ERTS: Surveying Earth's Resources from Space

Space flight is no longer surrounded by the glamor that accompanied the first satellite launchings or, more recently, the manned missions to the moon. The public has, if anything, grown incredibly blasé about space, accepting its daily satellite weather pictures and its television transmissions from China and Europe as a matter of routine, and seemingly paying only enough attention to the Apollo moon program to question its cost.

And yet the space program, especially the unmanned satellite program, has been highly productive in yielding information that is of immediate value to the citizenry whose taxes support it. The communications satellites and the Nimbus weather satellites have demonstrated unequivocably that space platforms can be used inexpensively on a daily basis to solve earthbound problems. What they haven't done, however, is demonstrate the multitude of different types of information that can be obtained by placing the appropriate remote sensing devices in orbit.

A major step in this direction is the Earth Resources Technology Satellite (ERTS), the first of two National Aeronautics and Space Administration orbiting observatories designed specifically for monitoring the natural resources required by man. Launched last July, its mission is to define practical problems where space technology can make beneficial contributions, to conduct research on remote sensors and their utility in observation of the earth, and to develop handling and processing techniques for earth resources surveying. Results so far suggest that its capabilities are significantly greater than had been anticipated and that satellite observation shows great promise for activities as disparate as inventorying crops, planning land use, prospecting for oil, minerals, and water, preparing new maps, census taking, and regulating pollution.

The ERTS orbit and coverage are designed to provide systematic, repetitive global land coverage under conditions of maximum consistency. The 891-kilogram satellite revolves around the earth every 103 minutes in a circular orbit 914 kilometers above sea level. The nearly polar, sun-synchronous orbit allows the satellite to cross the equator at about 9:30 a.m. local time on the north-to-south leg of each orbit. Previous experience with aerial photography has shown that shadows cast on the ground at this time of day provide the greatest assistance in interpretation of surface features.

The satellite completes 14 orbits each day, photographing three strips 185 km wide in North America and 11 similar strips in the rest of the world. Strips photographed the following day are contiguous to those of the first day, with a 14 percent overlap of coverage at the equator and a greater overlap near the poles. Thus ERTS passes over any location on the earth's surface once every 18 days, at the same time of day and with the same lighting. It is this repetitive coverage that provides ERTS with great potential for monitoring time-dependent changes in surface features.

The heart of ERTS is a pair of imaging systems called the Return Beam Vidicon (RBV) and the Multispectral Scanner (MSS) that photograph the earth in the visible and near-infrared spectrum. It also carries a data collection system (DCS) that relays telemetered information from about 100 collection stations located in remote regions of North America. These stations collect data on water quality, rainfall, snow depth, seismic activity, and the like, and transmit a 38-millisecond burst of data from all sensors every 3 minutes. When ERTS is in line-of-site contact with both a remote site and a ground station, it relays these messages automatically. The satellite's orbit is such that a message is relayed from each remote site at least once every 12 hours. The DCS was designed by the space division of General Electric Company, Valley Forge, Pennsylvania. GE also constructed the satellite.

The RBV, developed by the Astro-Electronics division of RCA Corporation, Princeton, New Jersey, is a set of three identical cameras filtered in such a way that each operates in a different band of the visible spectrum. Camera 1 functions in the 0.475 to 0.575-micrometer band; camera 2 functions between 0.580 and 0.680 μm, and camera 3 between 0.690 and 0.830 μm.

A shutter and lens system in each of the RBV cameras produces images on a photosensitive plate. These images are then scanned with an electron beam

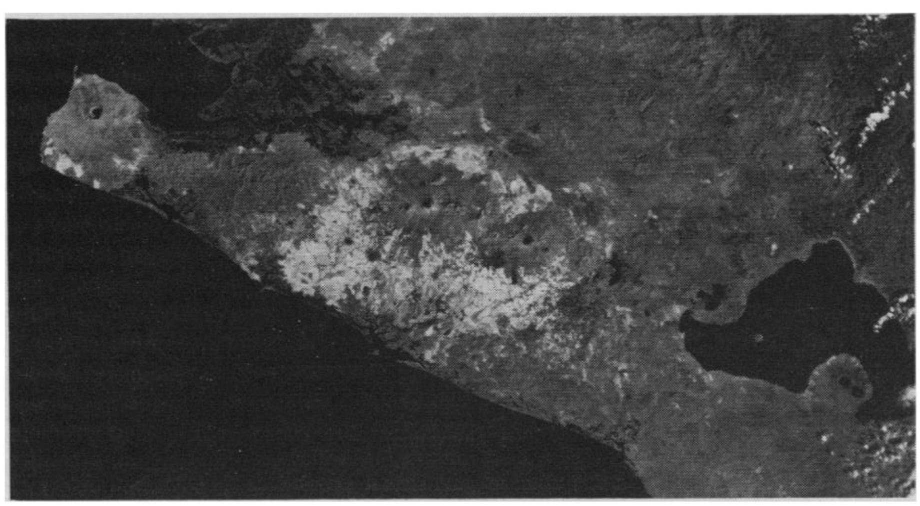

Fig. 1. Part of an MSS-6 image of Nicaragua taken 24 December 1972, one day after the Managua earthquake. Managua is in the extreme lower right under scattered cloud cover. Lake Managua (lower right) and the Gulf of Fonseca (upper left) occupy volcanic tectonic depressions, and the low mountains in the coastal region are the result of recent volcanic activity. Recurrent earthquake activity in Managua is probably caused by shifts along the geologic fault delineated by the string of volcanoes (small back circles) parallel to the coast. These volcanoes vary in width from 1.6 to 3.2 kilometers [Courtesy of NASA].

to produce a video output. When the RBV system is operated continuously, it produces a set of three images of the same surface area every 25 seconds, with about a 10 percent overlap along the direction of spacecraft motion.

The MSS system, developed by Hughes Aircraft Company, Culver City, California, is a line-scanning device that operates in three bands of the visible spectrum and one in the near-infrared. Band 4 encompasses the region between 0.5 and 0.6 μm, band 5 between 0.6 and 0.7 μm, band 6 between 0.7 and 0.8 μm, and band 7 between 0.8 and 1.1 μm. Bands 4, 5, and 6 of the MSS thus provide coverage similar to that of bands 1, 2, and 3 of the RBV; band 7 provides a near-infrared capability that is particularly useful for monitoring vegetation.

An oscillating mirror in the MSS causes light energy from a 185-km swath perpendicular to the satellite's path to be swept across the focus of a small telescope. At the focus is a four-by-six array of 24 optical fibers, six for each band monitored. The fibers carry light energy from each imaged spot through spectral filters to detectors that convert it to an electrical signal. Each fiber subtends an area about 79 meters square on the ground. The oscillating mirror is timed so that when it has returned for the next sweep, the satellite has advanced 474 meters and the next six lines are adjacent to the preceding six. As long as the MSS is operating, therefore, it produces a continuous strip photograph of the ground below the satellite.

Fig. 2. Part of an MSS-5 image showing Utah's Great Salt Lake (upper left), the Wasatch Mountain Range (right), Utah Lake (lower right, with Provo to its right), and greater Salt Lake City between the lakes. The sharp color demarcation in ERTS imagery of the Great Salt Lake marks the Union Pacific railroad causeway across the lake; this causeway inhibits circulation of water between the two lake segments and has created a previously unsuspected difference in salinity. Water north of the causeway is very saline and supports one type of algal growth. Water south of the causeway is diluted by influx from the Jordan and Bear Rivers and supports a second type of algae that appears darker. The white trapezoidal area at the top of the picture is a manmade salt evaporation bed. The pentagonal area at the southeast tip of the lake is a Kennecott Corporation tailings pond. The large white area in the mountains south of that pond is the Bingham open pit copper mine. The large white area that protrudes into the southwestern edge of the lake is NL Corporation's evaporation bed for recovery of magnesium [Courtesy of NASA].

Only the MSS is now being operated. An electronic failure in the RBV power supply circuitry last August made it difficult to switch between the two imaging systems, and the RBV was shut down. If the MSS fails while the rest of the satellite equipment is operational, however, the RBV can be reactivated for continued imaging.

Each of the RBV or MSS photographs covers an area about 185 km square, and each 34,000-km^2 target area—or scene—is photographed four times with the MSS or three times with the RBV. If the satellite is over North America, the imagery is relayed directly to one of three U.S. and one Canadian ground stations. (Brazil is now building an ERTS ground station that will be the only one outside North America.)

Imagery obtained over other countries is stored in one of two wideband videotape recorders for replay when the satellite passes over the United States at night on the south-to-north leg of its orbit. One of the recorders failed last August, however, and the other has completed about 80 percent of its designed 1000-hour lifetime, so it is used only for about an hour per day. There is a strong possibility, however, that videotape recorders for ERTS may be installed in Apollo ground stations in Spain and Australia to provide real-time coverage of Europe and Australia.

Using only the one videotape recorder, ERTS photographs 188 scenes each day, 44 of them in the United States. It thus maps an area of about 6.5 km^2 every day. All possible scenes are photographed whenever the satellite passes over North America. Selection of scenes in other areas is dictated by the presence of cooperating investigators in the country and by forecasts of cloud cover.

Since its launch, ERTS has imaged more than 33,000 scenes in four spectral bands, and more than 1.5 million photographs have been prepared. It has mapped more than 75 percent of the earth's land mass, including both poles; the areas that have not been mapped are principally in the U.S.S.R. and the People's Republic of China, where there are no cooperating investigators. It has also photographed the entire United

States 10 times. Transmitted imagery from the satellite is processed into photographs at NASA's Goddard Space Flight Center in Greenbelt, Maryland, and sent to cooperating federal agencies and to the 220 U.S. and 100 foreign principal investigators who are working with NASA to assess the utility of remote sensing in specific applications. A complete set of images produced by ERTS is also sent to the Department of the Interior's Earth Resources Observation Systems Data Center in Sioux Falls, South Dakota, for sale to the public.

The resolution capability of the imaging devices is quite impressive. ERTS photographs reveal significant surface features without loss of definition at a scale of 1 : 250,000 (1 cm is equivalent to 2.5 km) and information at a scale of 1 : 30,000. Some investigators have found that they can identify features as small as 90 meters in diameter or linear features only 15 meters wide. Major highways, for example, can thus be identified readily, and smaller streets can often be seen.

Even more information can be obtained from the black and white images by assigning a different color to each of the three (RBV) or four (MSS) spectral bands and superimposing the images to produce highly detailed false-color photographs. Bands 1 and 4 are generally assigned blue, bands 2 and 5 are assigned green, and bands 3 and 6 or 7 are assigned red. Photographs produced in this manner thus show dense vegetation as bright red because of the very high reflectivity of chlorophyll-bearing leaves in the near-infrared. Rural-urban interfaces appear pink, and highly developed or barren land appears gray. Rocks and granite mountains produce neutral colors similar to their real-world appearance, and deep lakes appear dark blue. These color variations provide much more information to the naked eye, but more importantly, they also allow a much greater amount of information to be obtained from computer processing of the different spectral bands.

Because of the satellite's height above the earth, the ERTS images are also orthophotographic; that is, each point on the image appears to have been photographed from directly above it, making the images especially useful for cartography. When maps are prepared by means of conventional medium- or high-altitude photography, sophisticated techniques must be used to remove distortions that arise because areas at the fringe of each image are photographed at an angle. Such corrections are not necessary with ERTS imagery, so the production of maps takes much less time. Also because of the satellite's altitude, only about 500 ERTS images are required for complete coverage of the United States, compared to the 500,000 required for mapping with high-altitude aircraft.

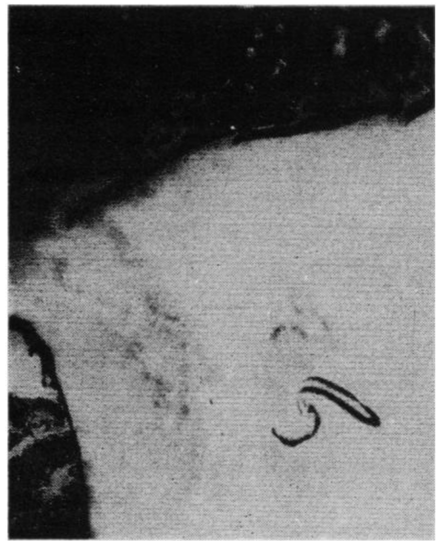

Fig. 3. Part of a reversed (negative) MSS-5 image of New York Bight taken 16 August 1972. Manhattan (under scattered black cloud cover) is at the top, Staten Island at the left. The black area in the lower right is the trail produced by a barge dumping industrial acid wastes in the bight. ERTS imagery would prove highly useful for monitoring such ocean dumping to regulate amounts and to ensure that dumping occurs in the proper location [Courtesy of C. T. Wezernak, Environmental Research Institute of Michigan].

The flow of data from ERTS has been so great that much of it may not be fully analyzed for months or for years. Preliminary results (to be discussed in a second article next week) are so promising, however, and many of the data are so immediately useful that the scientific community was severely disappointed when the tight NASA budget forced postponement of the second ERTS launching from November 1973 to the first quarter of 1976. The designed lifetime of ERTS is only one year. Even though similar Nimbus satellites have operated for about 36 months, therefore, it is probable that there will be a gap in ERTS coverage unless the second launching is moved forward again.

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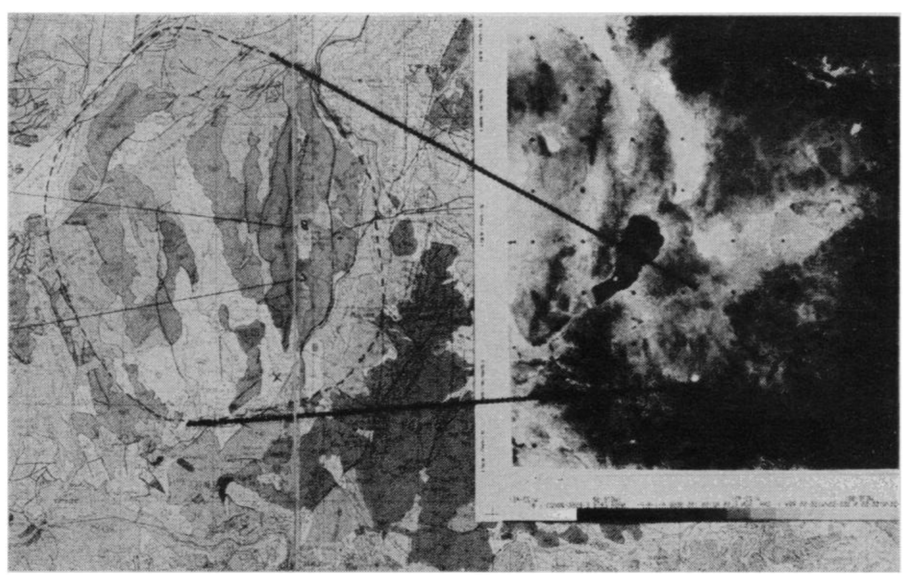

Fig. 4. An RBV image and part of a geological map showing the area around Pyramid Lake and Reno, Nevada. Pyramid Lake is at right center in the ERTS image and Honey Lake in California is at left center. The large circular feature outlined on the map and marked on the image had not been observed previously. It is about 40 kilometers in diameter, and is believed to be either a resurgent caldera—an old volcanic extrusive center that has uplifted and/or collapsed—or an eroded dome. Hot springs are located in the southeastern part of the circle. Identification of this feature may prove important in future studies of the distribution of mineral deposits or geothermal power sources in the region. Reno is at the southeastern edge of the circle (to the right of the dark area), and the Truckee River runs eastward through Reno, then north into Pyramid Lake. The large white area north and slightly to the west of the lake is the Smoke Creek Desert. Comparison of the ERTS image with previous maps shows that Pyramid Lake has shrunk substantially because of withdrawals from the Truckee River by California and Nevada [Courtesy of NASA].