Oil Spill and Pipeline Condition Assessment Using Remote Sensing and Data Visualization Management Systems

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Biographical Sketch

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Key Words: Remote sensing, satellite imagery, pipeline monitoring, oil spill, hyperspectral imagery, water pollution, emergency response, environmental risk assessment, waste management, GIS and GPS

1. Introduction

Advances in geospatial sensors, data analysis methods and communication technology present new opportunities for users to increase productivity, reduce costs, facilitate innovation and create virtual collaborative environments for addressing the challenges of security improvement and risk reduction. Sensor developments include a new generation of high-resolution commercial satellites that will provide unique levels of accuracy in spatial, spectral and temporal attributes.

In addition to the high resolution panchromatic imagery illustrated in figure 1, there are a number of other commercial imagery products that are potentially applicable to pipeline transportation and power industry infrastructure. They include air borne and satellite radar, LIDAR, multi-spectral, and hyper-spectral sensors. Part of the challenge is matching the best sensor to the specific transportation related application. Visualization and advanced data analysis methods are also important capabilities. Automated change detection within a defined sector is one example of analysis capability that will assist in detection of unauthorized intrusion events. A specific application of these techniques to power distribution security is the detection of unauthorized intrusion onto pipeline right of ways. Pipelines often cover thousands of miles and are located in remote areas that are difficult and expensive to monitor. In one case study satellite imagery and target identification analysis is used to detect unauthorized intrusion onto a pipeline right-of-way in a remote area of Canada.

There are also challenges that may slow or impede the application of geospatial technologies to the electric utility sector. These include the need for improved methods and authorities for better data sharing across institutional boundaries. The developers and user communities need to communicate better and overcome some significant disciplinary differences. There are also challenging technical issues in the multi-sensor data fusion area to be overcome. Finally, there is a need for a focused interdisciplinary effort to match geospatial capabilities with specific user requirements.

2. Pipeline Industry and Safety Issues

The pipeline network in the United States consists of approximately 1.9 million miles. Part of this network is made up of 302,000 miles of natural gas transmission pipelines operated by 1,220 operators and 155,000 miles of hazardous liquid transmission pipelines operated by 220 operators. In addition to transmission pipelines, there are 94 liquefied natural gas facilities operating in the United States. This vast network's was initially developed in the early 1900's and has continued to expand each year to meet the growing energy needs and product requirements of the United States (US DOT, 2003). Growing worldwide demand for gas-fired electric power generation and to a lesser extent by growing industrial, commercial and residential demand is driving demand for gas. Natural gas projects continue to dominate construction and engineering work.

Estimated miles of natural gas, crude oil and refined products pipelines underway or planned for construction outside the U.S. and Canada total 122,276 km. new construction linear distance is 17,564 km, which is above last year's figure of 15,214 km due to ongoing projects all over the world (A Staff Report, 2001). In addition, natural gas distribution pipeline systems are being built, expanded, replaced, and planned worldwide. Much of the new construction is in the Middle East and South East Asia. In a number of cases there have been environmental pollution problems associated with leaks and damage to pipelines in this area of the world.

Safe pipeline transportation of energy resources is a major concern for the public and the pipeline industry. The pipeline Safety Act of 1992 requires that Research and Special Programs Administration (RSPA) adopt rules requiring pipeline operators to identify facilities located in unusually sensitive areas and high-density population areas, to maintain maps and records detailing that information, and to provide those maps to federal and state officials upon request. The Department of Transportation's Office of Pipeline Safety (OPS) currently does not have access to a reasonably accurate and national depiction of natural gas and hazardous liquid transmission pipelines and liquefied natural gas facilities operating in the United States. To ensure the safe, reliable, and environmentally sound operation of the pipeline transportation systems, OPS is working with state agencies and the pipeline industry to create a National pipeline

Mapping System (NPMS, 2003). This system is a full-featured geographic information system database that will contain the locations and selected attributes of natural gas transmission lines, hazardous liquid lines, and liquefied natural gas facilities operating in onshore and offshore territories of the United States (NPMS, 2003).

The most widely used methods for pipelines monitoring include foot patrols along the pipeline routes and aerial surveillance using small planes or helicopters. These patrols perform facility inspections, check for construction activity in the vicinity of the pipeline, and maintain the pipelines' right-of-way. Heavily congested areas are inspected and patrolled more frequently. In addition, the pipelines undergo periodic maintenance inspections, including leak surveys, and safety device inspections. So the developments and events that could place high-pressure pipelines, the surroundings of pipelines or security of supplies at risk could be prevented. In a continuing effort to remove the guesswork from pipeline operations and reduce costs, many new techniques have been employed to develop software and hardware systems that analyze pipeline risks and maintenance needs in a scientific fashion.

Research and application efforts are developing cost-effective ways to enhance pipeline integrity, inspection, and monitoring, as well as new tools and techniques for managing the risks involved in pipeline operations (Willke, 1996). Some of these efforts have investigated the use of satellite-based technology for pipeline protection. This work has identified the potential for satellite imagery to detect significant slope motion and ground movements that could threaten nearby pipelines with a less expensive means (Hartdraft, 1998). Some specialized software systems such as PIMOS can model five types of pipeline defects: external corrosion, internal corrosion, stress corrosion cracking, material/ manufacturing defects, and mechanical damage (Leewis, 1998). Other work by Zirnig et al. (2001) has studied natural gas transmission pipeline monitoring using high-resolution satellite imagery

Pipelines and their associated facilities pose potential environmental pollution risks that can also be monitored by a variety of remote sensing systems. Pipelines are required to meet all EPA hazardous waste management standards. Some pipeline wastes are excluded from the hazardous waste standards but others are not. Some large volume, or "special wastes", are believed to be lower in toxicity than other wastes regulated as hazardous wastes under the Resource Conservation and Recovery Act (RCRA). Subsequently, Congress exempted these wastes from the RCRA Subtitle C hazardous waste regulations pending a study and regulatory determination by EPA. In 1988, EPA issued a regulatory determination which stated that control of exploration and production (E & P) wastes under RCRA Subtitle C regulations are not warranted. Hence E & P wastes have remained exempt from Subtitle C regulations (IOCC, 1990). However, the RCRA Subtitle C exemptions did not preclude these wastes from control under State regulations, RCRA subtitle D regulations, or other federal regulations. Although, these wastes are exempt from the requirements of hazardous wastes, this exemption does not mean that these wastes could not present a hazard to human health and the environment if they are ill managed. Management of these wastes continues to be a requirement of the pipeline industry (U.S. EPA, 1993, U.S. EPA 1988).

Hazardous wastes related to the transport process of oil and gas in pipelines is fully covered by EPA regulations for the control of hazardous material. Examples of these wastes include: 1) waste in transportation pipeline related pits, 2) waste compressor oil, filters, and blowdowns, 3) waste solvents, 4) Vacuum truck and drum rinsate from trucks transporting or containing non-exempt waste, 5) used hydraulic fluids, and 6) used equipment lubrication oils (Dutta and Alam, 1995).

3. Integrated Satellite Based Detection System for Pipeline Monitoring

One of the largest and fastest growing markets for high-resolution satellite imagery in digital mapping is the utility industry. Utility companies and semi government bodies are turning to high-resolution satellite imagery to identify optimum facility and infrastructure locations. Using highly accurate, digital, ortho-rectified images, utility companies have a valuable information resource for planning, implementing and maintaining facilities and infrastructure, supporting disaster management efforts (Lindsay, 2001). High-resolution satellite imagery can aid utilities in monitoring electric and gas transmission corridors and rights-of-way; accurate and economical corridor analysis for power and gas pipelines; monitoring vegetation intrusion on transmission and distribution lines; and mapping for cable placement.

The integration of high-resolution imagery with geographic information systems to allow accurate geo-positioning of pipeline and power line vector information on to the local land use and topography representation becomes a very useful planning and decision support tool. The pipeline location can be placed as a vector file over a one-meter spatial resolution satellite image and colored red. Sensitive environmental areas are then identified as green through a land classification analysis on the GIS product. The location of roads, agricultural areas and structures are also clearly distinguishable due to the high spatial resolution of the image.

Unauthorized intrusion by individuals onto power line or pipeline rights of way and the conduct of damaging activities to the pipeline infrastructure is a concern that has grown particularly in resent times. In North America there are thousands of miles of pipelines that are located in remote rural and wilderness areas. Monitoring of these vast networks on even an intermittent basis is difficult and costly. The most common monitoring method is to use small aircraft to fly over the rights of way on a monthly or less frequent basis and conduct a quick visual inspection. These methods provide a very limited monitoring effectiveness and even less security protection.

With the recent availability of high-resolution commercial satellite imagery, advanced radar system, and target detection algorithms significantly improved monitoring of power distribution networks are now possible. These imagery collects were sequenced in time and change detection analysis was conducted to identify potential security and encroachment events. In this example additional one-meter spatial resolution imagery was collected over the target area. In figure 1, the three different imagery products are shown as overlays in the area of highest interest.

An example of this kind of imagery coverage and data analysis system for a pipeline network in is shown in figure 1. In this application multi-spectral four-meter spatial resolution imagery was collected over larger areas of the pipeline system. In addition synthetic aperture radar (SAR) imagery was collected over the same area, which provides all weather, day and night coverage that is not possible with optical sensors. Multiple satellite systems can be tasked to image entire pipeline distribution networks on a daily basis. Time sequenced image analysis is then conducted using computerized change detection analysis to identify potential unauthorized encroachment, environmental risks and security problems. As shown in step four of figure 2, before and after changes in imagery are identified and analyzed. Detected target information is reviewed and geo-referenced to map locations. Additional higher resolution imagery maybe collected over the geo-referenced locations if needed to determine if the situation calls for a notice, alert or alarm category of response. If determined necessary field personnel would be notified and dispatched to the predetermined location.

4. Effectiveness of Satellite Based Pipeline Monitoring System

Conventional monitoring of the massive pipeline systems in Canada is most commonly done on a sporadic schedule by used on visual observation from aircraft flying the lines. Typical flight observation coverage is in the order of once every one to two months for most of the pipeline miles. Detection of unauthorized intrusion and security risk events with current practice is low due to a number of limitations that are inherent with this approach to monitoring. These limitations include; infrequent coverage, human error in detection, limited data analysis capability, high mobilization costs and limited trend analysis.

In an effort to evaluate alternatives to airborne remote sensing of the pipelines a study was conducted to compare this mode of data collection with satellite based remote sensing. A summary comparison of the results is given in table 1. Based on satellite coverage schedules three imagery collection frequencies were used. These included collection frequencies of once per week, twice per week and once per day. For each category the use of satellite based remote sensing was able to detect pipeline security problems 30 % to 100% better than aircraft based remote sensing. The most significant improvement was with once per week imagery collection where airborne systems had a 20% detection rate compared to a 32% to 55% detection rate for satellite systems. The highest rate of detection (93%) was also achieved with satellite systems with once per day imagery collection. For airborne systems the best detection rate of 88% was achieved using a twice per day imagery collection rate.

5. Hyperspectral Imagery and Detection of Oil Spills

Brownfields, refineries, tank farms, pipeline corridors, oil fields, and other industrial sites can have surface deposits of hydrocarbon-based materials. Sophisticated VNIR-SWIR hyper-spectral sensor is ideal for detecting soils and surfaces that have been impacted by oil-based materials. For example, in recent years hyper-spectral remote sensing is starting to getting applied to pipelines and tank farms. The technology allows the user to directly detect the presence of hydrocarbons in the soil and indirectly detect petroleum presence by measuring its effect upon local vegetation. It can detect underground pipeline leaks of as little as 20 bbl. Figure 2 is a Hyperspectral image of pipeline leaks into two areas ranging from 20 to 500bbl. The 300 to 500 bbl leak area is clearly identifiable. The smaller leak area requires detailed imagery analysis to identify. Remote sensing can also be an important tool in order to detect corrosion on the pipe; engineers can catch it before it becomes a full-fledged rupture. Environmental sensitive areas can be monitored over extensive areas and small pipeline leaks can be detected before becoming major spills. Early detection allows companies to reduce remediation costs by being more proactive.

Some researchers have found that the detection of oil spills in soil is related with the concentration of light hydrocarbons in the soil and in the air. Light hydrocarbons tend to evaporate fairly quickly, therefore is a time constrain with this way of detection. On the other side, the more hydrocarbons get evaporated from soil or the water the less environmental damage in can cause. Tests have shown that hydrocarbons in soil and plastics are characterized by absorption maxima at wavelengths of 1730 and 2310nm.

6. Patuxent River Oil Spill

The Piney Point oil pipeline failed on the morning of April 7, 2000, near the PEPCO (Potomac Electric Power Company) generating station in southeastern Prince George's County, Maryland, but the pipe fracture and oil spill were not discovered and addressed until the late afternoon. In the interim, over 140,000 gallons of fuel oil were released into the surrounding marsh, Swanson Creek and, subsequently, the Patuxent River (see figure 3). No injuries were caused by the accident; cost of the environmental response and clean-up operations totaled about $70 million. The rupture occurred at a wrinkle in a section of pipe that had been installed during construction of the pipeline in 1971-2. Longstanding regulations prohibit the use of pipe containing bends with wrinkles in new pipeline construction. However, pipe wrinkles that were not discovered during the construction phase or that formed sometime after installations are still found periodically in pipelines.

7. Hyperspectral Analysis

The sensor used for the study of the Patuxent River oil spill is the Airborne Imaging Spectroradiometer for Applications (AISA) sensor system. AISA hyper-spectral imaging sensor can measure up to 55 spectral bands of information; has an airborne DGPS (Differential Global Positioning System - to measure aircraft position); and an INS (Integrated Navigation System - to combine the DGPS and an IMU (Inertial Measurement Unit) - to measure aircraft attitude.

AISA is a solid-state, push-broom instrument of small size, which makes it perfect for use in aircrafts. The instrument can be mounted on a plate that is compatible with a standard aerial camera mount, and has the flexibility of selecting the sensor's spatial and spectral resolution characteristics. AISA is capable of collecting data within a spectral range of 430 to 900 nm, and up to 286 spectral channels within this range. Current operational collection configurations for the AISA hyperspectral sensor covers a range from 10 to 70 spectral bands, this will depend on the aircraft speed, altitude, and the specific mission goals. Table 2 shows the spectral and spatial resolutions achievable when holding ground speed constant, in this case 120 Kts.

The AISA sensor was used to study the oil spill in the Patuxent River (Figure 4) and the data acquired was later retrieved using the ENVI software. The sensor obtained the data using 25 bands from around the 400nm to 800nm. The reason to only study this area of the spectrum is because of the reflectance characteristics of water in this area. The image was analyzed using two different classifications: unsupervised and supervised.

The supervised classification image (Figure 5) was done using the maximum likelihood method. Nine areas were chosen through the images to be able to distinguish between vegetation, wetlands and the different concentration of oil in water. The pixels chosen for each class were let grow (looking for surrounding similar pixels) using the “grow” tab of the Region of Interest in ENVI. The reason to select different areas with water is because of the variation of concentration of oil, which can affect the correct classification of an area affected or not affected with oil.

8. Conclusions

The use of hyper-spectral imagery to detect oil spills in water and soil has a lot of advantages in the field. It can be use to monitor oil facilities and therefore prevent worst scenarios when a leak in the facility is found. Also can be use to help planning the cleanup of the area, by quickly identifying the affected areas and possible path of the spill to be one step ahead. The identification of oil in the image using the different software packages available needs to be done through a proficient person, someone that has experience in the field of remote sensing and has some background on the behavior of hydrocarbons. Still this area needs more research since there are hundreds of different hydrocarbons products, and several different type of crude oil around the world. Which can affect the signature of the soil/water of study. In this specific study (oil in water) since the signature can be easily misidentify as water, hyper-spectral imagery can help to obtain a more detail spectrum to be able to separate between pure water and oil-water. In the study there were certain water areas that might be not correctly identify, but this can be more related on the lack of the experience of the analyst and not in the ineffective use of hyper-spectral imagery.

Advances in Information systems, satellites imaging systems and improved software technologies have led to opportunities for a new level of information products from remote sensed data. The integration of these new products into existing response systems can provide a wide range of analysis tools and information products that were not possible before. For example, with the higher resolution imagery and change detection analysis pipeline situational awareness and damage assessment can be conducted rapidly and accurately. Power utility infrastructure and system wide evaluations over a broad area could also be addressed using remote sensing data sources. All of these information products can be useful in the response, recovery, and rehabilitation phases of infrastructure management preparedness.

The strength of any paradigm shift is realized if new questions can be answered along with traditional ones. Using remote sensing technologies combined with information sharing will address many, if not most, traditional safety, hazards, and disaster issues facing pipeline and infrastructure managers, as well as provide for those raised by deliberate acts of aggression. Despite technological advance, disaster risk continues to grow. Infrastructure emergency managers and others continue to be called on to make decisions during emergency events, as well as in the pre-and-post disaster phases, with incomplete information. In order to make optimal decisions to reduce the loss of life and property, stakeholders uniformly must be able to obtain the needed information in a format that is appropriate for their capabilities. There is also the need for parties at great distances from each other to be able to share information in a seamless fashion. The shared information needs to be interactive with local data allowing it to be used in creating new integrated products tailored to the situation.

APPENDIX 1

List of tables and figures

Frequency of Imagery Collection	Probability of Detection (%) With Aerial Sensor Systems	Probability of Detection (%) With Satellite Sensor Systems
Once per year	0.4%	
Once per 6 months	1.0%	
Once per 3 months	2.0%	
Once per month	5.0%	
Once per week	20.0%	32% to 55%
Twice per week	40.0%	50% to 70%
Once per day	70.0%	78% to 93%
Twice per day	88.0%	

Table 1: Comparison of Aerial and Satellite monitoring systems for pipeline security applications

[redacted]	**Altitude**	**Spatial Resolution**	
	1000 m (3280 ft)	1 meter	20
	1500 m (4920 ft)	1.5 meter	26
	2000 m (6560 ft)	2 meter	34
	2500 m (8200 ft)	2.5 meter	55
	3000 m (9840 ft)	3 meter	58
	4000 m (13120 ft)	4 meter	70

Table 2. Altitude and Spatial Resolution Relationship

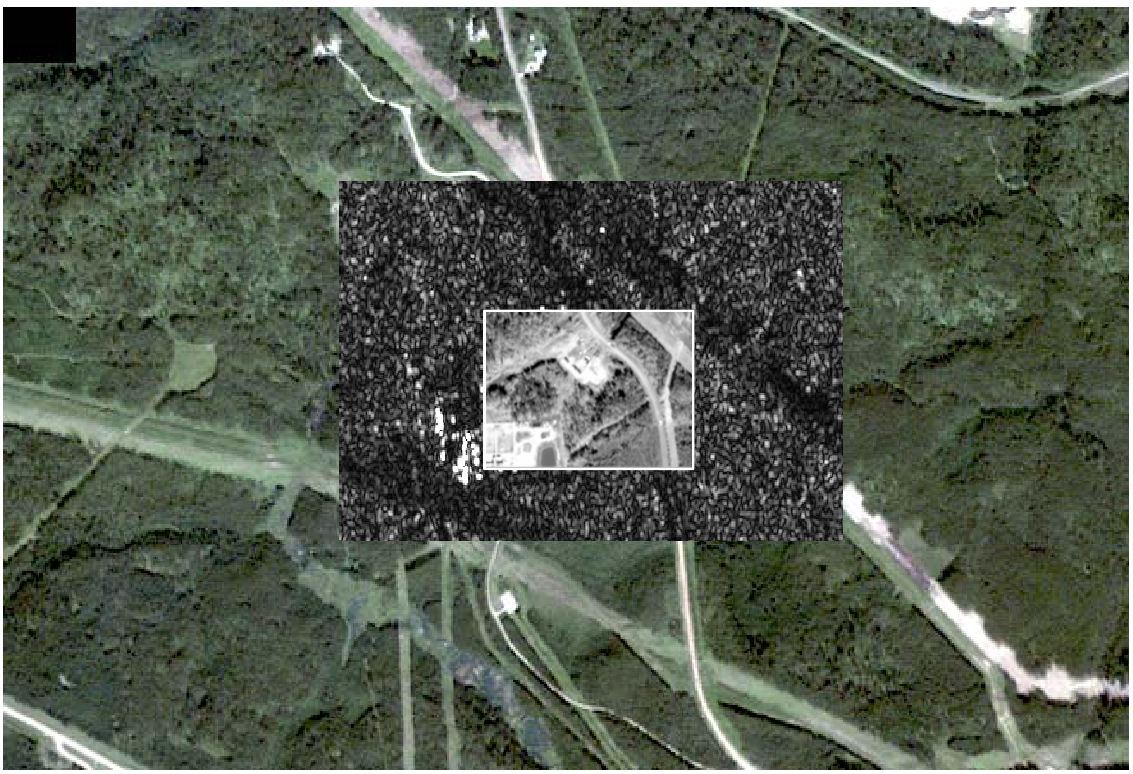

Figure 1: Multi-Sensor data fusion example for pipeline monitoring

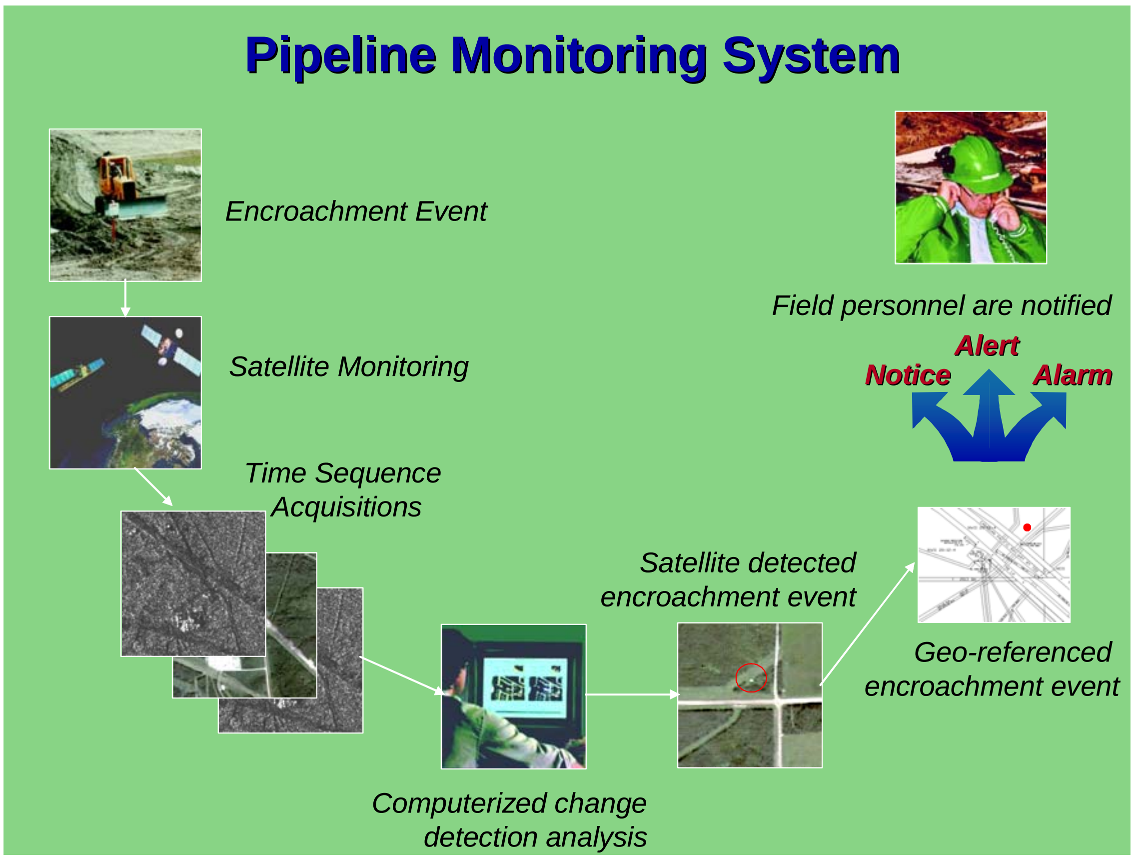

Figure 2: Satellite Imagery based decision support system for pipeline monitoring

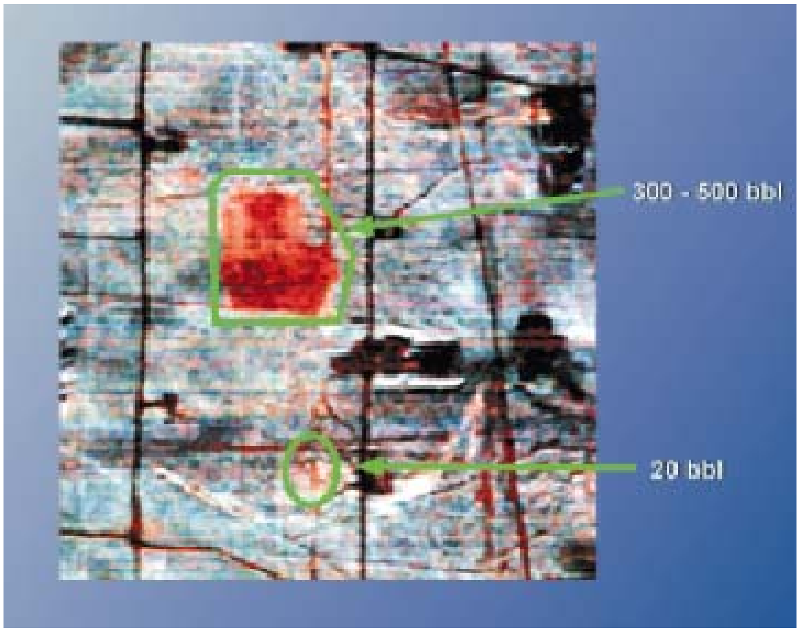

Figure 3. Hyperspectral image of pipeline leaks

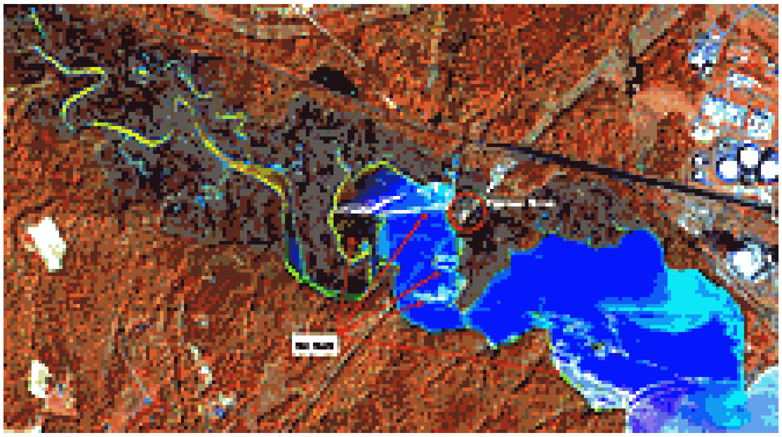

Figure 4. Image of study area on the Patuxent River, April 2000

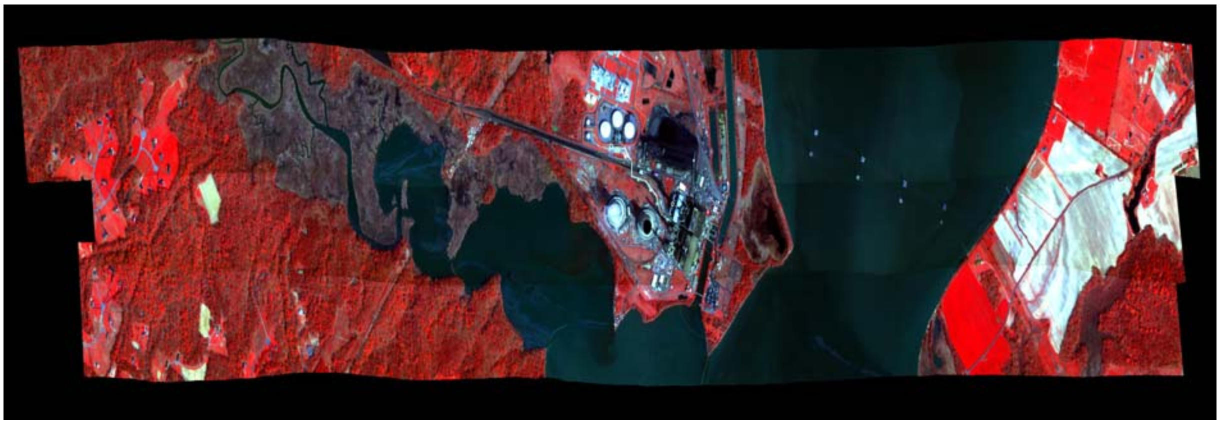

Figure 5. Data acquire by AISA and analyzed by ENVI

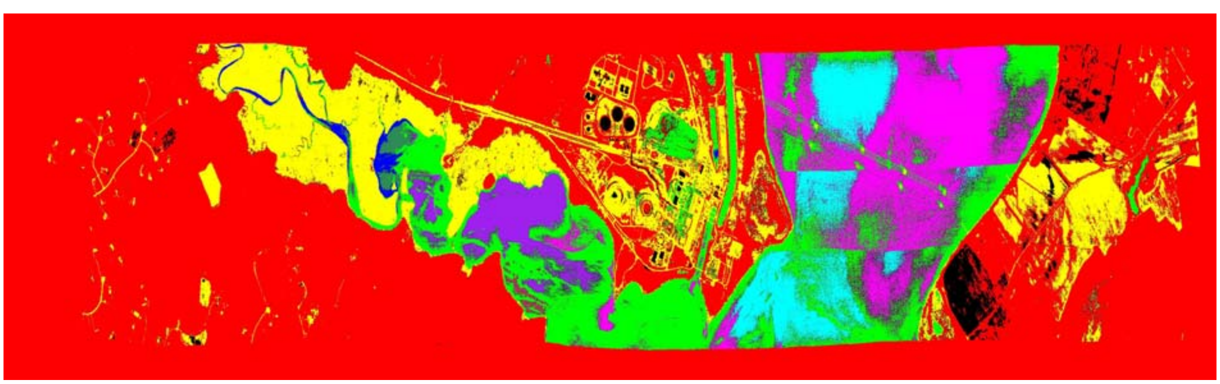

Figure 6. Supervised classification image (Maximum likelihood)

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