Finding Pollution with Aerial Infrared Thermography

The Environmental Protection Agency (EPA) has identified contaminated surface and drinking water as one of the more serious environmental problems facing the United States. Leaking sewage-collection lines, storm-water drain discharges, and illegal connections to storm-water drainage systems can be identified by their thermal infrared (IR) signatures during certain times of the year. As these sources of pollution leak, seep, or empty into creeks, streams, rivers, and lakes, their thermal signatures vary from their surroundings, and aerial IR thermography can accurately pinpoint them.

Typically, liquids flowing into a stream or lake appear warmer than the surface of the larger body of water, particularly during cooler times of the year, because of the relative warmth of the ground a short distance below the surface (Figure 1a). Leaks from nearby lines often come to the surface through lateral flows to a stream or lake bed, or to a slope (Figure 1b) leading down to the surface of the water. These leak areas and the warm plume of liquid joining or flowing downstream with the cooler water are visible in the thermal IR spectrum. In most parts of the United States, late fall, winter, and early spring are well suited to this type of inspection because of the greater difference in temperature between ground and surface water, as well as the minimal interference from overhanging foliage (Figure 1c).

Why the need?

The EPA enforces compliance with the federal Water Pollution Control Act and the Clean Water Act. Under these laws and other requirements, municipalities must develop, implement, and enforce a storm-water management program designed to minimize the amount of pollutants discharged into local surface waters.

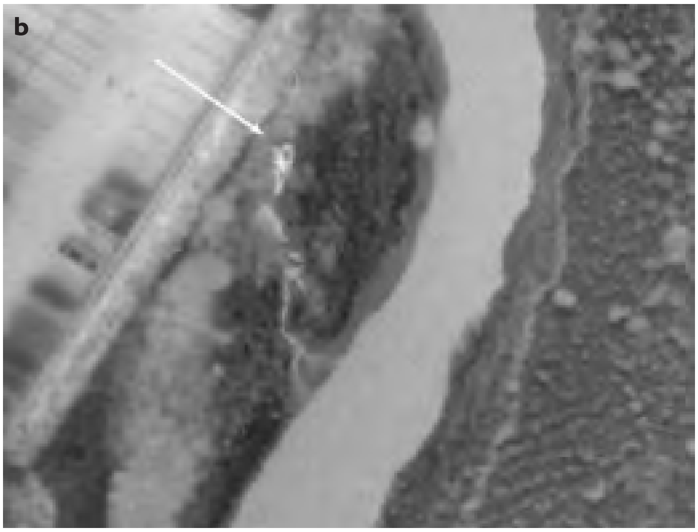
Aerial IR thermographic surveys can help municipalities fulfill this obligation. Storm-water collection systems are engineered to efficiently drain selected areas and to discharge the runoff into surface waters. All too often, these systems convey pollutants from illicit connections, degraded sanitary sewers and septic tanks, and other sources. Until now, locating these point sources has been a labor-intensive task that often relied on taking samples blocks or miles from the actual pollution source.

Traditional methods of pollution-source detection, including on-the-ground water-quality sampling and visual stream surveys, do not provide effective coverage of large surface waters, where many problems go undetected. Municipalities have become interested in using alternate, cost-effective means of pollution detection that overcome the limitations of the traditional labor-intensive approaches. They would like to identify and abate in-stream increases of bacteria, metals, nutrients, pathogens, and herbicides; other pollutants from urbanization; malfunctioning septic systems; illegal sanitary-sewer and storm-drain connections; and other illicit discharges.

An aerial IR survey provides an efficient and cost-effective way to find these point sources. After ground verification and analysis of the information collected during an aerial IR survey, officials can take action to deal with malfunctioning systems and illicit discharges. Municipalities can also identify areas that contain priority clusters or higher concentrations of pollutants and prepare lists of individual property addresses located within these clusters. This type of project demonstrates to local residents a heightened awareness by public officials of illegal stream connections, septic-system failures, and general water-quality issues, another requirement of the federal program.

Aerial IR surveys, ground verification, and remedial follow-up provide measurable environmental results, including enhanced in-stream water quality; recovery of aquatic species; and improved collection systems, septic-system maintenance, and animal-

Figure 1. Aerial infrared images show liquid outfall as a brighter (warmer) plume on December 1, 2000 (a), on a bank slope (b), and with reduced foliage on March 13, 2003 (c).



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waste management; as well as increased knowledge of groundwater movements.

Figure 2. A typical creek landscape, seen in early summer, illustrates the difficulty of ground-based surveys, which require walking the entire length on both sides.

Ground vs aerial

Conducting a ground-based visual survey of a stream requires walking the entire length on both sides (Figure 2). A ground-based IR survey offers few advantages over a visual survey and may cost more. Its major advantage is that inspectors need only test the water outfalls that show heat signatures, which potentially increases the speed of the survey if there are few anomalies. However, there are additional costs involved with a ground-based IR survey. Given the expense of the personnel and equipment needed, and assuming downtime for adverse weather, sick days, and/or injuries, either type of ground-based survey costs more than most municipalities can or will pay. In contrast, aerial IR surveying is quick and efficient. Under good conditions, aerial IR thermographers can scan up to hundreds of stream-miles in one night, and produce a complete, accurate report in a timely manner.

IR imagery often consists of gray-scale pictures whose varying shades represent differences in temperature and the emissivity of objects in the images. As a general rule, lighter colors designate warmer objects and darker colors indicate cooler ones. All objects in the images are detected at thermal IR wavelengths in the 3,000–5,000-nm (shortwave) or 8,000–14,000-nm (longwave) range. Lights and other relatively hot objects are evident because of their heat emissions.

Images taken with an IR camera during a flight are often recorded on videotape and/or saved digitally to on-board hardware and later converted to a digital image file, which can then be modified in several ways to enhance its value to the end user. Videotape records the highest-resolution IR images, although printed thermographs and map data may serve as convenient references when accompanying a report.

Equipment

Professional survey results require equipment specifically designed for the task. In applications that need a straight-down view or a large-area view, and/or where long distances must be covered in a limited time, aerial IR thermography is superior to ground-based IR in image quality and use. The selection of the proper aircraft, camera mount, IR imager, navigational aids, recording medium, workstation computer equipment, and pilot and crew is critical to success.

Both helicopters and light airplanes can perform aerial IR surveys. Spatial resolution and thermal sensitivity are all-important in aerial IR thermography. It is always better to use a large pixel array, although larger lenses help if the customer will accept some signal-strength degradation. Using a more powerful lens does improve clarity by reducing the ground resolution element (GRE)—the size of one pixel on the ground for a given distance. This reduced GRE, however, also reduces the sensor's field of view, which limits the total area covered on the ground. Moreover, an aircraft's movements and vibrations, particularly those of a helicopter, may cause image blurring or smearing, which results from an increase in the apparent speed of the sensor's view across the ground. The GRE and other thermal-imager characteristics need to be known before the aircraft and imager are selected for a particular job. Our research and experience in aerial IR applications have shown, for example, that a handheld, small-format imager held out the open window of a helicopter will not produce professional results.

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Well-maintained aircraft and IR, video-recording, and mapping equipment are essential to success. Everything in the aircraft must be secured, and wires clearly labeled for quick identification, placed out of the way, and shielded from electromagnetic interference. Precise navigation is important in any aircraft but particularly in nighttime aerial IR operations. To produce the most valuable report possible, one must record the imagery and exact location of all areas surveyed. Because the pilot and thermographer are extremely busy during the flight, one or both might miss an anomaly. Thus, all imagery and matching Global Positioning System (GPS) information need to be recorded. During postflight analysis, each frame of the video will receive methodical and detailed scrutiny. For this reason, the thermal-imager video output must be routed through a device that encodes the video with a continuous stream of GPS information. A digital videocassette recorder (VCR) tapes the annotated video imagery, while a laptop computer with specialized mobile mapping software is used to guide the aircraft and map the designated flight path.

Aerial IR imaging is not a job for IR equipment operators or pilots who have not received specialized training in such operations. The aircraft must fly over and along the surface-drainage system in a manner that allows the imaging and recording on digital videotape of the target creek, stream, river, or lake. In the cockpit, moving-map software with GPS antennas similar to that used in some automobiles permits the crew to monitor the flight path and the aircraft's location with respect to the drainage area, and guides the pilot along specific flight lines to ensure complete coverage. The IR operator usually interrupts the recording during turns outside the study area, which omits extraneous imagery.

Analysis

After the flight, the videotaped imagery is analyzed using a digital VCR, a high-resolution TV monitor, and an integrated computer system with video-capture hardware and software. As the tape plays, the GPS-coded signal received and recorded during the flight is decoded by a device called a video encoder/decoder, which re-creates the original GPS signal and sends it to the computer so that its mobile mapping software interprets the recorded signal as a live one. The mapping software shows the position of the moving airplane superimposed on a street map on the computer screen, while the recorded IR imagery of the area below the airplane appears on a second monitor. GPS signals update the airplane's position once every second throughout the flight and at the same rate during the post-flight analysis.

To find potential sources of pollution, users view the tape in its entirety—pausing and playing it backward and forward at regular speed and in slow motion as necessary. Each hour of tape requires many hours of analysis to complete a report. After all anomalous sources are found, they are marked on the topographic map, and IR thermographs are digitally captured on videotape using specially designed hardware and software. The captured image displays the annotation data—such as date, time, latitude, and longitude—as a strip at the bottom of the image. Each anomaly is assigned a number that corresponds to a number on a specific image. The maps and digital images are then brought into an image-processing software application and adjusted for such qualities as contrast brightness before being scaled for final editing.

A project's results

In February 2002, the Mecklenburg County Water Quality Program in North Carolina conducted a study to test alternate methods of pollution-source detection. It sought to determine the effectiveness of using aerial IR surveying along 27 miles of Little Sugar and Briar Creeks. The survey pinpointed 62 heat anomalies along the two streams. Field investigations of the anomalies revealed the following results:

- One anomaly was identified as a failing 15-in. sewer line. Charlotte Mecklenburg Utilities replaced the line, and the discharge stopped.
- Another anomaly was an illegal discharge into the storm-drain system from a convenience store. The discharge was removed from the storm drain and tied to the sanitary sewer system.
- Ten anomalies were identified as dry-weather flows to storm drains—that is, flowing water unrelated to precipitation—with elevated fecal coliform bacteria levels. Additional follow-up field investigations were conducted to identify the sources of these problems.
- Twelve anomalies were no longer found to be flowing during several field investigations. Inspectors carried out additional investigations to check for recurrence of the discharges.
- Ten anomalies could not be located on the ground. Additional follow-up was performed in an effort to identify them.
- Five anomalies proved to be sewer-collection system features with no discharges to surface waters. No further follow-up was required.
- Another twelve anomalies were identified as being dry-weather flows to storm drains but with no negative water quality impacts. No further follow-up was required on these.
- Eleven anomalies were attributed to groundwater flow. No further follow-up was required.

Conclusions

Municipalities must comply with federal clean-water laws, and each must develop, implement, and enforce a storm-water management program that has been designed to minimize the amount of pollutants discharged into local waters. By using specialized equipment and techniques, aerial IR thermographers can locate pollution point sources so officials can act to prevent con-taminants from entering our waterways. Aerial IR surveys will continue to assist municipalities in making U.S. waters, wetlands, and watersheds better suited for drinking water and recreation while creating a more hospitable environment for aquatic life. Ω

BIOGRAPHY

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