermal plume in a remote sensing image of a waterway may indicate the presence of an unauthorized discharge outlet, one submerged or otherwise concealed from view. It may also reveal the discharge of effluents that, although discharged from authorized outlets, have been released at unauthorized times or in quantities other than those stipulated in the permit. The value of thermal monitoring is compounded since it can be employed at night when visible, near infrared and ultraviolet photo-

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development have been available, the Corps has presented "before" and "after" imagery of the affected area to show the extent of the alleged encroachment into federal waters as a basis for permit jurisdiction. *See, e.g.*, United States v. Sexton Cove Estates, Inc., 389 F. Supp. 602 (S.D. Fla. 1975), *rev'd on other grounds and remanded in part*, 526 F.2d 1293 (5th Cir. 1976); United States v. Joseph G. Moretti, Inc., 331 F. Supp. 151 (S.D. Fla. 1971), *vacated in part and remanded*, 478 F.2d 418 (5th Cir. 1973), *on remand*, 387 F. Supp. 1404 (S.D. Fla. 1974), *rev'd on other grounds and remanded in part*, 526 F.2d 1306 (5th Cir. 1976); Letters from William E. Welch, Esq., District Counsel, Jacksonville District, U.S. Army Corps of Engineers, to author, May 7 and June 27, 1975; Letters from George H. Craig, Jr., Esq., Assistant District Counsel, Jacksonville District, U.S. Army Corps of Engineers, to author, Aug. 25 and Dec. 5, 1975.

38. As reported, for example, in Letters from Col. Max R. Janairo, Jr., Pittsburgh District, U.S. Army Corps of Engineers, to author, Sept. 8, 1975; Robert Halpern, Esq., New York District, to author, Sept. 8, 1975; Capt. Eric E. Thomas, New Orleans District, to author, Aug. 15, 1975; Saul Cooper, New England Division, Waltham, Mass., to author, Apr. 15, 1975. In conjunction with the South Carolina Wildlife and Marine Resources Department, the Fish and Wildlife Service of the U.S. Department of the Interior is using near infrared photography for the same purpose. Letter from Curtis A. Laffin, Fish and Wildlife Service, Charleston, S.C., to author, Nov. 5, 1975.

39. *See, e.g.*, Dybdahl, *Remote Sensing Study of Thermal Discharges to Lake Michigan*, in 3 CONFERENCE ON POLLUTION OF LAKE MICHIGAN AND ITS TRIBUTARY BASIN, ILLINOIS, INDIANA, MICHIGAN, AND WISCONSIN 523 (4th session, Sept. 21, 1972); T. Green, Thermal Plumes on the Wisconsin Shore of Lake Michigan (1975) (unpublished survey, University of Wisconsin, Madison). *See generally* Veziroglu & Lee, Feasibility of Remote Sensing for Detecting Thermal Pollution (1973) (STAR acc. no. N75-15199).

40. 33 U.S.C. § 1326 (Supp. V, 1975). The Department of Natural Resources of the State of Wisconsin has been collecting data on thermal plumes from power plants located on Lake Michigan. A correspondent anticipates that "this information will be utilized to determine if Wisconsin power plant discharges meet the mixing zone criteria of our water quality standards. This information would then be useful in the issuance of the WPDES permits to the power plants." Letter from Jerome R. McKersie, Chief of the Water Quality Evaluation Section, Department of Natural Resources, Madison, Wis., to author, Aug. 5. 1975.

41. Ambient water or air quality means the natural or normal condition of the surrounding environmental medium into which effluents are discharged.

graphy, all of which depend on reflection of the sun's radiation, are unusable.[42] Whether used to deploy onsite inspection teams or as direct evidence in pollution cases,[43] the superiority of thermal infrared sensing over conventional photography lies in its ability to detect discharges that would not be visible to the human eye.

The points to be emphasized at this juncture are these: recent legislation has mandated an extensive monitoring program over a large geographical area; conventional investigatory techniques either provide insufficient information, as in the case of aerial photography, or are excessively expensive, as in the case of periodic on-the-ground inspections of all waterways; and remote sensing techniques may provide alternative means to bridge the gap between social expectations and enforcement capabilities. For that reason, the EPA[44] and other agencies are actively pursuing the potential of remote sensing in enforcement situations.

2. *Control of Strip Mining*

The control of the environmental effects of strip mining also illustrates the progression from changing social needs to the enactment of regulatory legislation with concomitant information-gathering requirements to the probable introduction of remote sensing data in legal settings. Substantial attention has recently been devoted to the more intensive exploitation of American coal resources in response to

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42. The latter-named techniques depend on reflection (or reflectance) of solar energy from the terrestrial surface, whereas thermal scanners record emission (or emissivity) of energy attributable either to point sources such as volcanoes or industrial process or to reradiation of solar energy absorbed during the day. *See* CROUCH & MOWER, *supra* note 13.

43. Thermal infrared photography was used, for example, in the companion cases of People v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Jan. 27, 1976) and Metropolitan Sanitary Dist. v. Inland Steel Co., No. 67 CH 5682 (Ill. Cir. Ct., Cook County, Jan. 27, 1976) to help track a pollution plume in Lake Michigan that originated at the Inland Steel plant in East Chicago, Indiana and moved toward Illinois state waters. See text accompanying notes 160-67 *infra*.

44. *See, e.g.*, Remote Sensing Memorandum enclosed in Letter from Alan G. Kirk, II, Assistant Administrator for the Office of Enforcement and General Counsel, EPA, Washington, D.C. to author, Jan. 8, 1975, which describes the wide range of remote sensing applications being investigated by the various Regions within the Agency. In his response to our inquiry, the Director of the Region III Enforcement Division observed:

> To date, we have not used remote sensing data as primary evidence in any enforcement proceeding. We have used it for preparation and documentation of sources prior to other information gathering techniques, e.g., plant inspections and formal written inquiries. We do intend to use those techniques which are advanced sufficiently to stand on their own as evidence such as identification of unpermitted discharge points, thermal discharges, and unreported oil spills.

Letter from Stephen R. Wassersug, Director, EPA Region III Enforcement Division, Philadelphia, Pa., to author, Oct. 31, 1975.

increasing energy consumption and costs, desires for national energy independence, and the gradual depletion of alternative domestic energy resources.[45] From an economic perspective strip mining is the preferred recovery technique because it affords greater labor productivity and economies of scale than do subsurface operations.[46] In the light of current air pollution regulations, surface mining in the western states is especially attractive, since much of the coal in that region is often low in sulfur content and consequently has superior combustion characteristics.[47]

On the other hand, the environmental consequences of unregulated strip mining have been very severe.[48] Although eventually vetoed by the President,[49] a comprehensive strip mining control bill was passed by Congress in 1975, evincing widespread concern with the depredations caused by surface mining.[50] During the past few years, a number of the states that have experienced extensive strip mining have enacted or strengthened legislation to minimize its environmental effects.[51] It appears very likely that surface mining in the future will be carried out within the confines of strict regulatory controls.

The expanded information requirements associated with effective regulation of strip mining fall into three classes. Prior to the commencement of mining, topographical and ecological data is necessary to identify potential surface mining sites, to estimate the probable success of subsequent reclamation efforts, and to serve as baseline information against which the environmental impacts of strip mining can be

45. *See generally* Nephew, *The Challenge and Promise of Coal*, 76 TECH. REV., Dec. 1973, at 20; Naill, Meadows & Stanley-Miller, *The Transition to Coal*, 78 TECH. REV., Oct./Nov. 1975, at 18; Atwood, *The Strip-mining of Western Coal*, 233 SCI. AMER., Dec. 1975, at 23 [hereinafter cited as Atwood].

46. *See, e.g.*, Policy Study Group of the MIT Energy Laboratory, *Energy Self-Sufficiency: An Economic Evaluation*, 76 TECH. REV., May 1974, at 22, 37-41.

47. *See, e.g.*, Atwood, *supra* note 45, at 23; EPA OFFICE OF ENFORCEMENT, AN APPLICATION OF ERTS TECHNOLOGY TO THE EVALUATION OF COAL STRIP MINING AND RECLAMATION IN THE NORTHERN GREAT PLAINS 1 (1975). *Cf.* Hoffman, Curran, McMullen, Cox & Hunt, *E.P.A.'s Role in Ambient Air Quality Monitoring*, 190 SCIENCE, Oct. 17, 1975, at 243-44.

48. Atwood, *supra* note 45, at 26-29; Nephew, *supra* note 45, at 23; Pettyjohn, Rogers & Reed, *Automated Strip Mine and Reclamation Mapping from ERTS*, in THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 87, 88-89 (STAR acc. no. N74-30805) [article hereinafter cited as Pettyjohn, Rogers & Reed]. The Environmental Protection Agency estimated in 1973 that over 3 million acres of land had been despoiled by surface mining. EPA Environmental Facts, Land Use (July 1973).

49. Veto of Surface Mining Control and Reclamation Bill, 11 WEEKLY COMP. OF PRES. DOC. 535 (May 20, 1975) (Presidential veto message); N.Y. Times, May 21, 1975, at 19, col. 7.

50. H.R. Res. 25, 94th Cong., 1st Sess. (1975). *See* H.R. REP. No. 94-45, 94th Cong., 1st Sess. (1975).

51. *E.g.*, ILL. REV. STAT. ch. 93, §§ 201-16 (Supp. 1976); IND. ANN. STAT. tit. 14, art. 4, ch. 2, §§ 1-14 (1973); KY. REV. STAT. §§ 350.010-.990 (Supp. 1974).

measured. Thereafter, while mining and reclamation activities proceed, monitoring is required to ensure that they comply with the relevant regulations. Finally, the long-term development of reclaimed lands must be monitored to determine the viability of alternative reclamation techniques and the ultimate environmental costs of strip mining.[52] As in the NPDES illustration, effective compliance monitoring requires not collection of data at a single place and time, but repeated investigations covering large geographical areas over a long duration.[53]

Color infrared (CIR) photography is already being used on a large scale to obtain baseline information on the environmental and geological characteristics of potential surface mining areas.[54] The near infrared spectral band is used in preference to the visible light range because CIR photography has the capacity to make more sensitive identifications of vegetation[55] and surface water features. A number of studies have already demonstrated the feasibility of using satellite images to accomplish periodic monitoring at a far lower cost than that of onsite inspections.[56] For enforcement monitoring, aerial and satel-

52. Letter from Eugene H. Newell, Acting State Director, Bureau of Land Management, U.S. Department of the Interior, Billings, Mont., to author, Sept. 26, 1975:

> High altitude color infrared aerial photography has proven to be a tremendously versatile inventory and monitoring tool. We have photographed approximately 30,000 square miles of strippable coal lands in eastern Montana and western North Dakota since 1972. Based on this photography, we are able to generate highly accurate and *current* information on a variety of critical surface resources. These include vegetative types, watershed conditions, current land uses, surface hydrology and potential wildlife habitats. With this imagery we can establish an accurate environmental baseline record on these areas prior to strip mining. At present, none of this imagery or its interpreted data has been used by the BLM in any litigations. However, the following applications can be envisioned: checking for compliance with mining plans, reclamation plans, and monitoring changes in environmental quality as a result of mining or its associated activities.

See also WOBBER, *et al.*, *supra* note 21.

53. For example, section 517(a) of the vetoed Congressional strip mining bill provided:

> The Secretary shall cause to be made such inspections of any surface coal mining and reclamation operations as are necessary to evaluate the administration of approved State programs, or to develop or enforce any Federal program . . . .

Sec. 517(c)(1) further provided that:

> The inspections by the regulatory authority shall (1) occur on an irregular basis averaging not less than one inspection per month for the surface coal mining and reclamation operations for coal covered by each permit. . . .

H.R. Res. 25, 94th Cong., 1st Sess. § 517(a) (1975).

54. Letter from Eugene H. Newell to author, *supra* note 52; Letter from William D. Leavell, Associate State Director, Bureau of Land Management, Salt Lake City, Utah, to author, Aug. 1, 1975 (CIR photography taken of 40,000 square miles of Utah); Conversation between R. White and Bruce Keating, Bureau of Land Management, Cheyenne, Wyo., July 22, 1975 (CIR imagery of three-quarters of Wyoming).

55. See text accompanying notes 200-16 *infra*.

56. Anderson & Schubert, A Demonstration of ERTS-1 Analog and Digital Techniques Applied to Strip Mining in Maryland and West Virginia (Nov. 1974)

lite remote sensing may initially be employed to allocate agency inspection resources more efficiently,[57] but as the reliability of such techniques is established the likelihood increases that remote sensing information will be introduced as primary evidence.

II

REPRESENTATIVE LEGAL APPLICATIONS OF REMOTE SENSING

Remote sensing output will be relevant in a number of distinct legal forums with divergent criteria for determining what information may be considered. In this regard, legally significant remote sensing applications may be grouped into three general categories: (1) applications aimed at the development of public policy and especially at the creation of legislative and administrative standards; (2) investigatory applications designed to facilitate the allocation of enforcement resources; and (3) applications expected to produce evidence admissible in litigation. Applications in different categories may often address the same kinds of environmental phenomena, but with dissimilar requirements for particularity and precision.[58] Ideally, remote sensing information ought always to be obtained in a manner calculated to comply with the formal rules of evidence. Given limited institutional re-

(STAR acc. no. N75-15133) (Goddard Space Flight Center); EPA MINING STUDY, *supra* note 47; WOBBER *et al.*, *supra* note 21; Alexander, Dein & Gold, *The Use of ERTS-1 MSS Data for Mapping Strip Mines and Acid Mine Drainage in Pennsylvania*, in 1 SYMPOSIUM ON SIGNIFICANT RESULTS OBTAINED FROM EARTH RESOURCES TECHNOLOGY SATELLITE 569 (March 5-9, 1973) (STAR acc. no. N73-28267) (Goddard Space Flight Center) [hereinafter cited as Alexander, Dein & Gold]; Pettyjohn, Rogers & Reed, *supra* note 48.

57. The focus of our Landsat study is an economic analysis of the feasibility of using satellite acquired data in a multi-tier inspection system for surface mining. In other words, if satellite acquired data were to indicate a violation at a given mine, a field inspectiou would be dispatched to that mine to determine if a violation actually existed.

Letter from Robert E. Nickel, Chief, Office of Planning and Research, Kentucky Department of Natural Resources and Environmental Protection, Frankfort, Ky., to author, Aug. 18, 1975. *See also* Letter from Wesley C. Jockisch, Esq., Ohio River Division, U.S. Army Corps of Engineers, Cincinnati, Ohio, to author, Sept. 30, 1975.

58. For example, one of the Water Pollution Control Act Amendments of 1972, 33 U.S.C. § 1288 (Supp. V, 1975), requires the creation of areawide waste treatment management plans for areas having substantial water quality control problems. Another amendment, 33 U.S.C. § 1345 (Supp. V, 1975), requires those waste treatment facilities discharging sewage sludge to obtain NPDES permits, while 33 U.S.C. § 1342(h) (Supp. V, 1975) provides for an injunction prohibiting new discharges into a publicly owned waste treatment facility already in violation of the conditions of its permit. The level of information specificity required to justify the latter action may be much greater than that needed to accomplish the areawide planning function, although the environmental phenomeua to be identified are similar.

sources, however, data collection practices will vary widely with respect to reliability and procedural regularity. Organizations select particular information-gathering techniques, establish accuracy tolerances, and adopt operating procedures based on a comparison of the perceived utility of the data against the costs of collection and processing. The attempt or ability to conform to a given set of evidentiary requirements may influence both sides of this cost-benefit analysis. In each category of applications, remote sensing will prove attractive to the extent that it can provide sufficient information content in a more efficient manner than can conventional information collection techniques.

A. Policy, Planning, and Standards Applications

Remote sensing applications in this category are gaining widespread acceptance as a result of their ability to produce economical and timely data covering large areas of the nation. Nearly every major environmental and natural resources program requires comprehensive long-term planning and the development of areawide standards for environmental quality.[59] An adequate information base is a prerequisite for effective implementation of these functions. Although traditional measuring methods can usually obtain needed data at any single location with greater precision than can remote sensors, the extensive geographical coverage required for environmental protection programs often makes onsite collection practices prohibitively expensive or inordinately time-consuming.[60]

Information developed within the first category of remote sensing applications will typically be introduced in legislative hearings or administrative rulemaking proceedings. In such settings there are essentially no formal constraints upon the kinds of information that may be utilized beyond a threshold requirement that the data be relevant

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59. *See, e.g.*, Federal Water Pollution Control Act Amendments of 1972, 33 U.S.C. §§ 1251-1376 (Supp. V, 1975); Clean Air Act, 42 U.S.C. §§ 1857(a)-(h) (Supp. V, 1975); Noise Control Act of 1972, 42 U.S.C. §§ 4901-18 (Supp. V, 1975); Coastal Zone Management Act of 1972, 16 U.S.C. §§ 1451-64 (Supp. V, 1975); Water Bank Act, 16 U.S.C. §§ 1301-11 (1970), *as amended*, 16 U.S.C. § 1308 (Supp. V, 1975).

60. *See, e.g.*, T. THOMAS, D. SIMONETT, J. ANTENUCCI, J. GARBER, W. BROONER, W. ROHDE & D. WOODWARD, APPLICATION OF ERTS-1 DATA TO INTEGRATED STATE PLANNING IN THE STATE OF MARYLAND 2-8, 33, 35-37, 39-40, 73-74, 163-81 (Dec. 1974) (NASA Goddard Space Flight Center); Anderson, Carter & McGuinness, *Applications of ERTS Data to Coastal Wetland Ecology with Special Reference to Plant Community Mapping and Typing and Impact of Man*, in THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 1225, 1226; MAIRS, WOBBER, MACOMBER, STANEZUK, THIBULT, YUNGHANS, FEINBERG & STITT, APPLICATION OF ERTS-1 DATA TO THE PROTECTION AND MANAGEMENT OF NEW JERSEY'S COASTAL ENVIRONMENT 1-4, 15-16, 74-87, 139-42 [hereinafter cited as MAIRS & YUNGHANS],

to the issues at hand.[61] Legislative bodies are not obligated to hold public hearings or to articulate the factors evaluated in their formulation of public policy.[62] Administrative agencies ordinarily are expected to solicit the views of interested parties,[63] but are allowed great flexibility in fulfilling that mandate. Agencies may base decisions relating to "legislative facts" on their own factual determinations and expertise; in rulemaking proceedings they are not required to give all potentially affected persons the opportunity to submit information or to challenge the validity of observations provided by others.[64] Thus, the only control imposed on the introduction of remote sensing output in this context is the decisionmaker's perception of its utility and reliability.

1. Illustrative Applications

Several illustrations of policy and standards applications may make the nature of this category more concrete. One class of remote sensing applications involves the monitoring of natural environmental conditions and the impact of human actions upon them. When used to monitor water pollution,[65] for example, remote sensing is employed on a cost-effectiveness rationale to determine regional water quality and to detect specific contaminants, surface and subsurface phenomena (such as currents and thermal layers) that influence the dispersion of effluents, and large-scale ecological degradation associated with water pollution.[66] In like manner, techniques are in use or under develop-

61. *See* 5 U.S.C. § 553(c) (Supp. V, 1975); MCCORMICK, *supra* note 7, § 331.

62. Bi-Metallic Inv. Co. v. Board of Equalization, 239 U.S. 441 (1915); *see* New York v. United States, 331 U.S. 284 (1947).

63. *See, e.g.*, 5 U.S.C. § 553(c) (Supp. V, 1975); 33 U.S.C. § 1314(a) (Supp. V, 1975).

64. *See, e.g.*, City of Statesville v. AEC, 441 F.2d 962 (D.C. Cir. 1969); Flying Tiger Line, Inc. v. Boyd, 244 F. Supp. 889 (D.D.C. 1965); 1 K. DAVIS, ADMINISTRATIVE LAW TREATISE § 7.02 (1958).

65. See text accompanying notes 23-44 *supra.*

66. *See, e.g.*, Coker, Higer & Goodwin, *Detection of Turbidity Dynamics in Tampa Bay, Florida Using Multispectral Imagery from ERTS-1*, in PROCEEDINGS OF THE SYMPOSIUM ON SIGNIFICANT RESULTS OBTAINED FROM EARTH RESOURCES TECHNOLOGY SATELLITE-1 1715 (Mar. 9, 1973) (NASA Goddard Space Flight Center); Higer, Coker & Cordes, *Water-Management Models in Florida from ERTS-1*, in THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 1071; Lillesand, Scarpace & Clapp, *supra* note 33; Muir & Hanessian, The U.S. Earth Resources Satellite Program and Its Implications for Water Policy and Management (Paper No. 25 presented before the United Nations Panel of Experts on Water Resources Development Policies, Buenos Aires, Argen., June 8-13, 1970); Yarger, McCauley, James, Magnuson & Marzolf, *Quantitative Water Quality with ERTS-1, supra* note 15; Klooster & Scherz, *Water Quality by Protographic Analysis*, 40 PHOTOGRAMMETRIC ENGINEERING 927 (1974); Yeske, Scarpace & Green, *Measurement of Lake Currents*, 41 PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING 637 (1975). Wisconsin, for example, is employing remote sensing to investigate mixing zone characteristics on water bodies within or adjacent to the state. Letter from Jerome R. McKersie, Chief of the Water Quality Evaluation Section, Department of Natural Resources,

ment to accomplish analogous functions in connection with air quality indicia and atmospheric conditions.[67] In the aggregate these and similar applications are designed to replace the sporadic and intermittent sampling procedures of the past with economical methods able to obtain more comprehensive and current information. That information, the collection of which is often required by statute,[68] facilitates the creation of accurate environmental baselines against which subsequent changes can be identified and measured.

A second type of policy and standards application is designed to produce inventories of vegetation and natural resources. Using reflectance characteristics in several spectral bands, especially in the near infrared ranges, it is often possible to discriminate between different vegetation types and groupings,[69] and therefore to quantify the presence of each type in a given area by means of aerial and satellite reconnaissance.[70] This technique enables accurate

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Madison, Wisconsin, to author, Aug. 5, 1975. *See also* Green, *supra* note 39; Letter from James A. Kurtz, Director of the Bureau of Legal Services, Department of Natural Resources, Madison, Wis., to author, Aug. 6, 1975:

> At the present time the Department is actively involved in several programs to get data through the use of remote sensing. I anticipate the first application of this data will be utilized in the development of administrative rules and regulations. At such time as these regulations may become violated I would also anticipate that the supporting data used to establish a regulation would be utilized in the prosecution.

67. *See, e.g.*, Copeland, Bandy, Blais & Hilton, Correlation of Satellite and Ground Data in Air Pollution Studies (1973) (bimonthly reports for period Feb. 1, 1973 to May 31, 1973; Old Dominion University Research Foundation); Griggs, *A Method to Measure the Atmospheric Aerosol Content Using ERTS-1 Data*, in THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 1503; Lyons & Northouse, *The Use of ERTS-1 Imagery in Air Pollution and Mesometeorological Studies Around the Great Lakes*, in THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 1491; Murtha, *SO_2 Damage to Forests Recorded by ERTS-1*, in THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 137; Grant, Hake, Liston, Robbins & Proctor, *Calibrated Remote Measurement of NO_2 Using the Differential-Absorption Backscatter Technique*, 24 APPLIED PHYSICS LETTERS 550 (1974).

68. *See, e.g.*, the information requirements in the Federal Water Pollution Control Act Amendments of 1972, 33 U.S.C. §§ 1314-15 (Supp. V, 1975), and the Noise Control Act of 1972, 42 U.S.C. § 4904 (Supp. V, 1975).

69. *See, e.g.*, Gates, *Physical and Physiological Properties of Plants*, in REMOTE SENSING IN AGRICULTURE, *supra* note 6, at 224, 224-48; Myers, Heilman, Lyon, Namken, Simonett, Thomas, Wiegand & Woolley, *Soil, Water and Plant Relations*, in REMOTE SENSING IN AGRICULTURE, *supra* note 6, at 253, 253-64.

70. *See, e.g.*, Colwell, *Applications of Remote Sensing in Agriculture and Forestry*, in REMOTE SENSING IN AGRICULTURE, *supra* note 6, at 164, 164-68 [article hereinafter cited as Colwell]; Anderson & Carter, *Wetlands Delineation by Spectral Signature Analysis and Legal Implications*, (STAR acc. no. N72-29373), in 3 FOURTH ANNUAL EARTH RESOURCES PROGRAM REVIEW (Jan. 21, 1972) (NASA Manned Space Center, Houston, Tex.) [hereinafter cited as Anderson & Carter]; Welby, Occurrence of Eurasian Watermilfoil (*Myriophyllum spicatum*) in Currituck Sound and Alligator River, North Carolina, Jan. 24, 1974 (unpublished paper from the Department of Geosciences at North Carolina State University, Raleigh, for the U.S. Army Corps of Engineers, Wilmington District).

assessments of the acreage[71] and may permit estimations of the yields[72] of agricultural crops in the United States and the world.[73] The resulting data is directly relevant to consideration of such issues as farm production quotas, price subsidies, and export policies.[74] Similar inventory applications may address forest,[75] wildlife,[76]

71. "[T]he acreages of agricultural fields commonly can be measured to within 1 percent of their correct areas on conventional aerial photography." Colwell, *supra* note 70, at 177. For satellite sensing, accuracies of greater than 90 percent have been achieved. The resolution of Landsat sensors is insufficient at present to classify small plots reliably, which accounts for the lower accuracy rate. Fink, *supra* note 18, at 39. Using satellite data instead of aerial data, however, may result in a reduction in costs of up to 20 times. *Id.*

72. Yield is dependent not only on acreage but on crop health and growth characteristics; remote sensing can provide substantial information on each. *See* Gates, *supra* note 69, at 248-52; Colwell, *supra* note 70, at 181-85. A powerful rationale for the use of infrared remote sensing instead of visible wavelength photography is that healthy vegetation can easily be distinguished from less vigorous plants of the same species:

> The spongy mesophyll tissue of a healthy leaf, which is turgid, distended by water, and full of air spaces, is a very efficient reflector of any radiant energy and therefore of the near-infrared wavelengths. These pass the intervening palisade parenchyma tissue (which absorbs blue and red and reflects green from the visible). When its water relations are disturbed and the plant starts to lose vigor, the mesophyll collapses, and as a result there may be great loss in the reflectance of near-infrared energy from the leaves almost immediately after the damaging agent has struck a plant. Furthermore, this change may occur long before there is any detectable change in reflectance from the visible part of the spectrum, since no change has yet occurred in the quantity or quality of chlorophyll in the palisade parenchyma cells.

Id. at 169.

73. *See, e.g.*, Hammond, *Crop Foresting from Space: Toward a Global Food Watch*, 188 SCIENCE, May 2, 1975, at 434.

74. *See id.* at 434-35; V. HOOD, *supra* note 17, at 24-29.

75. [W]e have used color infrared photography to delineate woody vegetation types and densities for use in the preparation of environmental assessments and to prepare cost estimates for wood vegetation control.

Letter from Nelson W. Plummer, Acting Regional Director, Bureau of Reclamation, U.S. Department of the Interior, Denver, Colo., to author, May 6, 1975. *See also* Colwell, *supra* note 70, at 193-202.

76. Using low-altitude, high-resolution imagery, it is possible to count livestock or other open range wildlife. Colwell, *supra* note 70, at 205-15. The most common wildlife inventory technique, however, involves identifying habitats and food resources associated with differing wildlife species. *Id.* at 215-22. *See* W.F. Miller, Remote Sensing Applications in Environmental Impact Studies, 1974 (unpublished paper available from the Department of Forestry at Mississippi State University):

> Techniques developed in a multidisciplinary, ecological study of the Tennessee-Tombigbee Waterway were employed to delineate the major eco-systems along the route from Gainesville, Alabama, to Pickwick Lake on the Tennessee River. Following this delineation, which was made from 1:50,000, winter, color infrared imagery, recurring forest species groupings were identified. . . .

Id. at 1.

> Only through the use of operational remote sensing techniques can a valid impact statement be prepared on a real-time basis. A conservative estimate of the time required for ground cruising and sampling techniques to gather the volume of information obtained in this study would be 10 years: the study spanned a 17-month period.

Id. at 15.

marine,[77] and mineral[78] resources.

A third type of remote sensing application in this category is intended to identify natural phenomena that may directly affect and imperil human activities. In response to dangers posed by floods, for example, Congress has enacted the National Flood Insurance Act of 1968[79] and the Flood Disaster Protection Act of 1973.[80] Information on flood patterns and community susceptability is a prerequisite to adequate flood control and disaster relief.[81] The cost of ground surveys for floodplain mapping—estimated at $250 to $4000 per square kilometer depending on the area[82]—has prevented most locali-

77. *See, e.g.*, Anderson, *Multispectral Analysis of Aquatic Ecosystems in the Chesapeake Bay*, in PROCEEDINGS OF THE 7TH INTERNATIONAL SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT 2217 (May 21, 1971) (Willow Run Laboratories, University of Michigan, Ann Arbor, Mich.); Maughan, Marmelstein & Temple, *Application of ERTS-1 Imagery to the Harvest Model of the U.S. Menhaden Industry*, in SYMPOSIUM ON SIGNIFICANT RESULTS OBTAINED FROM EARTH RESOURCES TECHNOLOGY SATELLITE-1 1405 (Mar. 9, 1973) (NASA Goddard Space Flight Center); Savastano, Pastula, Woods & Faller, *Preliminary Results of Fisheries Investigation Associated with Skylab-3*, in 2 PROCEEDINGS OF THE 9TH INTERNATIONAL SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT 1013 (April 19, 1974) (Environmental Research Institute of Michigan, Ann Arbor, Mich.).

78. For this purpose the synoptic view characteristic of satellite and high altitude aerial remote sensing is of unparalleled value. For example, geologists in California have utilized Landsat imagery to delineate a distinct transverse fault system trending west-northwest, oblique to the prevalent trend of the San Andreas fault system. When the researchers plotted the locations of known mercury deposits onto the Landsat image, they found a "striking correlation" with the trending shear zones, raising the prospect that Landsat imagery may point the way to future mercury discoveries. Abdel-Gawad & Silverstein, *ERTS Applications in Earthquake Research and Mineral Exploration in California*, in 1A SYMPOSIUM ON SIGNIFICANT RESULTS OBTAINED FROM EARTH RESOURCES TECHNOLOGY SATELLITE-1 433 (Mar. 9, 1973) (NASA Goddard Space Flight Center). Similarly, the synoptic view afforded by Landsat imagery has enabled earth scientists to prepare regioual maps of anomalous geological features in the Anadarko Basin of Oklahoma. Of 35 "hazy" anomalies identified on one image, 33 were found to correlate with producing oil and gas fields or previously drilled structures. None of these anomalies were recognizable except on Landsat imagery, leading the researchers to concude that Landsat imagery "is an excellent tool for reconnaissance exploration of large sedimentary basins or new exploration provinces." Collins, McCown, Stonis, Petzel & Everett, *An Evaluation of the Suitability of ERTS Data for the Purposes of Petroleum Exploration*, in 1A THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 819. *See generally* Barringer, *Remote Sensing Techniques for Mineral Discovery*, in THE SURVEILLANT SCIENCE, *supra* note 5, at 47; Guild, *supra* note 20, at 709-11.

79. 42 U.S.C. §§ 4012, 4013-16, 4021, 4026, 4054, 4056, 4101, 4104, 4121 (Supp. V, 1975), *amending* 42 U.S.C. §§ 4001, 4011-20, 4022-25, 4027, 4041, 4051-56, 4071-72, 4081-84, 4102-03, 4121-27 (1970).

80. 42 U.S.C. §§ 4001-03, 4012a, 4013-16, 4026, 4056, 4101, 4104-07, 4121, 4128 (Supp. V, 1975).

81. *See, e.g.*, Rango & Anderson, *Flood Hazard Studies in the Mississippi River Basin Using Remote Sensing*, 10 WATER RESOURCES BULL. 1060, 1066-71 (1974) [hereinafter cited as Rango & Anderson].

82. Rango & Anderson, *supra* note 81, at 1066, 1079, *citing* Wolman, *Evaluating*

ties from preparing the necessary flood hazard reports.[83] A number of studies have demonstrated the feasibility of using satellites to obtain floodplain mapping and inundation information.[84] One source concluded that information similar to that obtained by ground surveys can be derived from sateliite images by a trained interpreter at a cost of about one man-hour per satellite image.[85] This differential highlights the cost-effectiveness of remote sensing techniques for appropriate applications.[86]

A final example of an application area intended to produce data primarily for use in legislative and rulemaking deliberations is that of regional land use planning and management. The desire to regulate the environmental consequences of land and natural resource development decisions and to resolve conflicts between alternative development strategies[87] has led to the enactment of a variety of programs fostering planning and management practices on a wider scale than in the past.[88] The success of such programs depends upon access to reli-

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Alternative Techniques of Floodplain Mapping, 7 WATER RESOURCES RESEARCH 1383-92 (1971).

83. Rango & Anderson, *supra* note 81, at 1066. *See* 42 U.S.C. § 4101 (Supp. V, 1975); 24 C.F.R. § 1909.22 (1976).

84. *See, e.g.*, Hallberg, Hoyer & Rango, *Application of ERTS-1 Imagery to Flood Inundation Mapping*, in 1A SYMPOSIUM ON SIGNIFICANT RESULTS OBTAINED FROM EARTH RESOURCES TECHNOLOGY SATELLITE-1 745 (Mar. 9, 1973) (NASA Goddard Space Flight Center); McGinnis & Rango, *Earth Resources Satellite Systems for Flood Monitoring*, 2 GEOPHYSICAL RESEARCH LETTERS 132 (1975); Moore & North, *supra* note 36; Rango & Salomonson, *Regional Flood Mapping from Space*, 10 WATER RESOURCES RESEARCH 473 (1974); Williamson, *Mississippi River Flood Maps from ERTS-1 Digital Data*, 10 WATER RESOURCES BULL. 1050 (1974).

85. Rango & Anderson, *supra* note 81, at 1079.

86. Applications logically analogous to flood susceptibility mapping include (1) geological fault identification as it relates to earthquake research, Lamar & Merifield, Application of ERTS Images to Study of Active and Potentially Active Faults, Santa Barbara Area, California (Sept. 1974) (STAR acc. no. N74-34770) (California Earth Science Corp., Santa Monica, Cal.); Abdel-Gawad & Silverstein, *supra* note 78, (2) identification of faults and fractures related to mining safety, WIER & WOBBER, *supra* note 16; Wier, Wobber, Rnssell, Amato & Leshendok, *Relationship of Roof Falls in Underground Coal Mines to Fractures Mapped on ERTS-1 Imagery*, in 1A THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 825, and (3) monitoring of sea ice conditions, Barnes & Bowley, *Monitoring Arctic Sea Ice Using ERTS Imagery*, in 1B THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 1453; Fink, *supra* note 18, at 37.

87. The increasing and competing demands upon the lands and waters of our coastal zone occasioned by population growth and economic development, including requirements for industry, commerce, residential development, recreation, extraction of mineral resources and fossil fuels, transportation and navigation, waste disposal, and harvesting of fish, shellfish, and other living marine resources, have resulted in the loss of living marine resources, wildlife, nutrient-rich areas, permanent and adverse changes to ecological systems, decreasing open space for public use, and shoreline erosion.

Coastal Zone Management Act of 1972, 16 U.S.C. § 1451(c) (Supp. V, 1975) (congressional findings).

88. *See, e.g.*, Coastal Zone Management Act of 1972, 16 U.S.C. §§ 1451-64 (Supp.

able information on current land use patterns, on characteristics of the environment, and on human activities which make some future uses preferable to others. Conventional data-collection techniques, however, are often unable to supply adequate information at reasonable cost.[89] Land use mapping by means of aerial photography is a widely accepted technique,[90] the major disadvantage of which is cost. The feasibility of employing satellite imagery to discern land development patterns has already been demonstrated[91] and operational systems are under development.[92] Satellite sensing possesses two major advantages over conventional ground survey and aerial techniques: the marginal cost of collecting information covering large geographic areas is

V, 1975); Forest and Rangeland Renewable Resources Planning Act of 1974, 16 U.S.C. §§ 1601-10 (Supp. V, 1975); 40 U.S.C. § 461 (Supp. V, 1975), *amending* 40 U.S.C. § 461 (1964).

89. Clapp, *et al.*, *The Application of ERTS-1 Data to the Land Use Planning Process*, in THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 425-26 [article hereinafter cited as Clapp, *et al.*]:

> At present, the regional decision maker typically lacks relatable basic information on the use, the composition, character, and the temporal change of the region. The most basic forms of these data, such as the extent of vegetation cover, wetlands distribution, urban growth and the ecological well-being of the landscape are examples of data that have been traditionally unavailable in formats directly useable in the regional planning process.

See also Fink, *supra* note 18, at 34.

90. *E.g.*, Letter from R.H. Lyddan, Chief of the Topographic Division, Geological Survey, U.S. Dept. of the Interior, Reston, Va., to author, Aug. 12, 1975:

> Practically all USGS maps made during the past 25 years are the result of remote sensing with aerial photographs, and a number of these maps have been introduced as evidence or used to settle suits out-of-court.

See, e.g., Schneider & Kolipinski, *Applications of Color Aerial Photography to Water Resources*, in THE SURVEILLANT SCIENCE, *supra* note 5, at 134; Avery, *Measuring Land Use Changes on USDA Photographs*, 31 PHOTOG. ENG. 620 (1965).

91. Because of the 80-meter resolution of the sensors on Landsat, only relatively gross distinctions can be drawn. One study achieved better than 90 percent accuracy in classifying land from Landsat (ERTS) images for categories such as deep and shallow water, tended grass, rangeland, bare earth (extractive), urban, forest land, and nonforested wet lands. Rogers & Reed, Automated Land-Use Mapping from Spacecraft Data 417, 427 (Mar. 1974) (STAR acc. no. N74-21965) (special report, Bendix Corp.) [hereinafter cited as Rogers & Reed]. *See generally* Clapp, *et al.*, *supra* note 89; Estes, Thaman & Senger, *Application of ERTS-1 Satellite Imagery for Land Use Mapping and Resource Inventories in the Central Coastal Region of California*, in THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 457 [hereinafter cited as Estes, *et al.*].

92. The Bendix Aerospace Systems Division is under contract to the State of Ohio to provide a statewide land-use inventory derived from the processing of Landsat multispectral data. The Department of Economic and Community Development, the Environmental Protection Agency, and the Department of Natural Resources are the cooperating Ohio state agencies. Bendix Aerospace Systems Division, Ohio Statewide Land-Use Inventory, Down to Earth Views, Bendix Earth Resources Newsletter, 2 Winter 1976, at 1, col. 1. The California South Central Coast Regional Commission has used and will continue to use Landsat and other remote sensing imagery "in the planning process directed by [Cal.] Public Resources Code section 27300 ff. [(West Supp. 1976).]" Letter from F.C. Buchter, Executive Director, California South Central Coast Regional Commission, Santa Barbara, Cal., to author, Sept. 22, 1975.

much lower;[93] and imaging of the ground on successive orbital passes allows resource managers and planners to monitor changes as they occur, and thus to identify development trends.[94]

In addition to its utility for comprehensive planning, land use and ecological information derived from remote sensing permits identification of sensitive or important regions that require special regulatory controls on development. In implementing the Florida Environmental Land and Water Management Act of 1972,[95] for example, Florida employed aerial and satellite imagery in studies which culminated in the designation of the Big Cypress, Green Swamp, and Florida Keys regions as "areas of critical state concern."[96] That designation has the legal effect of providing the State Planning Commission with the authority to override local development regulations in order to preserve the environmental integrity of such areas.[97]

2. *Legal Significance*

Policy, planning, and standards applications account for the majority of current legal uses of remote sensing output for several reasons. The very recent proliferation of information requirements appurtenant to new or expanded environmental laws should first be reemphasized. During the past decade, governmental institutions have devoted a major proportion of their efforts to the creation of planning and regulatory standards of general application. Clearly, development of such standards must precede the type of enforcement activities that would lead to the introduction of remote sensing data in other legal settings. In addition, when compared with the formal rules of evidence applied in adjudicatory contexts, the more flexible criteria for the acceptance of information in legislative and rulemaking proceedings[98] has probably contributed to the predominant use of remote sensing output in policy and standards applications. Given that the technology is rapidly evolving, that few explicit judicial precedents exist for the admission of remote sensing evidence, and that the premature submis-

93. Marginal cost is used since Landsat data users are not required to pay a proportional share of the equipment design and launch costs. Using visual interpretation of a single Landsat image, one study was able to identify development patterns in eastern Rhode Island at a rate of 30 sq. mi. per man-hour (40 hours for 1200 sq. mi.). Fink, *supra* note 18, at 34. *See also* Rogers & Reed, *supra* note 91, at 424.

94. Estes, *et al.*, *supra* note 91, at 480; Clapp, *et al.*, *supra* note 89, at 430.

95. FLA. STAT. ANN. §§ 380.012-.10 (1974), *as amended* §§ 380.05(b), -.055(5), -.06(4a), -.06(7), -.06(8), -.06(12), -.08(2), -.11, -.12 (Supp. 1976).

96. Letter from Eastern W. Tin, Chief of the Bureau of Land and Water Management, Division of State Planning, Tallahassee, Fla., to author, Aug. 7, 1975.

97. FLA. STAT. ANN. §§ 380.05(5), §§ 380.055 (1974), *as amended* §§ 380.05 (b), 380.055(5) (Supp. 1976).

98. See text accompanying notes 61-64 *supra.*

sion of insufficiently reliable output may lead to adverse decisions that could prejudice the future acceptance of remote sensing,[99] a number of our correspondents have indicated a reluctance to be among the first to rely on remote sensing information in court.[100]

As noted above,[101] there are fundamental trade-offs between geographical coverage, sensor resolution, and cost. The most economical forms of remote sensing—those employing satellite and high-altitude aerial imagery—may be quite useful for the creation of area-wide standards, but may lack sufficient detail to be effective in a litigation setting where the rights or liability of particular parties are determined.[102] Since an adjudicatory proceeding typically involves facts obtainable in a limited area, conventional investigatory techniques that provide more precise information will often be economically justifiable. It is in the realm of large area surveillance[103] that remote sensing cur-

99. *See* State v. Cary, 49 N.J. 343, 230 A.2d 384 (1967), *on remand*, 99 N.J. Super. 323, 239 A.2d 680 (L. Div. 1968), *aff'd per curiam*, 56 N.J. 16, 364 A.2d 209 (1970), in which the New Jersey Superior Court held that spectrogram voiceprint techniques had not yet attained a sufficient degree of scientific acceptance and reliability to produce results admissible as evidence. 99 N.J. Super. at 332-34, 239 A.2d at 685. This reasoning has been influential in persuading other jurisdictions not to accept voiceprint evidence. *See, e.g.*, People v. King, 266 Cal. App. 2d 437, 453, 461, 72 Cal. Rptr. 478, 488, 493 (2d Dist. 1968).

100. EPA's administrative and court proceedings pursuant to the Clean Air Act have, to date, been based on the more established means of documenting violations of the applicable state implementation plans (e.g. opacity readings). This policy was developed because EPA anticipated close judicial scrutiny of our enforcement actions. As a result, we were wary of using new scientific techniques that had not been widely tested and accepted within the legal and scientific communities. In this regard, the high standard of proof required to support a criminal conviction militates against the use of remote sensing evidence at this time. Civil actions, however, probably will provide the most hospitable environment for the introduction of such evidence in the future.

Letter from William F. Johnson, Division of Stationary Source Enforcement, U.S. Environmental Protection Agency, Washington, D.C., to author, Aug. 19, 1975.

101. See note 19 *supra*.

102. The [remote sensing] technique described in this report offers a relatively simple and economic procedure that can be used to quickly assess areas that have been inundated during recent flood periods . . . . These methods will not replace an engineering type of flood evaluation that requires specific information, i.e., depth of flooding in a basement, the amount or degree of damage resulting from undermined roads, and other structures, or the degree of damage to mechanical equipment and other property in buildings.

The method will provide regional disaster relief agencies with an overview from which they will be able to determine a first cut damage estimate, and thus be able to dispense assistance in the most expeditious manner.

Deutsch & Ruggles, *Optical Data Processing and Projected Applications of the ERTS-1 Imagery Covering the 1973 Mississippi River Valley Floods*, 10 WATER RESOURCES BULL. 1023, 1038 (1974).

103. Landsat, for example, produces a 185 km. on-a-side image that depicts a total area of over 34,000 sq. km., or about 13,000 sq. miles. *See* authorities cited in note 9 *supra*. Skylab images depict a rectangle measuring 72.4 km. by 100 km., for a total area of 7,240 sq. km. or about 2,800 sq. miles. *See* Coker, Higer, Rogers, Shah, Reed & Walker, Automatic Categorization of Land-Water Cover Types of the Green Swamp,

rently achieves its greatest economic superiority over traditional sampling methods.

Although remote sensing information collected for policy, planning, and standards applications is not primarily intended to serve as evidence, the adequacy of such data will occasionally be tested in litigation. One probable example involves the preparation of Environmental Impact Statements (EIS), as mandated by the National Environmental Policy Act of 1969.[104] In a series of cases, the courts have interpreted the EIS provision to require that a range of possible alternatives to any proposed federal action be considered[105] and that an EIS be tailored to the environmental effects of government programs on specific areas in light of local conditions.[106] Both of these prescriptions —the evaluation of local effects[107] and potential alternatives[108]—

Florida, Using Skylab Multispectral Scanner (S-192) Data at 8 (prepared for the annual meeting of the American Astronautical Society, Univ. of So. Calif., Aug. 20-22, 1974) (NASA Skylab EREP contract CC-30280A) [hereinafter cited as Coker & Higer]. The selection of these sensor characteristics for these vehicles indicates a preference for large area coverage at the expense of fine detail, so it is not surprising that the resulting satellite imagery would be of greater use in policy and standards applications than in litigation-oriented ones.

104. 42 U.S.C. §§ 4321-47 (1970), *as amended*, 42 U.S.C. §§ 4321, 4331-32, 4341, 4343, 4346-47 (Supp. V, 1975). The requirements for Environmental Impact Statements are set out in 42 U.S.C. § 4332 (1970), *as amended*, 42 U.S.C. § 4332 (Supp. V, 1975).

105. *E.g.*, Natural Resources Defense Council, Inc. v. Morton, 458 F.2d 827 (D.C. Cir. 1972), *denying motion for summary reversal of* 337 F. Supp. 167 (D.D.C. 1971); Committee to Stop Route 7 v. Volpe, 346 F. Supp. 731 (D. Conn. 1972); Jordan, *Alternatives Under NEPA: Toward an Accommodation*, 3 ENVT'L L.Q. 705 (1973).

106. *See, e.g.*, Natural Resources Defense Council, Inc. v. Morton, 388 F. Supp. 829 (D.D.C. 1974). In this case the Bureau of Land Management (BLM) was challenged after issuing a single programmatic EIS intended to apply to all its range management functions. The court rejected that approach on the ground that while the EIS purported to cover all 171 million acres of range land under BLM supervision, it did not particularize or adequately address "individual geographic conditions." *Id.* at 839-40.

107. In Natural Resources Defense Council, Inc. v. Morton, 388 F. Supp. 829 (D.D.C. 1975), the BLM argued that it had inadequate institutional resources to make multiple EIS's. The court followed the holdings of Calvert Cliffs' Coordinating Comm. v. AEC, 449 F.2d 1109 (D.C. Cir. 1971), and National Resources Defense Council, Inc. v. Train, 510 F.2d 692 (D.C. Cir. 1975), that cost considerations could not be permitted to subvert the intent of the National Environmental Policy Act. It quoted directly from Judge Leventhal's opinion in *Train*:

> Although these steps may be cumbersome, even awesome, they may well be within the agency's grasp, at least generally. The court's injunction should serve like adrenalin, to heighten the response and to stimulate the fullest use of resources.

388 F. Supp. at 841, *quoting* 510 F.2d at 712. Since the manpower of the BLM is approximately one field investigator for every 300,000 acres, it is understandable that the BLM is currently obtaining remote sensing images to identify the environmental condition of land under its management. Letter from Ralph A. Morrill, Chief, Office of Scientific Systems Development, Bureau of Land Management, Denver, Colo., to author, Sept. 10, 1975.

108. In considering the merits of three alternative routes proposed for a canal proj-

tremendously increase the volume of information that must be incorporated into the EIS production process, and thereby may increase the benefits to be obtained from the exploitation of remote sensing technology. Since it is already common for the sufficiency of an EIS to be challenged in court, remote sensing information will receive closer judicial scrutiny in the future as agencies increasingly rely on such information in the preparation of impact statements.

The employment of remote sensing to document baseline environmental conditions is another instance in which information collected for policy and standards applications may subsequently be relevant in litigation. Maps and resource inventories prepared by means of remote sensing will in the future be used to identify changes in the environment, including unauthorized developments and ecological depredations. Eventually, the imagery itself may be introduced in court to indicate the preexisting conditions, and consequently to facilitate a quantification of the differences between the time the baseline was established and the date of the litigation.

B. Investigatory Applications

Investigatory applications, like those in the policy and standards category, are not primarily intended to produce evidence for use in litigation. Instead, these remote sensing programs are designed to identify changed or irregular environmental conditions and, hence, to facilitate the allocation of investigatory resources by regulatory agencies and other potential litigants. Both application categories require the periodic monitoring of very large areas. Unlike the policy and standards category, however, which is oriented toward the accumulation of general information about environmental features and trends, investigatory remote sensing applications aim at the preliminary detection of violations of existing standards. Where remote sensing has provided

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ect to connect the Tennessee and Tombigbee Rivers, for example, the Army Corps of Engineers relied heavily on remote sensing data to identify ecologically productive areas that ought to be avoided. W.F. Miller, *supra* note 76; Letter from Sharon Kinsman and Paul W. Erickson, Stanley Consultants, Inc., to Professor W. Frank Miller, Department of Forestry, Mississippi State University, Starkville, Miss., Nov. 1, 1974, transmitted with Letter fom Professor Miller to author, June 27, 1975. In addition, remote sensing images aimed at the evaluation of alternatives have been introduced in Federal Power Commission hearings involving a request by the City of Seattle to raise the level of Ross Lake in order to generate additional hydroelectric power. Landsat and aerial near infrared images were introduced by opponents of the project in an attempt to demonstrate that the alternatives were either aesthetically unsuitable because of extensive logging operations or unreachable because of the absence of access roads. Transcript of Proceedings, FPC, City of Seattle, Project No. 553 (Mar. 5, 1975); FPC, Draft Environmental Impact statement, Ross Development of Project No. 553, Skagit River, Wash. (1973); International Joint Commission, Canada and United States, Environmental and Ecological Consequences of Raising Ross Lake in the Skagit Valley to Elevation 1725 (1971).

information relied upon to develop a regulatory standard, similar techniques may, in most cases, subsequently be employed to detect possible transgressions of that standard. Illustrative investigatory applications include detection of concealed effluent discharge outlets;[109] the identification of air pollution sources either directly, through sensing the emission plumes, or indirectly, by imaging the resulting deterioration of nearby vegetation;[110] the detection of undesirable mining practices;[111] the detection of irrigation violations;[112] the monitoring of ocean dumping;[113] and the identification of changes in land uses and development.[114]

The demarcation line between investigatory remote sensing applications and those developed to produce admissible evidence is neither clear nor permanent. The final decision to utilize remote sensing output as evidence will depend not only on the technical characteristics and information content of the imagery, but also on the alternative investigation resources available to an organization and on its comparative degree of confidence in remote sensing. Therefore, in an era in which the technology is evolving, in which familiarity with that technology varies greatly, and in which the law of evidence with respect to remote sensing information is unsettled, it is quite conceivable that organiza-

109. *See, e.g.*, Environmental Protection Agency, National Environmental Research Center, Las Vegas, Nevada, NERC-LV Facts at 2, March 1975; Letter from Matthew S. Walker, Senior Attorney, Enforcement Division, EPA Region IX, San Francisco, Cal., to author, Nov. 4, 1975:

> Infrared photography performed by the National Environmental Monitoring and Support Laboratory at Las Vegas was used in case preparation of a water pollution case under the Refuse Act of 1899 involving a discharge at Moss Landing in Monterey County, California. On another occasion, infrared aerial photography was used in case preparation of a similar action at Newport Beach in Orange County. Neither of these cases went to trial.

110. *See, e.g.*, Murtha, *supra* note 67, at 138.

111. See note 57 *supra*.

112. *E.g.*, Letter from Warren B. McBirney, Chief of the Technical Services and Publications Branch, Office of Design and Construction, Bureau of Reclamation, U.S. Department of the Interior, Denver, Colo., to author, July 31, 1975:

> The Truckee-Carson Irrigation District has used low-altitude infrared photographs to locate possible irrigation violations for further investigation, but these photographs have not been used in court.

113. *See, e.g.*, Wezernak & Roller, *Monitoring Ocean Dumping with ERTS-1 Data*, in SYMPOSIUM ON SIGNIFICANT RESULTS OBTAINED FROM EARTH RESOURCES TECHNOLOGY SATELLITE-1 635 (Mar. 9, 1973) (NASA Goddard Space Flight Center).

114. *See, e.g.*, MAIRS & YUNGHANS, *supra* note 60, at 53:

> [The New Jersey Division of Marine Services must] inspect all dredging and filling operations in the wetlands and all clearing and development activities in the adjacent upland. The Division employs numerous inspectors, the marine police, helicopters and light aircraft for the difficult monitoring required. The Division relies heavily upon citizen reports. Aerial photography of the entire coastal zone on a two-week frequency would provide the necessary data but certainly would not be cost effective. The task of monitoring change within large land areas, over extended periods of time (years) with a high frequency of coverage (days) was judged by the investigators to be a task which lent itself quite naturally to accomplishment from ERTS.

tions could reach different conclusions on the extent to which they should rely on any given remote sensing technique.

As the technology becomes more sophisticated and more familiar to the legal profession, the boundary between investigatory and evidentiary applications will shift, with more frequent introduction of remote sensing output as evidence. The distinction, however, is unlikely to disappear entirely. Some form of onsite inspection will be necessary in the prosecution of the vast majority of enforcement actions. Where physical inspections are required and are sufficient in and of themselves to document the existence of a violation, the litigator must decide if the incremental benefits obtained through the introduction of remote sensing images are worth the cost of maintaining the quality control and authentication procedures necessary to qualify the images as legally admissible evidence.[115]

1. Conformance to Regulatory Standard Prescriptions

There are two related situations in which remote sensing might be suitable for surveillance purposes but of little utility in an evidentiary context. The more obvious case is where the information content of an image is sufficient to warrant a closer inspection, but lacks the detail or certainty required to substantiate a putative infraction. In the other instance, the regulatory standard itself may be written in such a manner that it precludes the use of remote sensing output in an adjudicatory proceeding, even though the sensing technique reliably documents the existence of an unlawful condition to the satisfaction of the investigating agency.

The prevention of discharges of oil into navigable waters provides a concrete example of the latter circumstance. The Water Pollution Control Act Amendments of 1972 required the President or his desiguee to promulgate standards defining what constitutes "harmful quantities" of oil discharges.[116] The regulations developed to meet that responsibility include two principle definitions of "harmful quantities": discharges that violate applicable water quality standards,[117] and discharges that cause a fihn or sheen upon or discoloration of the water or adjoining shoreline.[118] Since proving a violation of water quality

115. Consider, for example, the contrast between the kind of proof needed to document the existence of an unauthorized water pollution discharge outlet and that required to document the discharge of effluents from an authorized outlet but at an unauthorized time or in excessive quantities. An investigatory application of the technology would be valuable in all three instances, but the evidentiary utility of the remote sensing output might be much greater in the second and third instances than in the first.

116. 33 U.S.C. §§ 1321(b)(3)-(4) (Supp. V, 1975).

117. 40 C.F.R. §§ 110.3(a), 110.4(a) (1975).

118. 40 C.F.R. §§ 110.3(b), 110.4(b) (1975).

standards presupposes a quantitative analysis of the discharge,[119] and since it is often impossible to obtain the water samples needed to make such a determination,[120] principal reliance has been placed upon the "sheen test" to document violations of the Act.[121]

The Code of Federal Regulations defines a "sheen" as "an iridescent appearance on the surface of water,"[122] creating a standard framed in terms of the visual perception of a film, discoloration, or multicolored appearance. In affirming the criminal conviction of a ship captain for failing to report[123] a spill of some 30 gallons, the Court of Appeals for the Ninth Circuit in *United States v. Boyd*[124] stressed the visual nature of the test:

> The statute and Regulation read together amount to a clear command to a ship captain: "If you can see the spill, report it!" That

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119. *See, e.g.*, U.S. Coast Guard, Commandant Instruction 5922.11B (Oct. 10, 1974) [Enforcement of the Federal Water Pollution Control Act, Section 311 (33 USC § 1321)], Enclosure 1 at 2 [hereinafter cited as Commandant Instruction 5922.11B].

120. Detection of spills alone is insufficient unless the spiller can be identified for further federal action. Presently, the polluter must either be caught in the act (and preferably photographed such that the pollution evidence is clear), or a sample of the spill must be compared by a laboratory analysis with a sample taken from the suspected ship or shore facility. While an aircraft can often detect oil on the water much easier than a surface vessel, it is often very difficult—even for a helicopter—to obtain a sample, or to direct a surface unit to the area in sufficient time to obtain a sample.

G. WRIGHT & D. OLSON, DESIGNING WATER POLLUTION DETECTION SYSTEMS 29 (1974) [hereinafter cited as WRIGHT & OLSON].

121. *See, e.g.*, Commandant Instruction 5922.11B, *supra* note 119, at 2. In *In re* License No. 336207, Albert B. Watts (No. 5952/1334, U.S. Coast Guard, 8th Coast Guard Dist., Port Arthur, Tex., Sept. 13, 1972) (license revocation/suspension proceeding), the Coast Guard introduced black and white photographs of an alleged oil slick in an effort to document violation of the quantitative standard of 100 parts of oil per million of discharged ballast water established by Section 1002 of the Oil Pollution Act of 1961, 33 U.S.C. §§ 1001-15, *as amended*, 33 U.S.C. §§ 1001-15 (Supp. V, 1975). The Coast Guard attempted to correlate the photographs taken of the offending vessel with photographs of vessels leaving slicks above the statutory minimum taken during controlled experiments conducted by the Coast Guard off the Louisiana coast. *See id.*, Transcript of Record, Vol. II at 44-64, Exhibit #7 (Deposition of J. Wardley Smith), Vol. III at 26-133. In rebuttal, a defense expert, Professor John Estes of the University of California at Santa Barbara, testified that the correlation between sets of photographs was not reliable because numerous variables were neither determined nor controlled, such as sun-angle, photo-quality, atmospheric, and other environmental conditions, sea state, and the like. *Id.*, Transcript of Record, Vol. IV at 18-73. The administrative law judge ultimately refused to accept the photographs as evidence of a quantitative violation on the basis of their lack of scientific reliability. *Id.*, Decision of the Administrative Law Judge at 7. The license of the master, Captain Watts, was nonetheless suspended, on the basis of testimony of the Chief Mate as to the discharge of ballast and the amount of oil contained therein. *Id.* at 6-8.

122. 40 C.F.R. § 110.1(*l*) (1975).

123. 33 U.S.C. § 1321(b)(5) (Supp. V, 1975) makes it a criminal offense to fail to report the discharge of oil or hazardous substances in harmful quantities.

124. United States v. Boyd, 491 F.2d 1163 (9th Cir. 1973).

> duty of reporting, depending as it does simply on one's sight, is anything but vague.[125]

In documenting a violation either of the duty to report or of the duty to prevent harmful discharges,[126] therefore, it appears that remote sensing techniques employing spectral bands other than the visible light ranges could not meet the standard set by the "sheen test" even if they were far more sensitive to the presence of oil than human sight or conventional photography.

Such a narrow regulatory standard prescription would not, however, preclude the employment of remote sensing in an investigatory application; sensing in a number of spectral bands has proved useful in the detection of oil spills and, in fact, that application is among the best recognized of present remote sensing capabilities.[127] For example, the U.S. Coast Guard has been experimenting for several years with multiple sensor packages mounted on aircraft.[128] Their current project, the Airborne Oil Surveillance System (AOSS), employs radar, a thermal infrared scanner, a passive microwave radiometer, and a low-light-level television camera in an effort to identify oil spills at long distance and from high altitudes. The system is designed to increase the efficiency of aerial search patterns and to locate discharges at night or in bad weather when visibility is severely limited.[129] In at least four instances, the Twelfth Coast Guard District has used the AOSS system to identify dischargers who were ultimately convicted of violations.[130] The evidence submitted in the informal Coast Guard hearings[131] consisted primarily of the visual observations of the aircraft personnel and video-tape images from the on-board television cameras. The principal

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125. *Id.* at 1169. *See also id.* at 1166.

126. 33 U.S.C. § 1321(b)(6) (Supp. V, 1975).

127. *See, e.g.*, Horvath, Third Type II Progress Report: Task IX, Oil Pollution Detection (Jan. 25, 1974) (STAR acc. no. N74-17090) (Environmental Institute of Michigan) (satellite MSS); Fantasia & Ingrao, *Development of an Experimental Airborne Laser Remote Sensing System for the Detection and Classification of Oil Spills*, in 3 NINTH INTERNATIONAL SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT 1711 (Apr. 15-19, 1974) (Ann Arbor, Mich.) [article hereinafter cited as Fantasia & Ingrao]; Wobber, *Imaging Techniques for Oil Pollution Survey Purposes* in 6 PHOTOGRAPHIC APPLICATIONS IN SCIENCE, TECHNOLOGY AND MEDICINE No. 4 (1971) (various spectral bands).

128. *See, e.g.*, WRIGHT & OLSON, *supra* note 120, at 40-41.

129. Aerojet Electrosystems Company, Technical Manual, Airborne Oil Surveillance System, Part No. 1315205-1, MS-1791, Change 1 of 1-5, April 15, 1975 (Change 1 refers to the first replacement of page 1-5 in a looseleaf manual).

130. The Sealand Finance (U.S. Coast Guard, 12th Coast Gd. Dist., hearing held Jan. 30, 1976); The Nissan No. 1 (No. 12/106-75-EP, U.S. Coast Guard, 12th Coast Gd. Dist., hearing held Dec. 2, 1975); The Itabera (No. SF-322-75, U.S. Coast Guard, 12th Coast Gd. Dist., date of violation, July 2, 1975); The Eastern Mariner (No. MON 008, U.S. Coast Guard, 12th Coast Gd. Dist., date of violation, June 2, 1975).

131. See Commandant Instruction 5922.11B, *supra* note 119, Enclosure 1, at 7-11, for a description of the Coast Guard hearing procedures.

utility of the nonvisual sensors lay not in documenting the violations but in finding them initially.[132]

Remote sensing may thus be effective as an investigatory tool in situations where its output does not conform to regulatory standard prescriptions, thereby rendering it unusable as primary evidence of a violation.[133] Such standards, however, are not immutable; they are likely to change in response to future technological innovations. For example, efforts are being devoted to developing techniques that can provide quantitative measurements of oil slick area and volume.[134] When the quantitative reliability of remote sensors is demonstrated, their imagery may be employed to document violations of current water quality standards[135] or may form the basis for the promulgation of new regulatory criteria.

2. *Documentation of Probable Cause*

In situations where remote sensing output cannot serve as substantive evidence of a violation because it lacks sufficient specificity or does not conform to the relevant regulatory standard, the sensing information may nevertheless prove essential to establish probable cause for an on-site investigation intended to obtain the evidence necessary for prosecution. This proposition, however, assumes the answer to an unresolved legal question—whether inspections carried out pursuant to environmental laws constitute "administrative searches" and therefore trigger fourth amendment protections. The general rule, as articulated in the companion cases of *Camara v. Municipal Court*[136] and *See v. City of*

132. In particular, the ability of radar to detect potential spills within a 25-mile radius and to operate under all weather and lighting conditions makes it of great value in identifying targets for subsequent visual inspection. MRS [Medium Range Remote Sensing] Specifications Appendix D (U.S. Coast Guard, Dec., 1975); Aerojet Electro-Systems Co., Technical Manual, Operation & Operator's Maintenance, Airborne Oil Surveillance System, Part No. 1315205-1, at 1-5, 1-7 to 1-8 (May, 1974).

133. *E.g.*, the opacity standards promulgated by the EPA, which uses the Ringelmann Chart, a visual aid employed by smoke readers, to monitor particulate emissions in various industries. 40 C.F.R. § 60.2j (1975) (opacity defined); 40 C.F.R. § 60.11 (1975) (compliance with opacity standards determined under Method 9, Appendix A, 40 C.F.R. at 784, describing the Ringelmann technique); 40 C.F.R. §§ 60.42, 60.62, 60.92, 60.102, 60.122, 60.132, 60.142, 60.152 (1975) (opacity standards for emission of particulate matter for various industries). The adoption of the Ringelmann Chart establishes a visual standard that remote sensing cannot meet, although laser systems are currently being developed to measure opacity with greater accuracy than could be achieved by observers using the Ringelmann test. *See* C. Ludwig & M. Griggs, Application of Remote Monitoring Techniques in Air Enforcement 157, 160-61, 126-36 (Science Applications, Inc., La Jolla, Cal., Apr. 1975) (EPA Contract No. EPA 68-03-2137) [hereinafter cited as Ludwig and Griggs].

134. *See, e.g.*, Fantasia & Ingrao, *supra* note 127, at 1711.

135. *E.g.*, 40 C.F.R. §§ 120.1-.115 (1975).

136. 387 U.S. 523 (1967).

Seattle,[137] is that an administrative inspection must be made with the consent of a responsible party or under a judicially approved warrant issued upon probable cause.[138] Otherwise, the inspection is an unreasonable search within the meaning of the fourth amendment.[139] Although a number of the most important environmental statutes authorize enforcement personnel on their own discretion to enter and inspect regulated facilities,[140] these provisions appear never to have been tested and approved in court.[141]

The general rule concerning warrants for administrative searches has been modified to exclude some "licensing programs which require

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137. 387 U.S. 541 (1967) (*Camara* explicitly extended to commercial premises).

138. *Camara* and *See* held that some form of probable cause is required although the degree of specificity concerning the violation necessarily may vary from the criminal model. Camara v. Municipal Court, 387 U.S. 523, 534-39 (1967); See v. City of Seattle, 387 U.S. 541, 545 (1967). *Camara* held that the probable cause test could be met by area-wide inspections, if based on reasonable legislative or administrative standards. 387 U.S. at 538. *See also* Note, *The Emergency Doctrine, Civil Search and Seizure, and the Fourth Amendment*, 43 FORD. L. REV. 571, 577-81 (1975).

139. *See generally* La Fave, *Administrative Searches and the Fourth Amendment: The Camera and See Cases*, 1967 SUP. CT. REV. 1; Rothstein & Rothstein, *Administrative Searches and Seizures: What Happened to Camera and See?*, 50 WASH. L. REV. 341 (1975); Note, *Administrative Search Warrants*, 58 MINN. L. REV. 607 (1974). *But cf.* Air Pollution Variance Bd. v. Western Alfalfa Corp., 416 U.S. 861, 864 (1974).

The fundamental concerns underlying the fourth amendment warrant requirement are to protect the privacy of individuals and to preclude official harassment, whether well-intentioned or not, by interposing a neutral judicial judgment. *See generally* Coolidge v. New Hampshire, 403 U.S. 443 (1971); Camara v. Municipal Court, 387 U.S. 523 (1967); Boyd v. United States, 116 U.S. 616 (1886).

140. *See* sections 1318 and 1321(m) of the Water Pollution Control Act Amendments of 1972, 33 U.S.C. §§ 1251-1376 (Supp. V, 1975); section 1857c-9(a)(2) of the Clean Air Act, 42 U.S.C. §§ 1857c-3 to 1857h (Supp. V, 1975); section 4912 of the Noise Control Act of 1972, 42 U.S.C. §§ 4901-18 (Supp. V, 1975). Section 1857c-9(a)(2) of the Clean Air Act provides:

> (2) [T]he Administrator or his authorized representative, upon presentation of his credentials—
>
> (A) shall have a right of entry to, upon, or through premises in which an emission source is located or in which any records required to be maintained under paragraph (1) of this section are located, and
>
> (B) may at reasonable times have access to and copy any records, inspect any monitoring equipment or method required under paragraph (1), and sample any emissions which the owner or operator of such source is required to sample under paragraph (1).

42 U.S.C. § 1857c-9(a)(2) (Supp. V, 1975).

141. Surprisingly, it also appears that the extension of the *Camara* and *See* rules to the area of environmental inspections has not been the subject of any article published in a legal periodical. The only source directly on point that we could locate is an unpublished manuscript by James B. Zimpritch, Administrative Searches and the Clean Air Act: Constitutionality of On-Site Monitoring As a Function of Technological Sophistication, 1974 (on file at Law Offices of Pierce, Atwood, Scribner, Allen & McKusick, Portland, Me.). The author argues that a warrant requirement is more likely to be imposed in the future as remote monitoring techniques are improved.

inspections prior to operating a business or marketing a product."[142] The rationale for this exception is that one who engages in a heavily regulated activity ought to expect to be subjected to periodic investigations.[143] The licensing program exception, however, has been applied only to businesses, such as the sale of liquor[144] or weapons,[145] where advance warning of a search might enable the proprietor to frustrate the intent of the inspection[146] and where the object of the search was well-defined and limited in scope. In contrast, environmental inspection statutes may, in their totality, authorize entrance upon the property of virtually every industrial, agricultural, and construction enterprise in the United States. If the object is to ensure compliance with permit terms or to detect unauthorized environmental impacts, then the scope of the search may be quite broad indeed, extending to most if not all aspects of industrial activity. It is one thing to decide that a person who chooses to sell liquor or guns may thereby waive fourth amendment protections with respect to searches of his premises for contraband liquor or guns; it is quite another matter to conclude that one who engages in any form of significant economic endeavor similarly waives his protections with respect to searches for any condition that might violate the panoply of environmental regulations.

It is settled doctrine in criminal procedure that a warrantless search may be conducted when two conditions are fulfilled: the authorities must have probable cause to believe a violation has occurred and

142. See v. City of Seattle, 387 U.S. 541, 546 (1967), expressly reserved that question.

143. In Colonade Catering Corp. v. United States, 397 U.S. 72, 75-77 (1970), the Court emphasized the long history dating back to Colonial times of governmental regulation of the liquor industry. In United States v. Biswell, 406 U.S. 311, 316 (1972), the point was made explicit:

> When a dealer chooses to engage in this pervasively regulated business and to accept a federal license, he does so with the knowledge that his business records, firearms, and ammunition will be subject to effective inspection.

144. Colonade Catering Corp. v. United States, 397 U.S. 72 (1970). The Court decided that a statute making it an offense to refuse entrance to the inspectors was constitutional, but it did not explicitly rule on the constitutionality of a forcible, warrantless entry. *Id.* at 77.

145. United States v. Biswell, 406 U.S. 311 (1972).

146. [I]f inspection is to be effective and serve as a credible deterrent, unannounced, even frequent, inspections are essential. In this context, the prerequisite of a warrant could easily frustrate inspection; and if the necessary flexibility as to time, scope, and frequency is to be preserved, the protectious afforded by a warraut would be negligible.

Id. at 316. The Court distinguished *See*:

> In [*See*] the mission of the inspection system was to discover and correct violations of the building code, conditions that were relatively difficult to conceal or to correct in a short time. Periodic inspection sufficed, and inspection warrants could be required and privacy given a measure of protection with little if any threat to the effectiveness of the inspection system there at issue.

Id.

"exigent circumstances" must require an immediate investigation.[147] In extending the warrant requirement to include administrative inspections, the Court in *Camara* explicitly did not intend "to foreclose prompt inspections, even without a warrant, that the law has traditionally upheld in emergency situations."[148] The building code inspection at issue in *Camara* did not meet the standard because there was "no compelling urgency to inspect at a particular time or on a particular day."[149] Similarly, no compelling urgency will attend many environmental inspections. Prior notification of the target facility will often prove essential to enable licensee records on emissions, remedial measures taken, and like factors to be assembled.

In instances where an enforcement agency has adequate reason—that is, probable cause—to believe that a violation is of a transient nature, such as an emission exceeding its authorized volume or concentration, the exigent circumstances exception may well justify an immediate inspection without a warrant. Where the violation is intermittent or continuing, but easily corrected, the question is somewhat more difficult. At the least, if there is probable cause to believe that such a a violation exists, the agency should be free to obtain a warrant without first seeking entry on a consensual basis.[150] In addition, *United States v. Biswell*[151] suggests that the ability of a potential transgressor to conceal or correct violations is itself a factor in determining whether a warrant must be obtained prior to an inspection.[152]

Given the variety of environmental programs, the multitude of potential transgressions, and the differing inspection procedures and time constraints associated with different problems, it is unlikely that a single judicial doctrine will or should evolve to address the fourth

147. *See, e.g.*, Coolidge v. New Hampshire, 403 U.S. 443, 468 (1971); Vale v. Louisiana, 399 U.S. 30, 35 (1970); Chimel v. California, 395 U.S. 752, 762-73 (1969); Warden v. Hayden, 387 U.S. 294, 298-99 (1967); McDonald v. United States, 335 U.S. 451, 456 (1948); Steigler v. Anderson, 496 F.2d 793, 796-97 (3d Cir. 1974); United States v. Green, 474 F.2d 1385, 1388-89 (5th Cir. 1973).

148. 387 U.S. at 539.

149. *Id.*

150. *See id.* at 539-40.

151. 406 U.S. 311 (1972).

152. *Id.* at 316. See text accompanying note 146 *supra.*

Implicit in the *Biswell* opinion is the conception that there is no way of determining whether a violation of gun control laws has occurred except through a physical, onsite inspection of the licensee's premises, so that a warrant must either be obtained for every possible location or for none. In the case of environmental infractions, it may often be possible for enforcement officials to identify likely violations without onsite inspections. In that circumstance, the ability of potential violators to conceal or correct the deficient conditions argues not for eliminating the warrant requirement altogether, but for the issuance of warrants upon probable cause without prior notification of the affected party.

amendment implications of all environmental inspection systems. In circumstances in which a warrant requirement is ultimately imposed, remote sensing techniques can conceivably be used to document probable cause[153] and therefore may be essential in securing the warrant. Where a warrantless search is authorized based on the existence of exigent circumstances, remote sensing techniques can be used to identify those conditions. That particular remote sensing output is insufficiently detailed to prove a violation or not cast in the form prescribed by the relevant regulatory standard would not preclude the admission of such imagery in court to establish probable cause or exigent circumstances. The test in that context is whether one could reasonably conclude, based on the remote sensing information, that a violation was probable, not proven.

The possibility that remote sensing data might be admitted to justify a warrantless search has already materialized in connection with border surveillance systems intended to enforce immigration and smuggling laws. Several kinds of sensors[154] are now maintained along the Mexican border in order to detect illegal vehicular and foot traffic.[155] In *United States v. Mora-Chavez*,[156] the Court of Appeals for the Ninth Circuit approved the use of such sensors to justify a sub-

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153. We have used aerial and satellite I.R. [infrared] imagery for evaluation of pollution problems and also for identification of potential salt marsh mosquito breeding sites. However, we have had no occasion where it became necessary to use such information beyond the "probable cause hearing" stage.
Letter from James F. Coerver, Bureau of Environmental Services, Louisiana Health and Human Resources Administration, Division of Health, New Orleans, La., to author, Aug. 4, 1975.

154. Some of the devices are magnetically sensitive, some are heat sensitive, and others detect the breaking of an electromagnetic beam. Conversation between G. Tannehill and Peter K. Nunez, Assistant U.S. Attorney, San Diego, Cal., Jan. 13, 1976.

The exact locations and capabilities of individual sensing devices along the international border is a confidential matter, which has not been publicly disclosed, so that their usefulness in law enforcement efforts is not compromised.
Letter from Peter K. Nunez, Assistant U.S. Attorney, San Diego, Cal., to author, Aug. 14, 1975.

155. The use of electronic sensor devices is relatively new along the international border. The border patrol does not have enough officers to maintain constant line watch at all times and along all the remote crossing areas. The electronic devices were developed for the military detection of night patrols and infiltrators. The devices are engineered to ignore small animals, but to record an alarm when metal or an animal weighing more than 40 pounds passes nearby. These alarms are recorded in a central station and forwarded by radio to vehicular patrols supplementing the line watch. The trial court was able to find from the government's explanation of the sensor technique adequate foundation for a decision to stop the automobile in this case.
United States v. Mora-Chavez, 496 F.2d 1181, 1182 (9th Cir. 1974), *cert. denied*, 419 U.S. 878 (1974). *See also* United States v. Rodriguez-Alvarado, 510 F.2d 1063, 1064 (9th Cir. 1975); United States v. Laird, 511 F.2d 1039 (9th Cir. 1975).

156. 496 F.2d 1181 (9th Cir. 1974), *cert. denied*, 419 U.S. 878 (1974).

sequent search of nearby automobiles, which resulted in a conviction for possession of narcotics:

> The prompt inspection of the first automobile to appear on the highway after the officers received the sensor alarm was not only well-advised, but was based on a founded suspicion. The officers knew that some person or persons had recently crossed the border illegally and that the two automobiles which were stopped were the only ones known to have been in the sensor-surveillance area near the time of the sensor alert.[157]

The sensor-based notification that someone had crossed the border could not be employed to convict any particular individual of illegal entry, but it was sufficient to provide the foundation for a subsequent warrantless search. In like manner, the output from many remote sensing techniques may potentially be admitted as evidence to establish probable cause or exigent circumstances even where it has little utility in proving a substantive violation of an environmental regulation.

C. *Evidentiary Applications*

Although remote sensing information has been introduced in litigation to portray a variety of environmental phenomena, an inspection of the relevant judicial and administrative records reveals that such evidence was generally intended[158] to accomplish one or more of three

157. *Id.* at 1182.

158. This section refers to a number of cases settled or otherwise terminated prior to actual trial. *See, e.g.*, Stipulation of Settlement, City of Cloquet v. Earl Ruble & Assocs., No. 17363 (Minn. Dist. Ct., Carlton County, 6th Jud. Dist., July 9, 1973); Letter from Dr. James P. Scherz, Department of Civil and Environmental Engineering, University of Wisconsin, Madison, Wis., to author, Apr. 16, 1975:

> I was involved in a lawsuit in 1972 between the City of Cloquet, Minnesota and Mr. Ruble (the engineer who designed an $8,000,000 water intake in the middle of a turbid water eddy on the Southwest end of Lake Superior). . . . ERTS imagery of the area on 12 August 1972 showed turbid water in the area of the intake. Before it could be used in court however, it was necessary to determine what caused the image tone, etc. After a rainstorm in November, 1972, I went to the area, took low altitude aerial photos and obtained water samples. From these and other aerial photos on file in the USDA offices, it was possible to ascertain the source of the turbid water, its movement and approximate percentage of time in the area. The case was worked out to great detail and it appears that the opposing attorneys were worried, for they settled out-of-court to avoid embarrassment to their client. Of course, I was disappointed since we were unable to get remote sensing evidence introduced at that time.

See also Agreement and Stipulation of Settlement, State v. Groveland Ranch Acres, Inc., Civil No. GCG 73-1495 (Fla. Cir. Ct., 10th Cir., Polk County, Nov. 29, 1973). In this action the state employed aerial and satellite data to force land developers in the Green Swamp area to modify operations that had been causing water pollution, threatening indigenous wildlife, and decreasing the level of the Floridian Aquifer. In assessing the utility of the satellite and aerial imagery, the Assistant Attorney General in charge of the case observed:

> Data gathered by imagery was to be testified about by employees of the United

compatible functions: (1) to document conditions over a large or inaccessible geographical area; (2) to document transient or intermittent conditions; and (3) to provide a visual representation of conditions primarily documented by more conventional types of evidence.[159] To some degree remote sensing has performed the third function in all of the identified litigation, since each case has featured substantial quantities of demonstrative evidence and expert testimony offered in conjunction with the sensing output. In the absence of reported opinions that explicitly consider the admissibility of remote sensing evidence, however, it is useful to distinguish between cases in which remote sensing images were relied upon to prove important factual contentions and those instances in which images were submitted to supplement other methods on the theory that graphic representations might clarify an issue and strongly impress the trier of fact. This discussion emphasizes cases in which remote sensing information was essential to establish a significant contention, because those cases provide the best available precedential support for the evaluation of similar evidence in the future.

1. Pollution Monitoring

Remote sensing probably played its most decisive role to date in *State v. Inland Steel Company*.[160] The State of Illinois sought to enjoin defendant's facility in Indiana from discharging effluents into Lake Michigan, because under certain conditions a portion of the effluents crossed the state boundary, thereby endangering the health and well-being of Illinois citizens. Since the company admitted the discharges and the plaintiff conceded that the discharges complied with Indiana law, the principal issue at trial was whether a significant volume of pollutants reached Illinois waters.[161] The state ultimately prevailed on

States Geological Survey. They verbally explained their information to attorneys for Defendants, and thereby helped to settle the case.

Letter from Kenneth F. Hoffman, Esq., Assistant Attorney General, Florida Department of Legal Affairs, Tallahassee, Fla., to author, Aug. 11, 1975. *See generally* Coker & Higer, *supra* note 103.

159. All of the cases identified by the authors have been cited in the text and footnotes of this section. The three general purposes for which the remote sensing evidence was usually obtained correlate well with the principal operational advantages of the technology described earlier. They are likely to remain preeminent in litigation at least until the reliability of sensors capable of quantitative pollution measurements is demonstrated.

160. Memorandum Ruling, State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Sept. 8, 1975) (liability); Findings of Fact (Jan. 26, 1976); Stipulation of Settlement (Jan. 27, 1976); Final Order (Jan. 27, 1976).

161. The Inland Steel Company's manufacturing facility at East Chicago, Indiana, is located on the Indiana Harbor Ship Canal, approximately 8 miles from the 79th Street shore water intake facility of the City of Chicago, Illinois, and some 9 miles from the crib intake at 68th Street. Findings of Fact at 3.

that issue.[162]

In order to document the dispersion of pollutants after their discharge, the state submitted thermal infrared images (Plates 6 and 9a) from two aerial missions conducted by the EPA to show effluents moving north toward the state line on a day when the wind vector was in that direction.[163] Contemporaneously with the remote sensing overflights, boats obtained water samples to demonstrate that the constituents of the imaged pollution plume matched the discharges from Inland Steel's plant.[164] The plaintiff also introduced a Skylab color photograph (Plate 8) taken on on a different day, when the wind was blowing toward the south and consequently away from Illinois, to indicate that an effluent plume could extend a distance longer than that from the plant to the Illinois border.[165] Submission of the thermal images and the satellite photograph was not redundant, since the State did not succeed in obtaining a single picture or boat survey which actually traced the plume into Illinois waters. Although the trial court noted that direct evidence demonstrating the full extension of the plume into Illinois would have been preferable,[166] the thermal images proving direction of movement and the Skylab image proving potential length of the plume were held sufficient, when taken together, to provide a basis for the decision.[167]

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162. Once the liability question was resolved in favor of the plaintiffs, the parties reached a settlement in which Inland Steel agreed to "recycle and filter all process water discharges to the Indiana Harbor Ship Canal or Lake Michigan from waste water discharge sources. . . ." Joint Submission of the Parties in Support of the Stipulation of Settlement at 2 (Jan. 20, 1976). The parties estimated that the new treatment facilities would reduce discharge of suspended solids by 98 percent and oil discharges by 93 percent. Installation costs were estimated at over $90 million. The state and the Metropolitau Sanitary District agreed to forgo imposition of a civil penalty; Inland Steel waived its right of appeal aud paid attorneys fees of $400,000 to plaintiffs. *Id.* at 2-3.

163. Record at 1884-98 (Jan. 27, 1976). During the first overflight, color photographs of the same scenes shown in the thermal infrared imagery were taken simultaneously. The color photographs (Plate 7b) showed a "slight discoloration of the water at the mouth of the Indiana Canal;" however, because of poor lighting conditions and the roughness of the lake's surface, these photographs "did not display the color tones of the water that we expected from the discharge of the Canal." *Id.* at 1881 (testimony of Albert E. Pressman, EPA, National Environmental Research Center [now the National Environmental Monitoring and Support Laboratory], Las Vegas, Nev.).

164. Record at 1870. The boat sampling stations were located next to "fixed marker buoys so that there would be no question as to the exact location of where the samples were taken." *Id.* at 1876.

165. *Id.* at 965-69. As the Skylab project was undertaken without reference to or knowledge of possible litigation, the resulting imagery was described by the state's counsel as fortuitous. *Id.* at 1284.

166. Upon initial receipt of the Skylab imagery for identification purposes, the trial court indicated surprise that the state did not simply use a boat to trace the pollution plume all the way into Illinois waters. *Id.* at 969.

167. The testimony of [the defendant's] expert witnesses was not persuasive

Remote sensing evidence has played some role in a number of other pollution cases,[168] of which the most significant is undoubtedly

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and the weight of their testimony was, in virtually every instance, dissipated upon cross-examination. In no instance did defendant overcome the *visual evidence* presented by the plaintiffs in these consolidated actions.

Memorandum Ruling at 12 (emphasis added).

168. In Vermont v. New York, 417 U.S. 270 (1974), for example, the State of Vermont introduced a Landsat image to show a discharge plume extending from an International Paper Company mill in New York across the state boundary in Lake Champlain. Deposition of Professor Aulis O. Lind, Oct. 4, 1973, at 4-5. *See generally* Lind, Application of ERTS-1 Imagery in the Vermont-New York Dispute Over Pollution of Lake Champlain (Oct. 1973) (STAR acc. no. N74-1183). Since low-altitude aerial photographs and observations based upon dye samples inserted into the effluent discharge were also submitted, the introduction of the Landsat image may best be characterized as a graphic supplement to more precise evidence. The case has little precedential value because it was settled prior to formal admission of the remote sensing image. Letter from Hon. R. Ammi Cutter, Special Master, to author, July 21, 1975; conversation with Paul Shemin, Environmental Protection Bureau, N.Y. Atty. General's Office, New York, N.Y., July 8, 1975; conversation with Allen Hemmenway, Region I, EPA, Boston, Mass., July 24, 1975.

Remote sensing pollution-monitoring can have utility not only in an interstate context but in international disputes as well:

> LANDSAT and Skylab imagery certainly have implications in this field [international law] . . . . An historic example is smelter smoke from the Douglas Arizona smelter drifting into Mexico as recorded on Apollo 6 in 1968. The Governor of Sonora, Mexico reportedly showed this to the Governor of Arizona and shortly thereafter Arizona enacted some of the most stringent air pollution controls in the country.

Letter from R.H. Lyddan, Chief, Topographic Division, U.S. Geological Survey, Reston, Va., to author, Aug. 12, 1975. *See also* Denial of Application for Preliminary Injunction, United States v. Florida Power & Light Co., 311 F. Supp. 1391 (S.D. Fla. 1970); Stipulation of Settlement, 53 F.R.D. 249 (S.D. Fla. 1971). Thermal infrared scanning was collected to show an unauthorized plume of heated water emanating from the power company's Turkey Point plant on Lower Biscayne Bay; however, "[s]ince there was never a hearing on a motion for permanent injunction in *United States v. Florida Power and Light Co.*, no evidence derived from remote sensing was ever introduced in that case." Letter from Thomas F. Bastow, Pollution Control Section, U.S. Department of Justice, Washington, D.C., to author, June 25, 1975.

For a reference to a criminal case, see Tuerkheimer, Legal Aspects of Water Pollution Detection Through Remote Sensing, 1 Remote Sensing of Earth Resources 302 (technical papers selected from Conference on Earth Resources Observation and Information Analysis System, Tullahoma, Tenn., Mar. 13-14, 1972) [hereinafter cited as Tuerkheimer]:

> Through the cooperation of the United States Attorney for the Western District of Wisconsin, remote sensing data was used in the spring of 1971 in an actual criminal case against a creamery polluting a major tributary of the Wisconsin River. [United States v. Wisconsin Dairies Cooperative, No. 71 Cr. 56 (W.D. Wis., Apr. 14, 1971)]. Since the case ended with a plea of *nolo contendere*, an admission of guilt for the purposes of the case, the data gathered was not actually used in court.

Id. at 303.

See also letter from Michael T. Marshall, Director, Air Quality Program, State of Missouri, Department of Natural Resources, Jefferson City, Mo., to author, Aug. 8, 1975:

> [The Department has] used high-level infrared photography . . . for study of vegetation effects from pollutants. We have one case pending, and the com-

United States v. Reserve Mining Company.[169] Both sides in that litigation introduced remote sensing output in conflicting attempts to define the extent to which the asbestos-like taconite tailings discharged by the defendant were circulated within Lake Superior. The company submitted Landsat and Skylab images to demonstrate that the bulk of the water turbidity was produced by natural causes, including beach erosion and suspended solids carried by rivers draining into the lake, rather than by its taconite discharges.[170] It appears from the trial court's opinion, however, that the satellite images produced the opposite effect from the one desired by the defendant.[171]

The Government submitted remote sensing information obtained from aerial overflights conducted by the EPA[172] and NASA.[173] The

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pany is willing to settle under "nolo contendere" for penalties for violation of our fence-line SO_2 standards. We are presently in the negotiating stage of this. The remote sensing was not a key issue for the analysis of violation or the agreement with the company on a settlement. The remote sensing was just to indicate to us the magnitude of the effect of the SO_2 damage.

Cf. Ewell v. Petro Processors, No. 143,388 (La. Dist. Ct., E. Baton Rouge Parish, La., 19th Jud. Dist., July 2, 1975), in which a "hasty" and unsuccessful attempt (improper foundation) was made to introduce remote sensing evidence to indicate the environmental degradation resulting from the spread of chlorinated hydrocarbons and other poisons onto the property of an adjoining landowner. Letter from Bryant W. Conway, attorney for the plaintiff, to author, Sept. 19, 1975.

169. 380 F. Supp. 11 (D. Minn.), *stayed in part and remanded*, 498 F.2d 1073 (8th Cir.), *motions to vacate denied*, 418 U.S. 911, 419 U.S. 802, *on remand*, 394 F. Supp. 233 (D. Minn. 1974), *motion to vacate stay pending appeal denied*, 420 U.S. 1000, *modified in part and remanded*, 514 F.2d 492 (8th Cir. 1975) (en banc), *assessment of damages and penalties on remand*, 408 F. Supp. 1212 (D. Minn.), *supplemental opinion on damages and penalties*, 412 F. Supp. 705 (D. Minn. 1976).

170. Defendant's Exhibits 251a-h were ERTS (Landsat) negatives and prints and were entered without objection through Dr. Rohert A. Ragotskie, University of Wisconsin, Madison, Wis., defendant's Exhibit 252a and b were Skylab photos. Letter from John P. Hills, President's Council on Environmental Quality, Washington, D.C., to author, June 3, 1975.

171. 380 F. Supp. at 39 n.21: "Satellite photographs of the green water in the western arm of the lake show the widespread dispersion of the tailings and also the phenomenon of upwelling."

172. Record of Proceedings at 969-1083 (testimony of Arthur W. Dybdahl, Chief, Remote Sensing Operations, Office of Enforcement & General Counsel, EPA, National Field Investigations Center, Denver, Colo.). *See also* Dybdahl & Rouse, Remote Sensing Study: Green Water in Lake Superior October 1972 (Jan. 1973) (Report No. 18, EPA National Field Investigations Center and EPA National Water Quality Laboratory, Duluth, Minn.).

173. Record at 2468-2555 (testimony of James L. Lindemann, Mission Manager, Earth Resources Program, NASA, Johnson Space Center, Houston, Tex.); *See also* Lindemann, Earth Observations Aircraft Program Project Support Plan for SRT Project X208, Oceanography: Characterization of Source and Dispersion of a Taconite Waste Outfall (Mar., 1973) (NASA, Johnson Space Center, Houston, Tex.). The NASA mission was ostensibly conducted as a research project at the behest of the National Oceanographic and Atmospherics Administration and NASA subsequently declined to further assist law enforcement authorities. Letter from R. Tenney Johnson, General

EPA mission produced both true-color and false-color infrared photographs, which were submitted to document the presence and extent of the "green water" phenomenon.[174] The EPA expert witness was allowed to testify that the reflectance characteristics of taconite tailings suspended in the normally blue water *caused* the lake water to appear green,[175] and that the green water observable over large portions of the Lake's surface differed in reflectance properties (color) from the turbid water produced by natural causes.[176] The EPA overflight also obtained thermal infrared images that were used to confirm in another manner the circulation of the pollutants.[177] The NASA mission obtained true- and false-color infrared photographs and also images produced by a 24-channel multispectral scanner, a device capable of sensing up to 24 separate spectral ranges simultaneously.[178] The resulting evidence was introduced to show the dispersion patterns of green water and, especially, that the color and appearance of the green water near the Reserve Mining operations were identical with those of the turbid water periodically visible in the body of Lake Superior.[179]

Counsel, NASA, Johnson Space Center, Houston, Tex., to John P. Hills, Pollution Control Section, U.S. Department of Justice, Washington, D.C., Aug. 3, 1973.

174. Record at 986-94, 997, 1002-04. The "green water" phenomenon or effect was au upwelling appearing to be a "lighter" or "milky" green as compared to the surrounding water, which was "a dark bluish-green color." *Id.* at 986. The area affected by the green water was calculated by the EPA expert to be 66 square miles at the time of the overflight. *Id.* at 994. *See also* 380 F. Supp. at 36-37:

> The often sighted "green water" phenomenon, one instance of which was proven in great detail by plaintiff, is consistent with the shearing off of tailings by the thermocline. Great quantities of light reflective tailings then appear in the surface water over many square miles of lake, giving the green appearance. These particles are then transported throughout the lake, towards Duluth and Wisconsin, by the normal surface currents and eventually can be found as far as the state waters of Michigan.

175. Record at 1017. The expert's opinion, based on his knowledge of optics, laboratory reflectometer tests of taconite tailings, earlier testimony regarding the composition of the green water mass, and the color appearing in the overflight imagery, was that "the green water effect is caused by taconite fines in suspension." *Id. See also* Dybdahl & Rouse, *supra* note 172, at 18, 25.

176. The witness stated that he knew of "no other substance that would give this type of a green water color" besides taconite; as an example he compared the color of the green water effect with that of yellow clays in water. Record at 1017-18. Earlier, the witness had testified that his densitometer analysis of the false color infrared film revealed the difference between the reflectance characteristics of the green water and those of naturally occurring "river teas." *Id.* at 1000-01.

177. *Id.* at 1018-22.

178. *Id.* at 2503. Although the MSS device is capable of imaging all portions of the spectrum from the extreme blue end of the visible range through the thermal infrared range, only the green band (.46 to .50 micrometers) was introduced. Compared to photographs, images in this spectral band display graphically and selectively materials reflecting light at .46 to .50 micrometers, *viz.*, taconite in suspension. *Id.* at 2503-09.

179. Specifically, the expert testified that in the remote sensing images the green near the Reserve delta, the green along the Minnesota shoreline towards Duluth, the

The NASA expert witness was not, however, permitted to testify that similar reflectance characteristics from land and water areas meant that the same substance was present in both places.[180]

2. *Environmental Impacts of Development Activities*

Remote sensing has been employed in litigation to identify the environmental consequences not only of pollution but also of changes in land use and development patterns.[181] The most prominent example of such a case is *Canal Authority v. Callaway*,[182] which involved an attempt on environmental and budgetary grounds to halt the completion of the Cross-Florida Barge Canal. Both sides introduced aerial near infrared photography to portray the ecological consequences, especially tree mortality,[183] of retaining an essential part of the canal

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green towards the middle of the lake, and the green near the Wisconsin shoreline were the same color. *Id.* at 2477-2502.

180. *Id.* at 2510-29. See text accompanying notes 242-47 *infra*.

181. *See, e.g.*, Sierra Club v. Department of the Interior, 398 F. Supp. 284 (N.D. Cal. 1975), in which the plaintiffs sought to protect the Redwood National Park from damage caused by logging operations on privately owned lands adjacent to the park. A report on environmental degradation within the park and on its periphery was prepared using conventional and near infrared photography, and was accepted without objection at trial. Conversation between R. White and Ralph Mihan, Field Solicitor, Department of the Interior, San Francisco, Cal., July 18, 1975. For the conclusions drawn in the report, see 398 F. Supp. at 291. The U.S. Geological Survey obtained similar infrared photographs of the area, which were also admitted without objection in conjunction with the testimony of Dr. Richard Janda. *Id.* at 292, 294; conversation between R. White and Dr. Richard Janda, U.S. Geological Survey, Menlo Park, Cal., July 30, 1975. State v. Arcata Redwood Co., No. 56558 (Cal. Super. Ct., Humboldt County, *filed* Oct. 31, 1974), is a state action arising from the same facts which presumably will employ much of the same documentary evidence. Conversation with Zan Henson, Deputy Attorney General, California Department of Justice, San Francisco, Cal., Oct. 15, 1975.

For other remote sensing cases in this class of evidentiary applications, see State v. Groveland Ranch Acres, Inc., Civil No. GCG 73-1495 (Fla. Civ. Ct., 10th Cir., Polk County, Nov. 29, 1973), *discussed* at note 158 *supra*; Application of City of Seattle, FPC Project No. 553 (Mar. 5, 1975), *discussed* at note 108 *supra*.

182. No. 71-92-Civ-J (M.D. Fla., Feb. 4, 1974), *rev'd and remanded*, 489 F.2d 567 (5th Cir. 1974), *on remand*, No. 71-92-Civ-J (M.D. Fla., March 25, 1974), *aff'd mem. and remanded*, 512 F.2d 670 (5th Cir. 1975). *See also* Environmental Defense Fund v. Corps of Eng'rs, 324 F. Supp. 878 (D.D.C. 1971) (preliminary injunction); *In re* Cross-Florida Barge Canal Litigation, 329 F. Supp. 543 (Jud. Pan. Mult. Dist. Lit. 1971) (consolidation of Environmental Defense Fund v. Corps of Eng'rs and Canal Authority v. Resor [subsequently Callaway] in the Middle District of Florida); United States v. 2,997.06 Acres of Land, 471 F.2d 320 (5th Cir. 1972) (condemnation proceeding). *See* 489 F.2d 567, 570-72 (5th Cir. 1974), for a condensed statement of the issues and the procedural history of the litigation to that time.

183. As the trial court noted:

> At the original injunction hearing . . . the question of the significance and condition of the trees, and the actual need for the drawdown sought in relation thereto, had turned on the weight of the expert testimony as to the number, vitality and predicted mortality of such remaining trees. The testimony of the witnesses on both sides rested controllingly on the general observations which

system, Lake Ocklawaha, at the 18-foot level prevailing when the action was commenced, and later of a drawdown to a 13-foot level ordered by the trial court.[184]

Canal Authority demonstrates the potential cost-effectiveness of remote sensing techniques in litigation involving environmental conditions over a large geographic area. It would hardly have been practical for either side physically to inspect the hundreds of thousands of trees whose health and continued existence were at issue. Consequently, field studies were performed on a selective basis in each of the affected areas,[185] while aerial near infrared surveys were obtained to reveal the overall dimensions of the environmental stress upon the forest regions. As the lake level was lowered, then restored to its original level, and subsequently lowered again in response to judicial rulings on behalf of one party or the other, the relevant environmental conditions periodically changed. Thus, the utility of comparatively inexpensive aerial reconnaissance was compounded, since it was necessary to monitor the consequences of such developments at fairly fre-

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they had made of the area and *on interpretations of infra-red photographs which had been taken of parts thereof.*

Memorandum on Motion of Federal Defendants for Relief from Part of Final Judgment at 5, Canal Authority v. Callaway, No. 71-92-Civ-J (M.D. Fla., Mar. 25, 1974) (emphasis added).

184. The federal defendants introduced vertical infrared pictures as a partial basis for their estimate of a high mortality rate if the initial lake level was maintained. The Canal Authority submitted oblique infrared images which led the interpreting expert to predict a much lower rate. Obviously, all parties agreed that infrared sensing could detect vegetative deterioration, but their respective experts differed on the issue of which aerial photographic angle could provide the more accurate representation. Record at 4561-68, 4596-4603 (Aug. 9, 1973). *See also* Higer, Kolipinski, & Lucas, Court Precedent for Acceptance in Evidence of Remotely-Sensed Data and their Interpretation, Cross-Florida Barge Canal, III 4th Annual Earth Resources Program Review at 77-1 to 77-2 (Jan. 17-21, 1972) (STAR acc. no. N72-29355) (Manned Spacecraft Center, Houston, Tex.) (abstract). *See generally* An Environmental Assessment of Lake Ocklawaha-Rodman Reservoir 1 Final Environmental Statement, Proposal for Oklawaha River, Appendix 14 (May 15, 1972) (prepared by the U.S. Department of Agriculture Forest Service).

185. Ground-truth (field information gathered to be correlated with remote sensing imagery) for the defendants' aerial photo-survey consisted of fonr forays into each affected area near Lake Oklawaha. A team of scientists examined the area by boat on April 18, 1972, 3 days prior to the pivotal aerial survey. On May 8 and 9, defendants' experts visited the area "to examine individual trees [within] different plots that had been established." On November 9, approximately 3 weeks after a subsequent aerial survey, defendants' experts "visited all the [affected areas] and compared the ground truth information with the aerial photography." Affidavit of Aaron L. Higer at 3, Nov. 1972, Marion County, Fla. (on file with author) [hereinafter cited as Higer Affidavit]. Ground truth for the Canal Authority's aerial oblique photography consisted of three visits to "the upstream reaches of that lake," the first taking place on approximately June 15, 1972, the second occurring during the first week of January, 1973, and the third being completed in early August, 1973. Record at 4560-61.

quent intervals.[186] Moreover, the infrared photographs produced by successive aerial missions served as graphic baselines against which subsequent forest deterioration or regeneration could be measured.

3. *Land and Water Boundaries*

Remote sensing in the near infrared spectral range has been utilized in a number of cases because of its capacity to discriminate accurately between land and water zones.[187] The majority of these cases involve the use of near infrared photography to accomplish one of two ends: to map coastlines and thereby determine the property rights of public and private litigants;[188] and to identify a boundary line

186. The federal government found it necessary to take vertical color infrared imagery of the affected areas on three separate occasions: June 16, 1971, Apr. 21, 1972, and Oct. 18, 1972. Higer Affidavit, *supra* note 185, at 4.

187. *E.g.*, Record on Appeal at 276-308, State v. Johnson, 286 N.C. 331, 210 S.E.2d 260 (1974) (infrared images employed to illustrate beach erosion and shifts in shoreline affecting property value of parcel in condemnation proceeding); Confession of Judgment, Iowa Dep't of Env. Quality v. Pampered Beef-Midwest, Inc., No. CL-125 (Iowa Dist. Ct., Cherokee County, Dec. 17, 1974); Petition for Vacation of Judgment (Mar. 1, 1975). The particulars of the case were described by an official of the Iowa Department of Environmental Quality:

> A certain large livestock confinement operation in the State of Iowa was under consent order with this Department to construct waste treatment facilities and had been issued a construction permit for the project. Numerous alleged violations of departmental requirements were revealed by inspection of the facility over a long period of time. A part of the alleged violations involved failure to construct the facility in accordance with approved plans and specifications. This Department used infra red photography taken, I believe, by the State Geological Survey to reveal the actual location of constructed portions of the project including lagoons and buried tile lines which were a part of the irrigation system. By comparing an infra red photograph which showed the actual location of various structures with the approved plans and specifications, we were able to determine variances between the two. . . . This case is now in litigation and it is anticipated that the infra red photography will be used as part of the evidence in this case.

Letter from Dean Powell, Compliance Officer, Iowa Department of Environmental Quality, Des Moines, Iowa, to author, Dec. 8, 1975. Experts from the Iowa Geological Survey will interpret the infrared imagery. Conversation between R. White and James C. Davis, Assistant Attorney General, State of Iowa, Apr. 1, 1976.

188. *See* State v. County of San Mateo, No. 144257 (Cal. Super. Ct., San Mateo County, filed Nov. 12, 1971), a pending action in which the State of California is seeking to prevent the development of tidelands and submerged lands in San Francisco Bay. Aerial infrared photography was employed to illustrate the mean low water lines in the relevant areas, at given tide levels, as a basis for asserting state ownership. Letter from William M. Lindsey, Regional Supervisor, Division of Realty, U.S. Department of the Interior, Fish & Wildlife Service, Portland, Ore., to author, Nov. 18, 1975; Conversations with John Briscoe, Dep. Atty. General, State of California, Department of Justice, San Francisco, Cal., Oct. 9, 1975; Walter Cook, California State Lands Commission, Sacramento, Cal., Oct. 9, 1975.

See also letter from Nora Duncan, Staff Attorney, State of Louisiana, Department of Justice, Baton Rouge, La., to author, Aug. 29, 1975:

> We are familiar with the type of information gathered by the earth resources technology satellite (ERTS) since NASA has been doing a study of our Atcha-

as a prerequisite to the assertion by regulatory agencies of jurisdiction over a particular area.[189] As an example of the first application, the Supreme Court in *United States v. Louisiana*[190] implicitly approved the use by the U.S. Coast & Geodetic Survey of near infrared photography in the preparation of official coastline maps.[191] While the State of Louisiana did not object to the techniques employed to prepare the maps on a general basis, it did contend that the maps should be superseded where more accurate information could be produced on the existence of certain islands allegedly located in Atchafalaya Bay.[192] The Supreme Court ultimately accepted the recommendations of the Special Master appointed to hear evidence in the case; his recommendations were in most instances based upon the infrared maps to the exclusion of the supplementary evidence submitted by the state.[193]

A series of cases initiated by the Jacksonville District of the Army Corps of Engineers illustrates the use of remote sensing output to estab-

falaya Basin from the Earth Resources Laboratory at the Mississippi Test Facility. Some of the information from this study has been used by the Atchafalaya Basin Commission in published reports. I do not know of any lawsuits in which that information has been used. However, there are a couple of lawsuits recently filed concerning accretion and state ownership of navigable waterbottoms in the Atchafalaya Basin. We are still in the investigatory stage of these suits and will not go to trial for at least another year. There is a good possibility that information from ERTS will be introduced in evidence at that time.

189. See cases discussed in text accompanying notes 273-79 *infra*. In Zabel v. Tabb, 430 F.2d 199 (5th Cir. 1970), *cert. denied*, 401 U.S. 910 (1971), the court of appeals defined the permit jurisdiction of the U.S. Army Corps of Engineers, under the Rivers & Harbors Appropriations Act of 1899, 33 U.S.C. §§ 401, 403-04, 406-09, 411-16, 418 (1970), to include private activities below the mean high tide line adversely affecting the environment even if they did not actually affect or impede navigation. Although Corps jurisdiction was thought to extend only to the mean high tide line (MHTL), the Fifth Circuit has since held that activities adversely affecting navigation, even if occurring shoreward of the MHTL, also come within the purview of the Act. *See* United States v. Sexton Cove Estates, Inc., 526 F.2d 1293 (5th Cir. 1976); Weiszmann v. District Eng'r, 526 F.2d 1302 (5th Cir. 1976); United States v. Joseph G. Moretti, Inc., 526 F.2d 1306 (5th Cir. 1976).

190. 420 U.S. 529 (1975) (acceptance of the Report of the Special Master); 422 U.S. 13 (1975) (supplemental decree setting out map coordinates to establish the boundary line between state and federal sovereignty).

191. Coast & Geodetic Survey, U.S. Department of Commerce, Descriptive Report, Planimetric and Mean-Low Water Line Mapping Projects PH-5903 and 20,000-819 Part I—Mississippi Delta T-10944 to T-10957, Dec. 23, 1959. In addition to aerial overflights, tide observers were stationed at strategic points to establish ground truth. *Id.*

192. Emphasizing their greater technical precision, the state contended that navigational charts based on depth soundings should be given precedenee in situations where they conflicted with the infrared maps produced by the Coast & Geodetic Survey. Report of the Special Master at 24, United States v. Louisiana, 420 U.S. 529 (1975).

193. The maps were regarded as prima facie valid by the Special Master, except where Louisiana reserved the right to challenge their accuracy. The Special Master found them highly persuasive, particularly in light of the ground-truth obtained by the Coast and Geodetic Survey to validate their accuracy. Report of the Special Master at 24-25, 43-44.

lish agency jurisdiction. The Corps is empowered to supervise only those dredging and filling operations that affect "navigable waters," and it must therefore first demonstrate that the activities it seeks to regulate or prohibit satisfy that condition.[194] In coastal areas this demonstration often requires the Corps to prove that unauthorized activities occurred on land located below the existing or former mean high water mark.[195] Infrared photographs of the Florida coastline taken by NASA in March 1970[196] have been successfully introduced by the Jacksonville District for two purposes: (1) to delineate, in conjunction with conventional aerial photographs and available tidal data, the precise boundary of the areas within the jurisdiction of the Corps;[197] and (2) to docu-

194. 33 U.S.C. § 1362 (Supp. V, 1975). "Navigable waters" is officially defined in 33 C.F.R. 209.120 (1976).

195. "Mean high water mark" means the line on the shore established by the average of all high tides. 40 Fed. Reg. 31325 (1975). *See* United States v. Freethy, No. C-73-1470 SC (N.D. Cal., Feb. 25, 1975). Since dredging and filling, especially the latter, are likely to produce a different high water line than the natural one, it is often necessary in cases where these activities have already occurred to find the former line in order to establish agency jurisdiction.

196. *See, e.g.*, United States v. Sexton Cove Estates, Inc., 389 F. Supp. 602 (S.D. Fla. 1975), *rev'd in part on other grounds and remanded*, 526 F.2d 1293 (5th Cir. 1976); Letter from William E. Welch, District Counsel, Jacksonville Dist., U.S. Army Corps of Engineers, Jacksonville, Fla., to Clifford Childsworth, Earth Resources Program Office, Johnson Space Center, Houston, Tex., Aug. 13, 1974:

> In 1970 and 1971 Sexton Cove Estates, Inc. excavated two canals and widened and deepened three other canals which connected with Blackwater Sound without a Department of the Army permit. The excavated material was used to fill the adjacent wetlands, creating waterfront property.
>
> . . .
>
> Accordingly [we] request that your photographic laboratory furnish us with three 27" x 27" copies of Frame #4813 taken from Roll #1, Line #1, Run #1 of Mission 122, RCA #1 Camera, Test Site 169 flown on 9 March 1970. Since it is intended that the photograph be used in connection with the litigation, [we] request that one copy of the enlargement of Frame #4813 be a certified true copy in order that we may avoid calling the custodian of the negatives as a witness.

197. *See, e.g.*, United States v. Frank Keevan & Son, 7 E.R.C. 1527 (S.D. Fla. 1974). The Corps' remote sensing expert employed tidal data supplied by the National Ocean Survey and a "signature" based upon the tone and texture of the lands appearing in the submitted photographs to construct a map indicating the mean high tide line and the area of the unauthorized encroachments. Government's Post-Trial Memorandum at 2-3, United States v. Frank Keevan & Sons, *supra*. *See* Letter from William Welch, District Counsel, Jacksonville District, U.S. Army Corps of Engineers, Jacksonville, Fla., to author, June 27, 1975:

> This office has numerous cases at various levels of preparation in which remote sensing technology will be used. In addition to using infrared photography and regular black and white and color aerial photography as trial evidence, we also use photography in negotiating settlements. Due to our recent courtroom success in the Florida Keys, this office has been fortunate in its ability to negotiate numerous settlements in similar cases in the Keys area. It has been my experience that when a developer realizes the quality of evidence available to the Government through the use of such photography, he frequently chooses to negotiate a settlement in lieu of a complete trial on the merits. This, of course, saves a great deal of money for the Federal Government, and generally results in very satisfactory Consent Judgements.

ment the condition of the coast in 1970 to serve as a baseline against which subsequent encroachments can be identified.[198] Where the court decrees restoration of the land to its prior state, the images obtained in 1970 may also be employed to determine the success of the process.[199]

4. *Biological Mapping in Wetlands Areas*

In riparian regions, where a clear boundary line between water and land cannot be identified by conventional surveying techniques or the aerial methods employed in the cases discussed immediately above,[200] remote sensing may be used to determine a "biological high

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198. *See, e.g.*, United States v. Frank Keevan & Son, 7 E.R.C. 1527 (S.D. Fla. 1974); United States v. Sexton Cove Estates, Inc., 389 F. Supp. 602 (S.D. Fla. 1975), *rev'd in part on other grounds and remanded*, 526 F.2d 1293 (5th Cir. 1976); Weiszmann v. Corps of Engineers, 7 E.R.C. 1523 (S.D. Fla. 1975), *rev'd in part on other grounds and remanded*, 526 F.2d 1302 (5th Cir. 1976); Letter from George H. Craig, Jr., Assistant District Counsel, Jacksonville District, U.S. Army Corps of Engineers, Jacksonville, Fla., to author, Aug. 25, 1975:

> [F]rame number 4813 was used in *United States v. Sexton Cove Estates*, 389 F. Supp. 602 [S.D. Fla.] (1975) [rev'd in part on other grounds and remanded, 526 F.2d 1293 (5th Cir. 1976)]. As a result of that decision and *Weiszmann v. District Engineer*, 7 E.R.C. 1523 [(S.D. Fla. 1975), *rev'd in part on other grounds and remanded* 526 F.2d 1302 (5th Cir. 1976)], the United States Attorney for the Southern District of Florida is currently engaged in settlement negotiations with a number of Florida Keys developers who excavated residential canals without a Department of the Army permit.
>
> When using aerial photography in environmental litigation, it is absolutely essential that the photograph be certified and that the exact time and date of the photograph be provided. When certified tide data is then obtained from N.O.A.A. [National Oceanographic and Atmospherics Administration], an expert witness has a solid basis upon which to testify. In every instance known to date, the certified photography has been entered into evidence without objection by the Court or opposing counsel.

199. Letter from William Welch, District Counsel, Jacksonville District, U.S. Army Corps of Engineers, Jacksonville, Fla., to author, June 27, 1975:

> Pleased be advised that *United States v. Keevan*, 7 E.R.C. 1527 (S.D. Fla. 1975) was not appealed to the Fifth Circuit. . . . It has just been reported that Mr. Keevan has completed a large segment of the restoration required by the final judgement in that case. . . . Just as we used aerial photography to prove the prior location of the mean high water line in that case, we will also use aerial photography to determine the accuracy and quality of the restoration work by comparing the very latest photography with those used at trial.

See also Letter from William Welch, District Counsel, Jacksonville District, U.S. Army Corps of Engineers, Jacksonville, Fla., to author, May 7, 1975:

> [The Jacksonville District uses] aerial photography extensively in connection with out-of-court settlements. It is usually the prime source of reference in discussing how much fill material is to be removed in a given case since "before" and "after" photographs are shown to the violator.

200. E. Feinberg, The Determination of Lands Now or Formerly Below Mean High Water at 2-3, Jan. 1973 (unpublished paper, on file at the N.J. Department of Environmental Protection, Office of the Commissioner) (footnotes omitted):

> The NOS [National Ocean Survey] has developed precise techniques, using aerial photography, to find the mean high water line on open shores and

water line" based upon distinctions between types of vegetation that thrive in a saline environment and upland or freshwater types.[201] This kind of application again relies upon aerial near infrared photography; however, in this context the most attractive aspect of remote sensing in the near infrared spectral region is not the capacity to discriminate directly between land and water surfaces, but to identify different plant species through their distinctive reflectance characteristics.[202] A bio-

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beaches. In a tidal marsh, however, the NOS approach cannot be used because the vegetation obscures the land-water interface.

The problem is made more difficult because local growth patterns of marsh vegetation greatly modify the movements of the tides: tidal datum planes can be distorted into complex three-dimensional surfaces, and areas only several hundred feet apart can differ by over an hour in the time of high tide. A high spatial density of tidal measurements is needed to obtain a reasonable approximation of the tidal datum. The difficulties are compounded by an additional characteristic of the New Jersey tidal marshes. The slope of the land surface is frequently less than 0.1% (the elevation of the land increases less than 1 foot for each thousand feet of distance away from the water. Displacement of the water level by 0.1 foot will shift the land-water interface by over 100 feet horizontally. Most tidal measurements are made to within an accuracy of only 0.1 foot. For more accurate measurements, the necessary time and costs increase drastically.

It is easy to understand why conventional techniques are not practical for accurately determining the mean high water line in a tidal marsh. The time required and the costs for men and equipment often approach the value of the land itself. Hence the mean high water line has not been established in most areas.

See also J. Guth, Will the Real Mean High Water Line Please Stand Up . . . , at 4-5, Sept. 1974 (unpublished paper presented at the Convention of the American Congress on Surveying and Mapping, American Society of Photogrammetry in conjunction with the XIV FIG International Congress of Surveyors, Washington, D.C.).

201. *See, e.g.*, Earth Satellite Corporation, Hackensack Meadows Botanical Delineation Program, Final Report at 19-21 (report prepared for the New Jersey Department of Environmental Protection, Sept. 1973) [hereinafter cited as Hackensack Report]:

> Tidal marsh vegetation can show, through its color infrared reflectance characteristics, relative degrees of tidal inundation throughout the normal range of tidal marsh growing sites. Dr. Richard Anderson and Dr. Frank J. Wobber of Earth Satellite Corporation jointly developed a remote sensing method for approximating the true ground position of the physical mean water line in coastal marshes through color infrared vegetation reflectance changes in *Spartina alterniflora.* The method depends upon the fact that *Spartina alterniflora* which occupies frequently inundated low marsh growing sites has a characteristic *high vigor* and high infrared reflectance. *Spartina alterniflora* which occupies slightly higher elevations is less frequently inundated by tides and has a characteristic *low vigor* aud lower infrared reflectance.

202. See text accompanying notes 69-70 *supra.* Depending upon the nature of the indigenous flora, the application may distinguish between two or more species, some of which require periodic inundation by the tide while the others cannot thrive when exposed to saline water. Hackensack Report, *supra* note 201, at 18-32. Thus, land where tidal vegetation prospers would be classified as below the biological high water line whereas the locations of the other species would be characterized as uplands. Alternatively, a single species may be identified if it is capable of growing in both wetland and upland sites but in different locations exhibits markedly different growth patterns, usually called plant vigors. *Id.* at 18-19. *See also* Transcript of Proceedings at 70 (June 17, 1975), N.J. Sports & Expo. Auth. v. M,B.M. Truck Leasing Co., No. L-26780-72

logical high water line developed in this manner may be employed to establish agency jurisdiction[203] or to produce official maps that delineate property boundaries.

In New Jersey, for example, there are approximately 244,000 acres of tidal marshland[204] that the state is attempting to map in order to determine the ownership of real property in or adjacent to its wetlands.[205] The adequacy of remote sensing and biological discrimination techniques for that purpose[206] is the central issue in *City of Newark*

(N.J. Super. Ct., Law Div., Sept. 19, 1975) (testimony of Dr. Edward B. Feinberg, N.J. Department of Environmental Protection):

> Q Would you please describe what is indicated on the overlay before you marked S-21A for Identification?
>
> A There are a series of lines and letters. The lines delineate portions of the area depicted on the map that were identified by the consultant to represent certain plant communities having characteristics specified in the contract specifications to meet certain criteria.
>
> These characteristics were based on the concept that plants exhibit measurable characteristics both in the field and on color infrared film that reflect the relative frequency with which they are inundated, totally or partially below the tide . . . .

203. *See, e.g.*, Stipulation of Settlement, United States v. Heniford, Civil No. 74-865 (D.S.C., Apr. 9, 1976). Infrared photographic data collected by the U.S. Fish & Wildlife Service was used to draw a biological mean high tide line for purposes of asserting Corps of Engineers permit-jurisdiction over a disputed development site. Conversation with Ann Fornes, Research Technician, Marine Institute, University of Georgia, Sapelo Island, Ga., Oct. 20, 1975; Letter from Curtis A. Laffin, Biologist in Charge, U.S. Department of Interior, Fish & Wildlife Service, Charleston, S.C., to author, Nov. 5, 1975; Letter from Ann Fornes, Research Technician, Marine Institute, University of Georgia, Sapelo Island, Ga., to Mary Ann Marwick, Assistant District Counsel, Charleston District, U.S. Army Corps of Engineers, Charleston, S.C., Oct. 4, 1975:

> [T]he mean high water line was to be located in order to determine if the developer had violated this boundary line with the construction of a dike. Color infra-red photography, flown prior to the initiation of dike construction, was interpreted for salt marsh plant species differentiation. The plant boundary appeared to approximate the mean high water line on this site. Field reconnaisance and subsequent surveyed elevations coordinated with tide data verified this.

The Government felt that the remote sensing evidence would be a critical element in its case. Conversation between R. White and Mark W. Buyck, U.S. Attorney, District of South Carolina, Columbia, S.C., Apr. 1, 1976. The remote sensing data will not be offered into evidence, however, as the ease has since been settled. *Id.*; Letter from Clerk, U.S. District Court, District of South Carclina, to author, June 8, 1976.

204. Porro & Teleky, *Marshland Title Dilemma: A Tidal Phenomenon*, 3 SETON HALL L. REV. 323 (1972).

205. Feinberg, *supra* note 200; Letter from JoAnn Stitt, Principal Environmental Specialist, State of New Jersey, Department of Environmental Protection, to author, May 14, 1975. *See also* Feinberg, Yunghans, Stitt & Mairs, Impact of ERTS-1 Images on Management of New Jersey's Coastal Zone, THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 497, 501.

206. *See generally* Dolphin Lane Assocs. v. Town of Southampton, 72 Misc. 2d 868, 339 N.Y.S.2d 966 (Sup. Ct. 1971), *aff'd mem.*, 43 App. Div. 2d 727, 351 N.Y.S.2d 364 (2d Dep't 1973), *modified*, 37 N.Y.2d 292, 333 N.E.2d 358, 372 N.Y.S.2d 52 (1975), where the trial court accepted a biologically determined mean high tide line in a dispute between the Town of Southampton and a private developer. 72 Misc. 2d at 884-85, 339

v. Natural Resources Council[207] and related litigation.[208] The applicable law in New Jersey provides for public control of all lands now or formerly flowed by the tides.[209] For that reason the state must not only map the wetlands as they currently exist, but must also identify those parts of filled and developed properties that private parties

N.Y.S.2d at 983-84. (*spartina alterniflora*). The adequacy of the remote sensing technique was not fundamental to the final outcome of the litigation, however, as the New York Court of Appeals held that the reliance by the developer (and its predecessors in title) on a boundary line previously established estopped the Town from asserting a line based on more advanced technology. The approach of the court of appeals in *Dolphin Lane* has been criticized, both for its assumptions regarding traditional surveying practices (as used in drawing the original boundary line), and for exalting such practices into fixed rules of property law. *See* Humbach & Gale, *Tidal Title and the Boundaries of the Bay: The Case of the Submerged "High Water" Mark*, 4 FORDHAM URB. L.J. 91, 105-28 (1975). Prior lower court cases in New York had approved, at least in principle, the biological technique for establishing the mean high tide line. *See* State v. Bishop, 46 App. Div. 2d 654, 359 N.Y.S.2d 817 (2d Dep't 1974), *rev'g* 75 Misc. 2d 787, 348 N.Y.S.2d 990 (Sup. Ct. 1973).

207. No. A-3311-72 (N.J. App. Div., July 18, 1973). *See* City of Newark v. Natural Resource Council, 133 N.J. Super. 245, 336 A.2d 46 (L. Div. 1974) (partial summary judgment on issues remanded from the appellate division). The City of Newark and a number of private property owners challenged the legality of maps published by the New Jersey Department of Environmental Protection, pursuant to N.J. STAT. ANN. § 13:1B-13.4 (West Supp. 1976), through an action filed in the appellate division. The maps produced by the Council divided the coastal wetlands into three categories: land asserted to belong to the State because it was clearly below the mean high tide line; land above the line conceded to belong to private property owners; and a "hatched" area, denoting a zone where the state asserted partial ownership, but with less assurance as to the exact boundaries or locations of the claimed lands. The trial court granted summary judgment for the plaintiffs because the "hatched" designation did not comply with the legislative command to "publish a map . . . *clearly* indicating those lands designated by the council as State-owned lands," pursuant to N.J. STAT. ANN. § 13:1b-13.4 (West Supp. 1976) (emphasis added); City of Newark v. Natural Resources Council, 133 N.J. Super. at 258-59, 336 A.2d at 53-54. The state has since claimed the entire "hatched" area as state-owned property. *See* Post-trial Memorandum of the New Jersey Department of Environmental Protection at 23, Opinion at 77, Sports & Expo. Auth. v. M.B.M. Truck Leasing Co., No. L-26780-72 (N.J. Super. Ct., L. Div., Sept. 19, 1975).

208. *See* Sports & Expo. Auth. v. M.B.M. Truck Leasing Co., No. L-26780-72 (N.J. Snper. Ct., L. Div., Sept. 19, 1975); Sports & Expo. Auth. v. Logothetis, No. L-26791-72 (N.J. Super. Ct., L. Div., Sept. 19, 1975); Sports & Expo. Auth. v. Parker, No. L-26792-72 (N.J. Super. Ct., L.Div., Sept. 19, 1975) (consolidated cases) [hereinafter cited as Hackensack Meadows Cases]. The New Jersey Sports and Exposition Authority brought condemnation proceedings to acquire land needed in the construction of the Meadowlands Sports Complex. The State of New Jersey intervened, seeking to quiet title in itself as to the land in question, and to receive the compensation that otherwise would have been paid to the record owners of the condemned property. The state based its claim on the maps prepared by the Department of Environmental Protection, this time alleging complete ownership of the "hatched" area. Since *City of Newark*, which would decide the issue of the validity of the maps, was pending, the record owners were given an option of waiting for its conclusion or of stipulating to the accuracy of the mapping methodology. Pretrial Order at 2-3, Hackensack Meadows Cases, *supra*. Evidence on the reliability of the biological mapping technique was received in the Hackensack Meadows Cases, however, to determine the weight to be accorded the maps, particularly the actively contested "hatched" portion.

209. N.J. CONST. art. 4, § 7, par. 6; N.J. STAT. ANN. § 18A:56-5 (1968).

wrongfully appropriated in the past.[210] In order to determine the original condition of the land, the New Jersey Department of Environmental Protection has relied on old aerial and conventional photographs, maps, tidal surveys where available, analysis of core samples taken from contested property, and an extrapolation of the biological high water line existing in wetlands areas[211] located adjacent to the properties at issue.[212]

It should be made clear at this juncture that the unopposed introduction of remote sensing output typical of past remote sensing cases does not necessarily reflect a belief by all parties that such information should be admissible. Frequently, the litigation strategy adopted by one side will preclude what it perceives as an extraneous challenge to evidence of doubtful reliability.[213] For example, in *Application of American Dredging Company*,[214] the applicant sought a permit for dredging in a New Jersey wetlands area classified as such by means of the biological high water line method challenged in *City of Newark*.[215]

210. O'Neill v. State Hwy. Dep't, 50 N.J. 307, 235 A.2d 1 (1967). *O'Neill* held that the burden of proof was on the state to show ownership of disputed tideland property "as to lands not now covered by [the] mean high tide. . . ." *Id.* at 327, 235 A.2d at 11. *See also* City of Newark v. Natural Resource Council, 133 N.J. Super. 245, 336 A.2d 46 (Law Div. 1974); Opinion at 27, Hackensack Meadows Cases, *supra* note 208.

211. Transcript of Proceedings, Vol. I, at 52-54, Hackensack Meadows Cases, *supra* note 208 (testimony of Dr. Edward B. Feinberg); Feinberg, *supra* note 200, at 5-7.

212. In the Hackensack Meadows Cases the court found that the state failed to carry its burden of proof, as required by *O'Neill*:

> [T]he State claims that 87 percent of the area embraced within the Walden Swamp area is or would have been covered by water which is visible in creeks, tributaries or mosquito ditches flowed by the mean high tide twice daily or would have contained plant species which would have required such flows or would have been lands flowed daily by mean high tides. . . .
>
> The State reasons that because of certain common characteristics referred to, the areas denominated "hatched" on the State's overlay were probably riparian. . . .
>
> According to this theory, 12 percent of the total hatched area . . . would be upland and would have been delineated by island-type areas. However, the State concedes it is unable to tell the Court where such upland areas would be located, or how large they are or how the Court could fin[d] or determine any precise high water line or upland line in relation to defendants' properties. In fact, not only could they not tell the Court where or how many or how large or where they could be located, but in no way how they could be described.

Opinion at 77-79, Hackensack Meadows Cases, *supra* note 208. The state has since appealed the adverse decision of the trial court. Sports & Expo. Auth. v. Logothetis, No. L-26791-72 (N.J. Super. Ct., L. Div., Sept. 19, 1975), *notice of appeal filed*, Sept. 26, 1975.

213. *See, e.g.*, Sierra Club v. Department of the Interior, 398 F. Supp. 284 (N.D. Cal. 1975), where the Interior Department based its defense on the discretion vested in the Secretary of the Interior rather than on claims that no environmental harm was occurring to the Redwood National Forest. 398 F. Supp. at 293. See note 181 *supra*.

214. App. No. W73-020 (N.J. Dep't of Env'l Protection).

215. Couversation with Sherman T. Brewer, Jr., Deputy Attorney General, State of New Jersey, Department of Law & Public Safety, Newark, N.J., Aug. 25, 1975.

The company's litigation strategy, however, focused not on the validity of the mapping techniques, but on its contention that the area was already so degraded as to be of little ecological value.[216]

It must be emphasized that the cases introduced in this section, while of varying degrees of significance in their own right, are only suggestive of the value of remote sensing evidence in the future. The majority of the satellite and aerial images submitted in the past were neither intended nor expected to play any role in litigation at the time they were obtained. As environmental applications dependent on remote sensing technology proliferate in the coming decade, it is certain that a large volume of remote sensing information will ultimately be introduced as evidence in judicial and administrative proceedings.

III

THE ADMISSIBILITY OF REMOTE SENSING EVIDENCE

The presentation to this point may be characterized as a functional analysis of remote sensing from a legal perspective, with particular emphasis devoted to the kinds of environmental information that can be collected and to the legal uses which may be made of that information. In order for remote sensing output to be accepted in courts and administrative hearings, the information must not only be useful but must, in addition, comply with the formal rules of evidence applicable in adjudicatory contexts. A reasoned assessment of the admissibility of remote sensing output requires knowledge of the scientific principles and techniques underlying the data collection process. Moreover, the collected information must be interpreted, which is to say that the party introducing remote sensing evidence must indicate not only its validity but also its significance. There is little question that the evaluation of remote sensing output falls outside the bounds of the everyday experience and average competence of laymen. Consequently, the submission strategy for remote sensing evidence must parallel that employed for most other types of scientific evidence.

As its principal focus, then, this section of the Article examines the nature of the data-collection process and the specific attributes of remote sensing output in light of the requirements for admission imposed on other types of scientific evidence. There is no reason to suppose that remote sensing information, as the product of an innova-

216. Conversation with Sherman T. Brewer, Jr., Deputy Attorney General, State of New Jersey, Department of Law & Public Safety, Newark, N.J., Aug. 25, 1975; Letter from Sherman T. Brewer to Hon. Anne E. Thompson, Presiding Hearing Officer, Trenton, N.J., Apr. 25, 1975) (Summation Comment of the State of New Jersey regarding Application No. W73-020).

tive and legally unfamiliar set of technologies, will necessarily fit neatly within traditional doctrines of the law of evidence, and in some important respects it does not. Those who intend to introduce remote sensing output in litigation would be well advised to select sensing techniques, interpretational methods, and image formats that minimize the current tension between remote sensing practices and the prescriptions of existing evidence doctrines. Thus, this section evaluates the evidentiary suitability of alternative remote sensing techniques and highlights areas of potential difficulty for future litigants in remote sensing cases. At the same time, particular attention is paid to formal rules of evidence that evolved in response to dissimilar types of documentary or scientific submissions, and that appear unreasonably restrictive when applied to reliable remote sensing information.

A. Expert Testimony

In some states individuals possessing the requisite qualifications are allowed to testify as experts on subjects about which the average person would be incapable of forming an accurate opinion or drawing correct conclusions.[217] In other jurisdictions the expert testimony must be limited to topics outside common experience.[218] Under the recently adopted Federal Rules of Evidence, an expert may testify if "scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue."[219] The world

217. *See, e.g.*, State v. Stevens, 467 S.W.2d 10, 23 (Mo. 1971), *cert. denied*, 404 U.S. 994 (1971) (expert testifying on neutron activation analysis).

> To warrant the use of expert testimony, then, two elements are required. First, the subject of the inference must be so distinctively related to some science, profession, business or occupation as to be beyond the ken of the average layman. . . .

McCORMICK, *supra* note 7, § 13, at 29.

218. If a witness is testifying as an expert, his testimony in the form of an opinion is limited to such an opinion as is: (a) Related to a subject that is sufficiently beyond common experience that the opinion of an expert would assist the trier of fact. . . .

CAL. EVID. CODE § 801 (West 1966). *See also* McCORMICK, *supra* note 7, § 13, at 30.

> [E]xpert testimony not only is unnecessary but indeed may properly be excluded in the discretion of the trial judge "if all the primary facts can be accurately and intelligibly described to the jury and if they, as men of common understanding are as capable of comprehending the primary facts and of drawing correct conclusions from them as are witnesses possessed of special or peculiar training, experience, or observation in respect of the subject under investigation . . ."

Salem v. United States Lines Co., 370 U.S. 31, 35 (1962) (citations omitted).

219. FED. R. EVID. 702. The Advisory Committee's Note quotes approvingly the test "whether the untrained layman would be qualified to determine intelligeutly and to the best possible degree the particular issue without enlightenment from those having a specialized understanding of the subject involved in the dispute." *Id., citing* Ladd, *Expert Testimony*, 5 VAND. L. REV. 414, 418 (1952). K. REDDEN & S. SALTZBURG, FEDERAL RULES OF EVIDENCE MANUAL 226 (1975) [hereinafter cited as REDDEN & SALTZBURG]. The federal formulation appears to expand the traditional scope to include situ-

cannot be perceived directly through the human senses in the same manner as it is recorded by remote sensors. Moreover, the validation and interpretation of remote sensing output cannot be performed by a witness without technical training. Therefore, whichever standard for expert testimony is applicable in a given jurisdiction, such testimony will be essential for the successful admission of remote sensing information.

This proposition must be analyzed in terms of the four logically distinguishable functions that expert testimony can perform in connection with the introduction of remote sensing evidence: (1) to establish the reliability of the scientific theories and techniques embodied in a class of sensors; (2) to document that the particular device employed to obtain the submission was constructed and operated in a manner consistent with those scientific principles; (3) to identify the submission as the sensing output originally produced or its lineal descendent; and (4) to interpret the information in a way that makes it meaningful to the trier of fact. It should be emphasized that a witness could be competent to accomplish one of these functions and yet lack sufficient knowledge or experience to qualify as an expert with respect to the others.[220]

As an illustration, the basic trustworthiness of the X-ray process, when properly conducted, is so well established that it is invariably considered a subject for judicial notice.[221] As a result, it is unnecessary to prove in court that X-rays are capable of producing accurate representations of subcutaneous or subsurface features.[222] Expert witnesses

ations where expert testimony would be helpful to explain matters difficult to comprehend but not necessarily "beyond ordinary understanding." *Id.* at 225.

220. *See, e.g.*, People v. King, 266 Cal. App. 2d 437, 445, 72 Cal. Rptr. 478, 483 (2d Dist. 1968). In that case, which involved the use of voiceprint identification techniques, the court rejected the principal prosecution expert in part because his training was solely in accoustical engineering and not in "anatomy, physiology, physics, psychology, and linguistics." *Id.* at 456, 72 Cal. Rptr. at 490. *See also* People v. Kelly, 17 Cal. 3d 24, 549 P.2d 1240, 130 Cal. Rptr. 144 (1976), rejecting voiceprint evidence where only a single witness, Lieutenant Ernest Nash of the Michigan State Police, was presented:

> The record in the instant case reveals that Nash has an impressive list of credentials in the field of voiceprint analysis. However, these qualifications are those of *a technician and law enforcement officer, not a scientist.* . . .
>
> From the demonstrably wide technical experience of Nash, it does not necessarily follow that academic and scientific knowledge are present as well
>
> . . . .

Id. at 39, 549 P.2d at 1250, 130 Cal. Rptr. at 154 (emphasis in original).

221. *See* cases cited in 3 WIGMORE (Chad. rev.), *supra* note 7, § 795; J. RICHARDSON, MODERN SCIENTIFIC EVIDENCE CIVIL AND CRIMINAL §§ 16.17-.19 (2d ed. 1971) [hereinafter cited as RICHARDSON]; SCOTT, *supra* note 7, §§ 1251-75; Annot., 5 A.L.R.3d 303 (1966).

222. *See* cases cited in SCOTT, *supra* note 7, §§ 1251-58; RICHARDSON, *supra* note 221, § 16.17. *See also* Scott, *X-Ray Pictures As Evidence*, 44 MICH. L. REV. 773 (1946).

must nevertheless explain what the developed images show in every instance because the features depicted vary from case to case and are ordinarily beyond common understanding. The anatomical or structural knowledge necessary to provide an interpretation of the images is altogether different from the knowledge of physics that would be required to validate the basic X-ray theory, were that issue to be reexamined in court. In like manner, the skills and knowledge needed to operate the X-ray machines, to develop the images, and to authenticate them are quite distinct from the credentials required of an expert interpreter.[223] Logically similar considerations apply to the treatment of remote sensing images.[224]

As a general rule of law experts may qualify for a given purpose on the basis of special knowledge, skill, experience, training, or education.[225] There is no predetermined formula by which the relative importance or irreducible minimum of these criteria can be calculated. Rather, the knowledge and background appropriate for recognition of expert status must be adjudicated in the context of the specific kinds of information and inferences that the prospective expert witness desires to impart.[226] Generalizations divorced from particular factual situations and evidentiary purposes are especially undesirable when considering remote sensing technology because of the diversity of sensing techniques and interpretive applications subsumed under that label.

The great majority of current remote sensing practitioners do not possess academic degrees or educational training in remote sensing per se. This characteristic is attributable not only to the comparatively recent emergence of the technology, but also to its utility for many different scientific disciplines. What has occurred is a convergence toward expertise in remote sensing from dissimilar starting points. At one extreme are scientists who were initially trained in traditional disciplines such as geography,[227] biology,[228] hydrology,[229] or forestry,[230]

223. *See, e.g.*, People v. King, 266 Cal. App. 2d 437, 458, 72 Cal. Rptr. 478, 491-92 (2d Dist. 1968); Lamb v. Moore, 178 Cal. App. 2d 819, 3 Cal. Rptr. 507 (3d Dist. 1960).

224. *See generally* Tuerkheimer, *supra* note 168, at 306-11.

225. *See, e.g.*, FED. R. EVID. 702; CAL. EVID. CODE § 720(a) (West 1966).

226. *See, e.g.*, Huffman v. Lindquist, 37 Cal. 2d 465, 234 P.2d 34 (1951); MCCORMICK, *supra* note 7, § 13, at 30.

227. *See, e.g.*, Deposition of Professor Aulis O. Lind, Oct. 4, 1973, at 1-2, Vermont v. New York, 417 U.S. 270 (1974); Transcript of Proceedings at 1269 (testimony of Albert Pressman), State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Sept. 8, 1975); Transcript of Record, Vol. IV, at 3 (testimony of Dr. John Estes), *In re* License No. 336207, Albert B. Watts (No. 5952/1334, U.S. Coast Guard, 8th Coast Guard District, Port Arthur, Tex., Sept. 13, 1972); Transcript of Proceedings at 8008 (testimony of Dr. H. Olav Slaymaker), Federal Power Commission, City of Seattle, Project No. 553, Mar. 5, 1975.

228. *See, e.g.*, Anderson & Carter, *supra* note 70.

229. *See, e.g.*, Higer Affidavit, *supra* note 185, at 1. Record on Appeal at 268-

and have subsequently developed an understanding of remote sensing technology because of its relevance to their respective fields of study. At the other extreme scientists with backgrounds in fields like physics[231] or aeronautics[232] which provided them with knowledge of the physical principles underlying the sensing technology itself have developed competence in selected interpretational applications.

Remote sensing, then, is not a self-contained or easily recognizable discipline if evaluated in terms of the formal academic training of its proponents. For that reason a number of alternative methods have been used in remote sensing cases to document the professional qualifications of potential expert witnesses. The factors considered include the exposure of the witnesses to some formal education in the technology,[233] familiarity with the professional literature,[234] publications directly on point or on related subjects,[235] membership in relevant professional societies,[236] other forms of professional recognition,[237] past and

71, State v. Johnson, 286 N.C. 331, 210 S.E.2d 260 (testimony of Limberios Vallianos, an expert witness for the State of North Carolina, who was trained as a coastal and hydraulic engineer).

230. *See, e.g.*, Transcript of Record at 4554-55, Canal Authority v. Callaway, No. 71-92-Civ-J (M.D. Fla., Feb. 4, 1974) (testimony of Dr. Charles Olson); Transcript of Proceedings at 9820-21, Federal Power Commission, City of Seattle, Project No. 553, Mar. 5, 1975 (testimony of Dr. Gerard F. Schreuder).

231. *See, e.g.*, Transcript of Proceedings, Aug. 9, 1973, at 973, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974) (testimony of Arthur W. Dybdahl).

232. *See, e.g.*, Transcript of Proceedings, Vol. I, at 47, Hackensack Meadows Cases, *supra* note 208 (testimony of Dr. Edward Feinberg).

233. *See, e.g.*, Stipulation of Settlement, United States v. Heniford, Civ. No. 74-865 (D.S.C., filed Apr. 9, 1976). The Government's principal expert, Ann Fornes, indicated that she received her formal degrees in geography, although her graduate program heavily emphasized remote sensing; Deposition of Ann Fornes, Mar. 31, 1975, at 198-208, United States v. Heniford, *supra*. *See also* Transcript of Proceedings at 9820-21, Federal Power Commission, City of Seattle, Project No. 553, Mar. 5, 1975 (testimony of Dr. Gerard F. Schreuder), where Dr. Schreuder indicates that he received a Certificate in Photogrammetry from the International Training Center for Aerial Survey, Delft, the Netherlands.

234. Dr. Feinberg of the New Jersey Department of Environmental Protection, an expert witness in the Hackensack Meadow Cases, was closely questioned about his familiarity with professional literature. Transcript of Record, Vol. I, at 143-44 (June 16, 1975) Hackensack Meadows Cases, *supra* note 208.

235. *See, e.g.*, Transcript of Record, Vol. IV, at 7-13, *In re* License No. 336207, Albert B. Watts (No. 5952/1334, U.S. Coast Guard, 8th Coast Guard District, Port Arthur, Tex., Sept. 13, 1972) (testimony of Dr. John Estes, listing publications and academic appointments); Transcript of Record at 4558, Canal Authority v. Callaway, No. 71-92-Civ-J (M.D. Fla., Feb. 4, 1974) (testimony of Dr. Charles Olson, a list of whose 45 publications was offered as an exhibit without objection).

236. For example, Doctors Lind, Olson, Estes, and Feinberg are all members of the American Society of Photogrammetry.

237. For example, Doctors Lind and Feinberg were principal investigators in research projects sponsored by NASA in connection with the ERTS-1 [now LANDSAT-1] program. *See* Feinberg, Yunghans & Stitt, Impact of ERTS-1 Images on Management

current occupational responsibilities,[238] and, above all, demonstrated experience in the collection and interpretation of remote sensing information.[239] Such methods of proof correspond with those generally employed to establish the competence of experts in technical disciplines that do not have a prescribed course of instruction or a mechanism for professional accreditation.[240]

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of New Jersey's Coastal Zone (Dec. 1973) (STAR acc. no. N74-30740) (ERTS-1 Symposium); Lind, *supra* note 168.

238. *See, e.g.*, Transcript of Record at 4554-57, Canal Authority v. Callaway, No. 71-92-Civ-J (M.D. Fla., Feb. 4, 1974) (testimony of Dr. Charles Olson, an instructor in remote sensing at University of Michigan); Transcript of Record, June 18, 1972, Vol. IV, at 3, *In re* License No. 336207, Albert V. Watts (No. 5952/1334, U.S. Coast Guard, 8th Coast Guard District, Port Arthur, Tex., Sept. 13, 1972) (testimony of Dr. John Estes, who has teaching responsibilities at University of California, Santa Barbara, in aerial photo-interpretation and remote sensing).

Although the academic degrees of the principal Government remote sensing witness in *Inland Steel*, Albert Pressman, were in geology, the majority of his occupational experience has been in photo-interpretation and remote sensing. Transcript of Proceedings at 1269-77, State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Sept. 8, 1975) (testimony of Albert Pressman).

239. For example, Arthur Dybdahl, EPA-Denver, a major Government witness in *Reserve Mining*, has directed 28 aerial photographic missions since joining EPA. Transcript of Proceedings, Aug. 9, 1973, at 973, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974) (testimony of Arthur W. Dybdahl).

Similarly, Dr. Edward Feinberg, who testified in the Hackensack Meadows Cases, while questioned closely as to his academic qualifications (see note 234 *supra*), was able to satisfy the court of his qualifications through his practical experience. Dr. Feinberg, both as a result of the wetlands mapping project and of an experiment involving infrared imagery obtained from LANDSAT-I (see note 237 *supra*), had examined numerous images of the New Jersey wetlands in conjunction with photo-interpreters and scientists specializing in remote sensing technology. This was enough to satisfy the court. Transcript of Record, Vol. I, at 149, Vol. II, at 99-108, Hackensack Meadows Cases, *supra* note 208. In comparison, Dr. Elmo Barghoorn of Harvard University, offered as an expert witness by the record owners of the property, and whose academic credentials were at least as impressive as Dr. Feinberg's, was rejected as an expert by the court for his lack of practical expertise. Transcript of Record, Vol. IX, at 9.3-9.120.

240. *Compare* Hodo v. Superior Court, 30 Cal. App. 3d 788, 106 Cal. Rptr. 547 (4th Dist. 1973), *with* People v. King, 266 Cal. App. 2d 437, 72 Cal. Rptr. 478 (2d Dist. 1968). In *King* the Court of Appeal refused to accept the qualifications of Lawrence Kersta as an expert for purposes of establishing the validity of spectrographic (voiceprint) analysis. The same technique was accepted in *Hodo*, however, on the strength of experimentation conducted by Professor Oscar Tosi of the University of Michigan. Unlike Mr. Kersta, Professor Tosi had an extensive academic background in audiology and phonetics. The court focused on Dr. Tosi's publications in the field, his receipt of a federal grant to conduct research in spectrographic analysis, his extensive independent experimentation, and his role in changing the opinions of other major figures in the field regarding the validity of voiceprints.

In addition to Dr. Tosi, the court accepted the testimony of Lieutenant Ernest Nash of the Michigan State Police, who had worked with Dr. Tosi and had analyzed over 80,000 voiceprint samples. Only Lieutenant Nash testified in People v. Kelly, 17 Cal. 3d 24, 549 P.2d 1240, 130 Cal. Rptr. 144 (1976), a major factor in the California Supreme Court's decision not to accept voiceprint evidence under the facts of that case. See note 220 *supra*. The court, however, also noted that Dr. Tosi had admitted that

Defining the area of expertise necessary to validate a given remote sensing technique must be done in the context of a specific application. To do so, however, requires a careful differentiation between the image production process and image interpretation. Validation of the former typically requires sufficient knowledge in fields like physics, optics, electronics, computer science, or related disciplines. Interpretation involves an understanding of the particular application area in which the image is to be used, such as geology or biology. Because remote sensing techniques require expert knowledge from a number of perspectives and do not fit comfortably in any single scientific discipline, courts would be justified in adopting a comparatively strict standard of scrutiny with respect to the qualifications of prospective remote sensing expert witnesses.

The minimally acceptable qualifications for expert witnesses cannot be defined in the abstract, but must be particularized with due regard for the specific purpose for which the testimony is proffered. With respect to remote sensing evidence, the distinction between validation of the sensing technique and interpretation of the results must be underscored.[241] Not only may an expert be qualified to address one function and not the other, but he may be competent to interpret remote sensing images in connection with one kind of application but not others, or he may be qualified to interpret some of the information contained in a single image but not the remainder.

The testimony of James L. Lindemann in *Reserve Mining*[242] provides an illustration of the manner in which the ambit of permissible interpretation may be narrowly circumscribed to fit the qualifications of an expert witness. As an experienced photo-interpreter, Lindemann was allowed to identify, describe, and compare the various photographs and scanner images obtained by his equipment, but only to the

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voiceprint evidence could not be 100 percent accurate under all circumstances. *Id.* at 35-36, 549 P.2d at 1247-48, 130 Cal. Rptr. at 151-52 (1976).

241. *See, e.g.*, Transcript of Record, Vol. II, at 95 (June 17, 1975) Hackensack Meadows Cases, *supra* note 208:

> MR. PORRO [counsel for the Owners of Record]: Isn't the crux and the gravamen of the [Earthsat Corp.] report that was done in the Hackensack Meadows a delineation within one [plant] species as compared to a delineation of various species?
>
> MR. RINDONE [counsel for the State]: Your Honor, what has that got to do with his [Dr. Edward Feinberg, State's expert witness'] qualifications with respect to infrared?
>
> MR. PORRO: Because he has testified to nothing as to his ability to delineate within one species, which is the highly novel aspect of it. . . .
>
> MR. PORRO: I'm trying to establish and distinguish that this man may very well qualify as a man who understands the principles [of infrared photography], and I don't dispute that, but to qualify as an interpreter is a different thing.

242. United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974). See text accompanying notes 178-80, *supra*.

extent that salient features were visible on the face of the imagery.[243] The witness, for example, was permitted to draw conclusions on the similarity or dissimilarity of colors of water in different parts of Lake Superior.[244] At one point, however, Lindemann was asked to make a connection between water color and the nature of "material" suspended in the water. An objection to that line of questioning was sustained[245] on the ground that the witness was unqualified to consider "the physics of light defraction and apparent color . . . ."[246] For the same reason—that the witness could describe the images, but did not have the proper background to explain the physical properties and phenomena that caused features in the imagery to appear as they did—the trial judge ultimately rejected those portions of Lindemann's testimony in which he attempted to correlate the appearance of turbid water in the vicinity of the Reserve Mining operations with the appearance of adjacent land areas.[247]

Although Mr. Lindemann was present aboard the aircraft during the NASA reconnaisance mission,[248] the expert witness who interpreted the output produced by the EPA overflights of Lake Superior[249] planned that project but did not actually accompany the aerial mission.[250] It may often be the case that the interpreting expert will not have been in physical attendance when the remote sensing information was collected; this will always be true, for example, when satellite imagery is interpreted in court. This observation raises an important

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243. Transcript of Proceedings at 2468-2555, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974).

244. *Id.* at 2477-79, 2481-83, 2498-2501, 2503-08, 2554.

245. *Id.* at 2496-97:

> MR. HILLS [counsel for the Government]: I'd just like to ask him [Lindemann] to describe what he sees here, and I want him to give his opinion if the green close to shore is the same material as the blue out away from shore, based upon his experience and observation of thousands of these [color infrared images].
>
> MR. HYDE [counsel for Reserve Mining Co.]: The point of my objection, Your Honor, is that Mr. Lindemann [is] primarily an operator of photographic equipment and the presenter of visual photographic infrared evidence, and so forth.
>
> Having performed that function and presenting the visual presentation of his work, he has come to the end of the rope so far as his expertise is concerned . . . .
>
> THE COURT: I sustain the objection at this point. He may, however, disclose the colors, but whether or not it's the same material apparently will have to wait . . . .

246. *Id.* at 2496 (objection by Mr. Hyde, counsel for the defendant).

247. *Id.* at 2510-29.

248. *Id.* at 2471.

249. *Id.* at 969-1083. See text accompanying notes 174-77 *supra.*

250. Transcript of Proceedings at 974-77, 981, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974).

legal question: whether an interpreting expert must be personally familiar with the area or environmental conditions depicted in the remote sensing image.

Under a questionable analogy to portraits, diagrams, and maps, the law first recognized conventional photographic images only as pictorial representations of the testimony of the witness through whom the images were entered.[251] As a consequence of that doctrine, a photograph is admissible "only when a witness has testified that it is a correct and accurate representation of relevant facts personally observed by the witness."[252] Such a requirement for personal observation would bar admission of all images produced by X-rays, infrared scanning, or other techniques that record parts of the electromagnetic spectrum that cannot be perceived directly by human beings. In an effort to justify the admission of such images and at the same time to achieve legal consistency, some commentators have considered X-ray machines and similar recording devices as merely instrumental extensions of the human senses.[253] The prevalent and more satisfactory rationale in modern legal commentaries separates these recording techniques from human capabilities and treats the output as independent evidence. In order to insure that the images are accurate representations, however, and thus to justify their treatment as independent evidence, it must be

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251. *See, e.g.*, Udderzook v. Commonwealth, 76 Pa. 340 (1874); Ruloff v. People, 45 N.Y. 213 (1871); RICHARDSON, *supra* note 221, § 16.3; SCOTT, *supra* note 7, § 1022, at 330-31.

252. MCCORMICK, *supra* note 7, § 214, at 530; 3 WIGMORE (Chad. rev.), *supra* note 7, § 790; SCOTT, *supra* note 7, § 1023, at 335-36. It is not necessary, however, that the verifying witness be the photographer. SCOTT, *supra* note 7, § 1026; Ahrens, *Scientific Evidence and the Law: Identification, Verification of Verbal Testimony and Physiological Proof*, 13 N.Y.L.F. 612, 617 (1967) [hereinafter cited as Ahrens]. Nor is expert interpretation usually required for conventional photography. SCOTT, *supra* note 7, §§ 1028, 1525. When interpretation is required, however, once a witness has testified that the photograph is a fair and true representation, an expert who did not personally observe the scene depicted in the photograph may provide interpretation. *See, e.g.*, Woyak v. Konieske, 237 Minn. 213, 54 N.W.2d 649 (1952); SCOTT, *supra* note 7, § 1525; RICHARDSON, *supra* note 221, § 16.8.

253. *See, e.g.*, 3 WIGMORE (Chad. rev.), *supra* note 7, § 795 (emphasis in original):

> It is obvious that, in using instruments based upon the science of physics, we obtain a representation of things not perceivable by the ordinary senses. . . . Upon the principles, then, of testimonial knowledge, can it be said that we have personal knowledge?
>
> Our impression is not received by the unaided senses, but depends for its verity upon the correctness of the intermediate instrument or process. It would seem plain, however, that the situation is the same as if our senses had been abnormally enlarged in scope or capacity, in that we may here also claim to have knowledge, in the ordinary sense, *provided only that the instrument or process is known to be a trustworthy one.*

See also Note, *Evolving Methods of Scientific Proof*, 13 N.Y.L.F. 677, 714-15 (1967) [hereinafter cited as Note, *Evolving Methods*].

demonstrated that they were produced by means of a reliable process.[254]

Proof of the reliability of the methods used to obtain remote sensing information is thus a prerequisite for the successful admission of the data itself. The necessary documentation must be furnished by expert witnesses qualified to address the scientific principles embodied in the equipment and the manner in which the sensors were operated. Once the trustworthiness of the process is established, any witness with the proper qualifications should be permitted to interpret the output of that process. In the majority of remote sensing cases, the interpreting expert witness has been involved with all phases of the data collection process, but that may be in large part attributable to the recent and often experimental nature of the techniques. Participation in the design and operation of a remote sensing system is not a logical or legal requirement for competence in the interpretation of its output. Similarly, if the output can be shown to be an accurate representation because it was produced by a reliable process, personal knowledge or observation of the geographical area depicted should not be a prerequisite for interpretation of the remote sensing information by a qualified expert.[255]

The legal effect of qualification as an expert is that such a witness may draw and express inferences from the evidence that the trier of fact would not be competent to draw.[256] Since the knowledge and background necessary to perform a given expert function must be evaluated in light of the particular circumstances and evidentiary purposes of each case, the determination of the sufficiency or inadequacy of a potential expert's qualifications is regarded as a matter within the discretion of the trial judge.[257] In jury trials this determination must be made by the judge before an expert witness is allowed to testify in the presence of the jury; however, once the qualification threshold is passed,

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254. 3 WIGMORE (Chad. rev.), *supra* note 7, § 795; SCOTT, *supra* note 7, § 1263; MCCORMICK, *supra* note 7, § 214.

255. *See, e.g.*, Higer, Kolipinski & Lucas, *supra* note 184, at 771:

> The remote sensing testimony [of Aaron Higer in *Canal Authority*] was challenged by the plaintiff on the basis that the photointerpreter had not been on the site. However, the judge overruled the objection, deciding that it was unnecessary to have been on the site to interpret color infrared photography. This decision was based on the fact that color infrared photography was developed for the military for camouflage detection in areas where ground truth was unavailable to the photo-interpreter.

See also Tuerkheimer, *supra* note 168, at 310-11.

256. MCCORMICK, *supra* note 7, § 13; 7 J. WIGMORE, EVIDENCE IN TRIALS AT COMMON LAW § 1923 (3d ed. 1940) [hereinafter cited as WIGMORE (1940)].

257. United States v. Bermudez, 526 F.2d 89 (2d Cir. 1975); Lakota Girl Scout Council, Inc. v. Harvey Fund-Raising Mgt., Inc., 519 F.2d 634 (8th Cir. 1975); MCCORMICK, *supra* note 7, § 13. *See also* Ahrens, *supra* note 252.

the knowledge, education, and experience of the expert may be made known to the jury in order to enable them to give proper weight to the subsequent testimony.[258]

Administrative hearings employ a different standard. Any witness is permitted to express opinions on the facts, subject only to the usual requirement for relevance and materiality.[259] Consequently, an expert's qualifications are significant only in assessing the value of his testimony. Objections to the sufficiency of the background of a witness are directed at the weight to be given his statements, not at whether he may testify as an expert at all.[260] Although in rare instances the determination of a trial judge about the qualifications of an expert witness may be reversed on grounds of a manifest abuse of discretion,[261] administrative adjudications cannot be overturned because a witness was allowed to testify on a contested issue.[262]

B. Reliability of Remote Sensing Techniques

Exclusionary rules are often founded on a desire to withhold potentially untrustworthy evidence from the trier of fact. This policy arises from skepticism about the ability of juries to assess properly the value of certain kinds of information and from a perceived need for uniformity in treatment. A recognition that the judicial system is ill-equipped to determine the validity of innovative scientific techniques, combined with a suspicion that juries may be unduly impressed by the aura of scientific perfection, has prompted many appellate courts to adopt unusually restrictive standards for the admission of scientific evidence. The treatment of legally familiar types of scientific evidence, a number of which provide useful analogies for remote sensing, is not uniform among the states nor consistent for all scientific techniques; nevertheless, it is clear that the great majority of jurisdictions require a higher degree of reliability for the admission of scientific data than for most other forms of evidence.

The conceptual process by which judges may determine if scientific evidence is sufficiently trustworthy to justify admission is not a simple one, for it includes both predictive and normative elements. In

258. 2 WIGMORE (1940), *supra* note 256, § 487; 9 *id.* § 2550.

259. K. DAVIS, ADMINISTRATIVE LAW TEXT § 14.11 (3d ed. 1972) [hereinafter cited as DAVIS]; MCCORMICK, *supra* note 7, §§ 350-53.

260. *See* Brockton Taunton Gas Co. v. SEC, 396 F.2d 717, 721 (1st Cir. 1968); Keller v. FTC, 132 F.2d 59, 61 (2d Cir. 1942).

261. MCCORMICK, *supra* note 7, § 13. *E.g.*, People v. Law, 40 Cal. App. 3d 69, 114 Cal. Rptr. 708 (5th Dist. 1974); People v. King, 266 Cal. App. 2d 437, 72 Cal. Rptr. 478 (2d Dist. 1968).

262. B. SCHWARTZ, ADMINISTRATIVE LAW 336 (1976); DAVIS, *supra* note 259, §§ 14.01, 14.07, 14.13.

other words, within the confines of the adversarial system a court must first estimate the actual reliability of an unfamiliar scientific submission, and then it must decide as a matter of law whether that predicted level of reliability is adequate to support admission of the evidence in a particular case. This process may be especially difficult to conduct in the context of remote sensing submissions, because many remote sensing applications are adopted on a cost-effectiveness rationale to supersede traditional methods that, in absolute terms, provide more precise information. Courts should not be insensitive to the increased demands for information imposed on government agencies and other potential litigants by recent environmental legislation, nor unresponsive to the efficiencies offered by remote sensing technology, but few judicial precedents sanction the deliberate substitution of less for more accurate methodologies.

Judicial opinions treating the admissibility of scientific evidence have seldom made explicit the dual predictive and normative nature of the analysis of reliability. An inspection of those decisions, however, reveals a number of separate predictive and normative criteria that will be relevant to a legal assessment of remote sensing technology. In any given case the relative weight to be assigned each element in the reliability analysis will vary with the legal setting and the type of scientific technique in issue. The subsequent discussion in this section indicates how each of the criteria influenced the judicial decision to accept or reject other kinds of scientific evidence, and then considers each factor in the context of the special characteristics of remote sensing methods and output.

1. Predictive Criteria

a. Acceptance in the Scientific Community

The single most important factor that courts have considered in their attempt to determine the actual reliability of a scientific technique is unquestionably the extent to which that technique is accepted within the relevant professional disciplines. Under the most common formulation of the applicable legal standard, an expert witness, no matter how well qualified, may not testify on the basis of facts or inferences derived from scientific methodology unless the principles on which he relies have achieved "general acceptance within the scientific community."[263] This doctrine was first articulated in 1923 in *Frye v. United States*:

> Just when a scientific principle of discovery crosses the line between the experimental and demonstrable stages is difficult to define.

263. Strong, *Questions Affecting the Admissibility of Scientific Evidence*, 1970 U. ILL. L.F. 1, 10-11 (1970) [hereinafter cited as Strong].

> Somewhere in this twilight zone the evidential force of the principle must be recognized, and while courts will go a long way in admitting expert testimony deduced from a well-recognized scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs.[264]

The requirement that a scientific technique have passed from the experimental to the demonstrable stage in its evolution is quite consistent with the rationale upon which X-ray images were accepted by the judiciary around the turn of the century.[265] The additional proviso that general acceptance of the principles embodied in a scientific technique is necessary to establish its reliability was imposed in *Frye* without extensive analysis or reference to authority. Nevertheless, the great majority of courts have subsequently applied the general acceptance standard, or at least proclaimed their allegiance to it, when confronted by unfamiliar scientific evidence.[266]

Commentators on the law of evidence have expressed little enthusiasm for the *Frye* doctrine.[267] The criticisms heard most frequently are (1) that general acceptance is a standard more appropriate for judicial notice than for admissibility;[268] (2) that the requirement of general acceptance precludes the admission of reliable information when the methods used to obtain it are innovative and have not yet

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264. 293 F. 1013, 1014 (D.C. Cir. 1923) (rejecting an early form of the lie detector).

265. *E.g.*, Bruce v. Beall, 99 Tenn. 303, 41 S.W. 445 (1897); Mauch v. City of Hartford, 112 Wis. 40, 87 N.W. 816 (1901).

> It is the duty of courts to use every means for discovering the truth reasonably calculated to aid in that regard. In the performance of that duty, every new discovery, when it shall have passed beyond the experimental stage, must necessarily be treated as a new aid in the administration of justice in the field covered by it. In that view courts have shown no hesitation, in proper cases, in availing themselves of the art of photography by the x-ray process.

Id. at 49, 87 N.W. at 819.

266. United States v. Addison, 498 F.2d 741 (D.C. Cir. 1974) (voiceprint analysis); United States v. Skeens, 494 F.2d 1050 (D.C. Cir. 1974) (lie detector); United States v. Stifel, 433 F.2d 431 (6th Cir. 1970), *cert. denied*, 401 U.S. 994 (1971) (neutron activation analysis); Lindsey v. United States, 237 F.2d 893 (9th Cir. 1956) (sodium pentathol); People v. Kelly, 17 Cal. 3d 24, 549 P.2d 1240, 130 Cal. Rptr. 144 (1976) (voiceprint analysis); Huntingdon v. Crowley, 64 Cal. 2d 647, 414 P.2d 382, 51 Cal. Rptr. 254 (1966) (Kell-Cellano blood test); People v. Morse, 325 Mich. 270, 38 N.W.2d 322 (1949) (drunkometer); State v. Cary, 56 N.J. 16, 264 A.2d 209 (1970) (voiceprint analysis). *But see* United States v. McDaniel, 538 F.2d 408, 412-14 (D.C. Cir. 1976).

267. *See generally* RICHARDSON, *supra* note 221, §§ 6.3, 6.14-.16, 6.18; MCCORMICK, *supra* note 7, § 203; Strong, *supra* note 263, at 10-15; Note, *Evolving Methods*, *supra* note 253, at 688-91.

268. *See, e.g.*, RICHARDSON, *supra* note 221, § 2.5; MCCORMICK, *supra* note 7, § 203, at 491.

been disseminated throughout the relevant scientific community;[269] and (3) that a special exclusionary rule for scientific evidence is unnecessary and undesirable because the law possesses other doctrines adequate to exclude objectionable evidence where warranted.[270]

Opponents of the *Frye* rule would prefer instead that all expert testimony be treated in a consistent manner: any relevant and probative scientific evidence would be admissible in the absence of a countervailing prejudicial effect.[271] The difficulty with this approach, adopted by only a few courts,[272] is that it effectively shifts the burden

269. *See, e.g.*, Boyce, *Judicial Recognition of Scientific Evidence in Criminal Cases*, 8 UTAH L. REV. 313, 314 (1963) [hereinafter cited as Boyce].

270. *See, e.g.*, MCCORMICK, *supra* note 7, § 203; Strong, *supra* note 263, at 14-15. It is not uncommon for critics to observe that not all scientific testimony is covered by the general acceptance standard, and to cite psychiatric testimony as a significant exception. *See* Boyce, *supra* note 269, at 323-26.

271. [T]he decision to admit scientific evidence, like other evidence, requires the striking of a balance between the probative worth of the evidence and its capacity to confuse or prejudice the jury. While in the case of scientific evidence the court will generally be forced to accept the probative value of the evidence as what a qualified expert testifies it to be, the court need not and should not ignore its usual task of weighing this probative value against the possible prejudice and confusion that the evidence is likely to engender. In fact, this function may be particularly essential with regard to scientific evidence in an era when the omnipotence of science is commonly assumed.

Strong, *supra* note 263, at 22. *See also* MCCORMICK, *supra* note 7, § 203; Note, *Evolving Methods, supra* note 253, at 682-86.

272. *See, e.g.*, United States v. Sample, 378 F. Supp. 44 (E.D. Pa. 1974); State v. Olivas, 77 Ariz. 118, 267 P.2d 893 (1954); People v. Bobczyk, 343 Ill. App. 504, 99 N.E.2d 567 (1951). These and other cases in this category require a close reading. In *Sample* the court emphasized that the case involved a probation revocation hearing rather than a criminal proceeding and that the defendant had offered no evidence challenging the reliability of the voiceprint technique. 378 F. Supp. at 53. *Olivas* relied on *Bobczyk*, which noted that there was sufficient evidence for the trial court to find that the defendant was intoxicated while driving even without considering the drunkometer breath test utilized in that case. 343 Ill. App. at 511, 99 N.E.2d at 570.

MCCORMICK, *supra* note 7, § 203 n.33, cites Coppolino v. State, 223 So. 2d 68 (Fla. App. 1969), *appeal dismissed*, 234 So. 2d 120 (Fla. 1969), *cert. denied*, 399 U.S. 927 (1970), as a leading case supporting the relevant and probative standard, which he espouses. The court in *Coppolino* quoted the following standard:

Where the evidence is based solely upon scientific tests and experiments, it is essential that the reliability of the tests and results thereof be recognized and accepted by scientists or that the demonstration shall have passed from the stage of experimentation and uncertainty to that of reasonable demonstrability.

223 So. 2d at 70 (citations omitted). The court then held that trial judges have wide discretion in admitting evidence and that the defendant had not proved an abuse of discretion. *Id.* at 70-71. It is quite clear that the test for succinylcholine chloride, which was developed specifically for the litigation, did not have general acceptance. The district court of appeal opinion observes: "The trial court listened to the testimony of the expert witnesses and in an exercise of his discretion ruled that the tests in question were sufficiently reliable to justify their admission." *Id.* Although *Coppolino* does not apply the *Frye* doctrine, the preliminary examination on reliability would not suggest that the trial judge limited himself to determining that the evidence was relevant and probative; to the contrary, the opinion appears to represent an intermediate standard requiring reasonable or demonstrable reliability before scientific evidence can be submitted to the jury.

of persuasion from the party desiring the admission of scientific evidence to the party opposed, who must then convince the trial judge that an unfamiliar submission is so confusing, misleading, or prejudicial that it should be excluded.[273] In addition, in order for exclusion to be deemed an appropriate remedy in the absence of special evidentiary requirements like the *Frye* doctrine, the Federal Rules of Evidence[274] and the majority of jurisdictions[275] require that the probative value of the evidence must be substantially outweighed by its prejudicial effect. Exclusion on the grounds of prejudice is generally considered a drastic remedy that courts are reluctant to employ.[276]

Reliance upon the prejudice doctrine to protect against the introduction of unreliable scientific information is anomalous for another reason. With respect to conventional evidence, the judiciary has been least resistant to claims of prejudice when alternative proof for the same point is available, or when the prejudicial submission relates to a matter either not central to the issues in the case or not seriously contested by the opposing party.[277] Under the balancing test mandated by the rules of evidence and advocated by proponents of the relevance standard for admissibility, it appears, then, that a trial court would be unlikely to exclude scientific evidence, of whatever reliability, when that evidence is indispensable to a party's presentation, for in that circumstance the probative value of the evidence might be very high. Thus in instances where unfamiliar and arguably unreliable scientific evidence is not supported by other information and the introducing party depends on it to prove an essential factual contention, the prejudice doctrine will seldom provide effective protection. This situation would be quite the reverse of the usual practice of courts when confronted by new scientific techniques. Voiceprint analysis, for example, has

273. Note that confusion, tendency to mislead, prejudice, waste of time, and unfair surprise are all subsumed under the "Prejudice Rule." *See generally* Dolan, *Rule 403: The Prejudice Rule in Evidence*, 49 S. CAL. L. REV. 220 (1976) [hereinafter cited as Dolan]. It should also be noted, however, that courts have a strong preference for letting parties prove their case in the manner of their own choosing. *See* MCCORMICK, *supra* note 7, § 58, at 134; 6 WIGMORE (1940), *supra* note 256, §§ 1869, 1871; *cf.* Fischnaller, *Technical Preparation & Exclusion of Photographic Evidence*, 8 GONZAGA L. REV. 292, 294 (1973) [hereinafter cited as Fischnaller].

274. FED. R. EVID. 403 provides:

> *Rule 403. Exclusion of Relevant Evidence on Grounds of Prejudice, Confusion, or Waste of Time*
>
> Although relevant, evidence may be excluded if its probative value is substantially outweighed by the danger of unfair prejudice, confusion of the issues, or misleading the jury, or by considerations of undue delay, waste of time, or needless presentation of cumulative evidence.

275. *See* Dolan, *supra* note 273, at 235-36 n.55.

276. *See id.* at 245-55; Ahrens, *supra* note 252, at 622.

277. *See, e.g.*, Dolan, *supra* note 273, at 269-72; MCCORMICK, *supra* note 7, § 47 (use of evidence for impeachment).

been more readily accepted in cases when employed to corroborate identifications obtained by conventional methods than when used as the sole means of identifying a criminal defendant.[278]

Critics of the *Frye* rule tend to focus on the deficiencies of the general acceptance standard when it is applied in its most extreme form. It is true that the *Frye* doctrine places a difficult burden of proof on litigants who wish to introduce the products of recent scientific advances, thereby excluding some information that might better be made available to the trier of fact.[279] The majority of modern cases, however, do not equate general acceptance with universal scientific approval. It has, for example, been held that a new process need only be accepted by scientists who might reasonably be familiar with it.[280] Other decisions indicate that the standard may be satisfied by a showing of something appreciably less than unanimity of professional opinion.[281] Where trial judges have conducted preliminary examinations to determine if submissions were trustworthy, some appellate courts have approved the admission of controversial scientific evidence on the theory that admissibility decisions should be reversed only when there is a manifest abuse of the trial court's traditionally broad discretion in that area.[282] Finally, a few courts have ruled that a determination of "sufficient" reliability is adequate ground for admission, irrespective of whether the technique in question is proven to have general acceptance within its field.[283]

278. *Compare* People v. King, 266 Cal. App. 2d 437, 72 Cal. Rptr. 478 (2d Dist. 1968) (voiceprint evidence excluded where essential to case), *with* Worley v. State, 263 So. 2d 613 (Fla. App. 1972), *and* State *ex rel.* Trimble v. Hedman, 291 Minn. 442, 192 N.W.2d 432 (1971) (voiceprints admitted to corroborate other evidence).

279. [*Frye*] sets forth a standard that is neither common to criminal litigation nor easily applied in the individual case. Equally obviously, the *Frye* standard retards somewhat the admission of proof based on new methods of scientific investigation by requiring that they attain sufficient currency and status to gain the general acceptance of the relevant scientific community. This is not to say, however, that the *Frye* standard exacts an unwarranted cost.

United States v. Addison, 498 F.2d 741, 743 (D.C. Cir. 1974).

280. *See, e.g.*, Hodo v. Superior Court, 30 Cal. App. 3d 778, 788-91, 106 Cal. Rptr. 547, 553-54 (4th Dist. 1973); People v. Williams, 164 Cal. App. 2d Supp. 858, 862, 331 P.2d 251, 254 (App. Dep't Super. Ct. 1958).

281. *See, e.g.*, United States v. Stifel, 433 F.2d 431, 438-41 (6th Cir. 1970), *cert. denied*, 401 U.S. 994 (1971); United States v. Wright, 17 U.S.C.M.A. 183, 37 C.M.R. 447 (1967); McKay v. State, 155 Tex. Crim. 416, 235 S.W.2d 173 (1950):

This Court may recognize generally accepted scientific conclusions, even though there should be some who disagree with them. In all probability a scientist may be found who will disagree with practically every generally accepted scientific theory.

Id. at 419, 235 S.W.2d at 174.

282. *See, e.g.*, United States v. Baller, 519 F.2d 463 (4th Cir. 1975), *cert. denied*, 423 U.S. 1019 (1975); Worley v. State, 263 So. 2d 613 (Fla. App. 1972); Coppolino v. State, 223 So. 2d 68 (Fla. App. 1969), *appeal dismissed*, 234 So. 2d 120 (Fla. 1969), *cert. denied*, 399 U.S. 927 (1970).

283. *See, e.g.*, United States v. Franks, 511 F.2d 25, 33 (6th Cir. 1975). All of

It is impossible to harmonize completely these disparate formulations, but the emerging trend appears to be toward a requirement of reasonable acceptance.[284] This standard serves two fundamental purposes: (1) to establish that a given technique is reliable because it is recognized as valid by those who should know; and (2) to satisfy the needs of the adversarial system by insuring that the opponents of a scientific submission have access to a pool of experts independently qualified to evaluate the reliability of the technique in question.[285] The inability of legal tribunals to determine the validity of scientific techniques and the prospect that juries may be unduly influenced by scientific evidence are well-recognized problems.[286] What further distinguishes scientific evidence from other kinds of potentially unreliable submissions is that a responsible, extrajudicial mechanism exists to assess the reliability of a scientific process. Inherent in the scientific method is the publication or other dissemination of hypotheses and the

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the early radar speedmeter cases focus on the accuracy of the technique rather than on its general acceptance. *See* Baer, *Radar Goes to Court*, 33 N.C.L. REV. 355, 370-80 (1955). In United States v. Stifel, 433 F.2d 431 (6th Cir. 1970), *cert. denied*, 401 U.S. 994 (1971), the court recites the *Frye* rule, but its analysis is oriented toward proof of sufficient reliability, not general acceptance. *But see* United States v. Addison, 498 F.2d 741 (D.C. Cir. 1974), *aff'g* United States v. Raymond, 337 F. Supp. 641 (D.D.C. 1972).

284. *See* Richardson, *supra* note 221, § 20.5. The new Federal Rules of Evidence do not explicitly address the general acceptance standard as such. The most relevant passage is contained in Rule 703, which states:

> The facts or data in the particular case upon which an expert bases an opinion or inference may be those perceived by or made known to him at or before the hearing. *If of a type reasonably relied upon by experts in the particular field* in forming opinions or inferences upon the subject, the facts or data need not be admissible in evidence.

FED. R. EVID. 703 (emphasis added).

This language could be read as a liberalization of the *Frye* doctrine, since reasonable reliance would not necessarily require general acceptance. REDDEN & SALTZBURG, *supra* note 219, at 230. No cases have yet construed that passage; consequently, a definitive interpretation is not yet available. *Cf.* People v. Sugden, 35 N.Y.2d 453, 459, 363 N.Y.S.2d 923, 928, 323 N.E.2d 169, 172 (1974) (data relied upon must be of the kind ordinarily accepted by experts in the field).

285. The reasons for the *Frye* doctrine were succinctly stated in a recent opinion by Judge McGowan of the Court of Appeals for the District of Columbia Circuit:

> The requirement of general acceptance in the scientific community assures that those most qualified to assess the general validity of a scientific method will have the determinative voice. Additionally, the *Frye* test protects prosecution and defense alike by assuring that a minimal reserve of experts exists who can critically examine the validity of a scientific determination in a particular case. Since scientific proof may in some instances assume a posture of mystic infallibility in the eyes of a jury of laymen, the ability to produce rebuttal experts, equally conversant with the mechanics and methods of a particular technique, may prove to be essential.

United States v. Addison, 498 F.2d 741, 743-44 (D.C. Cir. 1974).

286. *See, e.g.*, Forkosch, *The Lie Detector and Mechanical Jurisprudence*, 28 OKLA. L. REV. 288, 289, 299-300 (1975) [hereinafter cited as Forkosch]; Strong, *supra* note 263, at 13-14; Boyce, *supra* note 269, at 320-23.

results of experimentation.[287] Judges may, therefore, have recourse to assessments of innovative techniques by scientists working in an environment presumably more dispassionate and objective than that which exists during litigation.[288] It may be concluded, then, that a demonstration of professional acceptance is persuasive support for the reliability of a scientific process, while a reasonable level of professional familiarity and acceptance is also required to protect the integrity of the adversarial system. A showing of professional acceptance beyond the minimum required for the latter function is one, but not the only, manner in which the actual reliability of a technique can be documented.[289]

b. Assignability to a Scientific Discipline

In deciding whether to supplement or, occasionally, to replace proof of some degree of professional acceptance, courts have considered several factors. The first is the degree to which the scientific principles involved may be assigned to a single or limited number of well-recognized scientific disciplines.[290] This element is important in defining the relevant scientific community from which acceptance must be forthcoming; moreover, it is related to the question of what qualifications are required of the expert witness, who must explain a technique and interpret its output. In order to ascertain whether a technique is actually reliable, a court must first decide that the expert wit-

287. *See generally*, Ormrod, *Evidence and Proof: Scientific and Legal*, 12 MED. SCI. & L. 9 (1972) [hereinafter cited as Ormrod]; Kirk, *The Interrelationship of Law and Science*, 13 BUFFALO L. REV. 393 (1964) [hereinafter cited as Kirk]. Compare the emphasis placed by the court on the lack of professional literature relating to voiceprints in People v. King, 266 Cal. App. 2d 437, 451-53, 72 Cal. Rptr. 478, 487-88 (2d Dist. 1968), with the examination of the extant literature relating to neutron activation analysis in United States v. Stifel, 433 F.2d 431, 437-41 (6th Cir. 1970).

288. *Cf.* People v. Law, 40 Cal. App. 3d 69, 80-83, 114 Cal. Rptr. 708, 715-18 (5th Dist. 1974), which indicates that courts may take judicial notice of professional literature for the purpose of determining if a technique has achieved general acceptance.

289. In Coppolino v. State, 223 So. 2d 68 (Fla. App. 1968), *cert. denied*, 399 U.S. 927 (1970), a toxicology test specially developed for that litigation was ruled admissible. Although the test had not achieved substantial professional acceptance because of its novelty, it scored quite well in terms of the other indicia of reliability. In particular, the chemical test required no subjective interpretation by the conducting chemist, could be understood and assessed by other chemists or physicians, and would appear to be highly repeatable assuming the basic theory was correct. The *Coppolino* court did not, however, address the issues of subjective interpretation or repeatability; it merely refused to find an abuse of discretion by the lower court in ruling the evidence admissible. *Cf.* Comment, *Should Reliable Scientific Evidence be Conclusive and Binding on the Jury?*, 48 CHI.-KENT L. REV. 39, 45 (1971).

290. *See, e.g.*, Jones, *Evidence vel non: The Non Sense of Voiceprint Identification*, 62 KY. L.J. 301, 314-15 (1974) [hereinafter cited as Jones]; Strong, *supra* note 263, at 12.

ness offered for that purpose is qualified to make such a determination. In the case of techniques like voiceprint analysis[291] and the lie detector,[292] whose principles cut across the boundaries of many traditional disciplines, judges have closely scrutinized the credentials of prospective expert witnesses to insure that they possess the requisite knowledge and training in all of the areas necessary to validate the entire process. Often these credentials have been found wanting.[293] Thus courts may indirectly restrict the admissibility of a scientific technique through a more intensive than normal examination of the qualifications of expert witnesses in situations where it is unclear what disciplines should provide professional acceptance of the scientific principles.[294]

If remote sensing is treated generically, legal tribunals may experience considerable difficulty in determining the relevant scientific community. As discussed above,[295] the majority of current remote sensing practitioners are not readily identifiable as experts in that field because of their diverse educational backgrounds. Moreover, since remote sensing provides a general purpose tool applicable to many types of scientific research, it will hardly be possible to identify a single profession or discipline whose members would be most competent to evaluate information produced by a recording technique. Therefore, when faced with the introduction of remote sensing output, courts must exercise special care to assure that the testifying experts are fully qualified to address the extent of professional recognition accorded the techniques in question and the reliability of those techniques.

c. *Nonlegal Uses of a Technique*

In some instances a demonstration or judicial perception that a technique is extensively employed within the scientific community may

291. *See, e.g.*, People v. King, 266 Cal. App. 2d 437, 442-46, 450-59, 72 Cal. Rptr. 478, 482-84 (2d Dist. 1968); Jones, *supra* note 290, at 314-15.

292. *Cf.* Forkosch, *supra* note 286, at 298-305; Highleyman, *The Deceptive Certainty of the "Lie Detector,"* 10 HAST. L.J. 47, 53-54 (1958); Skolnick, *Scientific Theory and Scientific Evidence: An Analysis of Lie-Detection*, 70 YALE L.J. 694, 727 (1961).

293. *E.g.*, People v. Kelley, 17 Cal. 3d 24, 549 P.2d 1240, 130 Cal. Rptr. 144 (1976); State v. Lowry, 163 Kan. 622, 185 P.2d 147 (1947) (lie detector); State v. Cary, 56 N.J. 16, 264 A.2d 209 (1970) (voiceprints). *Cf.* Frye v. United States, 293 F. 1013 (D.C. Cir. 1923).

294. Because they find the *Frye* doctrine too indefinite or obstructive, some commentators argue that judicial inquiry should be directed not at professional acceptance but at the adequacy of the qualifications of an expert witness in a particular case. *See, e.g.*, Strong, *supra* note 263, at 14-15. The flaw in this analysis is that it ignores the aspect of the general acceptance standard aimed at assuring fairness within the adversarial system. If the developer of a new technique, no matter how qualified, is the only individual capable of authoritatively evaluating it, how could the opposing party present an adequate case? Moreover, just because an expert has impressive credentials does not guarantee that his newly developed technique is sound.

295. See text accompanying notes 227-50 *supra*.

obviate the need for proof that the underlying scientific principles have achieved substantial professional acceptance. The widespread nonlegal applications of X-ray imagery,[296] blood-type testing,[297] and radar[298] unquestionably facilitated judicial recognition of those techniques when introduced in court.[299] It should be emphasized that the important element here is reliance on a technique by the *scientific community*, not by law enforcement officials or the community at large. Public, but nonscientific, utilization of the lie detector, for example, has not appeared to influence judicial attitudes to any significant extent.[300]

In this regard the reliability of numerous remote sensing techniques may largely be established by a showing that scientists with no interest in legal applications utilize identical or similar techniques. As an illustration, hundreds of scientists in government, industry, and universities now employ Landsat images to identify diverse environmental and natural resources phenomena. In like manner, ultraviolet and infrared photography are used in a variety of technical applications;[301] in addition, they depend on a recording device, the camera, whose basic principles are universally accepted.[302] Although legitimate questions may arise about the suitability of these techniques for a particular evidentiary purpose, the courts are likely to rely heavily on the widespread use of these and similar methods for nonlegal purposes in determining professional acceptance and actual reliability.

This method of proof of reliability will not, however, be appropriate for all remote sensing applications, since some techniques will be developed whose sole or primary function is to provide information for use in adjudicatory proceedings. A likely illustration is the employ-

296. *See, e.g.*, Prescott & N.W.R. Co. v. Franks, 111 Ark. 83, 163 S.W. 180 (1914); Bruce v. Beall, 99 Tenn. 303, 41 S.W. 445 (1897).

297. *See, e.g.*, Lawrence v. City of Los Angeles, 53 Cal. App. 2d 6, 127 P.2d 931 (1942); Kuroske v. Aetna Life Ins. Co., 234 Wis. 394, 291 N.W. 384 (1940).

298. *See, e.g.*, People v. Magri, 3 N.Y.2d 562, 565-66, 170 N.Y.S.2d 335, 336-38, 147 N.E.2d 728, 729-31 (1958); State v. Dantonio, 18 N.J. 570, 115 A.2d 35 (1955).

299. Strong, *supra* note 263, at 12, indicates that widespread nonlegal applications should be the most important factor courts should consider. FED. R. EVID. 703, for example, provides that an expert witness may testify as to facts or data not admissible in evidence "[i]f of a type *reasonably relied upon* by experts in the particular field" (emphasis added). Although the main thrust of Rule 703 is directed toward the admissibility of medical reports, psychiatric examinations, and other forms of hearsay, the overall objective of the rule is to bring admissible expert testimony into alignment with typical out-of-court expert activity. REDDEN & SALTZBURG, *supra* note 219, at 229-30; Comment, *Opinion & Expert Testimony*, 27 ARK. L. REV. 292, 298-99 (1973).

300. *See, e.g.*, MCCORMICK, *supra* note 7, § 207; Boyce, *supra* note 269, at 321-22; Note, *Evolving Methods*, *supra* note 253, at 694-96.

301. See SCOTT, *supra* note 7, §§ 651-64, 681-95, 1414-15.

302. *See generally* Fischnaller, *supra* note 273; Biunno, *The Interdisciplinary Exchange between Lawyers & Experts*, 13 JURIMETRICS 21 (1972).

ment of quantitative sensors to document violations of different kinds of pollution standards. Such techniques, like others in the "police science" category,[303] may receive and deserve closer judicial scrutiny because no background of disinterested scientific experimentation and practical use will exist to document their reliability.

d. Subjective Interpretation

Reliability may usefully be further defined in terms of accuracy and repeatability. *Accuracy* is the ability to measure a phenomenon within a given tolerance level or margin of error; *repeatability* indicates the ability to produce consistent results (within a margin of error) when a process is applied to identical phenomena. The accuracy of a technique, as expressed in terms of a probable margin of error, must be established by expert testimony based on adequate experimentation. It is, however, important to emphasize that no process intended to determine real-world conditions is, or can be, completely accurate.[304] Thus the minimum degree of certainty imposed by a court is always a relativistic determination, to be decided in light of the purpose for which a scientific technique is employed. For that reason, the question of what margin of error should be acceptable is addressed below in the discussion of normative criteria.

The requirement of repeatability is a *sine qua non* of scientific measurement; if a process cannot produce consistent results within a known accuracy tolerance when applied to the same data, it is not only unreliable but unscientific. Judicial opinions rarely if ever make the distinction between accuracy and repeatability explicit. Some scientific evidence has undoubtedly been ruled inadmissible after a finding that the margin of error was too great for the intended purpose.[305] On

303. One commentator has asserted that experts skilled in "forensic science" are the best available witnesses on those law enforcement techniques employing scientific methodology, due to the interdisciplinary nature of such methods. Kirk, *supra* note 287, at 294-96. This argument overlooks the adversarial context in which police investigations are conducted, unlike the relatively dispassionate environment characteristic of most scientific investigations. (The police scientist may not be quite as interested in truth as he is in convictions).

304. *See, e.g.*, Walls, *What is "Reasonable Doubt"? A Forensic Scientist Looks at the Law*, 1971 CRIM. L. REV. 458, 459-61; Kirk, *supra* note 287.

305. *Compare* State v. Holt, 17 Ohio St. 2d 81, 246 N.E.2d 365 (1965) (neutron activation analysis (NAA) results held inadmissible because expert's use of term "likely" to describe probabilities of common origin did not reach degree of certainty that the law demands) *and* United States v. Wolfson, 297 F. Supp. 881, 891 (S.D.N.Y. 1968), *aff'd*, 413 F.2d 804 (2d Cir. 1969) (NAA results admitted but not considered in trial court's decision because insufficient background data to determine probabilities of common origin), *with* State v. Coolidge, 109 N.H. 403, 260 A.2d 547 (1969), *rev'd on other grounds*, 403 U.S. 443 (1969) (admission of NAA of clothing particles affirmed where expert testified that analysis showed similarity between particles) *and* Ward v. State, 427

the other hand, in instances where courts have rejected a scientific process in unqualified language for any legal purpose, it appears not only that the technique was insufficiently accurate, but also that significant questions were raised about its repeatability.[306] Doubts raised about repeatability may generally be traced to two factors: the need for a substantial amount of human interpretation of the output produced by a scientific technique; and the presence of uncontrolled variables that preclude the duplication of the environment in which a given test was conducted.[307]

As a general proposition, the more the conclusions of an expert witness depend on subjective interpretation of data, the more reluctant the judiciary has been to acknowledge the reliability of the underlying scientific process. When employed to detect vehicular speeds, radar is one remote sensing technique that produces quantitative output requiring little interpretation by an expert.[308] Similar remote sensing

S.W.2d 876 (Tex. Crim. 1968) (affirming admission of expert's testimony to the effect that NAA showed foreign hairs taken from the victim's body and hairs taken from the defendant were identical and probably came from the same source).

306. *See* State v. Holt, 17 Ohio St. 2d 81, 246 N.E.2d 356 (1969), where the fact that hairs subjected to neutron activation analysis were either destroyed or altered during the test so that they were unavailable for testing by the defendant appeared to be a factor in the court's holding that the NAA had been improperly admitted. Generally speaking, however, NAA is a nondestructive process, leading commentators to denote repeatability as one of NAA's prime virtues. Comment, *EVIDENCE—Admissibility of the Neutron Activation Analysis Test*, 18 ST. LOUIS L.J. 235, 237 (1973); Comment, *The Evidentiary Uses of Neutron Activation Analysis*, 59 CALIF. L. REV. 997, 997-98 (1971) [hereinafter cited as Comment, *Evidentiary Uses*]. *Cf.* Huntington v. Crowley, 64 Cal. 2d 647, 414 P.2d 382, 51 Cal. Rptr. 254 (1966). There, in rejecting the "Kell-Cellano" system of blood grouping as evidence in a paternity suit, the court quoted a medical report on the Kell test which stated that "the reactions are not always readily reproducible." *Id.* at 656, 414 P.2d at 389, 51 Cal. Rptr. at 261.

307. For example, a major objection to the admissibility of both polygraph and voiceprint evidence has been the subjectivity of the test examiners. *See* Lydden, *Psychology & the Lie Detector Industry*, 29 AM. PSYCHOLOGIST 725, 737 (1974) ("the examiner's brain is an integral part of the test"). The author notes the great difficulty involved in eliminating examiner subjectivity through training. *Cf.* People v. Kelly, 17 Cal. 3d 24, 29, 549 P.2d 1240, 1243, 130 Cal. Rptr. 144, 147 (1976). *See also* Note, *Evolving Methods*, *supra* note 253, at 692; Note, *The Admissibility of Lie Detector Evidence*, 51 N. DAK. L. REV. 681, 693-94 (1975) [hereinafter cited as Note, *Admissibility*]; Jones, *supra* note 290, at 306. This problem is compounded by the uncontrolled variables inherent in the evaluating process, such as the setting in which the test is given and the physical or mental condition of the person to be tested at the time it is given. Forkosch, *supra* note 286, at 303. The much more ready acceptance by the courts of neutron activation analysis may be explained by the comparative lack of subjective interpretation; the neutron activation evidence presented usually consists solely of statistical calculations. *See* Comment, *EVIDENCE—Admissibility of the Neutron Activation Analysis Test*, *supra* note 306; Comment, *Evidentiary Uses*, *supra* note 306, at 1020-25.

308. *See, e.g.*, Kopper, *The Scientific Reliability of Radar Speedmeters*, 33 N.C.L. REV. 343 (1955) [hereinafter cited as Kopper]. Radar may also be used to produce a pictorial image rather than a quantitative reading. See Plate 1b. In this form radar can be of great value in mapping and in other remote sensing applications. *See* J. Holtz-

methods may be developed to quantify the presence of specific pollutants.[309] Human interpretation is necessary, however, in the majority of remote sensing applications, which cannot be satisfied by a simple numerical reading of the type provided by radar speedmeters. Most remote sensing programs require a more diversified and detailed form of output, whether ultimately introduced in court as a photographic image or as a listing of computer data.[310] The necessity for subjective interpretation, with its corresponding problems, increases in direct proportion to the volume and scope of information required to achieve the aims of a given environmental remote sensing program.

Since subjective interpretation is an unavoidable element in most remote sensing applications, the bulk of remote sensing output must be explained in court in much the same way as are X-ray images. Although the possibility of conflicting interpretations may affect a court's assessment of reliability, it has never been held to bar the admission of X-ray photographs.[311] It is possible that a similarly indulgent judicial attitude will prevail with respect to conflicting interpretations of remote sensing images. But as in the case of X-rays, the judiciary must first be convinced that the basic imaging process is capable of producing a reliable result when properly conducted.

The most prevalent and satisfactory method of demonstrating the validity of an environmental remote sensing application is to coordinate the interpretation of remote images with an analysis of samples obtained from the area depicted in the image. Scientists generally refer to this procedure of verifying an interpretational theory as "ground-truthing."[312] Although the kind of environmental phenomena to be

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man, Radar Studies Related to the Earth Resources Program (Mar. 1972) (STAR acc. no. N75-18698) (Univ. of Kansas Space Technology Laboratories, Lawrence, Kan.); Lewis, *Evaluation of Multiple-Polarized Radar Imagery for the Detection of Selected Cultural Features*, in THE SURVEILLANT SCIENCE, *supra* note 5, at 296.

309. Several recent studies indicate a potential for the eventual remote quantification of oil spills on water. *See, e.g.*, Hollinger, The Determination of Oil Slick Thickness by Means of Multifrequency Passive Microwave Techniques, June 30, 1974 (STAR acc. no. N75-18790) (Naval Research Laboratory, Washington, D.C.); Fantasia & Ingrao, *supra* note 127. Similarly, LIDAR may soon provide quantitative estimates of air pollution loading. *See also* Ludwig & Griggs, *supra* note 133.

310. The development of computer programs able to categorize environmental features in a consistent manner may eventually reduce the possibility that subjective or self-serving considerations can influence the interpretations provided by expert witnesses; however, the state of the art is now quite rudimentary and computer applications will not approach the facility of a trained human interpreter for many years, if ever. For current efforts *see, e.g.*, Clapp *et al*, *supra* note 89; Rogers & Reed, *Automated Strip-Mine and Reclamation Mapping from ERTS*, in THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 1519-30.

311. *See, e.g.*, SCOTT, *supra* note 7, § 1266.

312. As defined by Dr. John Estes of the University of California, ground truth "is simply a method of verification of the actual conditions that are present on the sur-

recorded determines the type of ground-truth appropriate for a given application, most remote sensing experts believe that some form of ground-truthing is always essential.[313]

The development of the biological high water line at issue in *City of Newark v. Natural Resources Council*[314] and the Hackensack Meadows cases[315] provides an example. Location of the line was premised on the ability to differentiate between fresh water and tidal vegetation through interpretation of aerial near infrared photographs. The scientists who designed the interpretational technique used in that application first made field measurements of the reflectance characteristics of 19 marsh plant species in varied locations.[316] A correlation was established between the reflectivity of selected plant species or different plant vigors within single species, as calculated on the ground, and the appearance of those plants in the infrared images, after which the images were interpreted to develop a tentative biological high water line.[317] A portion of the biological line was then compared against a mean high water line constructed using conventional tidal data.[318] The

face of the earth or in any situation when aerial photography is being taken . . . ." Record, Vol. IV, at 4, *In re* License No. 336207, Albert B. Watts (No. 5952/1334, U.S. Coast Guard, 8th Coast Guard District, Port Arthur, Tex., Sept. 13, 1972). The term "ground truth" is also commonly used, albeit loosely, to refer to any surface study offering data that can be compared with remote sensing imagery. Thus, ground data acquired under conditions similar to those prevailing at the time the imagery was taken, but not acquired in conjunction with the remote sensing, sometimes serves as "ground truth." A good example of this second usage would be the root sample survey of trees inundated by the filling of Rodman Reservoir, published as Appendix 14 of Forest Service, Final Environmental Statement, Proposal for Oklawaha River (May 15, 1972). In *Canal Authority* the Canal Authority's expert compared this survey with aerial oblique infrared photography of the area. Record at 4559-79, Canal Authority v. Callaway, No. 71-92-Civ-J (M.D. Fla., Feb. 4, 1974). See notes 182-186 *supra* and accompanying text.

313. *See, e.g.*, Colwell, *supra* note 70, at 198; Klemas, Daiker & Bartlett, *Identification of Marsh Vegetation & Coastal Land Use in ERTS-1 Imagery*, in SYMPOSIUM ON SIGNIFICANT RESULTS OBTAINED FROM EARTH RESOURCES TECHNOLOGY SATELLITE-1, at 615, 617-18 (Mar. 9, 1973) (NASA Goddard Space Flight Center); Yarger, McCauley, James, Magnuson & Marzolf, *Water Turbidity Detection Using ERTS-1 Imagery*, in SIGNIFICANT RESULTS OBTAINED FROM EARTH RESOURCES TECHNOLOGY SATELLITE-1, at 651, 652 (Mar. 9, 1973) (NASA Goddard Space Flight Center) [hereinafter cited as Yarger *et al.*]; Estes, *Water Demand Studies in Central California*, in AN INTEGRATED STUDY OF EARTH RESOURCES IN THE STATE OF CALIFORNIA USING REMOTE SENSING TECHNIQUES, ch. 3, at 19 (R. Colwell ed. 1974).

314. No. A-3311-72 (N.J. App. Div., filed July 18, 1973); see text accompanying notes 200-16 *supra*.

315. See text accompanying notes 208-12 *supra*.

316. *See, e.g.*, Anderson & Carter, *supra* note 70, at 78-82. *See also* Hackensack Report, *supra* note 201, at 89.

317. Record of Proceedings, Vol. II, at 81-94, 137-38, Hackensack Meadows Cases, *supra* note 208; Deposition of Roland Yunghans, Vol. VI, at 343-64, City of Newark v. Natural Resouree Council, No. A-3311-72 (N.J. App. Div., filed July 18, 1973).

318. Record of Proceedings, Vol. II, at 75-81, Vol. VII, at 720-54, Hackensack

correspondence between the two lines, though not exact, was deemed sufficiently close by the state to justify the adoption of the biological mapping technique in those riparian areas where tidal surveys were regarded as impractical.[319] Whether this technique, including the ground-truthing methods selected, provides a legally sufficient basis for the determination of riparian property ownership is a principal issue in the litigation.[320]

Since there are hundreds of thousands of riparian acres in New Jersey, the ground-truth program contemplated physical inspections and sampling in a very small percentage of the contested area. The proponents of the interpretational technique must therefore establish that the mapping process is valid not only in the area in which ground-truthing was conducted, but in all other riparian regions as well. This, in turn, requires a showing that the vegetative reflectance characteristics and relevant environmental conditions are sufficiently constant over the entire area. In general, an interpretational theory asserted to be applicable over a large area should be supported by ground-truth obtained from a statistically valid cross section of the surface depicted by the remote sensing technique.[321] In the case of some applications, en-

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Meadows Cases, *supra* note 208; Deposition of Roland Yunghans, Vol. VI, at 341, City of Newark v. Natural Resource Council, No. A-3311-72 (N.J. App. Div., filed July 18, 1973).

319. Record of Proceedings, Vol. II, at 92-93, 128-31, Hackensack Meadows Cases, *supra* note 208 (testimony of Dr. Edward Feinberg); Deposition of Roland Yunghans, Vol. VI at 343, 356-57, City of Newark v. Natural Resource Council, No. A-3311-72 (N.J. App. Div., filed July 18, 1973).

320. The adequacy of this testing procedure has not been uniformly accepted:

> I have more recently been involved in a case in New Jersey in the Hackensack Meadows. Methodology here has been employed to differentiate between vigors of *Phragmites communis* on color infra-red photography to demarcate the mean high water line. In this case, however, no tidal data was obtained to correlate with the biological data. For this reason, I have been asked to aid in showing the weaknesses of this particular method.

Letter from Ann Fornes, Research Technician, Marine Institute, University of Georgia, Sapelo Island, Ga., to Mary Ann Marwick, Assistant District Counsel, Charleston District, U.S. Army Corps of Engineers, Charleston, S.C., Oct. 4, 1975. Concern about the accuracy of the testing procedure was also expressed by a representative of the National Ocean Survey, who had participated with state authorities in an experiment to test the accuracy of the technique. Record of Proceedings, Vol. VII, at 748, Hackensack Meadows Cases, *supra* note 208 (testimony of Carroll Thurlow).

Cf. Dolphiu Lane Assocs. v. Town of Southampton, 37 N.Y.2d 292, 333 N.E.2d 358, 372 N.Y.S.2d 52 (1975), discussed at note 206 *supra*, where a finding of estoppel precluded consideration of a similar remote sensing theory. In *Dolphin Lane*, however, the remote sensing maps employed were intended to be conclusive, unlike the situation in the *Newark* and Hackensack Meadows Cases, where the maps are simply prima facie evidence of the extent of state claims, shifting the burden of proof onto the record owners, who are free to present contrary evidence to the Natural Resource Council. *See* N.J. STAT. ANN. § 13:1B-13.5 (Supp. 1976).

321. Such a comprehensive ground-truth program is exemplified in the field surveys carried out to validate the interpretations of aerial infrared imagery introduced by the

vironmental conditions may be so variable[322] or there may be so many possible causes for an apparent feature[323] that ground-truthing must be conducted at the same time the images are taken if the collected samples are to be correlated to the contents of the images with any degree of certainty.[324]

e. Uncontrolled variables

In many remote sensing applications such environmental variables as sun angle, wind direction, precipitation, temperature, cloud cover, and background reflectance may significantly affect the appearance and reliability of sensor output.[325] As in the attempt to control the effects of subjective interpretation, minimization of the consequences of potentially uncontrolled variables usually requires a coordinated ground-truth

federal government in *Canal Authority*. See text accompanying notes 182-86 *supra*. For purposes of the litigation, the trees along Lake Oklawaha were divided into eight populations according to location. On or near the days of the overflights, a team of scientists examined each of the tree populations by boat; some of these populations received several visits. In addition, scientists entered one population "to examine individual trees within different plots that had been established." Higer Affidavit, *supra* note 185, at 3; Canal Authority v. Callaway, No. 71-92-Civ-J (M.D. Fla., Feb. 4, 1974).

322. For example, changes in wind direction, current flow, and effluent direction were documented in *Inland Steel*. See text accompanying notes 160-67 *supra*. There a number of boat-sampling stations were established next to fixed marker buoys at the same time as the aerial survey was being conducted. Record at 1870-76, State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Sept. 8, 1975).

323. The gathering of ground truth and the EPA overflight in preparation for the *Reserve Mining* litigation were originally scheduled for the same day. Excessive cloud cover, however, caused the aerial survey to be flown 2 days later. Counsel for the defense objected to a conclusion that the EPA expert based on the sampling and on the imagery, and tried to suggest that the "green water effect" apparent on the imagery might have been caused by something other than Reserve's discharge. The trial court, while agreeing that the lack of coutemporaneous ground truthing weakened the probative valne of the evidence, nonetheless allowed the expert to state his opinion. Record at 1007-17, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974). See notes 169-80 *supra* and accompanying text.

324. *See, e.g.*, Letter from Robert H. Arndt, U.S. Department of the Interior, Bureau of Mines, Oklahoma City, Okla., to author, July 2, 1975:

> Among other things, my proposed study of shell dredging in gulf coast waters by means of LANDSAT data required coordinated surface monitoring. For instance: A plume of suspended sediment originating at a shell dredge and carried by water currents is a common and obvious phenomenon that has been cited repeatedly as evidence of vast pollution in surrounding waters. Some surface studies have suggested that the plume, though highly visible from overflights, actually carries a very low content of suspended sediment when compared with the concentration of sediment in estuarine waters that have been stirred up under storm conditions. Probably there would be no question as to the size and configuration of an observed sedimeut plume from the dredge, but there certainly would be unanswered questions about the sediment conteut and degree of water pollution without specific [ground] control established in coordination with the overflight.

325. *See, e.g.*, Yarger *et al.*, *supra* note 313, at 1638-39; Leonardo, *Capabilities & Limitations of Remote Sensors*, THE SURVEILLANT SCIENCE, *supra* note 5, at 43.

program. While ground-truth may not ultimately be necessary for every operation of a technique once its reasonable reliability is established, proof that the theory is sound in the first place requires an initial showing that likely combinations of environmental variables do not negate the ability of the technique to obtain information within a reasonable margin of error. Thus, ground-truth may be essential to demonstrate that a remote sensor can produce repeatable results over the range of environmental conditions that might prevail when the images are actually collected.[326]

Repeatability problems caused by uncontrolled variables have led a recent study sponsored by the EPA to conclude that active systems such as radar and lidar[327] offer the most promise for future evidentiary applications of remote sensing.[328] Active systems contain their own power source; consequently they do not depend on reflection of the sun's energy or on unpredictable emissions from manmade or natural sources on the ground. In practice, active systems should be capable of greater accuracy and repeatability since they possess known energy

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326. *E.g.*, letter from Ralph A. Morill, Chief, Office of Scientific Systems Development, U.S. Department of the Interior, Bureau of Land Management, Denver, Colo., to author, Sept. 19, 1975:

> One parameter that has the largest single effect on the ability to accurately interpret multispectral satellite data is atmospheric radiance for various sun angles. The uncertainties in repeatability of valid interpretation (many observers of the same phenomena, or many samples and one observer) can be as high as 70 percent. This can be reduced to 10-20 percent only with fully competent correction of the radiance effect based upon accurate "ground truth" sample measurements of the specific phenomena taken at the same time as the remote sensing data.

Similar problems with environmental variables have occurred in connection with conventional photography. *E.g.*, Puskarich v. Trustees of Zembo Temple, 412 Pa. 313, 194 A.2d 208 (1963) (change of conditions, including sun angle, made photographs of accident scene inadmissible). *See also* Kirsch v. Dondlinger & Sons Const. Co., 206 Kan. 701, 482 P.2d 10 (1971) (same).

327. "Lidar" denotes Light Detection and Ranging (substituting a laser for the radio beams in radar):

> Output from the LIDAR system [a *Light Detection And Ranging* system that employs a laser as a sensor and a telescope as a receiving device] may be used to map the heights of an invasion and locate pockets or plumes of highly concentrated aerosols. The map is immediately displayed on a television screen in the aircraft, and it can be printed later in hard copy for delivery to air pollution officials on the ground.
>
> In one test, the LIDAR system provided a profile of the distribution of aerosols in a 35-mile path over St. Louis in less than 10 minutes. This synoptic information obtained so quickly over a large urban area or basin is needed to determine pollutant location and to predict potential air pollution episodes. It is particularly important to environmenal officials who need current and immediate data to deal effectively with these episodes.

NERC-LV Facts at 3 (EPA, National Environmental Research Center, Las Vegas, Nev., Mar. 1975).

328. Ludwig & Griggs, *supra* note 133, at 5, 156.

outputs and are less likely to be affected by extraneous energy emitters or absorbers.[329]

In many instances passive systems like infrared photography or scanning can make relative determinations, but not absolute ones. A passive sensor may reveal that one area in an image is darker, or greener, or cooler than another location in that same image, but it cannot identify the absolute magnitude of the quality in question.[330] For example, when thermal images are employed to depict an effluent plume, as in *Inland Steel*,[331] it can be seen that the plume is hotter than the surrounding water, but the actual temperatures within and outside the plume cannot ordinarily be determined unless surface readings are obtained at the time the image is taken.[332] As *Inland Steel* makes apparent, passive remote sensing images may be extremely useful where the issue is framed not in terms of the constituents or absolute magnitude of an environmental feature, but in terms of direction of movement or extent of areal dispersion. Since the majority of active systems are currently in the experimental stage and are still subject to power and safety constraints, passive systems will remain the most widely exploited remote sensing techniques for some time to come.

The predictive criteria identified above—extent of professional acceptance, assignability to a well-defined scientific discipline, nonlegal uses by scientists, need for subjective interpretation of output, and possibility of uncontrolled variables—will assist a court in evaluating the actual reliability of remote sensing evidence. In any given case the judicial analysis of these factors may indicate that some favor while others cut against admission. At such times the ultimate decision will be determined by the normative considerations advanced below. Al-

329. For a general discussion see Ludwig & Griggs, *supra* note 133, at 51-113.

330. When features within a single frame, or within a series of frames taken at about the same time and in the same general area are compared, the influence of environmental variables is minimized because all features are recorded under the same conditions. Many passive techniques have difficulty when an image obtained under one set of conditions is compared against a significantly later or earlier image of the same location. Even there, if the object is to discover human development activities or other changes that are very gross and obvious in nature, the existence of environmental variables may not be significant. *See, e.g.*, Goodyear Aerospace Corp., Aerial Surveillance Change Detection Study, Apr. 4, 1975 (Contract No. DACW07-75-C-0015) (report prepared for San Francisco Dist., U.S. Army Corps of Engineers).

331. State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Sept. 8, 1975). See note 160 *supra*.

332. T. Green, *supra* note 39, at 7. It may be possible to develop a thermal sensor that can produce absolute temperature readings by including two comparative heat sources of known temperature in the device itself. Conversation with Robert Landers, EPA National Environmental Monitoring & Support Laboratory, Las Vegas, Nev., Aug. 14, 1975.

though the reliability of some current remote sensing techniques is undoubtedly adequate for some legal purposes, it must again be emphasized that remote sensing comprises too diverse a set of technologies and applications for a single legal assessment of reliability to suffice.

2. *Normative Criteria*

a. *Legal Context*

The decisional standards applicable to the cumulative impact of admissible evidence in different legal settings are quite clear in theory, if not always in practive. Criminal proceedings, for example, require proof beyond a reasonable doubt;[333] civil cases require proof by a preponderance of the evidence;[334] and administrative decisions must be upheld on review if there is substantial evidence in the record to support the agency determination.[335] Whether courts should comparably adjust their standards for admissibility of any given item of evidence because of the jurisdictional and procedural setting of a case is much less certain.[336] When courts have been confronted with scientific evidence in the past, it appears that they have, in fact, adjusted their standards in different legal contexts.

Cases involving the validity of spectrographic analysis (voiceprints) substantiate this proposition. Although the reliability of the technique is still open to question,[337] several courts have already approved the admission of voiceprint evidence. The majority of the favorable decisions were rendered in nontrial contexts: voiceprint admissions have been affirmed in connection with a probable cause hearing,[338] a probation revocation hearing,[339] and an Air Force court-martial.[340] In contrast, the majority of appellate courts rejecting the process in its present form were reviewing evidence submitted in criminal trials.[341]

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333. Mullaney v. Wilbur, 421 U.S. 684 (1975); *In re* Winship, 397 U.S. 358 (1970); MCCORMICK, *supra* note 7, § 341.

334. *See, e.g.*, CAL. EVID. CODE § 502 (West 1966); MCCORMICK, *supra* note 7, § 339.

335. *E.g.*, Administrative Procedure Act § 10, 5 U.S.C. § 706 (1970); DAVIS, *supra* note 259, §§ 29.01-.02.

336. *See, e.g.*, Woolley v. Hafner's Wagon Wheel, Inc., 22 Ill. 2d 413, 176 N.E.2d 757 (1961); *cf. Kirk*, *supra* note 287, at 399.

337. *See, e.g.*, United States v. Addison, 498 F.2d 741 (D.C. Cir. 1974); Jones, *supra* note 290.

338. State *ex rel.* Trimble v. Hedman, 291 Minn. 442, 192 N.W.2d 432 (1971).

339. United States v. Sample, 378 F. Supp. 44 (E.D. Pa. 1974).

340. United States v. Wright, 17 U.S.C.M.A. 183, 37 C.M.R. 447 (1967).

341. *See, e.g.*, United States v. Addison, 498 F.2d 41 (D.C. Cir. 1974); People v. Kelly, 17 Cal. 3d 24, 549 P.2d 1240, 130 Cal. Rptr. 144 (1976); People v. Law, 40

A somewhat similar pattern can be discerned with respect to the admissibility of lie detector tests. In general, the polygraph has been the object of more judicial hostility than any other "scientific" instrument; the cases overwhelmingly reject admission of polygraph results in criminal or civil proceedings.[342] On the other hand, authority is divided more evenly on the use of lie detectors in administrative hearings.[343] Courts that have approved agency reliance on the device have rationalized their decisions in terms of the wide latitude of agencies to obtain relevant information, even where it would not be admissible in court, and in terms of the comparatively lesser penalties associated with administrative adjudications.[344]

The latter consideration was also reflected in the rapid acceptance of evidence produced by radar speedmeters. Although proceedings in which such evidence is introduced may technically be criminal in nature, the earliest courts to rule on the matter balanced the relatively minor penalties involved against the need for effective enforcement of speeding laws and readily admitted radar evidence once the technique was proven to be reasonably reliable.[345] Apparently, no appellate court ever rejected speedmeter evidence on grounds that the process, when properly conducted, was unreliable,[346] and the question of professional acceptance was never explicitly raised or considered.[347]

Cal. App. 3d 69, 114 Cal. Rptr. 708 (5th Dist. 1974); People v. King, 266 Cal. App. 2d 437, 72 Cal. Rptr. 478 (2d Dist. 1968); State v. Cary, 56 N.J. 16, 264 A.2d 209 (1970).

342. *See* McCORMICK, *supra* note 7, § 207; Forkosch, *supra* note 286, at 305. *But see* United States v. Ridling, 350 F. Supp. 90 (E.D. Mich. 1974); Commonwealth v. A Juvenile, Mass. Adv. Sh. 907, 313 N.E.2d 120 (1974) (stipulation).

343. *Compare* Frazee v. Civil Serv. Bd., 170 Cal. App. 2d 333, 338 P.2d 943 (1st Dist. 1959) *and* Chambliss v. Board of Fire & Police Comm'rs, 20 Ill. App. 3d 24, 312 N.E.2d 842 (5th Dist. 1974), *with* DeVito v. Civil Serv. Comm'n, 404 Pa. 354, 172 A.2d 161 (1961). *See also* McCain v. Sheridan, 160 Cal. App. 2d 174, 324 P.2d 923 (1st Dist. 1958).

344. *See, e.g.*, Frazee v. Civil Service Bd., 170 Cal. App. 2d 333, 334-35, 338 P.2d 943, 944-45 (1st Dist. 1959).

345. Everight v. City of Little Rock, 230 Ark. 695, 326 S.W.2d 796 (1959); State v. Moffitt, 48 Del. 210, 100 A.2d 778 (1953); State v. Dantonio, 18 N.J. 570, 115 A.2d 35 (1955); People *ex rel.* Igoe v. Nasella, 3 Misc. 2d 418, 155 N.Y.S.2d 463 (Magis. Ct. 1956); People *ex rel.* Laibowitz v. Katz, 205 Misc. 522, 129 N.Y.S.2d 8 (Yonkers City Ct. 1954); City of East Cleveland v. Ferell, 168 Ohio St. 298, 154 N.E.2d 630 (1958). *See also* Boyce, *supra* note 269, at 317; Forkosch, *supra* note 286, at 293-94. *See generally* Annot., 47 A.L.R.3d 822 (1973); Baer, *supra* note 283, at 370-81.

346. In the days when radar speedmeters were first relied upon by police departments, convictions based on radar evidence were reversed only in the absence of expert testimony explaining the construction, nature, and function of a radar speedmeter as a reliable instrument for measuring the speed of motor vehicles. *See, e.g.*, People v. Offerman, 204 Misc. 769, 125 N.Y.S.2d 179 (Sup. Ct. 1958); City of Buffalo v. Beck, 205 Misc. 757, 130 N.Y.S.2d 354 (Sup. Ct. 1954) (radar not a matter of "common knowledge").

347. *See generally* Annot., 47 A.L.R.3d 822, 831-35 (1973). Within a few years courts began to approve the taking of judicial notice as to the reliability of radar speed-

When evidentiary applications of remote sensing technology are evaluated in terms of the legal context in which the evidence is to be introduced, a comparatively liberal admissions policy may often be adopted. With respect to the introduction of remote sensing output in judicial proceedings, past experience indicates that a substantial proportion of environmental cases will be tried to a judge sitting without a jury.[348] In reviewing nonjury cases appellate courts may be less sensitive to the possibility that unreliable scientific techniques could have unduly influenced the trier of fact.[349] Environmental cases also tend to involve complex factual issues, requiring expert testimony on many aspects of the evidence,[350] so that the introduction of remote sensing information will often require a judicial analysis of one more type of scientific technique among several presented in each case. In this regard, remote sensing can be contrasted with lie detector or neutron activation tests, which usually stand out as the one "scientific" element in a criminal trial otherwise dependent on human, and therefore presumably fallible, observations. It is, in addition, questionable whether appellate courts will display the same degree of protectiveness towards the corporate defendants typical of environmental actions as they have demonstrated on behalf of the frequently indigent and uneducated defendants in traditional felony cases. If one of the principal policies underlying judicial requirements for professional acceptance of scientific techniques is to assure fairness within the adversarial system for the party against whom the evidence is introduced,[351] then the ability of that party to protect itself is not an irrelevant consideration.

The comparatively minor penalties and minimal social stigma associated with violations of environmental regulations also point to a liberal standard of admissibility for remote sensing evidence. Although many environmental statutes provide for the imposition of criminal liability, enforcement agencies more often press for civil fines or injunctive relief.[352] At the same time, the public need for adequate

meters, thus presupposing general acceptance by the community at large. *See, e.g.*, State v. Dantonio, 18 N.J. 570, 115 A.2d 35 (1955); People v. Magri, 3 N.Y.2d 562, 147 N.E. 2d 728, 170 N.Y.S.2d 335 (1958).

348. Two reasons account for this practice: (1) the complex factfinding and potential length of the litigation often discourage litigants from requesting juries; and (2) environmental litigation frequently involves requests for eqnitable remedies such as declaratory judgments and injunctions. *Cf.* Ross v. Bernhard, 396 U.S. 531, 538 n.10 (1970).

349. *But see* Dolan, *supra* note 273, at 281-83. "The judge, no less than the jury, can be prejudiced or confused." *Id.* at 281 (footnote omitted).

350. *See generally* Sullivan & Roberts, *supra* note 1.

351. See note 285 *supra.*

352. The Federal Water Pollution Control Act Amendments of 1972, 33 U.S.C. §§ 1251-1376 (Supp. V, 1975), provide both civil and criminal penalties for unauthorized or unreported oil discharges. *E.g.*, 33 U.S.C. § 1319 (Supp. V, 1975). In practice, the Coast Guard usually seeks the imposition of a fine rather than a heavier criminal penalty. *See* Commandant Instruction 5922.11B, *supra* note 119.

protection of the environment is great, and both the nature of the harms involved and the wide area of coverage required for effective surveillance militate in favor of technological enforcement methods. From the perspective of the legal context in which the information is offered, it thus appears that remote sensing techniques are more analogous to the radar speedmeter techniques employed to enforce vehicle codes than to the lie detector or voiceprint tests used in felony prosecutions.[353]

A final contextual consideration is that a substantial proportion of remote sensing submissions will be made in administrative proceedings. Not only are administrative agencies ordinarily vested with primary responsibility for enforcement of environmental laws, but the agencies will themselves frequently be the instigating force behind the development of new remote sensing techniques. The settled law in administrative proceedings is that all evidence should be admitted "which can conceivably throw any light upon the controversy."[354] The admission of all potentially useful information is explicitly provided for in the Federal Administrative Procedure Act:[355]

> Any oral or documentary evidence may be received, but the agency as a matter of policy shall provide for the exclusion of irrelevant, immaterial, or unduly repetitious evidence.

This prescription indicates that scientific evidence should be admitted in administrative hearings if it is relevant to a contested issue. Arguments for and against the reliability of remote sensing output in this context must therefore be directed at the weight to be accorded the submission rather than at its admissibility. Moreover, appellate courts are likely to approve agency determinations on the reliability of remote sensing techniques since the prevailing judicial attitude regarding administrative findings of a scientific or technical nature is one of "considerable deference" to the expertise of the agency.[356] The enforcement of environmental regulations by means of remote sensing is clearly an activity in which it is both appropriate and necessary for administrative agencies to acquire technical expertise of the sort toward which courts have been deferential in the past.[357]

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353. *See, e.g.*, Forkosch, *supra* note 286, at 293. *See also* Forkosch, *Speeding & Due Process*, 28 FORD. L. REV. 115 (1959).

354. Samuel H. Moss, Inc. v. FTC, 148 F.2d 378, 380 (2d Cir. 1945); FTC v. Cement Institute, 333 U.S. 683, 703-06 (1948); Concrete Materials Corp. v. FTC, 189 F.2d 359 (7th Cir. 1951). The exclusion of potentially relevant evidence, even if legally inadmissible in court, may be reversible error in an administrative proceeding. MCCORMICK, *supra* note 7, § 350.

355. 5 U.S.C. § 556(d) (1970).

356. *See, e.g.*, Deutsch v. AEC, 401 F.2d 404, 407-08 (D.C. Cir. 1968).

357. *See* Texas & Pac. Ry. v. Abilene Cotton Oil Co., 204 U.S. 426 (1907); Industrial Union Dep't, AFL-CIO v. Hudgson, 499 F.2d 467, 474-75 (D.C. Cir. 1974); Gaddy v. State Bd. of Registration for Healing Arts, 397 S.W.2d 347 (Mo. Ct. of App. 1965); DAVIS, *supra* note 259, §§ 19.01-.06; MCCORMICK, *supra* note 7, § 253. See also note 356, *infra.*

b. Importance of the Issue

The introduction of scientific evidence to establish a relatively minor factual contention in a murder trial, as an illustration, may clarify the distinction between admission policies shaped by the legal context of an action and those related to the importance of the particular issue on which the evidence is proffered. A felony prosecution creates a legal context in which stringent standards for admissible evidence are ordinarily applied. Yet within that context, courts apparently adopt a less restrictive attitude toward scientific techniques unlikely to be decisive in the litigation. In other words, courts require comparatively greater reliability from techniques whose output is offered or may be interpreted by the trier of fact as conclusive proof of an essential element.

For example, one common justification for the exclusion of evidence obtained from lie detectors, hypnosis, and narcoanalysis is that such evidence is offered not to prove a particular factual contention, but to prove guilt or innocence directly, and thus intrudes on "ultimate issues" in the case.[358] Lie detectors and similar techniques have been assailed because they "usurp" the function of the jury, insofar as they purport to measure a person's mental state and beliefs rather than externally observable and reproducible phenomena.[359] In that sense, it is argued, lie detectors may supplant the traditional factfinder in the adversarial system and give rise to a system of "mechanical justice."[360] That a scientific technique addresses important issues and may prove decisive is not, in and of itself, adequate grounds for exclusion; otherwise, blood tests to disprove paternity[361] and radar speedmeter readings[362] would not have achieved judicial acceptance. What the "ultimate issues" and "jury usurption" arguments reflect is a belief that the trier of fact will defer to the results of certain techniques more than is warranted by their demonstrable reliability.

It is not, therefore, sufficient to argue that lie detector tests should be admissible because they are "as reliable" as other judicially ap-

358. *See, e.g.*, Strong, *supra* note 263, at 13; Boyce, *supra* note 269, at 322; MCCORMICK, *supra* note 7, §§ 203, 207.

359. *See, e.g.*, RICHARDSON, *supra* note 221, § 617; Note, *Admissibility*, *supra* note 307, at 685-86; Boyce, *supra* note 269, at 322.

360. *See* Forkosch, *supra* note 286, at 289-98.

361. Such tests have been used to establish that the defendant could not possibly have been the father of the child-plaintiff. *See* Jordan v. Mace, 144 Me. 351, 69 A.2d 670 (1949) (jury finding to the contrary overturned on appeal); Beck v. Beck, 153 Colo. 90, 384 P.2d 731 (1963). Where, however, the blood tests indicate that the defendant might be the parent, the results are not admissible to prove paternity for fear that the jury may be unduly influenced by the results. *See* People v. Nichols, 341 Mich. 311, 67 N.W.2d 230 (1954); State v. Morris, 156 Ohio St. 333, 102 N.E.2d 450 (1951).

362. See radar cases cited in notes 345 and 347 *supra*.

proved scientific processes.[363] Nor can the exclusion of lie detector evidence be rationalized primarily on grounds that juries will be significantly influenced by it,[364] for that argument may apply with equal force to many other scientific submissions. A reasonable explanation for disparities in the judicial treatment of different kinds of scientific evidence is that courts in practice employ a sliding admissibility standard, which balances the perceived reliability of each technique against the probable consequences of admission. In any given case those consequences may be magnified because particularly important interests are at stake, because the scientific evidence is essential to establish a central element,[365] or because the evidence is submitted in a form that may be especially persuasive[366] or misleading[367] to the trier of fact. An

363. *See, e.g.*, Boyce, *supra* note 269, at 321-22; Note, *Evolving Methods, supra* note 253, at 689-90.

364. *See, e.g.*, Note, *Admissibility, supra* note 307, at 695; Ahrens, *supra* note 252, at 628. *See also* 3A WIGMORE (Chad. rev.), *supra* note 7, § 999.

365. *See, e.g.*, People v. Kelly, 17 Cal. 3d 24, 549 P.2d 1240, 130 Cal. Rptr. 144 (1976). Most police science techniques such as lie detectors, voiceprint analysis, and neutron activation analysis are typically introduced either to identify a criminal defendant or to prove truth or falsity, both of which evidentiary purposes are extremely critical in the context of a criminal trial. These may be contrasted with the technique of X-ray photography, which is seldom dispositive on the question of tort liability and is usually only one form of evidence submitted to prove damages.

Although the greater readiness of courts to accept scientific evidence offered to corroborate conventional evidence is in part a reflection of the increased probability that the scientific technique is reliable in that circumstance, the argument can be made that the scientific evidence is not as central to the case or as likely to prove decisive where it is used to support testimony that would, in itself, be sufficient to obtain a conviction. *See* Ward v. State, 427 S.W.2d 876 (Tex. Crim. 1968) (neutron activation analysis held admissible to support microscopic examination of particles).

366. For example, that psychiatric evidence has been readily accepted by the courts —although no one seriously contends that all psychiatrists hold the same views—has been explained on the basis that juries are unlikely to be swayed unduly by this particular variety of scientific evidence. Evidence produced by mechanical devices and tests, on the other hand, has not been treated similarly for fear that the jury would succumb to the apparent aura of infallibility. *See* Boyce, *supra* note 269, at 324; Note, *Evolving Methods, supra* note 253, at 707. As the New York Court of Appeals observed in People v. Leone, 25 N.Y.2d 511, 225 N.E.2d 696, 307 N.Y.S.2d 430 (1969):

> We are all aware of the tremendous weight which [polygraph] tests would necessarily have in the minds of a jury. Thus, we should be most careful in admitting into evidence the results of such tests unless their reasonable accuracy and general scientific acceptance are clearly recognized.

Id. at 518, 225 N.E.2d at 700, 307 N.Y.S.2d at 435.

In some cases evidence directed at a particular issue has been excluded because the evidence has been presented as if it were conclusive and therefore would in all likelihood he very persuasive to a jury, while similar evidence was admitted on the same issue because it was not alleged to be dispositive. Compare the treatment accorded neutron activation analysis of hair samples with that accorded NAA tests of clothing particles in State v. Coolidge, 109 N.H. 403, 260 A.2d 547, *rev'd on other grounds*, 403 U.S. 443 (1969).

367. It should be remembered that polygraphs measure physiological reactions, not mental processes, and the former must be interpreted by the examiner to determine if

analysis of typical lie detector cases reveals that all of these factors are present in large measure.[368] The overwhelming rejection of lie detector evidence is thus illustrative of the general proposition that courts have applied a progressively more restrictive standard as the probable consequences of admission increase in magnitude.

Remote sensing evidence may be introduced in litigation to supplement more detailed and conclusive evidence,[369] to establish a subsidiary contention,[370] or to prove an essential point.[371] Since remote sensing information is typically presented to the trier of fact in the form of a pictorial image that graphically identifies an alleged condition, it can often be extremely persuasive.[372] Moreover, since minimal variations in environmental features may be portrayed in a highly contrasted fashion, a remote sensing image could create a misleading impression.[373] Thus instances may occur in which the probable

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the subject is responding truthfully. *See* Note, *Admissibility*, *supra* note 307, at 693. In addition, what a subject believes to be true and what, in reality, is true, may be two different things. MCCORMICK, *supra* note 7, § 207. This distinction has also been a prime factor in the courts' exclusion of evidence obtained by means of truth serums (narcoanalysis) and hypnosis. *See* Ahrens, *supra* note 345, at 630-31; MCCORMICK, *supra* note 7, § 208.

368. *See* cases collected in Annots., 23 A.L.R.2d 1306 (1952); 53 A.L.R.3d 1005 (1973). *See also* People v. Leone, 25 N.Y.2d 511, 255 N.E.2d 696, 307 N.Y.S.2d 430 (1969); People v. Davis, 343 Mich. 348, 72 N.W.2d 269 (1955).

369. See the discussion of Vermont v. New York, 417 U.S. 270 (1974), in note 168 *supra*; Sierra Club v. Department of Interior, 398 F. Supp. 284 (N.D. Cal. 1975).

370. *See, e.g.*, Transcript of Proceedings, Federal Power Commission, City of Seattle, Project No. 553 (Mar. 5, 1975), discussed in note 108 *supra*.

371. *See, e.g.*, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974), discussed at text accompanying notes 169-80 *supra*; State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Jan. 27, 1976), discussed at text accompanying notes 160-67 *supra*; State v. Johnson, 286 N.C. 331, 210 S.E.2d 260 (1974).

372. *See, e.g.*, State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Jan. 27, 1976). The statement of the trial judge as to the persuasiveness of the remote sensing imagery is quoted in note 167 *supra*.

Because of their apparent similarity to photographs, which are generally regarded as highly persuasive evidence, SCOTT, *supra* note 7, §§ 2-3; MCCORMICK, *supra* note 7, § 214, courts may admit remote sensing images into evidence without completely understanding what the images represent. Unlike the typical photograph, a remote sensing image may consist of a computerized reconstruction of a scene with certain features artificially accentuated. See text accompanying notes 15-16 *supra*. The persuasiveness of such enhanced images can readily be seen from a comparison between a remote sensing image of a pollution plume and the relation of equivalent data by an expert witness. Consider the difference in effect of a tabular or oral presentation of pollution concentrations in parts per million as opposed to a remote sensing image designed to emphasize close differences in pollution levels. Using image enhancement techniques, even minor variations in parts per million (or temperature) can be made to appear visually distinctive. Such imagery may well have a much greater impact than a relatively dry recitation of the quantitative differences.

373. Thermal sensors, for example, differentiate between temperatures only within a very narrow range (on the order of 5 to 6 degrees centigrade), so that anything hotter results in total exposure of the corresponding area of the image, while anything cooler

consequences of admitting remote sensing evidence would be substantial; in such a case, the court should require proof of high reliability as a prerequisite for admission. The converse situation, however, is as likely to occur;[374] the consequences of admitting some remote sensing data will be comparatively minor. In view of the variety of potential sensing techniques, the range of environmental conditions that could be recorded, and the dissimilar evidentiary purposes for which remote sensing information could be entered, generalizations about the appropriate degree of reliability to be required of remote sensing should be regarded with suspicion.[375] It is doubtful whether any of the scientific techniques with which courts have grappled in the past present quite as diverse a set of possible applications as remote sensing technology.

c. *Acceptable Margin of Error*

A normative question emerges from the observation, made above, that even the most reliable technique can never be completely accurate: on what grounds may adjudicators select an acceptable margin of error? When the legal standard to be enforced and the accuracy tolerance of a measurement device can both be expressed quantitatively in comparable terms, it is possible to require that a violation be

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leaves the corresponding area of the image totally unexposed (that is, dark). Thus the final image may indicate similarities where the actual divergence in temperature between two features (both above and below the sensitivity range of the sensor) is greater than divergence in temperature between any features *within* the sensitivity range.

Output created by the *density slicing* of a thermal image might similarly be misleading. This technique is explained in note 16 *supra*. Density slicing produces an image in which increments in temperature (or in any other variable, such as near-infrared reflectance) may be assigned wholly contrasting colors, which makes relatively minor variations appear greater than they really are. Plate 9a, for example, shows a thermal image of a plume extending from the Indiana Ship Canal toward Illinois, and Plate 9b was produced by density slicing of that same thermal scan. The former was eventually introduced in *Inland Steel*, discussed at text accompanying notes 160-67 *supra*. The density slicing image, however, was not introduced because the temperatures of the land and the temperature of the hottest areas of the pollution plume were both above the sensitivity range of the thermal scanner; thus, both the land and the hot areas of the plume were assigned the same shade of red on the final image, even though the land may have been much warmer than any areas of the plume.

374. This situation is likely to occur for the following reasons. First, the context in which the remote sensing evidence is most likely to be offered (environmental litigation with relatively light penalties and in the absence of a jury) will usually foster a liberal standard for admissibility. See text accompanying notes 348-53 *supra*. Second, remote sensing evidence will often be introduced to supplement other scientific data; only rarely will it be sufficient by itself to establish a point at issue, and therefore only rarely will it be relied upon exclusively by its proponents. See text accompanying notes 358-68 *supra*. Third, in some cases there will be little dispute among the parties to the litigation as to what is shown by the remote sensing imagery. See, *e.g.*, the series of cases initiated by the Jacksonville District of the U.S. Army Corps of Engineers, described in text accompanying notes 194-99 *supra*.

375. See text accompanying note 304 *supra*.

documented in a manner which eliminates the materiality of an error within the tolerance of the technique.[376] Properly maintained radar speedmeters, for example, are generally accurate within 2 or 3 miles-per-hour.[377] It is, therefore, common practice, and in some states required by statute,[378] that police set their radar at a level several miles-per-hour higher than the posted speed limit. Thus, vehicles that trigger the device must be moving at a velocity greater than the sum of the maximum authorized speed and the error margin of the detection device.

In many instances this approach may be applied to remote sensing methods.[379] Since most environmental standards are defined in quantitative terms, the required proof of a violation may be scaled upward to take into account the probable margin of error of the sensing technique. In contrast, a number of the more familiar police science techniques, such as lie detector tests, voiceprint analysis, and neutron activation analysis, pertain to issues like identity and truth or falsity, which are largely considered in absolute terms. Sixty-three percent of a criminal defendant cannot be identified as the culprit nor, with respect to a single statement, can an individual lie and say the truth at the same time. Thus, if one of these techniques produces an error, its result is entirely wrong. If the accuracy tolerance of a radar speedmeter is known to be within 5 percent, courts can require that the device be set more than 5 percent above the lawful speed. If, however, it could be determined that the accuracy tolerance of a lie detector was within that same 5 percent range, there would still be no method by which the courts could protect lie detector test subjects from the possibility of error except by prohibiting the test entirely. This analysis suggests that a higher degree of accuracy should be demanded of a technique in situations in which the proof of wrongdoing required for a finding of liability cannot be adjusted to compensate for the margin of error associated with that technique. Beyond that observation, all of the other norma-

376. The possibility of statistical measurement error, which is often unavoidable where regulations set quantitative standards, does not detract from an agency's power to set such standards. It merely deprives the agency of the power to find a *violation* of the standards, in enforcement proceedings, where the measured departure from them is within the boundaries of probable measurement error.

Amoco Oil Co. v. EPA, 501 F.2d 722, 743 (D.C. Cir. 1974).

377. *See, e.g.*, State v. Graham, 322 S.W.2d 188 (Mo. App. 1959); People v. Nasella, 3 Misc. 2d 418, 155 N.Y.S.2d 463 (City Magis. Ct., Richmond County 1956); Kopper, *supra* note 308, at 350-52.

378. *See, e.g.*, GA. CODE ANN. § 68-2101 (Supp. 1975); PA. STAT. ANN. tit. 75 § 1002(d.1)(1)(iv) (1971). *See also* Comment, *Proposal for a Uniform Radar Speed Act*, 7 U. MICH. J. LAW REFORM 440 (1974) (collecting statutes).

379. *See* Ludwig & Griggs, *supra* note 133, at 121-44, for a technical comparison of the error rates and characteristics of different remote sensing techniques.

tive criteria identified in this section are relevant to the ultimate question whether a given margin of error should be acceptable in a given case.

d. Reliability of Alternative Methods

Whether a scientific technique is sufficiently accurate for a particular purpose must, in part, depend on the reliability of the alternative methods of proof available to the litigants. When the radar speedmeter was initially introduced, for example, it was observed that the subjective impressions of lay witnesses were traditionally admissible on the issue of automobile speeds.[380] Similarly, an early decision admitting voiceprint evidence noted that the tape recordings of voices might have been played in court so that a jury could compare them by ear, for lay identifications of voices were routinely accepted.[381] In like manner, neutron activation analysis was favorably compared to the process of examining particles under a microscope.[382] In each of these instances, the assumption, articulated or not, was that imperfectly reliable scientific techniques should nevertheless be admissible when conventionally accepted alternative methods were demonstrably less reliable.[383]

This proposition is likely to support the rapid acceptance of a variety of remote sensing applications designed to replace haphazard human inspections with systematic measurement and recording techniques. By way of illustration, the utilization of trained smoke plume readers is generally approved because there are now few other practicable means of enforcing the relevant air pollution regulations.[384]

380. In one early radar case, People v. Torpey, 204 Misc. 1023, 128 N.Y.S.2d 864 (Monroe County Ct. 1953), the prosecution introduced the opinions of the police officers that the defendant's car was traveling at 45 miles per hour, and also introduced a radar reading showing the defendant's car traveling at 43 miles per hour. The court held that the two forms of evidence, taken together, were sufficient to sustain the conviction, but it indicated that if the radar readings alone were to be relied upon, the state would have to introduce expert testimony on the accuracy of radar for measuring speed. *Id.* at 1026, 128 N.Y.S.2d at 866.

381. State *ex rel.* Trimble v. Hedman, 291 Minn. 442, 457, 192 N.W.2d 432, 441 (1971).

382. Ward v. State, 427 S.W.2d 876 (Tex. Crim. App. 1968).

383. McCormick, *supra* note 7, § 207, at 506 n.8 notes that no statistics from any study of the comparative accuracy of a lie detector and the jury in telling truth from falsity are available.

384. The most common visual smoke-reading technique is based on the Ringelmann Opacity Chart. *See, e.g.*, People v. Plywood Mfrs., 137 Cal. App. 2d Supp. 859, 291 P.2d 587 (App. Dep't Super. Ct. 1955), *appeal dismissed*, 351 U.S. 929 (1956); People v. International Steel Corp., 102 Cal. App. 2d Supp. 935, 226 P.2d 587 (App. Dep't Super. Ct. 1951). More recent cases upholding Ringelmann-based standards include Lloyd A. Fry Roofing Co. v. State Dep't of Health, 553 P.2d 800, 807 (Colo. 1976); City of St. Louis v. Eskridge, 486 S.W.2d 648 (Mo. App. 1972); State v. Lloyd A. Fry Roofing Co., 9 Ore. App. 352, 495 P.2d 751 (1972). *See also* Lloyd A. Fry Roofing Co.

Some courts, however, have expressed dissatisfaction with the administration of the smoke opacity tests because of the subjective nature of the inspectors' judgments.[385] It is thus probable that the introduction of automated opacity sensing systems[386] will be judicially approved as soon as their greater reliability can be demonstrated.

A more troublesome problem involves the use of remote sensing techniques not because they are more reliable than conventional methods, but because they are less expensive. It is not clear how often this problem will materialize in practice, since remote sensors will ordinarily be employed to supplement rather than supplant instruments capable of more precise measurements; the remote sensing images will reveal the broad dimensions of the environmental feature under study, while the more accurate methods will obtain detailed information at representative or critical locations. When the attempt is made to substitute remote sensing for other investigatory tools on a cost-effectiveness rationale, the courts must balance the diminution in reliability resulting from that decision against the economic realities of environmental litigation. The essential determination to be made in such situations is not whether there are more accurate methodologies, but whether the remote sensing technique introduced is *sufficiently reliable* for the intended purpose. All of the criteria[387] identified in this section

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v. Pollution Control Bd., 20 Ill. App. 3d 301, 314 N.E.2d 350 (1974), *cert. denied*, 420 U.S. 996 (1975); Southern Ill. Asphalt Co. v. EPA, 15 Ill. App. 3d 66, 303 N.E.2d 606, *aff'd*, 60 Ill. 2d 204, 326 N.E.2d 406 (1975). *See generally* Annot., 51 A.L.R.3d 1026 (1973).

385. *See, e.g.*, Western Alfalfa v. Air Pollution Variance Bd., 3 E.R.C. 1399 (Colo. Dist. Ct. 1971), *aff'd*, 510 P.2d 907 (Colo. App. 1973), *rev'd on other grounds*, 416 U.S. 861 (1974). The district court held that the Variance Board erred in rejecting evidence of an engineering study that contradicted Ringelmann chart readings. The court emphasized that Ringelmann readings are particularly suspect when the emission involved is one mixed with steam, a nonpollutant. A similar attack was made in State v. Lloyd A. Fry Roofing Co., 3 Ore. App. 352, 495 P.2d 751 (1972), where the defendant attacked the expertise of the state's smoke readers on the ground that they lacked experience in reading "wet plumes," and were therefore unable to determine opacity correctly in this instance. Conceding this contention to be a "close question," the court nonetheless upheld the state because of the extent of the smoke observed and the lack of a showing of the effect of "wet plumes" on Ringelmann readings. In Portland Cement Ass'n v. Ruckelshaus, 486 F.2d 375 (D.C. Cir. 1973), the court remanded to the EPA for further consideration a proposed particulate pollution standard based on opacity; the court relied on a test conducted for the National Center for Air Pollution Control, which showed wide variations among six trained smoke inspectors using the Ringelmann chart on a smoke plume of known opacity. *Id.* at 401. Upon receipt of more detailed evidence from the EPA, however, the court upheld the opacity standard, Portland Cement Ass'n v. Train, 513 F.2d 506 (D.C. Cir.), *cert. denied*, 423 U.S. 1025, *rehearing denied*, 423 U.S. 1092 (1975), emphasizing, though, the limited role of appellate courts in reviewing administrative determinations. *Id.* at 508-09.

386. Ludwig & Griggs, *supra* note 133, at 147-49.

387. Among the normative factors related to a determination of how much reliability should be required of a scientific technique are the legal setting of the action; the

may be germane to judicial analysis of that question. The availability of reliable alternatives, however, would clearly be material to that inquiry, and may prove to be the decisive element in situations where the remote sensing evidence is potentially prejudicial[388] or so complex and unfamiliar that its introduction would unfairly burden the opposing party.

A few concluding comments may help to restore a proper perspective to the subject of reliability. An exhaustive demonstration of the reliability of a scientific technique will not be necessary in conjunction with all submissions of remote sensing evidence. If past experience is any guide, remote sensing will be admitted in many environmental cases because the other litigants choose not to contest its use. Furthermore, after a few courts evaluate a particular technique and find it admissible, other judges are likely to take judicial notice of the reliability of the underlying scientific process.[389] Judicial notice may be especially useful when applied to general-purpose recording techniques, like infrared photography or thermal scanning; some care, however, should be exercised to distinguish between the scientific principles on which the sensors are based and those on which the interpretational theories depend.

C. Proper Conduct of the Remote Sensing Process

Judicial opinions and legal commentaries often discuss the issues of professional acceptance and reliability in terms of the validity of the relevant scientific principles. Yet those principles may only be brought to bear on real-world phenomena through the application of a given set of instruments, tests, and operating procedures. The preferable scope of investigation, then, is whether a scientific process, when viewed in its entirety, is sufficiently valid to justify the admission into evidence of its output. In the initial stage of this judicial examination, the process should be evaluated as an archetype: a decision must be made whether a typical application of the process is capable of producing acceptable information in the normal course of events. Once the archetype is recognized as valid, a second line of inquiry must be

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nature of the interests at stake; the importance of the issue on which the evidence is presented; the decisiveness, real or apparent, of the evidence; its prejudicial potential; the ability to compensate for the margin of error inherent in the technique; and the availability of more reliable alternatives.

388. The discussion of the prejudice doctrine and its application in the field of scientific evidence should not be read to suggest that otherwise admissible scientific evidence could not be rejected because it was prejudicial. Rather, reliance on the prejudice rule alone was deemed inadequate to protect the other litigants. See text accompanying notes 270-78 *supra*.

389. See note 298 *supra*.

undertaken in each case to determine if the particular methods used in that instance conform to the approved model. This analysis of the conduct of a scientific technique is directed not at whether the process *could yield* trustworthy results, but at whether the application of that process in a specific case *did yield* the desired degree of trustworthiness.

The logical distinction between the reliability of the archetypal scientific process and the reliability of the actual application has engendered considerable confusion with respect to the appropriate legal remedies should either element be insufficiently demonstrated.[390] Failure of the archetype to achieve judicial recognition leads inexorably to exclusion of the proffered evidence. When considering the second element in the analysis, however, some courts have asserted, as if it were black-letter law, that deficiencies in the operation of a technique go to the weight of the evidence rather than to its admissibility.[391] This formulation is much too facile, for substantial defects in the conduct of a process have often resulted in the exclusion of its output. Judges have invoked the *Frye* doctrine or some other rationale for exclusion in cases where the divergence of the application from the approved model was perceived as significantly affecting the reliability of the outcome. Moreover, evidence may be ruled inadmissible, and not simply reduced in probative value, when the discrepancy between the proper conduct and the actual conduct of a process impairs the ability of the opposing party to present an informed rebuttal. An inspection of past judicial treatment of scientific evidence reveals three general lines of inquiry relevant to an evaluation of the proper conduct of remote sensing techniques: (1) were the selected methods sufficiently parallel to those encompassed in the approved model of the process; (2) were the methods properly applied in the particular instance; and (3) was the process conducted by qualified individuals?[392]

1. Correspondence of Archetype and Application

In the legal assessment of particular scientific instruments, tests, and operating procedures, the initial consideration is whether the methods selected for use in a given application conform sufficiently to

390. Strong, *supra* note 263, at 18.

391. *See, e.g.*, United States v. Stifel, 433 F.2d 431, 439 (6th Cir. 1970), *cert. denied*, 401 U.S. 994 (1971); People v. Bobczyk, 343 Ill. App. 504, 511, 99 N.E.2d 567, 570 (1951); State v. Coolidge, 109 N.H. 403, 260 A.2d 547, *rev'd on other grounds*, 403 U.S. 443 (1969).

392. *See, e.g.*, RICHARDSON, *supra* note 221, § 6.3, *citing* J. WIGMORE, SCIENCE OF JUDICIAL PROOF 450 (3d ed. 1937), in which the three themes are expressed in terms of using a scientific "apparatus." These same general concerns, however, apply to testing procedures in which instruments play only a minor role, if any.

the judicially approved model of the relevant scientific process. Where the method under investigation features an unfamiliar scientific instrument, the test for congruence between the archetype and the application may be expressed in terms of the extent to which the device embodies the previously accepted scientific principles.[393] The instrument, in short, must conform to the scientific theory if it is to be deemed capable of producing valid results. This issue is seldom made explicit in connection with techniques for which only one applicable device-type exists, because the reliability of such a device would implicitly be assessed at the same time as the professional acceptance and reliability of the underlying principles. The question does materialize in applications like speed detection by radar[394] or proof of intoxication[395] where several alternative classes of instruments might be employed. That one type of radar speedmeter, for example, can accurately determine the velocity of a vehicle does not insure that different devices exploiting the microwave spectral range would be similarly reliable. Although no cases have been discovered in which a court explicitly held that certain principles were valid but that the evidence was inadmissible because the device used to obtain it did not successfully embody those principles, in states with statutes requiring radar devices to be of a type approved by a designated state official, evidence has occasionally been excluded in the absence of such proof.[396]

The validity of the testing procedures, taken as a whole, has more often been in issue than the utility of an instrument per se. In some cases, exclusion of evidence has been justified because the methods employed or the surrounding circumstances differed in an important respect from the technique used or the conditions prevailing when the archetype was approved. Thus in *People v. Alston*[397] a test conducted 22 months after blood samples were collected was invalidated on the ground that the original examination of that technique had involved recent samples; support for the reliability of the technique was

393. *See, e.g.*, Strong, *supra* note 263, at 15-18.

394. *See, e.g.*, State v. Tomanelli, 153 Conn. 365, 216 A.2d 625 (1966); City of East Cleveland v. Ferell, 168 Ohio St. 298, 154 N.E.2d 630 (1958). In each of those cases, the courts approved the taking of judicial notice of the validity of a speedmeter based upon the Doppler effect, although the military-type radars that have wide usage depend on a pulsed system. *See also* McCORMICK, *supra* note 7, § 210.

395. *See, e.g.*, City of Abilene v. Hall, 202 Kan. 636, 451 P.2d 188 (1969), where the court's acceptance of a gas chromatograph to determine alcohol level in the blood was based, in part, on a technical assessment in a scientific treatise not submitted at trial.

396. *E.g.*, Commonwealth v. Perdok, 411 Pa. 301, 192 A.2d 221 (1963); Annot., 47 A.L.R.3d 822, 868 (1973). *See also* N.D. CENT. CODE § 39-20-07(5) (Supp. 1975), which requires advance approval by the appropriate state official in connection with intoxication testing techniques.

397. 79 Misc. 2d 1077, 362 N.Y.S.2d 356 (Sup. Ct. 1974).

held insufficient after so much time had elapsed. In *People v. Law*[398] voiceprint evidence was not admitted to identify a defendant who disguised his voice, because all of the studies that attempted to validate the technique had involved the identification of unaltered voices. Similarly, in *State v. Stout*[399] neutron activation analysis was not approved for use on blood samples although the parties had agreed that the technique was a generally accepted method of chemical analysis. In view of the possibility that sodium and chlorine naturally present in blood might mask the presence of the elements used as the basis of the identification, the court held that experience gained in the testing of other substances could not be relied upon in the analysis of blood samples and, therefore, that additional scientific testing devoted specifically to blood was required prior to judicial acceptance of the technique.[400]

In contrast to these cases, where the scientific submissions were ultimately excluded under the *Frye* rule, *State v. Coolidge*[401] concluded that potential deficiencies in the conduct of a process go to the weight of the evidence rather than to its admissibility.[402] In *Coolidge* the defendant argued unsuccessfully that the neutron activation analysis (NAA) was fatally defective because the samples had not been exposed to the radioactive source for a sufficient period of time. If the underexposure in *Coolidge* had been by a factor of 100 or 1000 or more,[403] could not the court have decided that the disparity between approved and actual conduct was so great that, in effect, a fundamentally different test had been performed from the accepted model? Exclusion of the evidence in *Coolidge* would then have been as justifiable as it was in *Alston, Law,* and *Stout.* It is difficult to argue, on the facts presented in the opinions, that underexposure of NAA samples would necessarily be a less serious defect than deviations from the archetypes in the other cases. This comparison suggests that the choice of exclu-

398. 40 Cal. App. 3d 69, 114 Cal. Rptr. 708 (5th Dist. 1974).

399. 478 S.W.2d 368 (Mo. 1972).

400. *Id.* at 371-72. The court drew a parallel to scientific acceptance of NAA tests on hair samples:

> It is interesting to note that in 1969 the Supreme Court of New Hampshire, in State v. Coolidge, 109 N.H. 403, 260 A.2d 547 [*rev'd on other grounds*, 403 U.S. 443 (1969)], held that its trial court correctly excluded neutron activation analysis results on hair. Subsequent to that case, extensive testing on neutron activation analysis of hair was done. By 1971, neutron activation analysis of hair had become generally accepted in the scientific community, as reflected in State v. Stevens [467 S.W.2d 10 (Mo. 1971)].

Id. at 372.

401. 109 N.H. 203, 260 A.2d 547, *rev'd on other grounds*, 403 U.S. 443 (1969).

402. *Id.* at 221, 260 A.2d at 559. *See also* United States v. Stifel, 433 F.2d 431 (6th Cir. 1970), *cert. denied*, 401 U.S. 994 (1971).

403. No indication was given in the *Coolidge* opinion as to what degree of underexposure was alleged by the defendant.

sion or, in the alternative, diminution of weight as the remedy for inadequate conduct of a process is not always clear-cut.[404]

When remote sensing evidence is assessed in terms of the correspondence between the approved model of a process and the actual methods employed in a given instance, it will again be advisable to distinguish between sensing techniques and interpretational procedures. Aerial[405] and satellite cameras,[406] airborne thermal scanners,[407] aerial[408] and satellite multispectral scanners,[409] and radar sensors[410] have already produced information submitted in environmental litigation. In no case was the sensor technology challenged or even, to any significant extent, discussed in court. The output was consistently treated as if it were photography;[411] disputes involved what the images could show rather than how they were produced. It is not possible to determine from an inspection of the available transcripts whether the nonphotographic sensing techniques went unchallenged because they were acknowledged to be sufficiently reliable by all participants in the litigation or because the judges and attorneys did not comprehend the differences between cameras and other kinds of sensors.[412] There were probably enough published descriptions in technical literature, nonlegal uses within the scientific community, and familiar technological ana-

404. Indeed, *Coolidge* admitted some NAA results and excluded others. See note 366 *supra.*

405. *See, e.g.*, City of Newark v. Natural Resource Council, No. A-3311-72 (N.J. App. Div., filed July 18, 1973), discussed at text accompanying notes 207-16 *supra*; Record on Appeal at 276-307, State v. Johnson, 286 N.C. 331, 210 S.E.2d 260 (1974).

406. *See, e.g.*, State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Jan. 27, 1976) (Skylab color photograph, reproduced in Plate 8), discussed at text accompanying notes 160-67 *supra.*

407. *Id.* with reference to the EPA thermal scauner overflights of the Chicago area (Plates 6 and 9a). *See also* Record at 969-1083, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974) (testimony of Arthur W. Dybdahl regarding thermal infrared imagery taken over Lake Superior).

408. *See, e.g.*, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974), discussed at text accompanying notes 169-80 *supra.*

409. *Id.*

410. *E.g.*, the Coast Guard Airborne Oil Surveillance System (AOSS) and related administrative proceedings, discussed at text accompanying notes 130-32 *supra.*

411. *See, e.g.*, Record, Vol. 18, at 2511, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974); Record at 1284-88, State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Jan. 27, 1976).

412. The corporate defendants in State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Jan. 27, 1976), discussed at notes 160-67 *supra* and accompanying text; and United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974), discussed at notes 169-80 *supra* and accompanying text, had both hired technical consultants, and thus may be presumed to have understood the sensing techniques involved iu their respective cases. Conversations with Dr. Frank J. Wobber, Senior Scientist, Resource Managemeut Department, IBM Corporation, Gaithersburg, Md., June 10, 1975; Dr. Allan D. Marmelstein, Remote Sensing Coordinator, U.S. Departmeut of Interior, Fish & Wildlife Service, Washington, D.C., Aug. 6, 1975.

logues[413] for a party to document with relative ease the general validity of the remote sensors employed. It should nevertheless be emphasized that proof must be available that the particular sensor used in a given case is of an approved type.[414]

In some instances the validity of the sensing technique may be open to question, especially in connection with sensors designed to detect a specific natural phenomenon with great accuracy, as in the case of a quantitative sensor developed to measure a particular atmospheric pollutant. An analogy may be drawn to *State v. Stout*,[415] where the normal presence of sodium and chlorine in the blood raised serious questions about the reliability of neutron activation analysis of blood samples.[416] The validity of a quantitative sensor might similarly be doubted on the grounds that variable environmental conditions could affect the reliability of its measurements.[417]

Objections will more frequently be made to the interpretational theory selected and, thus, to the reliability of conclusions derived from the sensing output. The challenge may at times be based on the operational characteristics of the sensor itself. To use a hypothetical illustration, if the parties stipulate that photography or scanning in the near infrared range can be employed to discriminate between different plant species, a legitimate objection could still be raised to the introduction of Landsat images for that purpose, since the 80-meter resolu-

413. A party advocating admission of the output of nonphotographic sensors might well point to judicial acceptance of radar speedmeters and X-ray machines, for example.

414. The suitability of a device may be a proper subject for judicial notice. *See, e.g.*, City of Abilene v. Hall, 202 Kan. 636, 451 P.2d 188 (1969) (gas chromatograph); State v. Miller, 64 N.J. Super. 262, 165 A.2d 829 (1960) (drunkometer); State v. Dantonio, 18 N.J. 570, 115 A.2d 35 (1955) (radar); People v. Duskin, 11 Misc. 2d 945, 174 N.Y.S.2d 527 (1958) ("speed watch" device); State v. Gregoire, 88 R.I. 401, 148 A.2d 751 (1959) (alcometer). *See also* Boyce, *supra* note 269, at 316, 318; McCORMICK, *supra* note 7, § 330, at 763; RICHARDSON, *supra* note 221, § 13.5; Strong, *supra* note 263, at 6-9, 15-22; Annot., 47 A.L.R.3d 822, 831-35 (1973).

415. 478 S.W.2d 368 (Mo. 1972).

416. See text accompanying notes 399-400 *supra*.

417. For example, reliance upon the principle of differential absorption, which depends on the absorption of a particular wavelength of energy by a single type of molecule, may have to be proven valid as it relates to a specific chemical, rather than as a general theory. In other words, if it is possible that molecules other than those being quantified absorb the energy, then the results of the technique are invalidated. See NASA, REMOTE MEASUREMENT OF POLLUTION 84-89, 104 (1971); Ludwig & Griggs, *supra* note 133, at 66.

Another factor is that the great majority of pollutants also occur naturally. See note 324, *supra*. This makes it difficult to differentiate between that part of a given volume of pollutants attributable to industrial sources and that portion which may be ascribed to natural processes. Moreover, there is also a problem in phenomena discrimination. For example, investigation of the utility of Landsat for oil pollution monitoring found that reflectance associated with oil spills was "spectrally and quantitatively indistinguishable" from reflectance caused by suspended solids occurring naturally in the same area as a result of tidal cycling. Horvath, *supra* note 127.

tion of the Landsat multispectral scanner may not provide sufficiently detailed information to support the interpretation.[418]

In other situations the interpretational methods may themselves be suspect because they do not conform to optimal procedures. In *Reserve Mining*, for example, the EPA intended to obtain water samples contemporaneously with their aerial reconnaissance of Lake Superior; however, prevailing weather conditions were unsuitable for the aerial mission on the scheduled day, with the consequence that the overflight was conducted 2 days after the samples were collected.[419] The defendant objected to the testimony of the expert interpreter, arguing that simultaneous ground-truth was essential to establish that the green-water effect visible in the images was causd by taconite discharges rather than by natural phenomena.[420] After an extensive examination of the expert witness, the judge decided that the evidence was admissible but "weakened" by the lack of contemporaneous ground-truth.[421] It was thus held in *Reserve Mining* that the defective procedures were sufficiently minor or rebuttable to justify admission of the evidence, albeit with diminished weight, rather than to require its exclusion. In the context of another remote sensing program, however, the absence of contemporaneous ground-truth could prove decisive on the question of admissibility.[422]

A challenge to the validity of the basic interpretational theory employed in a particular case on the ground that it is substantially different from the approved theory is an additional possibility. Illustrative are the Hackensack Meadows cases, where counsel for certain record owners of riparian lands conceded that infrared photography could in some instances be used to draw a biological high water line predicated

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418. The ERTS false color photos are a tool which is relatively new. At the moment it has proved that it may be potentially useful in locating ground water sources, drainage patterns and gross land use patterns. It may also prove to be useful in confirming suspected possible insect and forest disease infestation and to determine their extent. However, it is almost impossible to differentiate from the photographs between forest types and between forest and brush.

Transcript of Proceedings at 9822, Federal Power Commission, City of Seattle, Project No. 553 (Mar. 5, 1975) (testimony of Dr. Gerard F. Schreuder).

419. Record at 981-82, 1008-09, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974).

420. *Id.* at 1009-16.

421. *Id.* at 1016.

422. *See, e.g., In re* License No. 336207, Albert B. Watts (No. 5952/1334, U.S. Coast Guard, 8th Coast Guard District, Port Arthur, Tex., Sept. 18. 1972). In that case photographs were introduced to show oil discharges in the bilge stream of a ship. The expert witness for the defense contended that the presence or quantity of oil could not be determined from photographs without analysis of water samples taken from the bilge stream. Letter from Dr. John Estes, Associate Professor, Department of Geography, University of California at Santa Barbara, to author, Sept. 22, 1975.

on discrimination between tidal and fresh water plant species; nonetheless, the validity of a biological line based on differences in vigors of growth within a single species was vigorously attacked.[423] Assuming that the interspecies interpretational application was judicially accepted, would the use of near infrared photography to detect intraspecies differences constitute an entirely distinct interpretational scheme with a concomitant need for adequate proof of professional acceptance and reliability? Or would it represent a deviation from the accepted model which should be relevant to weight rather than admissibility?[424] This example underscores the difficulty in selecting the appropriate legal remedy when the process actually conducted diverges to some extent from the approved archetype.

2. *Operation of the Process*

The preceding discussion focused on whether the methods selected for a given application were sufficiently similar to those employed in the judicially approved archetypal scientific process. The second general area of inquiry involves the problem of whether those methods were properly applied in a particular instance. In cases where the process utilizes a scientific instrument, it must be determined that the device was correctly operating and correctly operated. The former

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423. Transcript of Record, Vol. II, at 95, Hackensack Meadows Cases, *supra* note 208 (cross examination of Dr. Edward B. Feinberg, N.J. Department of Environmental Protection):

> MR. PORRO [counsel for the record owners]: Isn't the crux and the gravamen of the report that was done in the Hackensack Meadows a delineation within one species as compared to a delineation of various species?
>
> MR. RINDONE [counsel for the State]: Your Honor, what has that got to do with his [e.g., Dr. Feinberg's] qualifications with respect to infrared photography?
>
> MR. PORRO: Because he has testified as to nothing as to his ability to delineate within one species, which is the highly novel aspect . . . .
>
> No one is contending that you can't use this to delineate and use types of species in the wetland. But here we've got a completely different, new, and novel and untested technique and that is delineating within one prime species . . . .

424. The dispute between the parties in the Hackensack Meadows Cases extended only to the weight of the maps prepared by the New Jersey Department of Environmental Protection, and not to their admissibility. This was stipulated by the parties at the outset of the case. Pretrial Order, Hackensack Meadows Cases, *supra* note 208. The reason for the stipulation was that the issue of the validity of the scientific techniques used to prepare the maps was before the Appellate Division of the New Jersey Superior Court in City of Newark v. Natural Resources Council, No. A-3311-72 (N.J. App. Div., filed July 18, 1973). The record owners were given a choice between waiting for the decision in *City of Newark* or stipulating to the validity of the techniques in their own quiet title actions. The same types of technical criticisms, however, were submitted in the Hackensack Meadows Cases in order to decrease the weight given the state maps as could be made in *City of Newark* on the question of admissibility. For a general discussion of *City of Newark*, see text accompanying notes 200-16 *supra*.

requirement, often expressed as a need for calibration of the device, is designed to insure that the particular apparatus was capable of producing an accurate result at the time it was used. The latter requirement is that the instrument be handled in a manner consistent with its specifications. The doctrine of judicial notice, although occasionally appropriate to establish the utility of a selected method, should never be employed to eliminate proof that the method was properly applied in a particular instance.[425]

Although the specific procedures necessarily vary with the device, calibration is generally accomplished by testing a scientific instrument on a substance or condition whose relevant properties are already known. The accuracy of particular radar speedmeters, for example, has been documented in court through testimony that the device produced the correct readings when tested by a set of tuning forks, which vibrate at predetermined frequencies,[426] or that the readings corresponded with the speedometer readings of an automobile driven through the radar field.[427] Logically equivalent proof of calibration has been required for other types of scientific instruments as well.[428]

References to calibration procedures in the transcripts of the identified remote sensing cases have been minimal or nonexistent. The expert witness responsible for the thermal infrared scanning in *Inland Steel* mentioned an overflight of Lake Michigan the day before the evidence was collected to "check out the operation of our equipment," but amplification of that remark was not provided.[429] In *Reserve Mining*

425. State v. Tomanelli, 153 Conn. 365, 216 A.2d 625 (1966); SCOTT, *supra* note 7, §§ 1024, 1263; Boyce, *supra* note 269, at 316.

426. People v. Abdallah, 82 Ill. App. 2d 312, 226 N.E.2d 408 (1967); State v. Snyder, 184 Neb. 465, 168 N.W.2d 530 (1969); People v. Johnson, 23 Misc. 2d 11, 196 N.Y.S.2d 227 (Montgomery County Ct. 1960). *See* Kopper, *supra* note 308, at 352. It should be noted that the accuracy of a radar unit has been held not sufficiently established in the absence of proof that the tuning fork used to check the radar unit was itself accurate. People *ex rel.* McCaun v. Martirano, 52 Misc. 2d 64, 275 N.Y.S.2d 215 (Sup. Ct. 1966). A related method of calibrating radar apparatus is to inject into the devices known frequencies checked against those transmitted by the U.S. Bureau of Standards radio stations. This approach was approved in City of East Cleveland v. Ferell, 168 Ohio St. 298, 154 N.E.2d 630 (1958).

427. Dietze v. State, 162 Neb. 80, 75 N.W.2d 95 (1956); State v. Dantonio, 18 N.J. 570, 115 A.2d 35 (1955); People v. Sachs, 1 Misc. 2d 148, 147 N.Y.S.2d 801 (Magis. Ct. 1955). Some cases have also construed statutes as requiring proof that the automobile speedometer was properly calibrated prior to the test of the radar unit. Whitehead v. Lynchburg, 213 Va. 742, 195 S.E.2d 858 (1973); Sweeney v. Commonwealth, 211 Va. 668, 179 S.E.2d 509 (1971).

428. *See, e.g.*, City of Abilene v. Hall, 202 Kan. 636, 451 P.2d 188 (1969) (blood samples); State v. Stevens, 467 S.W.2d 10 (Mo. 1971), *cert. denied*, 404 U.S. 994 (1971) (NAA).

429. Record at 1876, State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Jan. 27, 1976) (testimony of Albert Pressman).

the EPA expert offered an opinion that the equipment was functioning properly, based on his visual inspection of the imagery and on a comparison of the output produced by two aircraft that flew essentially duplicate missions.[430] No reference to calibration could be identified in the other remote sensing cases.

This omission stems in part from the general lack of attention paid to the specific sensing techniques involved as distinguished from the interpretational procedures employed in the litigation. Moreover, the output of the sensors was usually discussed as if photographs were produced; by implication, therefore, the sensors must have been regarded as cameras. The legal rule requiring proof that a scientific device is operating correctly does not ordinarily apply in the context of photographic submissions.[431] This special treatment of cameras probably arises from the initial rationale under which photographs were admitted: as illustrations of a scene personally observed by a witness.[432] When a witness can and, indeed, must testify that a photograph is a fair and accurate representation of the facts depicted, additional proof that the camera was working properly may not be needed.[433] Such an exception from the requirement for calibration would be inappropriate in connection with remote sensing techniques that record parts of the electromagnetic spectrum inaccessible to the human senses.

430. Record at 983-84, United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974) (examination of Arthur Dybdahl):

> Q [Mr. Thomas Bastow, Pollution Control Section, U.S. Dept. of Justice, one of the Government Attorneys] Could you tell from examining the film whether the equipment was functioning properly?
>
> A Yes, I could, and it was functioning properly.
>
> Q How did you go about doing that?
>
> A The film was visually inspected for such things as exposure, for crispness or sharpness of a particular image in the film. This is to determine whether or not the film was moved in the camera while being exposed unduly, to determine if the exposure was over-exposed or under-exposed, and if the automatic exposure control had worked properly during the flight.
>
> Q Did both aircraft expose film on this study?
>
> A Yes, they did. They both flew the identical target areas.
>
> Q And did the results of their photography agree or not agree?
>
> A They were nearly identical. One aircraft might have flown a few feet one side or the other of the other aircraft, but essentially the target area—oh, incidentally, the next procedure after the imagery is checked for exposure and quality, we plot the imagery. That is to determine if in fact the aircraft did photograph the precise target area that we had specified. In the case of the imagery maybe not being exactly the same, one aircraft might have turned his cameras on a few seconds sooner than the other aircraft. That was the only difference.

In a subsequent discussion Mr. Dybdahl indicated that his office as a matter of course tests its sensors on known targets before each operational mission. Conversation with Arthur Dybdahl, EPA, National Field Investigation Center, Denver, Colo., Aug. 12, 1975. That process, however, was not described in his *Reserve Mining* testimony.

431. SCOTT, *supra* note 7, § 1044.

432. *See, e.g.*, Ruloff v. People, 45 N.Y. 213 (1871).

433. *See* SCOTT, *supra* note 7, § 1044.

The particular calibration procedures desirable for remote sensing applications will vary as a function of the type of instrument, the type of sensing platform,[434] the type of environmental conditions likely to prevail during a mission,[435] and the type of information to be collected. A given sensor may be sufficiently accurate to accomplish one function and yet inadequate for other purposes. As a general proposition the more specific and detailed the remote measurements are intended to be, the more rigorous must be the testing procedures designed to insure that the sensor is operating correctly. This assertion reflects a belief that the need for precise calibration increases proportionately as the margin of acceptable error associated with a remote sensing application is decreased.

The appropriate legal remedy in situations where a party fails to document the proper calibration of a scientific instrument is open to question. With regard to radar speedmeters, the legal application of technology in which calibration problems have most frequently been encountered, the courts appear split on whether exclusion is mandatory in the absence of proof that the device was accurate.[436] Some courts, probably the majority, have ruled radar evidence unconditionally inadmissible in that circumstance,[437] while other decisions have adopted the view that the evidence should be admitted but that a conviction cannot be founded solely on unsubstantiated radar readings.[438] In practice, such evidence is accepted only when corroborated by a police officer's opinion on the speed of an alleged offender. Thus, even the more permissive minority treatment of output from untested radar units goes somewhat beyond the issue of the weight to be accorded the scientific evidence to address its legal sufficiency. Although the trier of fact is normally entitled to assign admitted evidence whatever weight it believes is warranted, a judge or jury is foreclosed as a matter of law

434. The Landsat multispectral scanner, for example, is calibrated in several ways before the satellite is launched. ERTS HANDBOOK *supra* note 14, at G.10-.15. Once in flight, the sensor is calibrated before each image is obtained by having it record light from an on-board lamp element. Once each orbit, the scanner is also calibrated by having it record the sun's radiation as reflected in a mirror. *Id.* at A.9. The information derived from these procedures is then employed when the data is processed on the ground to correct for changes in the characteristics and sensitivity of the device.

435. *See, e.g.*, Ludwig & Griggs, *supra* note 133, at 48-49.

436. Boyce, *supra* note 269, at 316-17; MCCORMICK, *supra* note 7, § 210, at 515; Strong, *supra* note 263, at 18; Annot., 47 A.L.R.3d 822, 828 (1973).

437. Everight v. City of Little Rock, 230 Ark. 695, 326 S.W.2d 796 (1959); State v. Tomanelli, 153 Conn. 365, 216 A.2d 625 (1966); Honeycutt v. Commonwealth, 408 S.W.2d 421 (Ky. 1966); Kansas City v. Hill, 442 S.W.2d 89 (Mo. App. 1969); State v. Dantonio, 18 N.J. 570, 115 A.2d 35 (1955).

438. People v. Barbic, 105 Ill. App. 2d 360, 244 N.E.2d 626 (1969); People v. Abdallah, 82 Ill. App. 2d 312, 226 N.E.2d 408 (1967); People v. Dusing, 5 N.Y.2d 126, 155 N.E.2d 393, 181 N.Y.S.2d 493 (1959).

from convicting on the basis of unsupported evidence from an insufficiently tested radar device.

Operating procedures have been questioned in several remote sensing cases. In *State v. Inland Steel Co.*, for example, counsel for the company attempted to cast aspersion on the contemporaneous ground-truth program conducted by the state because only one water-sampling boat was clearly positioned within the boundaries of the pollution plume depicted in the thermal infrared imagery.[439] As another illustration, in *Canal Authority v. Calloway* both the plaintiff and the federal defendants introduced aerial infrared photography to portray the condition of the forest areas and other environmental features at issue.[440] In a lengthy cross-examination, the Authority's expert interpreter was forced to concede that the oblique camera angle employed to obtain the plaintiff's exhibits could not consistently reproduce the relevant environmental conditions with as high a degree of accuracy as could the defendant's vertical photography.[441] Moreover, the expert admitted that the use of a hand-held camera by the Authority photographer raised serious doubts about the repeatability of the imaging process.[442]

Despite wide acknowledgment by commentators that testimony showing the correct operation of a device or the proper performance

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439. Record at 1998-2005, No. 72 CH 259 (Ill. Cir. Ct., Cook County, Jan. 27, 1976). See notes 160-67 *supra*. The boats were positioned near fixed buoys so that it would later be possible to determine the precise locations where the water samples were collected. *Id.* at 1876. These positions were selected before the thermal sensing overflight, and it was not possible to know in advance exactly what path the effluent plume would traverse as it moved north.

440. Record at 4559-4605, Canal Authority v. Callaway, No. 71-92-Civ-J (M.D. Fla., Feb. 4, 1974); Higer Affidavit, *supra* note 185, at 4. See text accompanying notes 182-84 *supra*.

441. The Canal Authority's expert was cross-examined with respect to an affidavit prepared by one of the federal defendants' experts. This affidavit criticized oblique photography because of (a) atmospheric attenuation causing color variations, (b) scale variation as a function of distance from the "isocenter," (c) the "masking effect" of a tilted camera, and (d) the constant problem of repeatability with hand-held photography. The Canal Authority's expert generally agreed with the criticisms contained in the affidavit and with the conclusion contained therein that the vertical imagery was superior to the oblique imagery. He noted, however, that some of those criticisms applied in part to vertical as well as oblique photography, and he took exception to the claim contained in the affidavit that oblique photography is highly unreliable for quantitative determinations. Record at 4596-4603.

442. *Id.* at 4597-4603. It may also be noted that the ground-truth program carried out in connection with the Canal Authority's aerial oblique survey was minimal, and that the imagery might have been attacked on that basis. *Id.* at 4560-61. With respect to photographs generally, commentators have noted that height and camera angle can often cause distortion. SCOTT, *supra* note 7, §§ 246, 924; Fischnaller, *supra* note 273, at 296-310.

of a test is a necessary element in laying the foundation for scientific evidence,[443] this second aspect of the presentation has received relatively little independent consideration in the case law.[444] In situations where an archetypal scientific technique has not yet achieved legal recognition, the evaluation of operating procedures is apparently subsumed within the overall *Frye* doctrine analysis.[445] In instances where the model has been accepted, courts sometimes explicitly address inadequacies in the conduct of prescribed procedures,[446] but more often judicial reservations about the performance of a test manifest themselves in a more subtle fashion.[447] As with the other issues involved in proof of proper conduct, the demarcation line is unclear between those deficiencies in operating procedures that lead to exclusion of evidence and those that result in diminution of its weight.[448] In general, the admissibility decision hinges on judicial perceptions of the

443. *See, e.g.*, McCORMICK, *supra* note 7, § 209, at 511 (chemical tests); Ahrens, *supra* note 252, at 624 (sound recordings); Strong, *supra* note 263, at 20-21.

444. Annot., 47 A.L.R.3d 822, 838-39 (1973).

445. For example, it has been suggested that the possibility of error in the administration of breath tests for intoxication was a significant factor in judicial reluctance to accept that technique. *See, e.g.*, People v. Morse, 325 Mich. 270, 38 N.W.2d 322 (1949); Boyce, *supra* note 269, at 317-19. *See also* Portland Cement Ass'n v. Ruckelshaus, 486 F.2d 375, 400-01 (D.C. Cir. 1973), where variations in the results of Ringelmann opacity readings during a controlled experiment were cited by the court as justifying the rejection of the opacity monitoring technique for enforcement of air pollution standards until such time as the EPA could prove its reliability. The EPA subsequently conducted extensive tests on the Ringelmann technique, *see* 39 Fed. Reg. 39872, 74 (1974), and the court of appeals thereafter approved their use in enforcement actions. Portland Cement Ass'n v. Train, 513 F.2d 506 (D.C. Cir. 1975).

446. *See, e.g.*, State v. Brezina, 45 N.J. Super. 596, 133 A.2d 366 (Union County Ct. 1957); State v. Michener, 25 Or. App. 523, 550 P.2d 449 (1976); Reyna v. State, 508 S.W.2d 632 (Tex. Crim. 1974). *Cf.* City of Monroe v. Robinson, 316 So. 2d 119 (La. 1975); State v. Greul, 59 N.J. Super. 34, 157 A.2d 44 (Union County Ct. 1959).

447. *See, e.g.*, State v. Holt, 17 Ohio St. 2d 81, 246 N.E.2d 365 (1969), which held a conclusion based on neutron activation analysis that two substances were "likely" to have a common origin insufficiently certain to serve as a basis for admissibility. The court noted, however, that the hair samples had not been cleaned before the test was administered and that they were subsequently altered or destroyed, raising the possibility that these deficiencies affected the degree of certainty that the court chose to require of the evidence.

448. *Compare* Bortz Coal Co. v. Air Pollution Comm'n, 2 Pa. Commw. Ct. 441, 279 A.2d 388 (1971), in which an air pollution abatement order was remanded for additional evidence because the engineer who testified that the company had violated the applicable opacity standard did not have a copy of the Ringelmann opacity chart in his presence when he made his observations, *with* People v. International Steel Corp., 102 Cal. App. 2d Supp. 935, 226 P.2d 587 (App. Dep't Super. Ct. 1951), where the court held that an experienced smoke plume reader need not have the Ringelmann chart in his presence when making opacity observations. In a subsequent *Bortz* case, Bortz Coal Co. v. Department of Env'l Resources, 7 Pa. Commw. Ct. 362, 299 A.2d 670 (1973), the successor agency to the Air Pollution Commission reinstated its abatement order and was affirmed on the strength of Ringelmann data obtained with the assistance of the chart.

likelihood and severity of the error and on the probable consequences of admission or exclusion.[449]

3. *Operator Qualification*

An assessment of the correctness of the operation of an instrument or performance of a test is often linked in judicial opinions to the third general area of inquiry: whether a scientific process was conducted by properly qualified persons. There is little to say in this regard beyond the conclusions drawn in the section of this Article devoted to expert testimony.[450] What qualifications are essential must be determined in light of the tasks that a potential witness is expected to accomplish, and individuals should not be permitted to testify on subjects for which their particular qualifications are inappropriate. These principles are expressed in decisions holding that a given witness, although entirely competent as a technician to conduct an approved test, does not possess the proper credentials to establish the degree of professional acceptance and reliability necessary for judicial recognition of the archetype.[451]

When the conduct of a scientific process has become so routine that only a limited series of well-defined and objective actions are required, the acceptable qualifications of the operator may be quite minimal. This observation may be documented in connection with the backgrounds of X-ray technicians[452] and the police officers who ordinarily operate radar speedmeters.[453] When the process is routine but an element of subjective interpretation is involved, the courts must be

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449. *See, e.g.*, Bortz Coal Co. v. Air Pollution Comm'n, 2 Pa. Commw. Ct. 441, 279 A.2d 388, 398 (1971):

> The Commonwealth here, in effect, is ordering the shutdown of Bortz's coke ovens. This is no small matter. To permit the Commission to order an abatement based solely upon the visual tests and observations of one employee strikes at the heart of fairness envisioned in every judicial process known to our system of jurisprudence.

On appeal, a combination of additional economic data and opacity testing conducted with the assistance of the Ringelmann chart persuaded the court to affirm the reinstated abatement order. Bortz Coal Co. v. Department of Env'l Resources, 7 Pa. Commw. Ct. 362, 299 A.2d 670 (1973).

450. See text accompanying notes 217-62 *supra*.

451. People v. Kelly, 17 Cal. 3d 24, 36-40, 549 P.2d 1240, 1248-50, 130 Cal. Rptr. 144, 152-54 (1976) (voiceprints); People v. Torpey, 204 Misc. 1023, 128 N.Y.S.2d 864 (Sup. Ct. 1953) (radar).

452. McCORMICK, *supra* note 7, § 214; SCOTT, *supra* note 7, § 1263.

453. *E.g.*, People v. Stankovich, 119 Ill. App. 2d 187, 255 N.E.2d 461 (1970); State v. Graham, 322 S.W.2d 188 (Mo. App. 1959); Cromer v. State, 374 S.W.2d 884 (Tex. Crim. 1964).

assured that the operator has not only the requisite training but also the capability of producing consistently reliable results. In the case of smoke plume readers, for example, the relevant regulations require that trainees must be tested for proficiency before accreditation and not less than once every 6 months thereafter.[454] One conducting a routine scientific process need not in all instances be characterized as an expert witness, but can testify on the basis of personal knowledge.[455] On the other hand, the qualifications of the operator of a process will be closely scrutinized when subjective interpretation is a major component of the technique or when the validity of the process is itself in doubt.[456]

4. *The Appropriate Remedy for Improper Conduct*

As with most other issues in the law of scientific evidence, the determination that proper methods were selected for use in a given case and that qualified individuals correctly applied those methods lies within the discretion of the trial court. The exercise of that discretion will be shaped by the particular legal and factual setting in which the evidence is introduced.[457] In this regard, two related criteria are preeminent in assessing potential deficiencies in the conduct of a process: (1) the likelihood and severity of the discrepancies; and (2) the extent to which the opposing party can bring out the shortcomings in the process as conducted.

When the operation of a technique is in issue, the *Frye* doctrine and reliability analysis will already have established an approved model of the process and, also, the existence of a pool of experts qualified to evaluate the selected methods. In each case the trial judge must decide that the particular methods selected for use do not diverge so much from the approved model that a new professional acceptance and reliability inquiry is required. Judicial approval of the methods selected in effect acknowledges that the process could produce valid results if properly conducted. In cases where valid archetypes exist

454. *See, e.g.*, Lloyd A. Fry Roofing Co. v. State Dep't of Health, 553 P.2d 800, 807 (Colo. 1976); State v. Lloyd A. Fry Roofing Co., 9 Ore. App. 189, 495 P.2d 751, 755-56, 51 A.L.R.3d 1007, 1014-15, *remanded*, 263 Ore. 300, 502 P.2d 253, *adhered to on remand*, 11 Ore. App. 403, 502 P.2d 1162 (1972); 39 Fed. Reg. 39872, 39874-75 (1974).

455. *See, e.g.*, City of Portland v. Lloyd A. Fry Roofing Co., 3 Ore. App. 352, 357-58, 472 P.2d 826, 829 (1970); State v. Lloyd A. Fry Roofing Co., 9 Ore. App. 189, 495 P.2d 751, 756, *remanded*, 263 Ore. 300, 502 P.2d 253, *adhered to on remand*, 11 Ore. App. 403, 502 P.2d 1162 (1972); Annot., 51 A.L.R.3d 1007, 1014 (1972).

456. Forkosch, *supra* note 286, at 302-05; McCORMICK, *supra* note 7, § 207; Strong, *supra* note 263, at 21.

457. Stricter compliance with recognized procedures might, as an example, be required in a felony prosecution than in a civil or administrative action. *Cf.* People v. Kelly, 17 Cal. 3d 24, 32, 549 P.2d 1240, 1245, 130 Cal. Rptr. 144, 149 (1976).

against which to compare the actual conduct, and where expert witnesses are available to criticize the conduct, it may not be inequitable to require the opposing party to document potential deficiencies if able to do so. In these cases, therefore, potential deficiencies in the conduct of a scientific process should lead to diminution of the weight rather than to exclusion of evidence.

That conclusion must, however, be limited to situations in which the opposing party is able to establish deficiencies to the extent they exist. In some instances—for example, when the accuracy of a scientific instrument was not documented near the time of its use or when influential variables were not controlled—no amount of contrary testimony or cross-examination will be sufficient to determine the probability or severity of error. After the admission of output from an untested device, the trier of fact must decide as a matter of faith whether the instrument in question was or was not functioning properly. In a technologically oriented society it is reasonable to suppose that a presumption of reliability will often be entertained. In this and similar situations, the best an opposing litigant could do would be to point out the uncertainties involved; yet such a showing may be inadequate to counteract the usual persuasiveness of scientific evidence. As an equitable consideration the opposing party could seldom prove that a given device was inaccurate, whereas the proponent of a scientific technique has the opportunity to establish the reliability of the instrument at the time it is operated.[458] When the discrepancy between the archetypal process and the actual application prevents the opposing party from presenting an informed critique of the results, the appropriate judicial action should be exclusion of the evidence. This conclusion is a corollary of the proposition, advocated throughout this Article,[459] that the burden of persuasion ought to be placed on the litigant who conducts a scientific process, collects the evidence, and urges its admission in court.

D. Authentication and Proof of Contents

1. Relevant Legal Doctrines

The quest for *reliable* evidence is at the heart of the legal requirement that a scientific process be proved to be valid and properly con-

458. Courts generally require not only that adequate tests must be conducted, but that they must be conducted near enough in time to the operational use to insure that the device did not become inaccurate in the intervening period. *See, e.g.*, City of St. Louis v. Boecker, 370 S.W.2d 731 (Mo. App. 1963); Royals v. Commonwealth, 198 Va. 876, 96 S.E.2d 812 (1957) (same). *But see* Thomas v. Norfolk, 207 Va. 12, 147 S.E.2d 727 (1966) (holding sufficient tests conducted at the beginning and end of a 7-hour period, despite the fact that the device had been moved during that time).

459. See text accompanying notes 263-78 *supra*.

ducted in each specific instance. Assurance of reliability is equally basic to the requirement for authentication of demonstrative evidence,[460] but authentication involves establishing the identity of a submission rather than the truth of its contents.[461] In the case of X-ray evidence, for example, the image must in fact be one of the person who is allegedly depicted.[462] There must, in addition, be proof that the X-ray image has not been so altered in the interval between when it was taken and the time it is introduced into evidence that it no longer reflects the original conditions.[463] For graphic representations, including photographs and remote sensing output as well as X-ray images, the authentication prerequisites may be addressed in terms of two essential issues: (1) does the image actually portray what it purports to depict; and (2) is the image submitted in court legally equivalent to that which was initially obtained? The authentication formulation in the Federal Rules of Evidence is even more generally phrased, providing that the requirement may be satisfied "by evidence sufficient to support a finding that the matter in question is what its proponent claims."[464] Although on a conceptual level the function of authentication is quite straightforward,[465] this area of the law of evidence is unfortunately

460. McCormick defines demonstrative evidence as follows:

> There is a type of evidence which consists of things, e.g., weapons, whiskey bottles, writings, and wearing apparel, as distinguished from the assertions of witnesses (or hearsay declarants) about things. Most broadly viewed, this type of evidence includes all phenomena which can convey a relevant firsthand sense impression to the trier of fact, as opposed to those which serve merely to report the secondhand sense impressions of others.

MCCORMICK, *supra* note 7, § 212, at 524 (footnotes omitted).

461. *See generally* MCCORMICK, *supra* note 7, §§ 218-19, 222, 227; Comment, *Authentication & the Best Evidence Rule Under the Federal Rules of Evidence*, 16 WAYNE L. REV. 195 (1969); Comment, *Authentication & Identification*, 27 ARK. L. REV. 332 (1973) [hereinafter cited as Comment, *Authentication & Identification*].

462. *See* 3 WIGMORE (Chad. rev.), *supra* note 7, § 795, at 245; RICHARDSON, *supra* note 221, § 16.19; Comment, *Demonstrative Evidence*, 27 ARK. L. REV. 379, 386-87 (1973) [hereinafter cited as Comment, *Demonstrative Evidence*]; Ahrens, *supra* note 252, at 619; Note, *Evolving Methods, supra* note 253, at 714-16 (1967); Annot., 5 A.L.R.3d 303, 316-29 (1966).

463. Annot., 5 A.L.R.3d 303, 331-32 (1966).

464. FED. R. EVID. 901(a). *See also* CAL. EVID. CODE § 1400 (West 1966):

> *Authentication defined.* Authentication of a writing means (a) the introdnction of evidence sufficient to sustain a finding that it is the writing that the proponent of the evidence claims it is or (b) the establishment of such facts by any other means provided by law.

465. *See, e.g.*, the Advisory Committee's Note to FED. R. EVID. 901(a), at 411:

> Authentication and identification represent a special aspect of relevancy. Michael and Adler, Real Proof, 5 Vand. L. Rev. 344, 362 (1952); McCormick §§ 179, 185; Morgan, Basic Problems of Evidence 378 (1962). Thus a telephone conversation may be irrelevant because on an unrelated topic or because the speaker is not identified. The latter aspect is the one here involved. Wigmore describes the need for authentication as "an inherent logical necessity." 7 Wigmore § 2129, p. 564.

REDDEN & SALTZBURG, *supra* note 219, at 345. *See also* MCCORMICK, *supra* note 7,

beset by tenuous distinctions of questionable utility[466] with the result that, in more than a few instances, form and characterization have prevailed over substance and common sense.[467] The prescribed and sometimes rigidly applied rules for authentication vary according to the nature of the particular type of submission in question. For that reason the general authentication provision in the Federal Rules of Evidence is of less practical import than the 10 illustrative examples that accompany it.[468]

In contrast to everyday practice,[469] the law usually requires the identity of a submission to be proved by extrinsic facts and testimony rather than by an inspection of the contents or properties of the submission itself.[470] The first step of an ideal authentication process, then, consists of testimony by a witness who personally observed the object used, the document written, or the scene portrayed by a photograph. Thereafter, a complete chain of custody for the exhibit must be documented: the evidence should be directly traceable from the moment it is created or assumes legal significance to the time of submission, and each custodian should be able to substantiate that the object, document, or image was preserved in an essentially unchanged condition during the period of his possession.[471]

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§ 218; Broun, *Authentication & Contents of Writings*, 1969 J. LAW & SOC. ORDER 611 [hereinafter cited as Broun].

466. *See, e.g.*, MCCORMICK, *supra* note 7, § 212 for the distinction between *direct* and *circumstantial* demonstrative evidence, or that between *real, original* and *illustrative* evidence. *See also* Broun, *supra* note 465, at 624-25 (discussion of the best evidence rule in the context of whether the evidence is submitted as proof of its contents).

467. *See, e.g.*, Alexander & Alexander, *The Authentication of Documents Requirement: Barrier to Falsehood or to Truth?*, 10 SAN DIEGO L. REV. 266 (1973); MCCORMICK, *supra* note 7, § 218, at 544-45; Broun, *supra* note 465, at 611-12, 615-20.

468. FED. R. EVID. 901(b)(1)-(10).

469. In the everyday affairs of business and social life, it is the custom to look merely at the writing itself for evidence as to its source. Thus, if the writing bears a signature purporting to be that of X, or recites that it was made by him, we assume, nothing to the contrary appearing, that it is exactly what it purports to be, the work of X. At this point, however, the law of evidence has loug differed from the commonsense assumption upon which each of us conducts his own affairs, adopting instead the position that the purported signature or recital of authorship on the fact of a writing will *not* be accepted as sufficient preliminary proof of authenticity to secure the admission of the writing in evidence.

MCCORMICK, *supra* note 7, § 218, at 544 (emphasis in original) (footnote omitted).

470. *See* Berger, *Article IX: Authentication & Identification*, 33 FED. BAR J. 79 (1974) [hereinafter cited as Berger]. It is also noteworthy that the provisions relating to the self-authentication exceptions in FED. R. EVID. 902 begin with the following language: "Extrinsic evidence of authenticity as a condition precedent to admissibility is not required with respect to the following: . . .", which suggests that under the Federal Rules of Evidence, extrinsic evidence is ordinarily required for purposes of authentication.

471. MCCORMICK, *supra* note 7, § 212, at 527-28.

Although an exposition at trial of the full chain of custody for each item of demonstrative evidence might be desirable from the limited perspective of compliance with the rules of evidence, it would often be unnecessarily cumbersome, expensive, and time-consuming in the absence of a serious challenge to the authenticity of the exhibit. Many of the illustrative examples in the Federal Rules of Evidence are directed at simplifying proof of authentication in situations where a less extensive presentation is likely to produce a sufficiently reliable outcome. As a general proposition the courts have required a more elaborate development of the chain of custody with respect to types of evidence perceived as easily exchangeable or especially susceptible to intentional or accidental alteration.[472] In view of the diversity of potential remote sensing techniques and the different formats in which remote sensing information may be introduced in court, the authentication procedures appropriate in any given case may range from a minimal showing of identity to an exhaustive demonstration of the complete chain of custody.

The requirement for authentication is closely related to the "best evidence" rule, since both seek to insure that an exhibit introduced in litigation is the article it purports to be. The best evidence rule, however, goes further by prohibiting any testimony or other evidence concerning the contents of a document unless the original is produced or a satisfactory explanation for its absence is provided.[473] The Federal Rules of Evidence explicitly broaden the traditional scope of the best evidence rule to include recordings and photographs as well as written documents.[474] Moreover, the definitions of "writings," "recordings," and "photographs" incorporated in Rule 1001 and the accompanying commentary make clear that an expansive coverage was intended whenever the contents of a submission are in issue.[475] In view of the

472. *Compare* Annot., 21 A.L.R.2d 1216 (1952), *with* Annot., 5 A.L.R.3d 303 (1966).

473. The basic rationale for the rule is that oral testimony regarding the contents of a document is more likely to be unreliable than an inspection of the document itself. *See, e.g.*, Broun, *supra* note 465, at 615-20; MCCORMICK, *supra* note 7, § 231.

474. Requirement of Original

> To prove the content of a writing, recording, or photograph, the original writing, recording, or photograph is required, except as otherwise provided in these rules or by Act of Congress.

FED. R. EVID. 1002.

475. Definitions.

> For purposes of this article the following definitions are applicable:
>
> (1) Writings and recordings.—"Writings" and "recordings" consist of letters, words, or numbers, or their equivalent, set down by handwriting, typewriting, printing, photostating, photographing, magnetic impulse, mechanical or electronic recording, or other form of data compilation.
>
> (2) Photographs.—"Photographs" include still photographs, X-ray films, video tapes, and motion pictures. . . .

FED. R. EVID. 1001.

specific inclusion of X-ray films and computer data within the purview of the best evidence rule, it appears extremely probable that similar requirements will be imposed on remote sensing evidence.[476]

2. *Authentication of Public Records*

In past remote sensing cases the substantial majority of submissions were initially collected by government agencies and could be authenticated as public records. The color infrared photographs entered by the Army Corps of Engineers in the unauthorized landfill cases cited above,[477] for example, were supplied to the Jacksonville District of the Corps as certified true copies of official records maintained by the records custodian of the Johnson Space Center in Houston.[478] The NASA mission manager who directed the aerial reconnaissance also submitted a notarized affidavit in which the identifying characteristics of the film and the flight plan were described in greater detail.[479] In much the same manner the United States Geologi-

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476. *See, e.g.*, the Advisory Committee's Note to FED. R. EVID. 1002:

> On occasion, however, situations arise in which contents are sought to be proved. Copyright, defamation, and invasion of privacy by photograph or motion picture fall in this category. Similarity [sic] as to situations in which the picture is offered as having independent probative value, e.g. automatic photograph of bank robber. . . . The most commonly encountered of this latter group is of course the X ray, with substantial authority calling for the production of the original. . . .

Id. at 434 (citations omitted); REDDEN & SALTZBURG, *supra* note 219, at 366.

As noted earlier in this Article, remote sensing images must similarly be treated as independent evidence rather than as illustrations of the personal observations of a witness. Therefore, their contents are in issue and the original image may well be required.

477. See text accompanying notes 194-99 *supra.*

478. The operative passage from the certification form, prepared pursuant to 14 C.F.R. § 1204.505 (1976) and dated July 30, 1975. was as follows:

> I hereby certify that the annexed documents, listed or described below, are true copies of official records (or extracts therefrom) maintained in *Photographic Technology Division, NASA/Johnson Space Center, Houston Tx 77058,* and that I am the custodian thereof: *Photograph—27" x 27" color copy of Frame 4815 of Roll #1, Line #1, Run #1 of Mission 122, RC8 #1 Camera, Test Site 169 flown on March 9, 1970.* Edward O. Zeitler, Records Custodian. [text in italics was typewritten, text in roman was printed]

479. 1. I, Frank B. Newman, Chief Mission Manager Section, Flight Operations Branch, Aircraft Operations Division, Flight Operations Directorate, NASA/Lyndon B. Johnson Space Center (JSC), Houston, Texas, give the following statement which is true and complete to the best of my knowledge and belief.

> 2. As Mission Manager of NASA/JSC's Earth Resource Aircraft Mission 122 during March 1970, I certify that Frame 4879 of Roll 1, Line 1, Run 1, RC8 Camera of Mission 122, Task Site 169, was exposed on March 9, 1970, between 20 hours 17 minutes and 20 hours 43 minutes Greenwich Mean Time. The most proximate time of exposure of Frame 4879, described above, is 20 hours, 42 minutes, 11 seconds, Greenwich Mean Time, or 15 hours, 42 minutes, 11 seconds, Eastern Standard Time on March 9, 1970. . . .

Affidavit of Frank B. Newman, Harris County, Fla., May 23, 1975, Taylor v. United States (District Engineer), No. 75-150-CIV-WM (S.D. Fla., Dec. 5, 1975).

cal Survey, which is responsible for the regular distribution of satellite data and other earth resources information to the public, prepared certified copies[480] of selected Landsat (ERTS) images for introduction by the Vermont Attorney General in *Vermont v. New York*.[481]

Remote sensing images may be authenticated as public records under Federal Rules 901 and 902. These Rules represent similar treatments, differing only in the necessity for extrinsic evidence of authenticity in the case of submissions not certified as true copies by an authorized official. When certification is lacking, testimony from a responsible government custodian that the data introduced in court is an accurate reproduction of the information lawfully recorded in a public office is sufficient to satisfy the authentication requirement.[482] In those cases where a certified copy is produced, it is self-authenticating and no testimony will be necessary on the issues of identity and chain of custody.[483]

Since the entry and operating costs of remote sensing are fairly high and since a growing body of official sensing images is readily

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480. *PURSUANT to the act approved August 24, 1912,* (37 Stat. 497) *as amended* (43 U.S.C., sec. 1460), *I hereby certify that the annexed* is a true photographic copy of imagery obtained from the Earth Resources Technology Satellite (ERTS-1) on which the annotations show that the data were obtained on October 10, 1972, at 10:12:20 AM Eastern Standard Time from an altitude of 570 statute miles and an identification number E-1079-15122-5. The copy is an enlargement representing a scale of approximately 1/1,000,000 obtained from the Multispectral Scanner band number 5 showing the region between the Northwest coruer (44°03.5'N, 74°42.5'W); the Northeast corner (43°42.5'N, 72°17'W); the Southeast corner (42°03'N, 73°05'W); and the Southwest corner (42°29.5'N, 75°17'W). I further certify that the negative used to produce this copy was received from the National Aeronautics and Space Administration and is in the official files of the Geological Survey. . . . [text in italics was printed; text in roman was typewritten.]

Affidavit of Acting Director, U.S. Geological Survey, Washington, D.C., Mar. 23, 1973; Vermont v. New York, 417 U.S. 270 (1974).

481. 417 U.S. 270 (1974).

482. (b) *Illustrations.* By way of illustration only, and not by way of limitation, the following are examples of authentication or identification conforming with the requirements of this rule:

. . . .

(7) *Public records or reports.* Evidence that a writing authorized by law to be recorded or filed and in fact recorded or filed in a public office, or a purported public record, report, statement, or data compilation, in any form, is from the public office where items of this nature are kept. . . .

FED. R. EVID. 901.

483. *Self-authentication*

Extrinsic evidence of authenticity as a condition precedent to admissibility is not required with respect to the following:

(1) *Domestic public documents under seal.* A document bearing a seal purporting to be that of the United States, or of any State, district, Commonwealth, territory, or insular possession thereof, or the Panama Canal Zone, or the Trust Territory of the Pacific Islands, or of a political subdivision, department, officer, or agency thereof, and a signature purporting to be an attestation or execution.

(2) *Domestic public documents not under seal.* A document purporting

available to the public, it is likely that much of the future sensing activity with potential relevance for environmental litigation will be conducted by government agencies. For that reason the introduction of remote sensing images as public records will often prove to be the most expeditious way to fulfill the requirement for proper authentication. It must, however, be emphasized that submissions adequately authenticated may still be inadmissible as evidence, because authentication is only one element of the necessary foundation. The following discussion is directed at remote sensing images that cannot qualify as public records, because those submissions pose more serious conceptual problems when evaluated in the context of the authentication and best evidence prescriptions of the law of evidence. In the course of this analysis it will be necessary to distinguish between three general classes of remote sensing output, previously described as (1) photographic images, (2) reconstructed images, and (3) enhanced images.[484]

3. *Treatment of Photographic Images*

Conventional photographs are ordinarily introduced to illustrate the personal observations of a testifying witness.[485] Consequently, the typical authentication procedures are quite cursory, requiring only testimony that the images submitted in court accurately portray matters seen by the witness.[486] The procedures designed to compensate for the absence of firsthand knowledge about the contents of X-ray images provide a more relevant model for the authentication of photographic

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to bear the signature in his official capacity of an officer or employee of any entity included in paragraph (1) hereof, having no seal, if a public officer having a seal and having official duties in the district or political subdivision of the officer or employee certifies under seal that the signer has the official capacity and that the signature is genuine.

FED. R. EVID. 902.

484. See text accompanying notes 12-16 *supra* for a detailed description of the most common kinds of output.

485. *See, e.g.*, Paradis, *The Celluloid Witness*, 37 U. COLO. L. REV. 235, 240-41 (1965); Comment, *Contents of Writings, Recordings, & Photographs*, 27 ARK. L. REV. 357, 366 (1973) [hereinafter cited as Comment, *Contents of Writings*]; MCCORMICK, *supra* note 7, § 214; SCOTT, *supra* note 7, § 1021; 3 WIGMORE (Chad. rev.), *supra* note 7, § 790. This is not the only rationale under which photography may be introduced into evidence, however. Photographs may also serve as "silent witnesses," based upon the demonstrated reliability of the photographic technique. 3 WIGMORE (Chad. rev.), *supra* note 7, § 795, at 244 n.1; *see also* MCCORMICK, *supra* note 7, § 214.

486. *See, e.g.*, Comment, *Demonstrative Evidence*, *supra* note 462, at 383; Comment, *Authentication and Identification*, *supra* note 461, at 343. *See also* authorities cited in note 485 *supra*. Where the photography is offered as independent evidence, however, instead of as an adjunct to the testimony of a witness, a somewhat more detailed foundation is required. The reliability of the particular camera as well as some indication of when, where, and how the pictures were taken must be established. SCOTT, *supra* note 7, §§ 1024-27.

images produced by remote sensing techniques.[487] In the case of X-ray images, the identity of the subject can be established through the presentation of several complementary or alternative modes of proof. Commonly, the technician or doctor[488] responsible for operation of the device testifies that the image submitted in court is in fact the X-ray photograph of the alleged subject taken at a particular place and time.[489] The operator ordinarily marks the original plate with identifying information when it is exposed,[490] or, in some instances, the X-ray machine may have the capacity automatically to include this identifying data in the image itself. Additional testimony is then elicited that the image was preserved in an orderly manner to preclude the possibility of substitution or confusion.[491] A doctor may also testify that features revealed in the submission correspond with physical conditions unique to the alleged subject,[492] so that the image is unlikely to be one of another person. Moreover, X-ray images have been accepted by some courts on a business records rationale[493] when the device operator and supervising physician were unavailable or unwilling to testify.[494]

In regard to the possibility of intentional or accidental modification of the evidence, X-ray negatives are relatively impervious to deteriora-

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487. McCORMICK, *supra* note 7, § 214, at 531-32; SCOTT, *supra* note 7, § 1262; Comment, *Demonstrative Evidence, supra* note 462, at 386-87; Note, *Evolving Methods, supra* note 253, at 714-16.

488. Ahrens, *supra* note 252, at 619; SCOTT, *supra* note 7, §§ 1263-65; Comment, *Demonstrative Evidence, supra* note 462, at 386-87. It is not necessary that the supervising doctor be present when the X-rays are taken. SCOTT, *supra* note 7, §§ 1264-65. The radiologist or X-ray technician responsible for operating the X-ray machine under the doctor's supervision is thought sufficiently competent to assure that the device has been operated in accordance with proper procedures. Identification of the image offered in evidence with the object or person it purports to depict is provided by the record-keeping procedures employed at the hospital at which the X-ray image is taken.

489. Ahrens, *supra* note 252, at 619; SCOTT, *supra* note 7, § 1263; Annot., 5 A.L.R.3d 303, 320-27 (1966).

490. SCOTT, *supra* note 7, §§ 1265, 1267; Annot., 5 A.L.R.3d 303, 327-29 (1966). Markings are not by themselves sufficient to authenticate the X-ray plates in evidence, however, and usually are offered in combination with testimony of the supervising physician or X-ray technician as to the procedures used to assure authenticity. *Id.*

491. *See, e.g.*, Texas Gen. Indem. Co. v. Thomas, 428 S.W.2d 463 (Tex. Civ. App. 1968), *error ref. n.r.e.*; SCOTT, *supra* note 7, §§ 1265, 1267.

492. *See, e.g.*, Stamets v. Wilson, 89 Ind. App. 403, 164 N.E. 300 (1928); SCOTT, *supra* note 7, § 1263.

493. Although the business records exception is usually applied in the context of the hearsay rule, its underlying rationale, that a reliable recordkeeping system has been employed, makes it equally applicable to authentication. *See* cases cited in SCOTT, *supra* note 7, §§ 1263, at 99-100, 1265, 1267. *See also* Comment, *Authentication & Identification, supra* note 461, at 364-65. As with hearsay, however, the same considerations limiting the business records exception to data not gathered in preparation for litigation should apply. *Cf.* Palmer v. Hoffman, 318 U.S. 109 (1943); MCCORMICK, *supra* note 7, § 308.

494. *See, e.g.*, Beard v. Turritin, 173 Miss. 206, 161 So. 688 (1935).

tion or alteration once the film has been developed, so that establishment of a complete chain of custody at trial is rarely required. Testimony of the supervising custodian is generally deemed sufficient, and such testimony may be based on the general recordkeeping practices of the office or institution rather than on direct personal knowledge.[495] There is ordinarily no necessity to document the handling of an X-ray image by each participant in the recordkeeping process, as there may be in connection with chemical samples or specimens of body tissue,[496] because it is improbable that the content of the image would have changed significantly in the interval between creation and submission. This argument applies with equal force to the handling of remote sensing images recorded directly on film.

Paralleling the pattern customary for the introduction of X-ray photographs, the testimony devoted to authentication in the remote sensing cases discussed in this Article primarily concerned the operating characteristics of the sensors, the nature of the film employed, and the identity of the features depicted in the images. In no instance was the operation of the sensing process fully described, nor was documentation of a subsequent chain of custody ever provided.[497] Although none of the cases involved a sustained challenge to the authenticity of the remote sensing evidence,[498] it cannot be determined in what meas-

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495. SCOTT, *supra* note 7, § 1287.

496. *See, e.g.*, Novak v. District of Columbia, 160 F.2d 588 (D.C. Cir. 1947); Note, *Evolving Methods, supra* note 253, at 762-63 n.17; Annot., 21 A.L.R.2d 1216 (1952).

497. In *Reserve Mining*, for example, the details of the chain of custody procedures adopted by the National Field Investigation Center of the EPA were not presented at trial. With respect to the handling of film, the following is a summary of the more important steps: (1) when the film is received from Kodak, it is inspected to make sure all seals are properly in place; (2) the film is then kept in a freezer to prevent deterioration and not removed until the day before the mission; (3) the original seals are not broken until the film is loaded into the surveillance aircraft's camera magazines; (4) after exposure, the film is immediately taken to a darkroom where it is replaced in the original film cans and resealed; (5) the film is hand-carried to an Air Force base where it is processed according to Kodak specifications; (6) the film characteristics (type of emulsion) are reverified and the processor is first certified with precalibrated process control strips; (7) the film comes out of the processor as dry negatives or positives; (8) the film is then returned to NFIC by the person who carried it to the Air Force facility and remained with it during the processing stage; (9) the resulting images are checked for quality control, including whether the color balance and exposure level are proper for the film, filter and camera combination used; (10) the images are plotted to make sure the entire target area was covered; (11) finally, each roll of film is assigned a unique designation number and stored in a locked film library. Conversation with Arthur Dybdahl, EPA, National Field Investigation Center, Denver, Colo., Aug. 13, 1975.

498. There is some intimation that authentication problems played a role in Ewell v. Petroleum Processors, No. 143, 388 (La. Dist. Ct., E. Baton Rouge Parish, 19th Jud. Dist., July 2, 1975). The transcripts of that case, however, were not available to the authors of this Article for examination. A correspondent described the case as follows:

> This particular case involved an attempt on the part of the plaintiff's attorney

ure this uniform acquiescence was attributable to the adequacy of the procedures employed by proponents of the evidence, to the prevailing tendency in litigation to treat remote sensing images as if they were conventional photographs, to the fact that most of the images were collected by government agencies and thus had some claim to status as public records,[499] or to the overall strategy adopted by opposing litigants. Unquestionably, each of these elements contributed to the acceptance of remote sensing evidence in particular cases.

In *State v. Inland Steel Co.*[500] counsel for the defendant stipulated to the authenticity of the Skylab color photograph (Plate 8),[501] but insisted on an explicit foundation for the other remote sensing images. The EPA expert witness, who had planned and accompanied the reconnaissance mission, first introduced a mosaic of color photographs (Plate 7b) taken at the same time as the thermal infrared submissions (Plates 6 and 9a).[502] The mosaic was used to show the flightline of the aircraft and to identify geographical features in the Chicago area, but it did not reveal the extent or the direction of the effluent plume.[503] The witness then emphasized the simultaneity of the photographic and thermal infrared sensing operations in order to identify the areal coverage of the thermal imagery.[504] In addition, some of the geographical features visible in the color photographs were also distinguishable in the corresponding thermal output.[505]

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to introduce a 35 mm color slide (copy) of an infra red aerial photograph taken by NASA. The slide in question depicted the property that was involved in the litigation. However, as the slide which I had was only a copy, and at that, not an official one, the defense attorney objected to its introduction; but not before the slide had been projected on the screen. The defense attorneys evidently had some experience with infra red color photography and were successful in asking questions concerning the slide in question. The answers to these questions indicated that much of the area depicted in the slide contained healthy vegetation. This, however, was not entirely true, but due to the timing, it was too late for the attorney for the plaintiff to go back and defend what was shown by the slide.

Letter from J. Dale Givens, Assistant Chief, Division of Water Pollution Control, Louisiana Wild Life & Fisheries Commission, Baton Rouge, La., to author, Oct. 28, 1975. Mr. Givens served as expert witness for the plaintiff in the *Ewell* case.

499. See text accompanying notes 477-84 *supra*.

500. No. 72 CH 259 (Ill. Cir. Ct., Cook County, Jan. 27, 1976), discussed at text accompanying notes 160-69 *supra*.

501. Record at 1282.

502. *Id.* at 1879.

503. *Id.* at 1880-81.

504. *Id.* at 1882-83.

505. *Id.* at 1885:

MR. KARAGANIS: Q Mr. Pressman, would you describe to the Court what, if anything, is disclosed by Plaintiff's Exhibit 242 in evidence?

A For orientation purposes, this is the—this very bright area is the land mass, this is the coastline over here, this is the Indiana Canal. It's slightly less white or cooler than the land, very hot compared to the water. This is the Calumet breakwater, this is the 68th Street Crib. The warmer—the

Although the testimony devoted to authentication was rather perfunctory in *Inland Steel*,[506] it suggests several methods for establishing the identity of a remote sensing image. The first is testimony based upon the personal knowledge of a witness, which may be sufficient itself in the case of conventional photographs. In respect to thermal imagery or other graphic representations of nonvisible spectral bands, the accuracy of which cannot be confirmed by personal observation, the witness could testify that images were obtained by particular equipment operated in a given location at a designated time.[507] Another approach may be to identify distinctive characteristics of the target area reflected in the sensing output.[508] The features discernible in the thermal imagery in *Inland Steel* may have been especially persuasive on the issue of identity because of the comparison made between the thermal output and the contemporaneous color photographs.[509] Direct and circum-

brighter tones, which indicate warmer water, represent the discharge from the Indiana Canal trending this direction towards the Calumet area.

506. The types and technical characteristics of the camera and thermal scanner, for example, were only brought out upon cross-examination. *Id.* at 1985-89.

507. This suggestion presupposes that the sensing technique is shown to be an accurate one. *See, e.g.*, FED. R. EVID. 901(b)(9): "(9) *Process or system.* Evidence describing a process or system used to produce a result and showing that the process or system produces an accurate result." The Advisory Committee Note explains that illustration (9) "is designed for situations in which the accuracy of a result is dependent upon a process or system which produces it. X-rays afford a familiar instance." For the views of an individual member of the Rules Advisory Committee on illustration (9), *see* Berger, *supra* note 470.

508. *See, e.g.*, FED. R. EVID. 901(b)(4): "(4) *Distinctive characteristics and the like.* Appearance, contents, substance, internal patterns, or other distinctive characteristics, taken in conjunction with circumstances."

509. *See, e.g.*, FED. R. EVID. 901(b)(3): "(3) *Comparison by trier or expert witness.* Comparison by the trier of fact or by expert witnesses with specimens which have been authenticated." Although the commentary on this illustration is largely devoted to the comparison of handwriting exemplars, *see, e.g.*, Berger, *supra* note 470, at 81-82, the Advisory Committee's Note makes clear that other kinds of visual comparisons were also contemplated and approved:

> Example (3) sets no higher standard for handwriting specimens and treats all comparison situations alike, to be governed by Rule 104(b) . . . .
>
> Precedent supports the acceptance of visual comparison as sufficiently satisfying preliminary authentication requirements for admission in evidence.

REDDEN & SALTZBURG, *supra* note 219, at 347. The comparator must itself first be authenticated, but, as *Inland Steel* indicates, it may be quite easy to authenticate conventional photographs and then to employ them as the exemplar. In addition to its utility for authentication, simultaneous photography may be beneficial even where it does not reveal the critical condition, because it can enable the trier of fact clearly to grasp the additional kinds of information available from remote sensing in nonvisible spectral ranges. For example, the expert witness in *Inland Steel* educated the judge on the utility of thermal infrared output by showing and contrasting pairs of thermal and photographic images taken of a variety of features in the Chicago area. These images were not relevant to the case itself, nor were they introduced into evidence. Their only function was to familiarize the judge with the appearance and potential of thermal images. Record at 1876-78, State v. Inland Steel Co., No. 72 CH 259 (Ill. Civ. Ct., Cook County, Sept. 8, 1975).

stantial evidence of these types can reinforce each other, since the legal test for authentication is whether the cumulative impact of the evidence submitted on that issue is sufficient for a prima facie showing that a remote sensing image is what it purports to be.[510]

The methods employed to authenticate the remote sensing information introduced in *Reserve Mining*[511] were not unlike those in *Inland Steel*. Color photographs, false-color infrared photographs, and thermal infrared images were simultaneously taken by the EPA aerial mission, and various geographical features visible in the imagery were subsequently identified in court by the expert witness.[512] These distinctive characteristics were supplemented by testimony on the flight plan and operating procedures used to locate and photograph the specified target areas.[513] Perhaps the most significant difference from *Inland Steel* is that the expert witness in *Reserve Mining* planned the project but was not actually present when it was conducted.[514] The witness stressed that all phases of the operation were carried out under his supervision[515] and also made occasional references to the maintenance of a chain of custody after the film was exposed.[516] The testimony

510. At this stage of the proceeding, only the proponent of authentication need be heard for purposes of establishing prima facie authenticity. *See* MCCORMICK, *supra* note 7, § 227; REDDEN & SALTZBURG, *supra* note 219, at 342-43 (1975). The ultimate decision as to authenticity is reserved for the actual trier of fact. United States v. Schipani, 289 F. Supp. 43, 55 (E.D.N.Y. 1969) (Weinstein, J.); *see* REDDEN AND SALTZBURG, *supra* note 219, at 342-43.

Particularly in connection with FED. R. EVID. 901(b)(9), which specifies that authentication can be achieved by proof that the process used to produce the evidence is a reliable one, care must be taken to distinguish between authentication and admissibility. Even if a one-sided showing of accuracy is sufficient for authentication purposes, the opposing party must be permitted to submit evidence on the larger question whether the technique is sufficiently accepted within the scientific community and sufficiently reliable to be admissible in light of the considerations raised in earlier sections of this Article. Doubts will often be resolved against the proponent of scientific evidence where the overall reliability of the technique is in issue.

511. United States v. Reserve Mining Co., 380 F. Supp. 11 (D. Minn. 1974), discussed at text accompanying notes 169-80 *supra*.

512. Record at 984-87 (color photography); *id.* at 989, 992 (color infrared photography); *id.* at 1019-21 (thermal images).

513. *Id.* at 975-81.

514. *Id.* at 982.

515. *Id.* at 976-77, 981.

516. *Id.* at 982:

> Q [Mr. Bastow] Was the film processed?
>
> A [Mr. Dybdahl] Yes, it was.
>
> Q How?
>
> A It was processed with the color processor at the Lowery Air Force Base Training School, which is very near the airport.
>
> Q Did you participate in the processing of the film?
>
> A We specify how the film is to be processed. One of my subordinates was with the film the entire time it was being processed and maintaining the chain of custody.

directed towards authentication was not, however, very detailed because the defendant did not object to the receipt of the images into evidence.

Remote sensing images in both *Inland Steel* and *Reserve Mining* were plotted against maps in order to delineate the exact locations of relevant features and the distances between them. In *Inland Steel*, for example, the thermal images were registered against an official National Ocean Survey map, and then the position of the effluent plume was transcribed onto the map face.[517] This procedure suggests a possible means of partial authentication based on matching distinctive characteristics visible in remote sensing output with corresponding features on a map. Such a practice differs from the authentication by comparison method described above,[518] because here the remote image and the map were not produced simultaneously. Therefore, although the geographical area depicted in an image may be precisely defined by comparison with a map, legal proof of identity would require additional evidence on the time when the specific image presented in court was obtained and on the conditions prevailing at that time. In addition, the map itself must be authenticated,[519] which ordinarily may be accomplished by introducing it as a "self-authenticating" submission under Rule 902.[520]

Q After you received the processed film were you able to tell from an examination of it whether it had been exposed according to your instructions?

A Yes, very definitely. That is the first item that is carried out in standard operating procedure in our laboratory, is to determine the quality of the imagery taken or recorded.

Q And was the film exposed according to your instructions?

A Yes, it was.

See note 497 *supra*.

517. Record at 1280, State v. Inland Steel Co., No. 72 CH 259 (Ill. Civ. Ct., Cook County, Sept. 8, 1975).

518. See text accompanying notes 508-10 *infra*.

519. *Cf.* Rhoads v. Virginia-Florida Corp., 476 F.2d 82 (5th Cir. 1973).

520. The difficulty of authenticating certain items of evidence has been eased over the years by judicial decisions and by legislative enactments which have provided that some matters can be self-authenticating. In other words, no evidence other than the document or item itself is needed to authenticate a document or item. Rule 902 gathers together some of the more common examples of self-authentication and expands several categories.

REDDEN & SALTZBURG, *supra* note 219, at 352. FED. R. EVID. 902 provides in part:

Extrinsic evidence of authenticity as a condition precedent to admissibility is not required with respect to the following:

. . . .

(4) *Certified copies of public records.* A copy of an official record or report or entry therein, or of a document authorized by law to be recorded or filed and actually recorded or filed in a public office, including data compilations in any form, certified as correct by the custodian or other person authorized to make the certification, by certificate complying with paragraph (1), (2), or (3) of this rule or complying with any Act of Congress or rule prescribed by the Supreme Court pursuant to statutory authority.

(5) *Official publications.* Books, pamphlets, or other publications pur-

In addition to the need for authentication, remote sensing evidence must in most situations also comply with the formal requirements of the best evidence rule in order to qualify for admission. The latter requirement, however, should seldom pose a significant problem with respect to the photographic category of sensing output. In the first place most litigants wish to introduce the output itself, rather than to describe its contents without producing it for inspection in court.[521] In fact, as we have occasionally noted, the persuasive impact of graphic representations often provides the strongest incentive for employing remote images to supplement conventional methods of proof. Regarding images that are public records, probably the majority of remote sensing submissions, testimony or certification that the images are accurate reproductions is sufficient to satisfy the best evidence requirements.[522] Moreover, the Federal Rules of Evidence reflect a liberalization of the traditional common law doctrine,[523] in that a duplicate may be admitted to the same extent as an original unless a genuine question is raised as to the authenticity of the original or unless admission would be unfair to the other litigants.[524] This approach in effect shifts the burden of

porting to be issued by public authority.

See also CAL. EVID. CODE §§ 1450-54 (West 1966) (presumptions of authenticity).

521. For the same reason, the best evidence rule is seldom an issue in respect to conventional photography. *See, e.g.*, Paradis, *supra* note 485, at 249-51; *cf.* Comment, *Contents of Writings, supra* note 485, at 366-67.

522. The contents of an official record, or of a document authorized to be recorded or filed and actually recorded or filed, including data compilations in any form, if otherwise admissible, may be proved by copy, certified as correct in accordance with rule 902 or testified to be correct by a witness who has compared it with the original. If a copy which complies with the foregoing cannot be obtained by the exercise of reasonable diligence, then other evidence of the contents may be given.

FED. R. EVID. 1005.

523. Most commentators have attributed this liberalizing trend to the development of mechanical duplication devices (such as the photocopying machine) and procedures which have substantially eliminated copyist's error. *See, e.g.*, the Advisory Committee's Note to FED. R. EVID. 1001 in REDDEN & SALTZBURG, *supra* note 219, at 362-63; Broun, *supra* note 465, at 613; Comment, *Contents of Writings, supra* note 485.

524. ADMISSIBILITY OF DUPLICATES

A duplicate is admissible to the same extent as an original unless (1) a genuine question is raised as to the authenticity of the original or (2) in the circumstances it would be unfair to admit the duplicate in lieu of the original.

FED. R. EVID. 1003. Professors Redden and Saltzburg have noted:

While not without some support in the decided cases, Rule 1003 departs from the common law in providing that a duplicate is admissible to the same extent as an original unless a genuine question is raised as to the authenticity of the original or it would be unfair to admit the duplicate under the circumstances of a particular case. In essence, someone opposing the introduction of a duplicate must show some reason why the original should be produced. In common law jurisdictions, the assumption is that the Best Evidence Rule, adopted for purposes of avoiding fraud and insuring accuracy, must rest on the opposite premise, i.e., the original must be favored without any special showing.

One of the explanations for this particular Rule is that Article X as a

persuasion on this issue from the proponents to the opponents of admission.

The photographic category of remote sensing output occupies an advantageous position with respect to the best evidence rules of preference set forth in Article X of the Federal Rules of Evidence. Under the definitions incorporated in that Article, an "original" of a photograph includes the negative and any prints obtained from it.[525] As indicated before, the term "photographs" is interpreted expansively to include X-ray films, videotapes, motion pictures,[526] and by implication remote sensing images collected by an essentially photographic process.[527] Thus, it would appear that the negatives and prints produced by the majority of current remote sensing techniques would qualify for admission as originals. Although the Rules treat conventional photographs and the output from recordings of nonvisible spectral bands in an identical manner, it would be preferable if prints made from the negatives of nonvisible bands were handled as duplicates, not as originals.[528] A variety of intentional or accidental distortions can occur during the printmaking process. In the case of conventional photographs, compensation for the possibility of error is provided by the usual requirement that a witness testify that the submission, in whatever form submitted, accurately depicts a scene he has personally observed. There is no equivalent check on the validity of prints or transparencies ostensibly created from X-ray and remote sensing negatives. If such submissions were treated as duplicates, rather than as originals, they

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whole deals with items that differ greatly from the traditional writing covered by the Best Evidence Rule.

Xerox machines and other familiar devices for reproducing writings and recordings have provided us with new ways of insuring accuracy. Article X expands coverage of the Best Evidence Rule to reach all of these devices, but pays tribute to their accuracy by making duplicates presumptively acceptable.

REDDEN & SALTZBURG, *supra* note 219, at 368.

525. (3) *Original.* An "original" of a writing or recording is the writing or recording itself or any counterpart intended to have the same effect by a person executing or issuing it. An "original" of a photograph includes the negative or any print therefrom. If data are stored in a computer or similar device, any printout or other output readable by sight, shown to reflect the data accurately, is an "original."

FED. R. EVID. 1001(3).

526. "(2) *Photographs.* 'Photographs' include still photographs, X-ray films, video tapes, and motion pictures." FED. R. EVID. 1001(2).

527. Although the Federal Rules of Evidence make no explicit reference to them, infrared and ultraviolet photographs have been admissible for some time in a variety of applications. SCOTT, *supra* note 7, §§ 1414-15.

528. (4) *Duplicate.* A "duplicate" is a counterpart produced by the same impression as the original, or from the same matrix, or by means of photography, including enlargements and miniatures, or by mechanical or electronic re-recording, or by chemical reproduction, or by other equivalent technique which accurately reproduces the original.

FED. R. EVID. 1001(4).

would still be admissible in most circumstances, but it would be incumbent on the proponents of admission to establish that the images presented in court accurately reproduce the original.

4. Treatment of Reconstructed Images

The dividing line between photographic and reconstruction techniques is somewhat arbitrary, since both require several stages of processing and since the eventual output of both is likely to be a film negative. The distinction is intended to emphasize that in some remote sensing techniques a substantial amount of intermediate processing is necessary before images are produced in a relatively unalterable format. A second distinction is that the data incorporated in the final reconstructed output may not exactly reproduce the information initially recorded by the sensor, but may, instead, reflect manipulations to compensate for distortion or other limitations inherent in the sensing process. Consequently, reconstruction techniques may yield a more accurate representation of a given scene than a comparable aerial or satellite photographic technique.[529] Nonetheless, compliance with chain of custody and best evidence requirements must reflect the more complicated processing and the modifications of sensing data frequently associated with reconstructed images.

In considering the authentication of reconstructed remote sensing images, the preeminent legal question is whether the evidence submitted in court is the product of a reliable process or system.[530] The process or system in question must be viewed broadly to include the methods used to produce and preserve the final output in addition to the basic recording techniques. A comprehensive production and distribution scheme, such as that employed for Landsat images, may serve as a focus for a discussion of the legal issues attendant upon the introduction of reconstructed images. Radiant energy in selected spectral bands is detected by the Landsat multispectral scanner (MSS) and converted into digital information to record, for each small area sensed

529. As noted in the text, the distinction between photographic and reconstruction techniques is not always clear. In *Inland Steel*, for example, the thermal images were initially recorded on magnetic tape rather than film. Record at 1989, State v. Inland Steel Co., No. 72 CH 259 (Ill. Cir. Ct., Cook County, Sept. 8, 1975). We chose to characterize the final output as photographic rather than reconstructed because no attempt was made to compensate for distortions in the sensed output and because proof of identity, not chain of custody or best evidence, was the legal issue raised in connection with the evidence. One kind of distortion possible in aerial images can be seen by comparing Plates 6 and 9a. The streets in the area around the South Chicago Water Filtration Plant are accurately depicted as straight lines in Plate 6. The same streets appear curved in Plate 9a. This distortion was probably caused by the data being recorded while the aircraft was banking in a turn.

530. FED. R. EVID. 901(b)(9), quoted at note 507 *supra*.

(called a pixel[531]), the intensity of the energy reflected from the earth's surface.[532] The information is then immediately telecommunicated to NASA earth-receiving stations, where it is recorded on videotape. The videotapes are processed by a computerlike device, called an electron beam recorder, which accomplishes several functions: it combines data representing thousands of pixels into a coherent image;[533] it manipulates the images to correct for distortion introduced by the positioning of the satellite with respect to the earth or by the earth's rotation;[534] and it inserts ephemeris data, such as time, location, and sun angle, into each Landsat image.[535] The output from the electron beam recorder takes the form of 70-mm positive film, referred to by NASA as a first-generation tape, which is permanently stored for archival purposes.

The first-generation tape is used only to produce duplicates, usually in the form of film negatives, for distribution to the three Federal Data Centers that ordinarily serve as suppliers of Landsat images to other government agencies and the public. The most extensive collection of remote sensing and aerial photographic images is maintained at Sioux Falls, South Dakota, by the Earth Resources Observation Systems Data Center (EROS) of the United States Geological Survey.[536] EROS receives from NASA a second-generation duplicate of Landsat images, which it employs to produce third-generation output in several formats.[537] Landsat images are generally available from EROS within

531. A pixel represents an 80 meter-per-side square and, since all reflection from that area is added together to determine the reflectance value for the pixel, it imposes the limiting factor in the resolution of the MSS. See note 19 *supra*.

532. This description of the Landsat process is condensed from the ERTS HANDBOOK, *supra* note 14, and conversations with Dr. Stan Freden, ERTS project scientist, and Luis Gonzales, communications engineer, NASA, Goddard Space Center, Greenbelt, Md., July 31, 1975. When the two Landsat satellites were first inserted in orbit, they were known as Earth Resources Technology Satellites, so much of the relevant literature continues to make reference to ERTS.

533. The Landsat images distributed by NASA are about 100 nautical miles on a side. See Plate 2 for an example.

534. The satellite contains instruments that determine its pitch, yaw, and roll angles, as well as its altitude, at any given time. This information is telemetered down to earth along with the MSS data. The compensation for rotation of the earth results in a somewhat skewed image, which is reflected in the diagonal sides of Plate 2.

535. The ephemeris data is included in the image as a line of print along its lower edge, as in Plate 2.

536. EROS regularly receives all earth resources satellite data, including that from special missions like Skylab, in addition to the regular Landsat output, most NASA aerial remote sensing data, and all USGS aerial photography. *See* SKYLAB EARTH RESOURCES DATA CATALOG 177 (1974). The other two data centers were established by the U.S. Department of Agriculture and the National Oceanic & Atmospheric Administration to support their respective remote sensing interests. Each has developed computer classification and image enhancement techniques in its areas of specialization.

537. EROS distributes contact paper prints, contact film positives and contact film negatives in 70-mm and 9-inch sizes. The images may be obtained for a single spectral

2 months of the time Landsat records the data and, like other aerial and satellite images preserved in the EROS repository, the public may purchase Landsat output for a moderate charge.

EROS also maintains and distributes computer-compatible tapes (CCT's) of Landsat data recorded in digital form.[538] In order to create the prototype, NASA bypasses the electron beam recorder output and instead reformats the information on the original earth-receiving station videotapes. In this case the amount of MSS data in each tape record is standardized, but no corrections are made to compensate for distortions caused by satellite positioning. Consequently, investigators who work with Landsat images in digital form receive a more exact reproduction of the original remote sensing information, but are responsible for eliminating distortion and integrating the accompanying ephemeris data into their output. After NASA prepares a CCT of Landsat information, it releases a copy to EROS, which files the copy in its tape library and then makes third-generation duplicates available to customers.

The preceding description, though oversimplifying the production and distribution of Landsat images, nonetheless serves to demonstrate that the authentication and best evidence provisions of the Federal Rules of Evidence, to say nothing of the common law rules, may not be easy to apply to reconstructed remote sensing images.[539] Unlike information-recording techniques such as xerography or the computerization of business records,[540] data collected by the Landsat multispec-

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band and as black and white or color composites of several bands. *See* ERTS HANDBOOK, *supra* note 14, at Y.1-Y.2. Plate 2 is a color composite of the red, green, and longer-wavelength near infrared bands sensed by the Landsat MSS.

538. *See* ERTS HANDBOOK, *supra* note 14, at 3.14-3.19.

539. In practice, laying this part of the foundation for Landsat images will not prove difficult, because they can be introduced as public records. Nonetheless, the production procedures highlight general issues associated with sophisticated image processing. Moreover, it should again be emphasized that the presumption of the reliability of official records, as reflected in FED. R. EVID. 901(b)(7), 902, and 1005, does not foreclose challenges questioning the actual reliability of scientific evidence in the larger context of admissibility.

540. The vast majority of computerized records cases to date have involved the introduction of machine-stored data as business records. *See, e.g.*, United States v. DeGeorgia, 420 F.2d 889 (9th Cir. 1969); D & H Auto Parts, Inc. v. Ford Marketing Corp., 57 F.R.D. 548 (E.D.N.Y. 1973); Union Elec. Co. v. Mansion House Center North Redevelopment Co., 494 S.W.2d 309 (Mo. 1973); Transport Indem. Co. v. Seib, 178 Neb. 253, 132 N.W.2d 871 (1965); Sierra Life Ins. Co. v. First Nat'l Life Ins. Co., 85 N.M. 409, 512 P.2d 1245 (1973); State v. Springer, 283 N.C. 627, 197 S.E.2d 530 (1973). In those few cases not involving actual business records, computerized records of public agencies have been admitted under a "regular course of business" rationale. *See, e.g.*, Wheeler v. Cain, 62 Tenn. App. 126, 459 S.W.2d 618 (1970) (record of calls to police dispatcher); City of Seattle v. Heath, 10 Wash. App. 949, 520 P.2d 1392 (1974) (Department of Motor Vehicles records). For a general discussion see

tral scanner and many other remote sensors is unintelligible to human beings in its initial form.[541] To become meaningful such information must undergo a series of manipulative operations, which in the aggregate raise the question whether the input to that process or its output should be considered the "original" for purposes of the best evidence rule. If the underlying rationale for authentication and best evidence requirements is to promote the introduction of reliable evidence, is that purpose best served by requiring the submission of a reproduction of the initial sensor data, with distortion often inherent in the uncorrected sensing process, or by the submission of a reconstructed and rectified image that more accurately portrays conditions on the ground? Adoption of the latter position would necessarily be premised on a sufficient showing that the reconstructed image is in fact a superior representation of actual conditions.

Although the Federal Rules of Evidence purport to recognize the proliferation of technological recording methods,[542] they afford little guidance for the treatment of recorded information that could not be a document in the ordinary meaning of the word. Except in the case of public records, the only example of authentication relevant to the problems set forth above is Rule 901(b)(9), which requires that a process be shown to produce accurate results.[543] That proviso, when

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Bernacci & Larsen, *Philosophy, Data Processing & the Rules of Evidence*, 10 LAW NOTES 11 (1974); Tapper, *Evidence from Computers*, 8 GA. L. REV. 562 (1974); Comment, *Evidence—Admissibility of Computer Print-outs*, 52 N.C.L. REV. 903 (1973); Note, *Admissibility of Computer-Kept Business Records*, 55 CORNELL L. REV. 1033 (1970); Annot., 11 A.L.R.3d 1377 (1967).

541. Consider the problems posed by the American common law "regular entries" exception and some modern statutes, which require that the maker of the business record have personal knowledge of the events or transactions recorded. The personal knowledge requirement under the common law has been liberally construed to comport with modern business practices. *See, e.g.*, Massachusetts Bonding & Ins. Co. v. Norwich Pharmacal Co., 18 F.2d 934 (2d Cir. 1927) (L. Hand, J.); King v. State *ex rel.* Murdock Acceptance Corp., 222 So. 2d 393 (Miss. 1969). In contrast, the personal knowledge requirement contained in the Texas business statute [TEX. REV. CIV. STAT. ANN. art. 3737e (Cum. Supp. 1975)] has been strictly applied. *See, e.g.*, Railroad Comm'n v. Southern Pac. Co., 468 S.W.2d 125 (Tex. Civ. App. 1971), *error ref. n.r.e.*; Arnold D. Karmen & Co. v. Young, 466 S.W.2d 381 (Tex. Civ. App. 1971), *error ref. n.r.e.* The English Criminal Evidence Act 1965 takes a more moderate position, requiring only that the *supplier* of the information, rather than the maker of the record, "reasonably be supposed" to have personal knowledge. Criminal Evidence Act 1965, c. 20, § 1(1)(2). *See generally* Tapper, *supra* note 540, at 571-79, 586-90, 600-02.

542. Article X, for example, defines "writings" and "recordings" to be information set down by "handwriting, typewriting, printing, photostating, photographing, magnetic impulse, mechanical or electronic recording, or other form of data compilation." FED. R. EVID. 1001(1).

543. See note 507 *supra* for the complete text of FED. R. EVID. 901(b)(9). It should be noted that the Advisory Committee's Note specifically mentions X-rays and computerized data as being covered by this provision of the rules. REDDEN & SALTZ-

applied to scientific evidence, merely extends the usual admissibility requirement for reliability of a scientific process through the chain of custody stage to the time of the actual submission. When reconstructed images are considered in light of the purposes underlying Example (9) of Rule 901(b), it appears that introduction of a reliable reconstructed image would be preferable to introduction of a comparable image in which distortions caused by the sensing technique were not corrected. If the objective of remote sensing evidence is to depict specific conditions, the most accurate portrayal should be the most readily admitted.

A similar conclusion can be drawn by interpreting the relevant provision of Article X, the federal version of the best evidence rule, in the context of reconstructed images: "If data are stored in a computer or similar device, any printout or other output readable by sight, shown to reflect the data accurately, is an 'original.' "[544] Undoubtedly, the drafters of this provision did not contemplate that recording techniques might exist which distort information in a manner that can be systematically rectified, so they assumed accurate reproduction of the input data would lead to the most reliable presentation of the underlying information in court. With respect to computerized business records, for example, that assumption is certainly valid. Since reliability is the basic objective of the best evidence rule, the phrase "shown to reflect the data accurately" may be interpreted to mean data reflecting real world phenomena rather than data reflecting a limited duplication of the input. Again, assuming that the reconstruction process is proved to be reliable, its output is a more accurate portrayal of actual conditions than the initial sensing data. If that interpretation is adopted, reliable reconstructed images could qualify for admission as originals.

As a matter of policy, however, it would be better to treat reconstructed images as "duplicates"; this approach would provide the opposing party with more leverage to demand production of the initial data in circumstances where a genuine question can be raised about the reliability of the reconstruction process.[545] Although the reconstructed image, if reliable, more accurately reflects actual conditions, the process also contains opportunities for intentional or inadvertant alterations to the sensing data. Thus the traditional role of the best evidence rule

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BURG, *supra* note 219, at 348. If a reconstruction process is proved to be reliable, then all of the methods for establishing proof of identity described in connection with photographic images may also be utilized for reconstructed images.

544. FED. R. EVID. 1001(3), quoted in full at note 525 *supra*.

545. For a similar argument in the context of remote sensing and photographic images, see text accompanying note 528 *supra*.

in preventing fraud and "copyist error"[546] suggests that the initial sensing data ought, after all, to be considered the original. An image created by a reliable reconstruction process should be deemed to "accurately reproduce the original," the standard for a legal duplicate,[547] even though certain corrective changes are made to the remotely sensed information, since the basic objective of the best evidence requirement is to insure that the original conditions are accurately portrayed in court.

5. Treatment of Enhanced Output

a. Characterizations of Enhanced Output

Enhancement techniques span a continuum which from a legal perspective may be roughly divided into four categories: (1) methods that clarify rather than modify the visible contents of a photographic or reconstructed remote sensing image; (2) methods that emphasize features or relationships not apparent on the face of the original image, but that do not significantly alter its contents; (3) methods that intentionally alter, suppress, or accentuate certain phenomena in order to highlight target conditions of particular interest to the investigator; and (4) purely computational methods whose output is statistical rather than graphic in nature. Enhancement techniques may be conceptually simple or extraordinarily complex; they may be well accepted within the relevant scientific community or uniquely innovative; their output may closely resemble or markedly diverge from the photographic model. The one safe generalization is that enhancement output, excepting the products of techniques within the first category, poses serious characterization problems for the law.

The first category includes enhancement techniques, like enlargement or stereoscopic viewing,[548] directed solely at improving the clarity of features already identifiable in the original remote sensing image or data. The Federal Rules of Evidence define "duplicates" in an expansive manner to incorporate enlargements, miniatures, electronic rerecordings, or equivalent methods that accurately reproduce the original.[549] Consequently, applying techniques in this category to photo-

546. MCCORMICK, *supra* note 7, § 231.

547. FED. R. EVID. 1001(4).

548. Stereoscopic viewing (or stereoscopy) employs the parallax effect, whereby two images of the same scene, simultaneously taken by cameras a slight distance apart, are merged by the viewer to create a three-dimensional representation. For sample applications, *see* WIER & WOBBER, *supra* note 16, at 4-5. Stereoscopic photointerpretation was employed by the New Jersey Department of Environmental Protection in its wetlands mapping program, the validity of which is the major issue in the *Hackensack Meadows* and *City of Newark* cases, discussed at text accompanying notes 200-16 *supra*. *See* Hackensack Report, *supra* note 201, at 148.

549. FED. R. EVID. 1001(4), quoted at note 528 *supra*.

graphic or reconstructed images should not present any legal issues unaddressed in previous portions of this section.

The second category, which differs only in degree from the first, involves the manipulation of the original images or data in a nondestructive manner to bring out features not ordinarily apparent.[550] In film sandwiching, for example, a black and white negative transparency is superimposed upon its positive counterpart.[551] The effect is to produce an image in which tonal contrasts between adjacent areas are suppressed and only the boundary lines are clearly distinguishable. Such a representation can be extremely useful for emphasizing linear features such as geological fractures and faults.[552]

Techniques in the second category do not actually modify the underlying remote sensing data, but their output may not closely resemble the original image. A film-sandwich, for example, is composed of two products that, taken separately, would probably qualify as "originals" under the Federal Rules of Evidence.[553] To find, however, that such an enhancement qualifies even as a duplicate would require a tortured construction of the phrase "accurate reproduction." Yet even a close inspection of the legal original(s) could not reveal features identifiable by means of the enhancement technique. This notion that the contents of a "writing" or "recording" within the meaning of the Federal Rules[554] could not be completely deciphered by an inspection of the original records could hardly have occurred to the drafters.

The difficulty in characterizing enhanced output for purposes of admission is compounded when considering the third category of enhancement techniques: those that intentionally modify the original data in order to identify particular relationships or conditions. The accompanying Plates illustrate the output of several representative techniques in this category. In Plate 4 the intensity of certain colors[555] was

550. One technique in this category involves viewing an image 12 to 18 inches from the face through a Ronchi grating (a grid of closely spaced, ruled lines on a transparent backing) held approximately 1 inch in front of the eye. Due to the resulting refraction of the image, linear features oriented normal to the grating lines are emphasized; by rotating the grating during viewing, the photointerpreter can emphasize selected orientations associated with features of interest, such as fractures or stream drainage lines. *See* WIER & WOBBER, *supra* note 16, at 4-14 to 4-15.

551. *Id.* at 4-6.

552. *Id.* at 4-6 to 4-8. *See also* Wobber, *Regional Structural Analysis Using Snow Enhancement Techniques*, in ABSTRACTS OF PAPERS FOR A CASE HISTORY RESEARCH CONFERENCE: REMOTE SENSING 65, 66 (Feb. 20, 1975) (Space Technology Center, University of Kansas, Lawrence, Kan.).

553. See text accompanying note 525 *supra*.

554. FED. R. EVID. 1001(1).

555. The process by which Plate 4 was produced is called multiband additive color

amplified to distinguish heavily vegetated areas from regions with a sparse cover overlying a primarily rocky substrate. Plate 5a portrays the output of a computer classification[556] of Landsat data designed to determine the principal plant and terrain types in the remotely sensed region. Note that the technique assigns a unique color to each pixel based on the *dominant* feature in that location, although in nature vegetation does not grow in neat rectangular plots. Plate 5b represents a further enhancement of the initial Landsat data, in which a few selected ecotypes were emphasized and all other features were submerged in the background. Finally, Plate 9b illustrates the technique of density-slicing, in which similar colors are assigned to those portions of an original image that exhibit similar traits.[557] In the density-sliced image the different colors correspond to temperature levels defined by the developer of the enhancement technique; thus the boundaries between these different levels are somewhat subjective and arbitrary.[558] As a comparison of Plate 9b with the initial image recorded in Plate 9a reveals, density-slicing may break a very gradual range of responses in the original into a series of highly contrasting bands, with distinctions within each level suppressed and distinctions between levels accentuated.

Enhancement techniques in the fourth category are exclusively computational and do not produce output resembling a photographic image.[559] Band-ratioing, for example, involves comparing reflectance

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projection. Lights of varying colors are beamed through a number of transparencies of the same scene imaged in different spectral bands, and the projections thus generated are focused to form a single composite image. *See* WIER & WOBBER, *supra* note 16, at 4-8 to 4-9.

556. Computer pattern recognition programs have been used to produce ground-cover classification maps of wetlands. *See* Cartmill, *Evaluation of Remote Sensing and Automatic Data Techniques for Characterization of Wetlands*, in THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 1257. The feasibility of operational automated strip mine and reclamation mapping using Landsat data has similarly been demonstrated. *See, e.g.*, Pettyjohn, Rogers & Reed, *supra* note 48; Alexander, Dein & Gold, *supra* note 56.

557. *See* note 373 *supra*. *See also* Wier & Wobber, *supra* note 16, at 4-9 to 4-12; Anderson, Carter & McGinness, *Applications of ERTS Data to Coastal Wetland Ecology with Special Preference to Plant Community Mapping and Typing and Impact of Man*, in THIRD ERTS-1 SYMPOSIUM, *supra* note 15, at 1225, 1229 (STAR acc. no. N74-30789). A similar technique is isodensity processing, a laborious technique whereby a separate image is obtained for each density slice; then the images are color-coded and combined photographically or lithographically. *See* WIER & WOBBER, *supra* note 16, at 4-13 to 4-14.

558. Anderson, Carter & McGinness, *supra* note 557, at 1229.

559. Computer categorization producing quantitative output falls within this category. *See, e.g.*, Coker, Higer, Rogers, Shah, Reed & Walker, Automatic Categorization of Land-Water Cover Types of the Green Swamp, Florida, Using Skylab Multi-Spectral Scanner (S-192) Data, Aug. 20-22, 1974 (paper prepared for the American Astronautical Society Annual Meeting, University of Southern California, Los Angeles, Cal.); Pettyjohn, Rogers & Reed, *supra* note 48; Alexander, Dein & Gold, *supra* note 56. Also

intensities in two or more separate spectral ranges in order to compensate for environmental variables, like sun angle, that interfere with absolute measurements or to draw significant distinctions between apparently similar phenomena.[560] From a legal point of view, the important aspect of output in this category is that it may provide the basis for an expert opinion or it may be introduced as a computer printout in court, without appearing to be an actual portrayal of environmental conditions. For that reason the output may not be as potentially misleading to the trier of fact as a comparably enhanced photographlike image.

The major legal determination required in the characterization of enhanced output is whether such submissions are offered as independent demonstrative evidence or as illustrations of the methods and conclusions adopted by the expert witness through whom the output is entered. The legal significance of this characterization is that illustrative submissions arguably fall outside the purview of both the authentication and best evidence requirements. The Federal Rules of Evidence may be applied with some measure of certainty to documents and conventional photographs, whose contents can ordinarily be discerned and comprehended by all parties to the litigation. In contrast, X-ray images and remote sensing output, whether in initial or enhanced form, must always be interpreted by an expert witness. Such images can in no sense speak for themselves. On the other hand, the expert cannot personally observe phenomena in nonvisible spectral bands; therefore, the images do not merely illustrate his testimony but provide a substantial basis for it. In the case of enhanced images, which do not purport exactly to depict actual conditions, the validity of the evidence is altogether dependent on the reliability of the manipulative techniques employed by the expert. Yet the expert employs the output not primarily to illustrate conditions for the benefit of others, but to identify those conditions himself. Thus it appears that enhanced output is more than illustrative, but less than independent, evidence.

Federal Rule 703 provides that an expert may base an opinion on facts perceived by or made known to him if of a type reasonably relied upon.[561] Federal Rule 705 further stipulates that the witness

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falling within this category is the technique of densitometer analysis, whereby features in an image are categorized by measuring the optical density of the image. The EPA expert in *Reserve Mining* used this method to distinguish the "green water phenomenon" from "river teas" shown in the imagery. Record at 998-1002, United States v. Reserve Mining Corp., 380 F. Supp. 11 (D. Minn. 1974).

560. *See, e.g.*, Thomson, Basic Investigations for Remote Sensing of Coastal Areas (Oct. 15, 1974) (STAR acc. no. N75-18708) (ERIM, Ann Arbor, Mich.).

561. *Bases of Opinion Testimony by Experts*

The facts or data in the particular case upon which an expert bases an opinion or inference may be those perceived by or made known to him at or

may present his opinion without prior disclosure of the underlying facts and data.[562] These prescriptions suggest that a remote sensing expert who reaches particular conclusions on the basis of his inspection of enhanced output could testify to those conclusions without contemporaneously introducing the enhancement or its underlying sensing data. If that interpretation is accepted, it is difficult to see why the enhanced output would not be admissible for illustrative purposes even if the original remote images were not introduced. The best evidence rule, in apparent contradiction, requires the production of a writing, recording, or photograph to prove its contents if they are in issue.[563] Since the opinion of the expert witness is not merely illustrated by the enhanced output but may be exclusively predicated on it, the argument can certainly be made that his testimony is offered to prove the contents of the enhancement and, therefore, that submission of the enhancement should be required as a matter of law. The enhanced output, in turn, is substantially predicated on the initial sensing data and is entered, in reality, to prove some of the contents of that original information. Thus, the conclusion may be reached that introduction in court of the sensing data should, under the Federal Rules, be required. It would, however, be irrational to require that conditions in the real world be established by the remote information in its original form, for the entire purpose of the enhancement process is to reveal features not ascertainable from the original.

The closest legal analogy lies in the treatment of X-ray images, where authority is split over whether an expert may testify on the basis of his inspection of X-ray photographs without submitting them. In some cases the courts have reasoned that the image itself is meaningless without expert interpretation. From that conclusion they have characterized expert testimony as the primary evidence of the asserted condition and, therefore, have held that introduction of the X-ray image is optional.[564] At the other extreme, some cases have been reversed on best evidence grounds where the image was not formally introduced, even though the plates were produced at trial and were made available

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before the hearing. If of a type reasonably relied upon by experts in the particular field in forming opinions or inferences upon the subject, the facts or data need not be admissible in evidence.

FED. R. EVID. 703.

562. *Disclosure of Facts or Data Underlying Expert Opinion*

The expert may testify in terms of opinion or inference and give his reasons therefor without prior disclosure of the underlying facts or data, unless the court requires otherwise. The expert may in any event be required to disclose the underlying facts or data on cross-examination.

FED. R. EVID. 705.

563. FED. R. EVID. 1002; MCCORMICK, *supra* note 7, § 231.

564. SCOTT, *supra* note 7, § 1273, at 134.

to the opposing party.[565] These precedents provide little guidance in regard to remote sensing evidence in general, but they afford even less instruction in connection with enhanced output, which unlike X-ray images does not purport to accurately reproduce the full range of actual conditions.

b. Reliability of Enhanced Output

It would be possible to continue indefinitely the procrustean attempt to characterize enhanced output in terms of the best evidence provisions of the Federal Rules, but those provisions did not contemplate and do not comfortably fit this type of submission. If they must be held to apply, then enhanced images may best be characterized as charts, summaries, or calculations under Rule 1006.[566] Although that rule was designed to cope with voluminous recordings rather than substantially altered ones, it at least affords the opportunity to require production of the underlying data in court if the reliability of the enhancement is seriously challenged. By implication, the party introducing an enhancement would also have to make available the computer programs and other analysis techniques employed to manipulate the original sensing data in order to produce the final output.

Since the validity of enhancement is altogether dependent on the reliability of the methods selected by the interpreting expert witness, characterization of enhanced images as illustrations of the witness' testimony would avoid contortion of the best evidence provisions without sacrificing any protection for the party opposing admission. If enhancements are deemed to be independent evidence, so that the best evidence rule might apply, the remote sensing evidence must ordinarily be authenticated under Rule 901(b)(9),[567] which requires that it be produced by a reliable process or system. If, on the other hand, enhanced output is regarded as illustrative evidence and therefore falls outside the purview of the best evidence rule, the expert would nevertheless be prevented from illustrating and testifying about enhancement

565. *See, e.g.*, Fuller v. Lemmons, 434 P.2d 145 (Okla. 1967), *noted in* 14 WAYNE L. REV. 1218 (1968); SCOTT, *supra* note 7, § 1273.

566. *Summaries*

> The contents of voluminous writings, recordings, or photographs which cannot conveniently be examined in court may be presented in the form of a chart, summary, or calculation. The originals, or duplicates, shall be made available for examination or copying, or both, by other parties at reasonable time and place. The court may order that they be produced in court.

FED. R. EVID. 1006.

567. Rules 901(b)(7) (authentication of public records or reports) and 902 (self-authentication) will seldom be of any use in authenticating enhanced images other than enlargements, since it is the data user, and not the government, who performs the enhancement techniques.

techniques that were not established as sufficiently reliable—the general rule for admission of all scientific evidence. To the extent that the expert's opinion was based upon inferences derived from his inspection of enhanced output, Rule 703 would similarly require that the enhancement techniques be reasonably reliable. Thus, regardless of whether the enhanced output is characterized as independent or illustrative evidence, the party introducing enhanced images must demonstrate that they are reasonably reliable.

Emphasis on the reliability of the information submitted in court, in whatever format, may also resolve the dilemma of how to treat the initial sensing data from which enhanced output is produced. Reliability of the final product presupposes two conditions: (1) the manipulative process is valid and correctly applied; and (2) it is applied to accurate data. Whether the initial remote sensing information is formally submitted and admitted is much less important than whether it is available to the opposing party so that its reliability can be determined. The critical concern is that the original data be produced for inspection if its validity is questioned.

In any given case the reliability criteria identified in prior sections of this Article must be applied in light of the specific characteristics of the enhanced output submitted and with regard to the probable consequences of admission. It should be observed, however, that enhanced output as a class presents more opportunities for misleading or prejudicing the trier of fact than any other form of remote sensing information. When a party intentionally alters data that initially reflects environmental phenomena as recorded by a sensor, in order to emphasize features and relationships which that party deems favorable to its position, the potential for abuse is obvious. This observation is not intended to denigrate the reliability or value of many enhancement techniques; however, where the potential for abuse is great, a convincing demonstration should be required that the evidence is valid.

CONCLUSION

The stated objectives of this Article were twofold: to introduce the legal profession to diverse remote sensing applications that may attain legal significance in the near future, and to evaluate the characteristics of remote sensing techniques and information in the context of the law of scientific evidence. The principal impetus behind the growth of remote sensing is the expansion of the nation's information requirements resulting from heightened social aspirations for natural resources exploitation and environmental protection. Remote sensing evidence will inevitably be introduced in new forms and in new legal contexts as those information requirements change in the future. The

range of technological capabilities and potential applications precludes a reductionist treatment of the admissibility of remote sensing information. For that reason, the Article sought to identify the conceptual process by which legal applications of remote sensing could be evaluated in the future, rather than to determine the current suitability of any particular technique for a given legal purpose.

The legal utility of remote sensing is preeminently dependent upon proof of its reliability, but this subject also cannot be examined in a monolithic fashion. Not all reliability criteria identified in this analysis will be relevant in any given factual setting; nonetheless, it is important to understand the distinct elements that contribute to legal assessments of how reliable a specific process is and of how reliable it must be to warrant judicial acceptance. It must in addition be recognized that this testing or reliability will be conducted within the adversarial system, and that the introduction of scientific evidence often poses significant problems in that context.

It has been argued that the burden of persuasion should be placed on the proponents of remote sensing evidence, because they are in the best position to maximize the reliability of the process by which it is produced. At the same time, however, the nature of the adversarial system requires the opponent of admission to rebut the evidence once a prima facie showing of validity has been made. Proper functioning of this system, then, requires that the opponent have effective access to the requisite equipment, information, and technical expertise.[568] This premise forms the basis for our final conclusion: surprise should play no role in litigation featuring the introduction of unfamiliar scientific information.[569]

Within the context of the adversarial system, it might be appropriate to impose an affirmative obligation for disclosure on parties who contemplate the introduction of evidence produced by innovative techniques, and to condition the amount and the timing of required disclosure on the complexity and novelty of the process—factors well within the ability of the proponents to assess. The common law and the Federal Rules of Evidence provide that evidence may be excluded at the discretion of the trial court in cases of unfair surprise.[570] This

568. Thus some requirement of professional acceptance must be retained in order to insure that experts exist who are competent and willing to assess the validity of the techniques employed. Moreover, in the case of indigent defendants, it may be incumbent on the government to provide the financial resources necessary to conduct an informed defense. *See* United States v. Stifel, 433 F.2d 431, 441 (6th Cir. 1970), *cert. denied*, 401 U.S. 994 (1971).

569. *See* United States v. Kelly, 420 F.2d 26 (2d Cir. 1969); *cf.* Martin v. Island R.R., 63 F.R.D. 53 (E.D.N.Y. 1974) (Weinstein, J.).

570. *See, e.g.*, FED. R. EVID. 403; Dolan, *supra* note 273.

rule provides an effective remedy in situations where substantial time and resources are required for a litigant to evaluate the validity of scientific evidence and where the proponents of that evidence fail to provide sufficient notice.[571] Since the law more often at present requires that litigants protect themselves,[572] participants in environmental litigation should exercise available discovery and other pretrial procedures to determine, as best they can, if remote sensing or other scientific techniques are likely to be employed against them. Yet it would be no great burden, in connection with scientific processes that require substantial expertise and preparation, for proponents to provide reasonable notice. Remote sensing evidence will prove useful and legally acceptable in many situations, but it ought to be admitted on the basis of demonstrated reliability and not by default.

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571. *See, e.g.*, United States v. Kelly, 420 F.2d 26 (2d Cir. 1969).

572. *See, e.g.*, State v. Stevens, 467 S.W.2d 10 (Mo. 1971), *cert. denied*, 404 U.S. 994 (1972).