

# ***Application and Methodology for Locating Stormwater Discharges using Aerial Infrared Thermography***

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## **ABSTRACT**

The US Environmental Protection Agency (EPA) has identified contaminated surface water and drinking water supplies as one of the most serious environmental problems facing the United States. Leaking sewage collection lines, stormwater drain discharges and illegal taps into stormwater drainage systems can be identified by their thermal infrared 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 they can be pinpointed accurately from the air by using aerial infrared thermography. This paper describes the need, application, methodology and equipment required to perform aerial infrared surveys of stormwater drainage systems and waterways to identify specific areas where leaks are occurring so that action can be taken to abate the leaks.

**Keywords:** Aerial infrared, thermography, stormwater, illegal discharges, pollution, Environmental Protection Agency (EPA), Clean Water Act, Federal Water Pollution Control Act, articulating gimbal, Pollution FindIR™, global positioning system (GPS).

## **INTRODUCTION**

The flow of a liquid into the body of another liquid can be identified using infrared thermography if there is a temperature difference between the two liquids. Typically, liquids flowing into a stream appear warm as compared to the surface water in a creek, stream, river or lake – particularly during cooler times of the year, due to the relative warmth of the ground a short distance below the surface (See Figure 1). Leaks from nearby lines often come to the surface through lateral transfer to a creek, stream, river or lakebed, or to a slope (See Figure 2) leading down to the surface of the water. These leak areas and the warm plume of liquid joining and flowing downstream with the body of water are visible in the thermal infrared spectrum due to the difference in temperatures of the two liquids. In most parts of the United States, late fall, winter and early spring are well suited to this type of inspection because the difference between water temperatures (ground and surface waters) is present and because interference to view due to overhanging foliage is minimized (See Figure 3). Ground water seeps and outfalls of all types are also distinguishable for similar reasons.

## **THE NEED AND THE APPLICATION**

The US Environmental Protection Agency enforces compliance of the Federal Water Pollution Control Act and the Clean Water Act. As a requirement, municipalities in the United States must develop, implement and enforce a stormwater management program that has been designed to minimize the amount of pollutants discharged to local surface waters.

Aerial infrared thermographic surveys can help municipalities identify, quantify, document and remove previously unidentified illicit stream discharges. Stormwater collection systems are engineered to

discharge into surface waters to efficiently drain selected areas. All too often these systems convey pollutants from illicit connections, degraded sanitary sewers and other sources. Until now, locating these point sources has been a labor-intensive task, often relying on sampling data from sites that may be blocks or even miles from the actual source. An aerial infrared survey of these waterways is an efficient and effective way to find these point sources, allowing municipalities to prioritize areas of concern and concentrate efforts and scarce resources on those locations first.

Through ground verification and analysis, information collected during an aerial infrared survey can accurately identify “true positive” instances of remotely identified illicit discharges and then officials can take actions to remove them. The municipalities are also able to 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 a heightened public awareness (another program requirement) of illegal stream connections, septic system failures, and general water quality issues to local citizenry.

Illicit discharge detection activities such as these include performance monitoring to measure the effectiveness of pollution abatement programs. In instances where direct pollutant abatement is impractical, the municipality will identify critical areas and enforce best maintenance practices (BMP) implementation to resolve the intrusion of pollutants into waterways.

Aerial IR surveys, ground verification and remedial follow-up provides measurable environmental results including enhanced in-stream water quality, recovery of aquatic species, improved animal waste management, improved collection system maintenance, improved septic system maintenance and an increased knowledge of ground water movements.

## **GROUND-BASED SURVEYING**

Traditional methods of pollution source detection include on-the-ground water quality sampling and visual stream surveys; however, these methods have limitations – they are time consuming and labor-intensive. Traditional methods do not provide effective coverage of large surface waters where so many problems go undetected. Elevated fecal coliform levels cause officials to close beaches and prevent the public from using the water. Downstream, elevated bacteria levels may be detected but the source of the problem is not known. Municipalities have become interested in utilizing alternate, cost-effective methods of source detection in an effort to overcome the limitations of traditional labor-intensive approaches. They would like to identify and abate in-stream increases in mass loading of bacteria, metals, nutrients, pathogens, herbicides and other pollutants from urbanization, illegal sanitary sewer connections, illegal drain connections, malfunctioning septic systems and other illicit discharges.

To conduct a ground-based visual survey, it is necessary to walk the entire length (both sides) of the stream from within the stream banks. At best, to cover 100 stream miles by foot would take 1600 man/hours (100 miles x two member crew x two banks at ¼ mph-maximum reconnaissance speed), sampling every (visible and/or mapped) outfall. In addition to time constraints, walking surveys include hazards and difficulties such as being in high-risk neighborhoods, working in insect and snake infested areas, overgrown vegetation, steep, hole-ridden banks and varying depths of water. A ground-based *infrared* survey offers few advantages and may even cost more than a visual survey. The advantage is that only outfalls that are showing heat signatures need to be tested, thus potentially increasing the speed of the survey if there are few anomalies. However, there are additional costs involved with the ground-based infrared survey. The cost of the rental or purchase of an infrared camera or hiring a service contractor must be added. The cost of insuring the camera against misuse, breakage or dropping it into the water must be added. Also, there are added risks and costs involved in surveying at night under these already logistically challenging conditions (See Figure 4). Nighttime infrared surveys increase the chance of injury to the crew and damage to the equipment. The weather needs to be right for infrared surveying, so a survey of even 100 stream miles could not be completed by one two-man crew in 100 days in a limited season. Given that it will probably rain many times during the survey timeframe, postponing and increasing the cost since normal stormwater flow will make it impossible to perform the IR survey until the drainage system has emptied of all its rainwater. Using the same formula as above and doubling the speed yields 800 man/hours, but the increase in equipment cost and the additional risk involved make the

infrared survey even more expensive than the visual survey. Whether using visual or infrared on-ground surveying methods, in-house report generation must also be added to costs.

Considering the cost of the manpower and equipment and assuming down time for adverse weather, sick days or injury, either ground-based survey cost more than most municipalities are willing or able to pay. In contrast, aerial infrared surveying is quick and efficient. In one night, under good conditions, aerial infrared thermographers can complete hundreds of stream-miles and produce professional results in the form of a complete accurate report in a timely manner.

## **UNDERSTANDING AERIAL INFRARED BASICS**

Infrared imagery is often a grayscale picture whose scales (or shades of gray) represent the differences in temperature and emissivity of objects in the image. As a general rule, objects in the image that are lighter in color are warmer and darker objects are cooler. No object in the images is detected via visible light wavelengths (400-700 nanometers) rather, only from thermal infrared wavelengths in the 3000-5000 nanometers range (shortwave) or 8000-14000 nanometers range (longwave). Lights and other relatively hot objects are very evident, but as a result of their heat, not light emissions.

When an image is taken with infrared camera, it is often recorded on videotape and/or saved digitally to on-board hardware storage and later converted to a digital image file with the help of a computer. The image may be then modified in a number of ways to enhance its value to the end user. The highest resolution infrared images are usually found on videotape, while the printed thermographs and map data may be used as a convenient reference when accompanying a report.

## **EQUIPMENT**

In order to get professional results, equipment that is specifically designed for the task must be utilized. In applications where a straight-down view and/or large area view is needed and/or where long distances must be covered in a limited amount of time, aerial infrared thermography is superior to ground-based infrared in image quality, usability and economic feasibility. The selection of the proper aircraft, camera mount, infrared imager, navigational aids, recording medium, workstation computer equipment, pilot and crew is absolutely critical to success. The job must be done right and safely...the first time. The data must be collected efficiently and effectively in order to produce an easy to understand, high quality and useable report.

### ***Platform and Imager***

Both helicopters and light airplanes can be used to perform aerial infrared surveys. Spatial resolution and thermal sensitivity are all-important in aerial infrared thermography. It is always better to use a large pixel array although larger lenses can help if some signal strength degradation is acceptable. Using a more powerful lens does help to reduce the ground resolution element (GRE) – the size of one pixel on the ground for a given distance, but then the sensor's field of view is reduced, limiting the area covered over a given period of time. Also, the aircraft's movements and vibrations are more evident in the form of image 'shaking'. Image 'smearing' may also occur due to an increase in the apparent speed of the sensor's view across the ground. The needed GRE and other thermal imager characteristics should be known before the aircraft and imager are selected.

**Our extensive research and experience in this and many other aerial infrared applications has shown that a hand-held, small format imager held out the open window of a helicopter will definitely not produce professional results.**

### ***Video Recorder and Other Equipment/Considerations***

Well maintained aircraft, IR equipment, video recording equipment and mapping equipment are essential to success. Everything in the aircraft must be secured with wires labeled, shielded from electromagnetic interference and out of the way. Precise navigation is important in any aircraft and particularly so in nighttime aerial infrared operations. In order to produce the most valuable report possible, the imagery and exact location of all areas surveyed must be recorded. Since the pilot and thermographer are extremely busy during the flight, one or both may not see every possible anomaly, therefore all imagery

and matching GPS information need to be recorded. During post-flight analysis, more methodical, detailed and accurate scrutiny can be given to each frame of the video. 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. The annotated video imagery is recorded with a digital videocassette recorder. A laptop computer with specialized mobile mapping software is used to map and fly flight lines.

## **FLIGHT METHODOLOGY**

Aerial infrared imaging is a NOT a job for airsick prone IR equipment operators or pilots that have not been specifically trained in nighttime aerial infrared operations.

The aircraft is flown over and along the surface drainage system in a manner that allows the creek, stream, river or lake to be imaged and recorded on digital videotape. In the cockpit, the moving map software with 'bread crumb trail' feature engaged, permits the crew to monitor their flight path and location with respect to the drainage area highlighted and guides the pilot along flight lines to assure to insure complete coverage. The recording device is often paused during the turns outside the study area so that extraneous imagery is omitted.

## **ANALYSIS METHODOLOGY**

After the flight, the imagery is analyzed by playing back the videotape 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 that was received and recorded during the flight is decoded. The decoder then recreates the original GPS signal and sends it to the computer so that the mobile mapping software 'thinks' it is receiving a live signal. The mapping software shows the moving position of the airplane superimposed on a street map on the computer screen while the recorded infrared imagery of the area below the airplane is visible on the TV monitor. GPS updates the airplane position once per second throughout the flight and at the same rate during the post-flight analysis.

To find outfalls, the tape is viewed in its entirety, paused, played backward and forward at regular speed and in slow motion, as necessary. For each hour of tape, many hours of analysis are required to complete the report. When the entire tape has been reviewed and all anomalies are found, they are marked on the topographical map (See Figure 5) and infrared thermographs are digitally captured using specially designed hardware and software. The captured image displays the annotation data as a strip at the bottom of the image. The map is marked using this information and updated showing the exact location of each anomaly with a flag denoting the report anomaly number designation. The maps and digital images are then brought into image processing software and adjusted for contrast, brightness, etc., before being scaled and placed in report software for final editing.

## **REPORT PRODUCT**

Stockton Infrared's aerial infrared division, AITscan (Aerial Infrared Thermographers) has trademarked its Pollution FindIR™ Service product for this type of work. The reports include:

- A complete bound hard copy report printed in high resolution on photo-quality paper consisting of:
  - A written report noting flight conditions, scope of work, and the location of each anomaly identified by latitude/longitude and by location/image number.
  - Printed infrared images of selected areas with the name coordinated to the exact location.
  - Printed maps indicating the exact location of each anomaly.
- CD-ROM containing all from the project files including the entire digital report, all digital image files and all digital map files.
- Infrared videotape copy of the original digital video of all recorded infrared imagery.

## EXAMPLE PROJECT RESULTS

In February 2002, the North Carolina Mecklenburg County Water Quality Program conducted a study to test alternate methods of source detection in an effort to overcome the limitations of traditional illicit discharge detection methods. The study sought to determine the effectiveness of utilizing aerial infrared surveying technology to isolate and identify point sources of pollution such as sanitary sewer overflows, illicit connections to the storm drain system, dry weather flow from stormwater outfalls and failed or failing septic systems and sewer collection systems along 27 miles of stream in the Little Sugar Creek watershed. The survey pinpointed 62 heat anomalies along Little Sugar and Briar Creeks in the targeted basin. Field investigations were performed of these anomalies that revealed the following results:

- 1 anomaly was identified as a failing 15-inch sewer line. *Charlotte Mecklenburg Utilities replaced the line and the discharge stopped.*
- 1 anomaly was identified as an illegal discharge to the storm drain system from a convenience store. *The discharge was removed from the storm drain and tied to the sanitary sewer system.*
- 10 anomalies were identified as dry weather flows to storm drains with elevated fecal coliform bacteria levels (>1,000 and <4,000 ecfu/100ml). *Additional follow up field investigations were conducted to identify the sources of these problems.*
- 12 of the anomalies were determined to be no longer flowing after several field investigations. *Additional follow up investigations were performed to check for recurrence of the discharges.*
- 10 of the anomalies could not be located on the ground. *Additional follow up was performed to identify the anomalies.*
- 5 of the anomalies were identified as sewer collection system features with no discharges to surface waters (manholes, laterals). *No further follow up was required.*
- 12 anomalies were identified as dry weather flows to storm drains but with no negative water quality impacts (groundwater, water leaks, etc.). *No further follow up was required.*
- 11 of the anomalies were attributed to groundwater flow. *No further follow up was required.*

## CONCLUSIONS

Municipalities must comply with the Federal Water Pollution Control Act and the Clean Water Act. They must develop, implement and enforce a stormwater management program that has been designed to minimize the amount of pollutants discharged to local waters. By using specialized equipment and techniques discussed herein, aerial infrared thermographers can locate pollution point sources so that officials can act to prevent pollution from entering our waterways.

On October 18, 2002, our Nation marked the 30th anniversary of the Clean Water Act and began the observance of the Year of Clean Water. Aerial infrared surveys will continue to help municipalities make United States waters, wetlands, and watersheds better suited for drinking and recreation while creating a more hospitable environment for aquatic life.

For more information on aerial infrared surveys of stormwater drainage systems and waterways visit [www.aitscan.com](http://www.aitscan.com) or call 800-AIT-SCAN.



Figure 1) Aerial infrared image of outfall.



Figure 2) Aerial infrared image of outfall on bank slope.



**Figure 3) Aerial infrared image of outfall into a creek, foliage reduced in early spring.**



**Figure 4) Photograph of typical creek landscape, taken in early summer.**



**Figure 5) Example of a topographical map marked with anomaly locations.**

