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Color Infrared Survey for Identification of Failing Onsite Treatment Systems

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Abstract:
Color Infrared (CIR) Photography was used to identify failure of these onsite wastewater treatment systems within a large geographical area without depending on field surveys, which require time, personnel, and money. Once the CIR photos are obtained by flying a small commercial plane with a recording device, experienced analysts using the remote sensed data, GPS and GIS can identify and geo-reference the failed systems. Investigations show this approach reduces time, labor, and materials for identifying septic system failures.

Key Words:
Color infrared monitoring, remote sensing, GPS, GIS, onsite treatment systems, failing septic systems

1. Introduction:

EPA has recognized the need for identifying failed onsite treatment systems because it impacts on the surface and groundwater quality, as well as threatens the public health. Field surveys are time consuming, costly, and requiring expert personnel to interpret the photos. These systems could fail from lack of maintenance by not removing the sludge; back ups in the pipes, cracks on the walls and pipes getting plugged up.

Traditionally, public health was considered protected if the wastewater permanently stayed below the ground surface, providing zero risk of direct human contact. Thus, recorded studies of malfunctions are overwhelmingly documented cases of partially treated wastewater backing up onto the ground surface or into house plumbing drains. Less frequently reported have been instances where the system provides inadequate treatment and contaminates ground water or nearby surface waters that are the receptors of the wastewater in its re-dispersal into the environment and its natural water cycle. Because most regulatory agencies do not have adequate records or do not actively investigate every possible onsite system within their jurisdiction, administrative malfunctions are unlikely to be documented, especially for older systems that were constructed before more modern record keeping and permitting.

In most states, the ground water is required to meet government-designated drinking water standards wherever a drinking water well can be legally located or within a designated zone of influence for a municipal well supply. For littoral systems where ground water rejoins nearby surface water in a relatively short time, it must not result in the degradation of beneficial uses (i.e., established recreational, shellfish growing, or other standards) of that surface water. A typical septic system with a directional drain field is shown in figure 1.

The traditional engineering and public health definition of malfunction is if any soil-based system or subsurface wastewater infiltration system fails to accept the entire volume of wastewater and backs up onto the ground surface. In this document, this type of malfunction is defined as *hydraulic*. Although many codes include household plumbing backups in this definition, these often are caused by plumbing blockages and can also occur in dwellings served by collection systems; therefore, they do not necessarily mean that the onsite or decentralized wastewater treatment system has failed hydraulically. Thus, some percent of *plumbing backups* might be hydraulic malfunctions, but these can only be determined by onsite investigation.

Public health authorities, epidemiologists, and monitoring organizations have also documented failures of soil-based systems to protect ground and surface waters from pathogens or disease-causing microbes. Similarly, numerous qualitative studies have identified septic systems to be a significant source of nutrients in nearby surface waters, resulting in impaired recreational uses and habitat destruction, which degrades the proliferation of more desirable aquatic species. However, routine detection of such treatment malfunctions is far less common and far more difficult to quantify than the more universally understood hydraulic malfunctions. This dichotomy has certain nuances regarding the attitudes of citizens served by septic systems. They vigorously

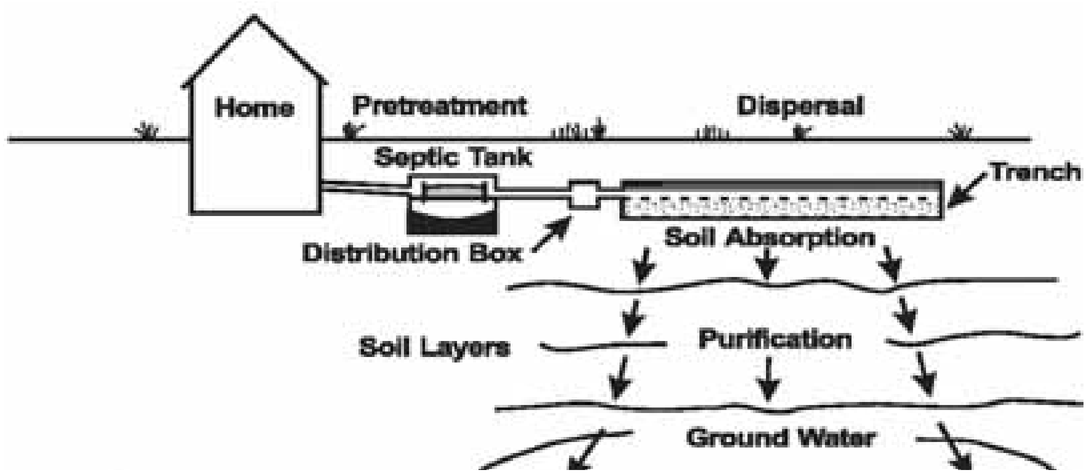

Figure 1: Illustration of typical septic system with field drain distribution

react to their drinking water being contaminated or widespread hydraulic failures, but are less upset by downstream wastewater impacts on the environment unless those impacts have a direct impact on their quality of life or economic welfare.

The main characteristics of a failed onsite system are dead vegetation, high soil moisture, and surface effluent. These conditions are due to an upward or lateral movement of the partially treated or untreated wastewater near the ground surface and perhaps are indicative of possible water quality problems. Usually as the wastewater moves upward, the high nutrient loadings in the wastewater effluent can inhibit the vegetation growth directly above the drain field. As the wastewater reaches the ground surface, the high nutrient loadings, combined with the imbalance of the air-water ratio, causes the vegetation to get stressed until it dies. Finally the effluent wastewater either will become stagnant or drain down to a low point, depending on the topography.

Before an aerial survey is done, all the available information including publications, studies, soils survey, water resource data, geology, climate and regulations, which are applicable to the onsite treatment system, should be analyzed. The collected information is very important in order to know and select the appropriate seasonal conditions for obtaining the aerial photos without any atmospheric interference (clouds) or leaf canopy conditions. Aerial survey should be done during high seasonal groundwater table, which coincides, with occurrences of failures. This collected background information provides the person analyzing the CIR photos with an insight as to what they expect as far as the type and rate of failures. There are two types of failures: Surface failure and Seasonal failure. Surface failures involve the presence of effluent on the ground surface. Seasonal failure involves the effluent not present on the surface, but signs do exist suggesting that the onsite treatment system have failed in the past and will definitely failed in the future.

2. Background:

Images that are obtained with Color Infrared (CIR) Photography can provide local officials, engineers and scientists with a tool to identify onsite treatment system (septic tank) failures. Color-infrared Aerial Surveys can record scenes of the earth surface using both visible and invisible sections of the Electromagnetic Spectrum. Near-infrared light is invisible to the naked eye, but adding to these images permits to see the earth surface in other than natural colors resulting in “color-infrared photography. Recently aerial photos have been used to identify failures on the CIR photographs by examining the images for signatures of surfacing septic tanks and drain fields, surfactants, or stressed vegetation surrounded by lush vegetation outlying the onsite systems. When the vegetation roots absorb the effluent wastewater, it enhances the vegetation growth through irrigation and fertilization. However, if the wastewater short circuits the onsite system and reaches the ground surface, it ponds and eventually kills the vegetation over the onsite system. Certain limitations do exist with CIR aerial surveys because the photos need to be recorded on a clear day, without atmospheric interference or a leaf canopy. CIR photography of failed systems can produce a False Signature and then the process needs to be verified with ground-truthing by the personnel. These photographic signatures of failed onsite treatment systems can be identified more accurately and less expensive with an Unmanned Vehicle Aircraft (UAV) with an infrared camera under the fuselage.

The objective of this study is to identify failure of these onsite treatment systems within a large geographical area using CIR without depending on field surveys, which require time, personnel, and money. Once the CIR photos are obtained by flying a small commercial plane with a recording device, experience analysts can readily identify the failed systems. Investigate other available technology to reduce time, labor, and materials for identifying septic system failures.

3. Case Study Application

The selected study area in Gwinnett County, Georgia was photographed using a standard color and color infrared film at a scale of 1:8000, which provides for the necessary resolution quality and still will provide for enough area coverage to make CIR cost effective. CIR is the main source for photo interpretation because it can detect changes in the vegetation growth patterns. The standard color photographs were used for comparison purposes. This procedure uses high powered optics and stereoscopy which gives the appearance of depth, to evaluate each lot for signs of unusual vegetation growth, stressed vegetation, and excessive soil moisture.

The stressed vegetation pattern associated with the upward and lateral movement of the effluent wastewater reflects light differently than the adjacent vegetation on both CIR and standard photos. Because the CIR film records Near Infrared Electromagnetic wavelength (700 – 900 nm), and some visible (400 – 700 nm) wavelength the resulting images are more sensitive to reflected light. Vegetation can reflect as much as nine times as much NIR radiation as visible light, therefore, CIR photos can reveal changes in vegetation density and lushness invisible to the human eye and not recorded by conventional aerial photos. Depending on the health and age of the vegetation, it will affect the amount of CIR radiation been reflected. Healthy or productive areas are easily differentiated from dead or stressed vegetation. Similarly, water does not reflect; and the ponding of the effluent wastewater will show as particles of black or dark gray in the images. Aerial Photos taken with color infrared film will show the failures pattern, or photographic signature of an onsite treatment system as a deep red color outlining the subsurface drain-line absorption area.

Gwinnett County developed a countywide *Watershed Protection Plan* that recommended that the septic system inspection program be augmented to provide for mandatory inspections paid for by the owners to ensure ongoing and appropriate maintenance. The recommended change is significant and would require considerable assessment, cooperation between inter-governmental authorities and the general public, and political acceptance and legislative action. It should be noted that current State law does not provide the local Board of Health with the power to coerce septic system owners into completing maintenance on their systems. The Gwinnett County Board of Health is limited to enforcing correct installation and repair of septic systems that have been declared as failing {OCG 31-3-5(b)(6)}.

In order to assess septic system performance and identify the location of properties containing failing systems, the Gwinnett County Storm Water Management Division proposes the acquisition and analysis of color infrared (CIR) leaf-off aerial photography for the entire County at a scale of 1:8,000. Utilizing the properties of CIR film, which is more sensitive than the naked eye or other films to vegetation density and lushness, analysis of CIR aerial photography seeks to identify "photographic signatures" that indicate the presence of a stressed or failing septic system. This is illustrated in figure 2 where lush green grass is present in the area of the septic tank over flow area. This is also visible from over head infrared imagery. These signatures are created because healthy and luxuriant vegetation reflect proportionately more infrared radiation than stressed or dead vegetation. In addition, pooling water reflects almost none. These signatures allow an experienced analyst to identify, with a significant level of confidence, those properties with failing or stressed septic systems. It should be noted that CIR photography would only detect failures of systems where such failure results in the lateral or upward movement of effluent. CIR photography will not identify failures characterized by sewage back up into the facility connected to the septic system, groundwater contamination or illicit connection.

Figure 2: Signature of a failing septic system in true color at ground level and the airborne Infrared image of the same area with the darker red signature to the right of the home

Eighteen miles of streams located in the Upper Chattahoochee River watershed (HUC 03130001) in Gwinnett County have been identified in the *April 2002, Final Georgia 2002 305(b)/303(d) List Document* as violating current water quality standards for fecal coliform (Reference: www.dnr.state.ga.us/dnr/environ). In addition, fecal coliform Total Maximum Daily Loads (TMDL) have been developed for 93 miles of streams located in the Upper Ocmulgee River watershed (HUC 03070103) in Gwinnett County (Attachment). Subsequently, the County has developed a TMDL Implementation Plan for each of these streams in the Upper Ocmulgee River watershed for fecal coliform.

Gwinnett County has identified sanitary sewer overflows, inappropriate housing, keeping or handling of animals, inappropriate disposal of animal waste, illegal dumping, wild animals and failing septic systems as “potential” sources of fecal coliform. Subsequently, Gwinnett County established a source identification program that actively seeks to identify and correct problems within the County’s sanitary sewer system, such as inflow and infiltration and sanitary sewer overflows. However, it is estimated that Gwinnett County contains between 70,000 and 100,000 on-site septic systems. It is considered likely, although anecdotally, that failing septic systems contribute substantially to this fecal coliform loading within County waterways.

Currently, these systems are inspected by the Gwinnett County Board of Health, Environmental Health Section upon installation and in response to public complaints. However, a program to ensure the maintenance of septic systems or to methodically identify failing septic systems does not exist at this time.

4. Results of CIR Aerial Photography:

CIR photos obtained in the case study provided by the Gwinnett County Stormwater Management Division clearly showed that septic systems can be easily identified on aerial photos. CIR has the advantage that signatures can be obtained with an infrared camera and ground truth calibrations performed at the site to verify that the signatures are not secondary or false. CIR not only can identify failures of septic systems, but can also be used to locate point and non-point pollution sources. Also if a non-point source can be identified on an aerial photo, the photo signature can be tracked upstream to locate the pollution source. New technology available that has been successfully tested in identifying failures of onsite systems is the integration of infrared cameras and other electronics in an Unmanned Vehicle Aircraft (UAV) which can be remotely controlled from the ground. The onsite system locations can be geo-referenced before the flight route is establish allowing for the UAV to locate the tanks and beamed the infrared sensor to the source. Images can then be sent to a ground control station where can be analyzed by experienced personnel. This technology will generate the county significant savings in time, labor and materials

This CIR aerial photography and analysis technique has been successfully employed elsewhere in the United States to identify failing septic systems and provides a cost-effective method of identifying these systems. A report published by the USEPA refers to this technique as “less expensive, more complete, and more accurate than other survey methods (Farrell, 1985).” Information on system failures will allow the creation of a unique GIS database that, when incorporated into our existing GIS, will provide a powerful tool for priority establishment, decision making, and the cost effective implementation of specified remedial actions.

Information obtained from the analysis of the CIR film will be used to:

- Identify, for specified remedial action, priority areas with high concentrations of remotely identified septic system failures located within TMDL and 303(d) listed watersheds;
- Prioritize public education efforts within remotely identified priority areas;
- Develop “Priority Lists of Properties” (PLOP) that will direct the investigation of a minimum of 300 remotely identified failures by the Environmental Health Section;
- Prioritize petition requests for the County’s Septic to Sewer Transition Program; and
- Provide information necessary to evaluate septic system inspection programs in response to recommendations contained in the County’s *Watershed Protection Plan*.

5. Hyperspectral Analysis

Imaging spectrometers or "hyperspectral sensors" are remote sensing instruments that combine the spatial presentation of an imaging sensor with the analytical capabilities of a spectrometer. They may have up to several hundred narrow spectral bands with spectral resolution on the order of 10 nm or narrower. Imaging Spectrometers produce a complete spectrum for every pixel of the image (Figure 3). Compare this to broad-band multispectral scanners such as Landsat Thematic Mapper (TM), which only has 6 spectral bands and spectral resolution on the order of 100 nm or greater (Figure 3). The end result of the high spectral resolution of imaging spectrometers is that we can identify materials, where with broad-band sensors we could previously only discriminate between materials.

In this study a comparison will be made to another identification technique which can provide another way of identifying failures of septic tank systems instead of the present Color Infrared (CIR) technique by analyzing a flightline over a wider geographical area. The technique is Hyperspectral Imaging System (HSI) using AVIRIS and analyzing the images using the Environmental Visualization Software (ENVI) and atmospherically corrected with FLASSH Software.

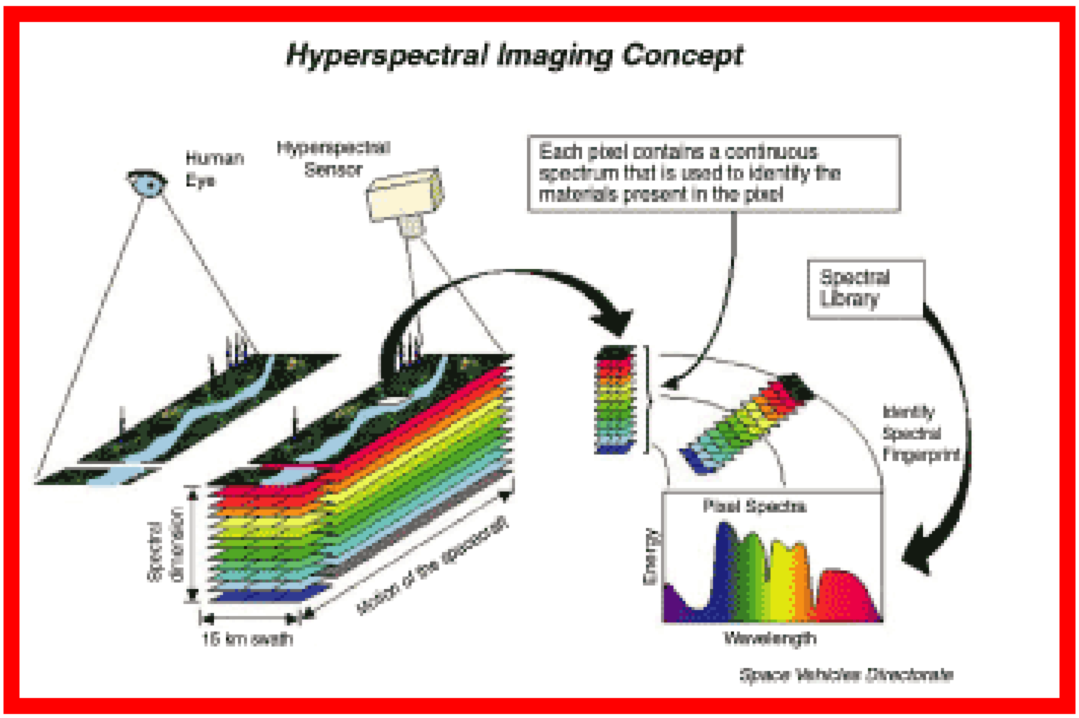

Figure 3: Illustration of the hyperspectral Imaging concept that generates a unique spectral signature that can be compared in a spectral library to identify the material

5.1 AVIRIS Data Processing

The data files for the septic tank failure site was downloaded from the AVIRIS Quicklooks website. The images were cloud free. The flightlines and AVIRIS files (1997) for the Gwinnett County region were provided by Mr. Robert Green and Sarah Lundeen of NASA's Jet Propulsion Lab in Pasadena, California. The data files were not atmospherically corrected and/or georectified. Because most images are acquired in the flightlines, to insure independent sampling, only one scene was selected. The atmospherically corrected files were opened wit the ENVI software for manipulation and analysis. The high altitude AVIRIS data has a spatial resolution of 20 m which was atmospherically corrected with the FLASSH software. FLASSH is a plug-in for the ENVI software which stands for Fast Line-of-Light Atmospheric Analysis of Hyperspectral Hypercubes. FLASSH handles data from AVIRIS and other Hyperspectral sensors, supports off-Nadir, as well as nadir viewing, and incorporates algorithms for water vapor and aerosol retrieval effect correction. FLASSH incorporates the MODTRAN4 plus radiation transfer properties and operates on a pixel-by-pixel basis which takes advantage of spectral information for each pixel. It corrects for water vapor, oxygen, carbon dioxide, methane, and ozone n the atmosphere as well as molecular and aerosol scattering. FLASSH calculates the atmosphere water vapor by using an average radiance for 2 sets of bands. FLASSH support images from any high spectral resolution instrument that measures in and around the major water absorption features at 840, 930, or 1130 nm with 15 nm or smaller bad spacings. The input parameters into FLASSH were: Input Radiance Image, Output Reflectance File, and Georeferenced Information, such as Latitudes, Longitudes, Ground Elevation, Type of Sensor, Altitude, Flight Date and Time. The atmospheric model selected was U.S. Standard, aerosol retrieval, was selected with specific polishing, aerosol model selection, was urban, Initial visibility was 20 km and number of bands were 224.

5.2 AVIRIS Results

The data files received from JPL were opened with ENVI Version 4.0. Three different bands were chosen to analyze the image. The band numbers selected for Red was 53 Green was 19 and Blue was 31. As the pixel locations were changed on the scroll image, different spectral profiles were generated. The Spectral Signature was obtained from the ASTER Library and it is shown on Figure 4. Note the distinct difference between the lush and dry grass signatures. This characteristic is used to match signatures in the AVIRIS image to identify the areas of lush grass growth and the potential of leaking septic systems.

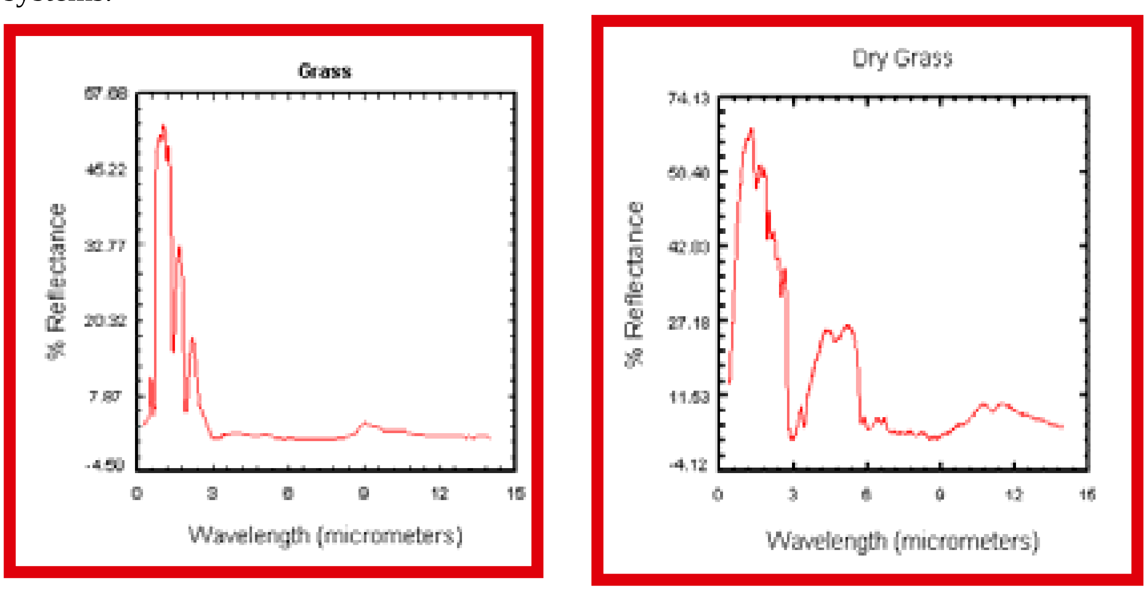

Figure 4: Comparison of spectral signatures of lush grass and dry grass from ASTER library

5.3 Unsupervised Classification

An increase in nutrient concentration leads to an increase in reflectance in the Red and the Near-Infrared Region (NIR) range of the spectrum. The reflectance in the NIR range of the spectrum shows that it depends mainly on the scattering. The locations of the pixels were on the lower section of the scatter plot because there is better absorption. Future ground truthing can be directed to areas which exhibit future abnormal conditions, minimum and maximum concentration areas along environmental gradients and can be reduced in pervious and developed areas. The Unsupervised Classification technique, K Means was used to cluster imagery into spectrally similar categories. This classification technique was made rather than the Supervised Classification technique because the identification made under the Supervised Classification depends on the naked eye which is limited to visible wavelength range (see figure 5).

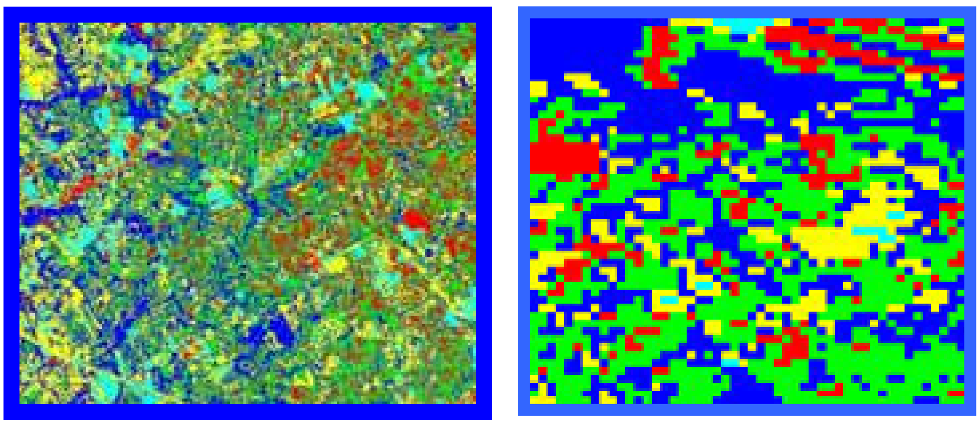

Figure 5: Comparison of hyperspectral image on left and the unsupervised classification of the image on the right showing lush grass in red

6. Conclusions:

CIR aerial photos can evaluate the problems of onsite treatment system failures over a large geographical area and can assist in the need for better management of the onsite wastewater program. CIR aerial photos are more cost effective, less labor intensive, quick and do not require previous permission from a homeowner. It is a proven fact that when experienced analysts interpret the photos, very few errors are made. There are disadvantages of CIR aerial surveys such as CIR can only locate the effluent wastewater on the surface, but it cannot identify a back up into the home or an illegal connection. CIR aerial surveys will no reveal surface effluent if there are bad weather conditions, or leaf canopy over the system. Failed systems can be located only if the signatures are present at the time the aerial photo is taken.

Hyperspectral Imagery Systems (HIS) such as the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) managed by NASA’s Jet Propulsion Laboratory is a unique optical sensor that delivers calibrated images in 224 spectral bands ranging in wavelengths from 400 to 2500 nm and it is flown aboard an ER-2 airplane at either high or low altitudes. AVIRIS main objective is to identify measure and monitor constituents of the earth’s surface based on molecular absorption and spectral signatures of the constituents. AVERIS hyperspectral data can be used to measure and map concentration of Chlorophyll on the surface above these onsite treatment systems delineating the lush or stressed vegetation. One of the main advantages that HSI has over CIR is that the geographical area been covered is much larger in which each pixel cover 20 m^2 with some overlap resulting in a ground coverage area of 11 km wide by 10 km long. The spectral signatures collected by the sensor of the vegetation above the onsite systems can be matched with those of spectral libraries such as USGS, JPL. or John Hopkins. The Spectral Mapping Method such as the Spectral Angle Mapper (SAM), which compares the spectra using full wavelength range, was successful in matching spectral signatures for vegetation under stress. Imaging processing was performed using the Environmental Visualization Software (ENVI) Version 4.0 with FLASSH Atmospheric Correction plug-in. Low altitude sensor data was not available for this flight line from JPL which could have given a better zooming capabilities with the ENVI software than the high altitude sensor. The field spectrum of the surrounding vegetation of the onsite treatment systems was chosen as the point of reference. Ground truthing was not performed with an spectrometer because of time constraints however; the county did perform a field survey of these systems for verifying the failures.

The Color Infrared method can discriminate between stressed and healthy vegetation. CIR method also can identify whether the discharge is originated from a point or non-point pollution source. Finally, it can be concluded that CIR could be tested in an UAV mounted with infrared cameras and other electronics and the results measured with respect to savings in time, labor, and materials. Both methods, CIR and Hyperspectral Imaging Systems (HSI) can identify the failures of onsite treatment systems; however, CIR it is more labor and material intensive that HSI, but an advantage is that failures can be determined at a lower flying altitudes than the HSI.HSI can produced results by discriminating between a false and a real spectral signature eliminating the need for groundtruthing. HSI using the AVIRIS sensor and processing the images with the ENVI software will make it possible to discriminate any surface pollution sources at a much lower costs in manpower and materials than the CIR. However, in order to obtain real time data a flyover needs to be coordinated with ground truthing.

7. Acknowledgements

Gwinnett County, Georgia Department of Public Utilities, Stormwater Management Division, Steve Leo provided Color Infrared photographs and literature

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