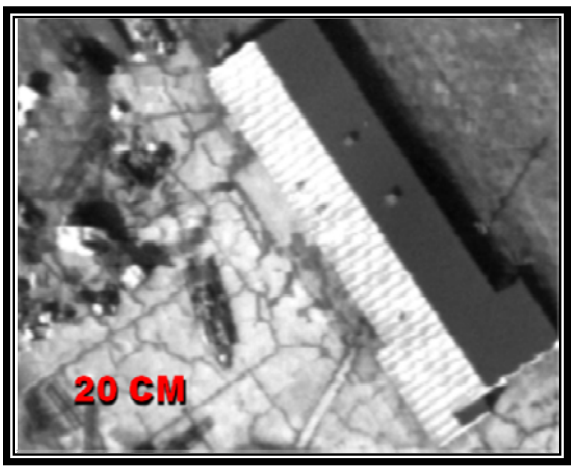
Missouri Department of Natural Resources

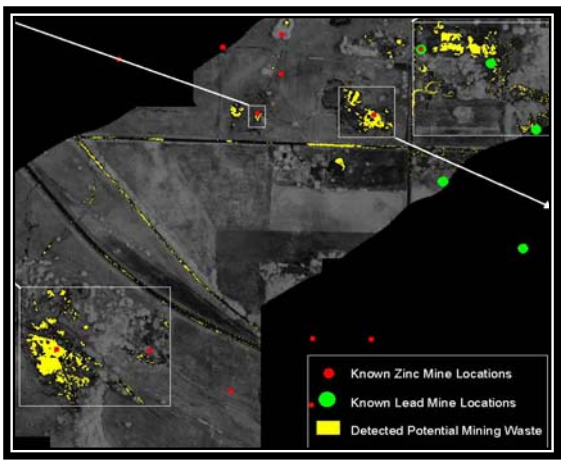
2005 – 2009 Project to Develop Applications
of

Civil Air Patrol Hyperspectral Imagery
for

Characterizing Contamination, Monitoring Remediation,
And
Continued Site Stewardship

June 2009





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Acronym List

AML	Abandoned Mine Land
ARCHER	Airborne Real-Time Cueing Hyperspectral Enhanced Reconnaissance
AWG	ARCHER Working Group
CAP	Civil Air Patrol
CDEM	CO Dept Emergency Management
CERC	USGS-Columbia Environmental Research Center
COWING	Colorado Wing, CAP
CPTS	Center for the Promotion of Sustainable Technologies
DOI	Department of Interior
EER	Environmental Emergency Response
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FPXRF	Field-Portable X-Ray Fluorescence
FWS	U.S. Fish and Wildlife Service
GIS	Geographical Information Systems
GPS	Global Positioning System
HQ	Headquarters
HRI	High Resolution Imagery
HSI	Hyperspectral Imagery
HWP	Hazardous Waste Program
ITRC	Interstate Technology & Regulatory Council
LRP	Land Reclamation Program
MMII	Minuteman II
MODNR	Missouri Department of Natural Resources
MORAP	Missouri Resource Assessment Partnership
MOU	Memorandum of Understanding
MOWING	Missouri Wing, CAP
MSU	Minnesota State University
MUS&T	Missouri University of Science and Technology
NRDA	Natural Resource Damage Assessment
SAM	Spectral Angle Mapper
SEMA	State Emergency Management Agency
SWMO	Solid Waste Management Office
UMC	University of Missouri Columbia
USACE	US Army Corp of Engineers
USAF	U.S. Air Force
USGS	U.S. Geological Survey
VI	Vegetation Indices

1. Executive Summary

In 2004, the Missouri Wing (MOWING) Civil Air Patrol (CAP) offered to take aerial photos of Missouri Department of Natural Resources' (MODNR) sites during training missions. The initiative would improve their training and support state objectives. In 2005, CAP began taking delivery of 16 Airborne Real-Time Cueing Hyperspectral Enhanced Reconnaissance (ARCHER) aircraft with Hyperspectral and High Resolution Imagery (HSI/HRI) sensors. That year the Department, knowing the potential benefits of HSI for environmental analysis and the cost effective support CAP provides, obtained a grant and began a series of projects funded by the Environmental Protection Agency (EPA), to evaluate and develop applications of CAP's HSI/HRI capability for environmental emergency response (EER), environmental assessment and remediation projects, and monitoring stewardship sites. After two years of working with MOWING, the Department's proposed Memorandum of Understanding (MOU) between MOWING and the state was signed, providing all state agencies the capability to task and fund CAP for non-emergency support.

Since 2005, the program has provided confirmed information about significant problems with a closed landfill, information that appears to provide the area of asbestos deposition from a bottled gas facility fire, the extent of airborne lead deposition from an active smelter, locations of abandoned mining operations, and examples of high resolution imagery for monitoring property use at former Minuteman II missile sites. The on-going 2009 project includes support to EPA Region VII's search for the source of elevated lead levels in a large number of wells around Carthage, MO, a search for seeps from underground coal mining using the signature of a known spring or seep, defining the extent of airborne deposition from a second lead smelter, and locating abandoned mineshafts.

In 2007, the Department began collaborating with the US Geological Survey (USGS) Denver on applications of ARCHER HSI following their analysis of the extent of oil contamination from a refinery flood. As other users of ARCHER imagery and agencies in need of the technology grew, an ARCHER Working Group (AWG) was formed, co-chaired by the Department and USGS Denver. The AWG now includes USGS Reston, which is evaluating ARCHER HSI for monitoring delisted Superfund sites; USGS Denver using ARCHER HSI for characterizing the extent of pine beetle infestation in CO; MNDNR through Minnesota State University, evaluating ARCHER HSI for monitoring Blue Earth River contamination from farm run-off; and ongoing MODNR projects.

The Department will cease its own collection and analysis in State Fiscal Year 2010 (SFY2010) under its current funding mechanism, and begin supporting other Department projects as well as state and federal agencies in developing ARCHER HSI/HRI programs. The Department submitted a proposal to use ARCHER aerial imagery to monitor deed restriction compliance at former Minuteman II sites to meet the U.S. Air Force's (USAF) inspection requirements. EPA Region VII has expressed an interest in using ARCHER to image and analyze select areas of Lawrence County for mine waste and lead contamination in residential areas, in advance of a large-scale survey. USGS Reston has ARCHER imagery of SW MO mining for evaluation of lead induced stress in residential areas, and is interested in other MO imagery for EPA Headquarters' (HQ) HSI evaluation. Missouri University of Science and

Technology (Missouri S&T) has an upcoming program to use HSI to pre-survey trees in groundwater-contaminated areas in advance of tree core sampling. Missouri S&T has expressed an interest in the Department's support and collaboration. As interest in the AWG and ARCHER projects grows, the Department expects its experience with MOUs, tasking, analysis and project support to be useful in spreading cost effective HSI and HRI technologies to government agencies.

The purpose of this report is to summarize the HSI project as it relates to environmental applications and report findings to date. This report will

- give a brief history of the project (Section 2)
- document successes/outputs of the project to date (Sections 3 and 4)
- explain the data collection process (Section 5)
- discuss applications found to be useful for HSI/HRI technology (Section 6)
- describe working relations formed throughout the project (Section 7)
- give an outlook on potential HSI/HRI projects (Section 8)
- present lessons learned throughout the project (Section 9)
- and offer a path forward for this technology (Section 10).

2. Project History

The Department, through an EPA grant, conducted a pilot project in 2005 to evaluate potential applications of HSI for identifying and characterizing contamination. CAP collected the HSI with their ARCHER system, and the University of Missouri Columbia (UMC), through the Missouri Resource Assessment Partnership (MORAP) with MODNR and other state and federal agencies, analyzed the imagery. HSI collected of a variety of contaminated sites, including a closed landfill, cleanup of dispersed asbestos from a fire, several sites with groundwater contaminant plumes, several lead mining areas in southwest and southeast MO, and operational/inactive lead smelters.

Following the initial indications that there could be environmental applications, MODNR continued HSI projects funded by EPA and focused on Brownfields lead mine inventory related sites. In 2007, the project used HSI from the 2005 Pilot Project, evaluated different analytical processes and collected field data for three lead-zinc mining areas in southwest MO. The objective was to evaluate HSI for determining lead levels in soil, to locate mine waste over large areas, and to characterize the extent of lead and zinc contamination through vegetation stress.

The 2008 project used ARCHER HSI that was collected as part of a June 2007 State Emergency Management Agency (SEMA) earthquake exercise. The sites were the Leadwood and Desloge tailings piles, including a portion of the Big River, and the Doe Run lead smelter in Herculaneum. Analysis and field work in Leadwood and Desloge centered on locating undocumented and reused mine waste, lead contamination in residential areas and along haul roads, and the effects of airborne lead deposition on vegetation. It also used signatures of Big River sediment to evaluate the potential to locate mine waste in sediment and sand bars from tailings and chat impoundment releases. In Herculaneum, HSI analysis of trees and vegetation provided an indication of the extent of airborne lead contamination from the smelter.

The 2009 project collected over 83 square miles of new imagery, under the new MOWING-MO MOU, including two smelters and a former tailings pile, now a state park in southeast MO. Lessons learned from Herculaneum are being applied to the two smelters to characterize the extent of lead contamination from airborne deposition. In southwest MO, HSI was collected of a MODNR Land Reclamation Program (LRP) closed mining operation where a spring or seep is draining from a subsurface mine, an area with known open mine shafts, an EPA Region VII project south of Carthage to identify the source of lead contaminated wells, and a revisit of Granby to continue characterizing lead contamination through vegetation stress.

Reports of the 2005 and 2007 projects are available from the MODNR website at http://www.dnr.mo.gov/env/hwp/hsi/hsi-project.htm. The Department will post the 2008 and 2009 reports when they are available.

3. Imagery Collection and CAP Support

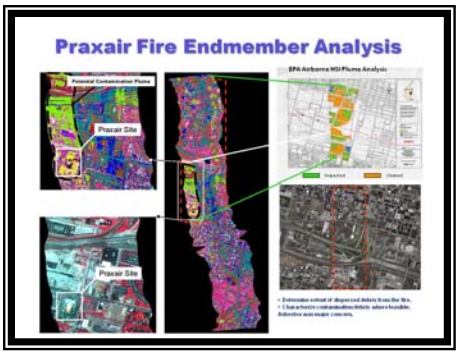
Since 2005, HSI projects have collected over 125 square miles of HSI/HRI of 20 different sites. The imagery covers a variety of contamination/remediation conditions including environmental emergency response, landfill monitoring, chemical and radiological groundwater plume areas, mine waste, smelter airborne deposition, natural resource damage, long-term stewardship sites, open mine shafts and mine drainage. The Department has reserved one Terabyte of space on the local server to warehouse and maintain this data for any government studies or projects.

The Department's Hazardous Waste Program (HWP) was instrumental in establishing a MOU between MOWING CAP and all state agencies for CAP non-emergency support including HSI/HRI and aerial photo collection. CAP provides cost effective assets to meet a wide variety of imagery and photo requirements. The HWP coordinated with various inter-department offices to create a list of target sites for CAP flights. There is a standing list of hundreds of target sites provided by Department offices with interest in collection of aerial photos for site monitoring and HSI/HRI data collection. The Department maintains this list and coordinates collection for future flights when available.

4. Products to Users

In addition to collection and analysis for project objectives, the project has supplied analyzed products to Department offices and other agencies to support ongoing remediation planning and field survey. The Department can support similar future projects with funding from the respective agencies. Attachment 1 provides samples of these products.

- **Praxair Fire, MODNR Environmental Emergency Response (EER).** A fire at the Praxair gas storage facility in downtown St. Louis caused gas tanks to explode. Many of the tanks were lined with asbestos. Heat and smoke carried and dispersed the asbestos over a wide area north of the facility. The 2005 pilot project was 45 days after the fire, when crews had located and cleaned up most of the asbestos. However, HSI showed potentially more extensive dispersal of asbestos than cleanup was addressing. Had



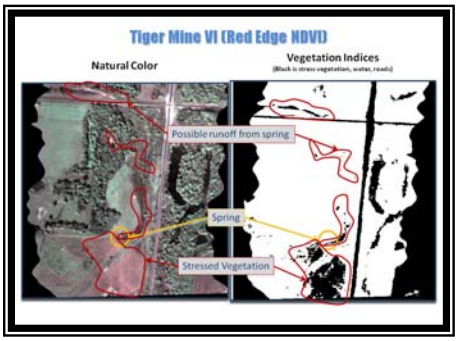
Details at Attachment 1-1

ARCHER been available, it could have participated in the initial characterization of the deposition, and flown again later to monitor cleanup.

- **JZ and Bueneman Landfill, MODNR Solid Waste Management Program (SWMP).** The JZ and Bueneman landfill contained areas of illegally placed hazardous materials. The owner abandoned the site, leaving the state the remediation responsibility. The remedy had been in place 10 years when ARCHER flew. The remedy included collection and storage of leachate in a detention pond to prevent seepage into an adjacent creek, two wetlands to filter the leachate and extensive cover to prevent infiltration. The Project Manager (PM) recommended using the leachate pond for the spectral signature. HSI analysis indicated that a surface seep, which had been covered with additional soil, had returned; one wetland had ceased to function, old and many new seeps appeared along the creek, and a possible new dumpsite was noted across the creek. A field survey confirmed HSI analysis.

Details at Attachment 1-1

- **Tiger Mine, MODNR LRP.** The Land Reclamation Program reclaimed much of theTiger Mine; however, a spring or seep, possibly from a subsurface mine, continues to flow at a nearby Abandoned Mine Land (AML) site. The spring brings iron rich water to the surface. The situation provided an opportunity to evaluate HSI for tracing and monitoring mine drainage and identifying other potential seeps and drainage. Analysts used the spectral signature of the known spring, and applied it to all imagery. The analysis identified other locations around the mining complex with the same signature. Vegetation analysis showed stressed vegetation around the spring, possibly from spring run-off, and indicating the path and extent of run-off. A field survey confirmed the path of run-off, and identified low lying areas where the mine drainage may also have deposited iron. Most locations were inaccessible for sampling or survey.



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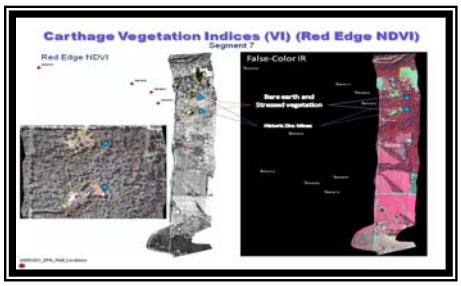
- **Webb City-Carthage, EPA Region VII.** EPA located numerous lead contaminated wells around Carthage, and needed help identifying potential sources. ARCHER collected HSI of Webb City and Carterville, an area of heavy lead and zinc mining not far from Carthage, and one area south of Carthage with contaminated wells. The objective was to use signatures of mine waste and stressed vegetation from Webb City/Carterville to locate potential mining operations around the wells. PMs used preliminary analysis of Webb City/Carterville to select the source signatures for Carthage. Vegetation analysis of Carthage showed



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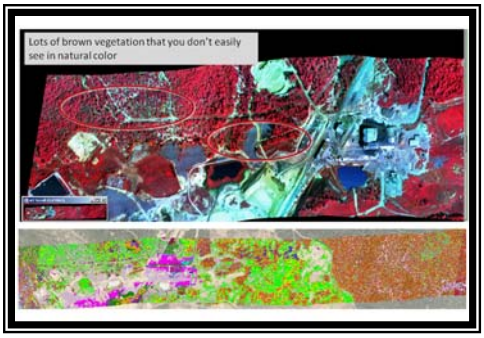
stressed vegetation near historic zinc mining sites that were also near several wells. Preliminary analysis using the Webb City mine waste and stressed vegetation signatures provided locations in the Carthage area with similar signatures. The analysis produces precise locations that PMs can download to field instruments for rapid movement to areas of interest.

- **Buick & Asarco Smelters, MODNR HWP.** Based on analysis of airborne lead deposition from the Herculaneum smelter, the project is evaluating HSI for monitoring/characterizing airborne lead deposition from the Buick lead recycling smelter, and residual contamination from the idle Asarco lead smelter. Analysis in the immediate vicinity of the smelter showed extensive vegetation stress. Analysis of 50 square miles around the smelter showed some patterns of potentially contaminated trees. Additional analysis will be conducted using source signatures identified in preliminary and vegetation analysis. MODNR Permits Section will use the analysis and locational data for field surveys, and to monitor airborne deposition.



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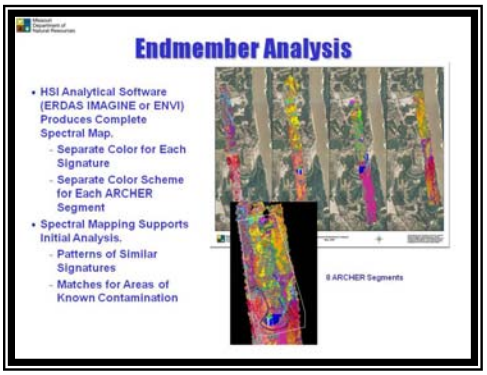
5. Project Support Process

Over the years, MODNR and UMC have evolved a simple and timely process to identify requirements, collect and analyze imagery, and deliver a product. The process begins with the site and program PMs and imagery analyst discussing the area and contamination conditions, information requirements and the potential application of HSI. If applicable, the program PM generates an ARCHER mission request and forwards in accordance with the MOU.

UMC first conducts an "endmember analysis" on the imagery. This process develops a spectral signature for each pixel of the digital imagery with a unique color assigned for each similar signature providing a spectral map of the entire area. The endmember analysis allows the PMs to see similarities between known areas of contamination and other areas where the same conditions may exist. The analyzed data can be exported for use on Geographic Information Systems (GIS) or Global Positioning System (GPS) equipment for field survey. Attachment 2 provides examples of various imagery products.



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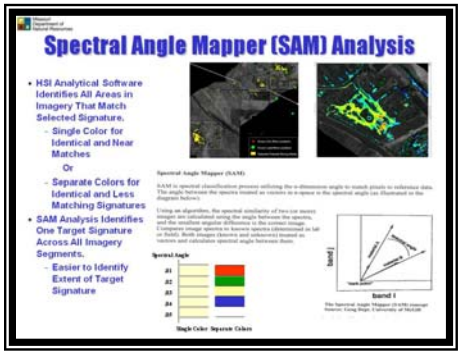

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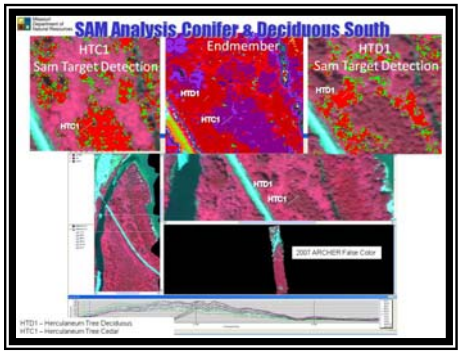
The PMs and UMC analyst review the endmember analysis and select spectral signatures for further review. The signature-



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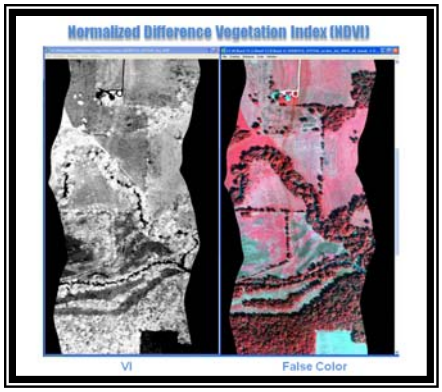
to-color mapping of an endmember analysis changes with each imagery segment. To provide a uniform picture, UMC conducts a Spectral Angle Mapper (SAM) process using the signatures of interest. SAM analysis maps a signature to the entire imaged area. Like the endmember data, the SAM data can be used on GIS and GPS systems.

Other imagery tools that provide information about stress in vegetation are Vegetation Indices (VI) and false color. VIs are a series of algorithms that use different combinations of spectral bands to identify stress from different conditions, e.g., lack of water or nutrients in trees and vegetation. False color analysis reverses the Red/Blue/Green color combinations and incorporates the near infrared spectrum to display healthy vegetation in bright red and stressed vegetation in brown. PMs can use these tools to locate some types of contamination and monitor re-vegetation.



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Where HSI is applicable, PMs can incorporate this process into project planning to provide current high-resolution imagery (aerial photography) of an area for orientation, and HSI analysis to help characterize the extent of contamination. The discussions between PM and imagery analysts ensure that the right signatures are used and false positives are limited. The PM can use the analyzed data on his/her systems for further analysis and precise locations in the field. The data can also be provided in Adobe files and hard-copy maps.

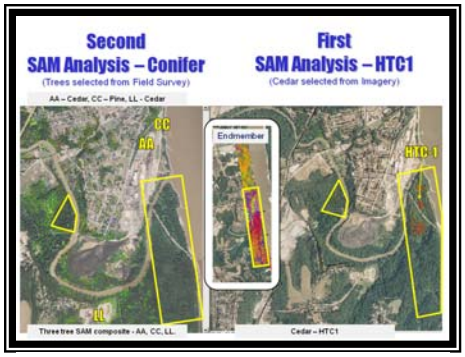
6. Applications

The Department has identified potential near-term and prospective applications for ARCHER HSI/HRI. Attachment 3 provides examples of some of the following applications.

- Locating abandoned mining operations and materials. The HSI projects each year have included sites with known locations of mine waste. The objective has been to locate other sites in the area where mine waste or abandoned mining operations exists that were not previously recorded, or where mine waste may have been reused for driveways or other purposes. Limited field surveys using the HSI analysis have indicated that there can be false correlations of tailings and chat with concrete surfaces and some other materials due to similar color characteristics, but that the analysis does provide usable, georegistered data for planning and field surveys.

Details at Attachment 3 - 1

- Identifying the extent of airborne contaminant deposition from smelters. Projects have imaged two operational lead smelters. Endmember analysis of the Doe Run smelter showed a pattern in the trees south of the smelter that may provide the extent of airborne deposition. SAM analysis



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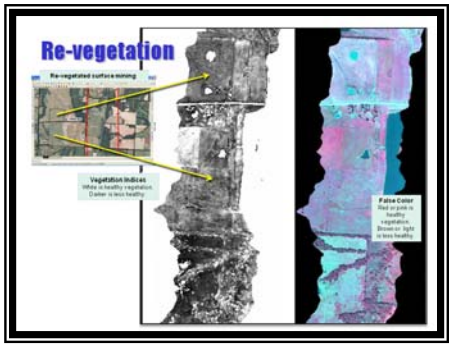
using cedar trees from other areas around the smelter provided additional confirmation that the cedar immediately south of the smelter were spectrally different. Field survey confirmed lead in cedar and pine needles north and southwest of the smelter. The area immediately south of the smelter was not accessible for sampling. HSI analysis and field survey of cedar and vegetation along a haul road in Leadwood also detected lead from probable dust deposition. These preliminary efforts indicate that HSI has application to characterizing and monitoring some types of airborne deposition. Analysis of the second smelter is ongoing.



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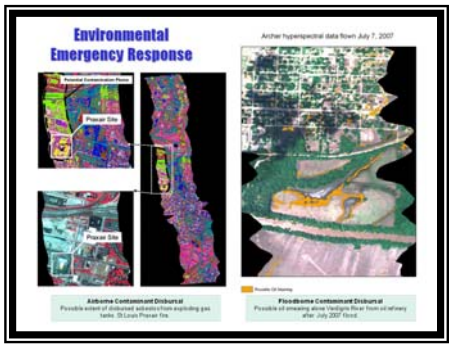
- Monitoring remediation and re-vegetation. False-color and VIs provide an indication of the health of vegetation. Large area environmental projects, such as re-vegetation of surface mining sites, clearing of mine waste and vegetative covers on landfills, can be monitored using HSI. This allows PMs to focus field inspections on most likely problem areas, and to monitor areas that are not easily accessible.

- Environmental Emergency Response. HSI and HRI can support near real-time evaluation of a variety of contamination conditions including defining the area of large spills and locations where spill material is day lighting after entering underground pathways, and characterizing the spread of potentially hazardous materials from explosions and fires. Endmember analysis of the dispersal of asbestos after the Praxair fire in St. Louis showed areas where the material might be concentrated. USGS analysis of ARCHER HSI of oil dispersed by the Coffeyville, KS, refinery flood showed indications of oil smearing along the river banks. Toxic chemicals dispersed in plumes might have a near term effect on vegetation that could be detected through vegetation stress.



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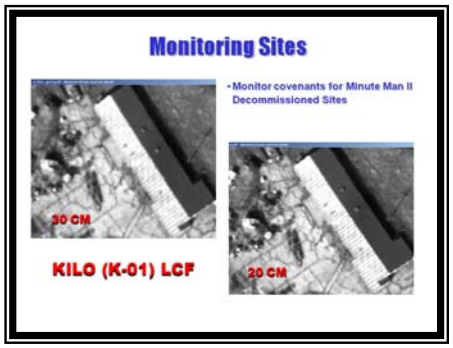
Long-Term Stewardship inspections. The Department has proposed using ARCHER aerial imagery to monitor property use at former Minuteman II missile sites to ensure property owners comply with deed restrictions. Sample coverage of several sites provided 20 cm (8 inch) resolution imagery that can be archived in GIS databases. Many sites are not accessible for inspection from the ground, and CAP can do the required number of yearly inspections for the missile sites during one weekend drill. Use of ARCHER to conduct the inspection component of long-term monitoring at these sites is expected to provide a significant cost savings when compared with the current method of traveling by car. The program also provides increased flight time for CAP personnel and establishes a process for disaster relief missions.



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- Monitoring access denied or inaccessible sites. The Department has many permitted or project sites that are not easily accessible for routine monitoring. The cost in time, travel and funding for limited staff makes the use of CAP assets a cost effective staff multiplier. The MO-MOWING CAP MOU established a process for all state agencies that is easy to apply.

Details at Attachment 3 - 4

- Pre-project site orientation. The Department has used CAP assets for aerial photography and HSI/HRI for site orientation. Two PMs flew with CAP for a site survey and observed conditions that had not been seen in previous ground surveys. CAP squadrons are located throughout the state, making aerial photography an easy weekend task.

These applications can be further developed and brought to fruition by other agencies with support from the Department.

7. ARCHER Working Group

In the last year, several agencies using ARCHER HSI have formed an ARCHER Working Group (AWG) to share project information and analytical procedures. The Department and the USGS Denver co-chair the AWG. Members include:

- **USGS Denver.** USGS Denver was tasked by EPA Region VI to analyze ARCHER HSI of a refinery flood in Coffeyville, KS. The objective was to trace the extent of oil contamination down the Verdigris River to Oologah Lake, OK, a major water supply. Denver also has an ongoing study of the pine beetle infestation in Grand County, CO. ARCHER imagery showed pine trees that were in initial stages of infestation, a condition that was not observed in satellite imagery.

- **USGS Reston.** USGS Reston had success identifying lead stress in vegetation using non-ARCHER HSI. MODNR provided ARCHER HSI of Webb City and EPA Region VII provided sample data for an evaluation of Reston's process. Webb City and Carterville are in the center of a heavily mined corridor in southwest MO, and a long-term remediation project is underway. Reston also has an ongoing study for EPA HQ evaluating HSI for monitoring remediated/delisted Superfund sites. MODNR provided information on tasking ARCHER, and offered imagery of project sites to support the study.

- **Minnesota State University (MSU).** Minnesota DNR, through Minnesota State University, Mankato, is evaluating ARCHER HSI for determining and monitoring the effects of farm run-off on water quality and sediment in MN rivers. MSU's initial findings indicate a correlation between turbidity and some contaminants, and the potential to identify contaminants in sediment. MODNR is exploring the application of MSU's work to support Natural Resource Damage Assessment (NRDA) studies of lead contamination in the Big River.

- **Missouri University of Science & Technology.** Missouri S&T has an ongoing project to use tree core sampling to characterize and monitor solvent contaminated ground water plumes. Dr. Burken, Missouri S&T, is seeking a grant to evaluate HSI applications for pre-surveying and monitoring trees in conjunction with tree core sampling, and is interested in working with ARCHER and MODNR. This process could be used to pre-survey redevelopment and other sites.

- **Bolivia.** Christian Romero, Center for the Promotion of Sustainable Technologies (CPTS) Bolivia, contacted the Department after an HSI presentation to the Interstate Technology & Regulatory Council (ITRC) Mine Waste Team. The Department provided contacts with commercial HSI operating in South America and with the AWG contact at USGS Denver. CPTS is now pursuing the use of HSI for lead mine contamination surveys in Bolivia.

- **Interested agencies**. Nine state and federal environmental and emergency response agencies have expressed an interest in AWG conference calls including: EPA Regions 6,7 & 8; USGS Denver, Reston, Rolla & Columbia, U.S. Fish and Wildlife Service (FWS), Universities of Kansas, Minnesota State University (MSU) and Missouri University of Science and Technology (Missouri S&T), Federal Emergency Management Agency (FEMA), OK Department of Conservation and CAP HQ.

8. Potential Projects and Cooperative Efforts.

Department PMs have discussed the following projects with various agencies and could support the projects under funding from those agencies.

- **Big River NRDA – FWS, HWP NRDA, USGS-Columbia Environmental Research Center (CERC) and MSU**. MSU and UMC could evaluate the current Big River HSI for potential application of turbidity and sediment studies to support on-going Natural Resource Damage Assessment of mining impacts on MO rivers. If promising, HSI of the entire Big River and other affected water bodies could be collected and analyzed under a Department of Interior (DOI) - MODNR project.

- **Lawrence County Pre-survey – EPA Region VII and MODNR**. Region VII will be conducting lead contamination surveys of cities/towns in Lawrence County. Jamie Bernard-Drakey, EPA Region VII, has asked about the feasibility of using ARCHER to locate mine waste and lead stress in residential areas to support survey planning. ARCHER's wide area coverage and developing experience with HSI analytical steps and mine waste make these type of projects good candidates for ARCHER.

- **HSI for Tree Core Sample Surveying - MS&T**. Dr. Burken is interested in ARCHER as a cost effective collector to support his study and follow-on application. The Department can support ARCHER tasking, and PMs can provide information and data for contaminated sites.

- **Superfund Site Monitoring Study – EPA HQ**. EPA HQ requested information about the Department's HSI program in 2008, and is now evaluating HSI for monitoring delisted superfund sites. Terry Slonecker, USGS Reston, is project lead. TheDepartment has offered to provide archived imagery and collaborate on analytical procedures and results to date.

Mr. Slonecker has offered to review the imagery and its applicability to algorithmic processes he has used in successful identification of arsenic in grasses.

- **ARCHER versus Commercial HSI for Decision-making - USGS Denver**. Carol Mladinich, USGS Denver, was developing a collaborative study with MODNR, funded by NASA, to compare spectral resolution requirements for environmental decision making. The study was to use the Department's archives of ARCHER HSI and a commercial sensor. Unfortunately, the commercial sensor was too expensive, and the initiative was dropped. USGS Denver is still interested in collaborative work with the Department.

- **ARCHER Integration into FEMA, SEMA, EER Responses** - MODNR**.** Department PMs acquired sample ARCHER imagery of the Mississippi River flood and the Windsor, CO, tornado through contacts with MoWING and Colorado Wing (COWING), CAO. USGS Denver processed the imagery for GIS. Department staff demonstrated the potential uses of the imagery to FEMA, MO SEMA, CO Dept. Emergency Management (CDEM) and the Department's EER staff. Response was positive. The Department will continue to recommend federal funding for the software needed to make ARCHER imagery available to emergency responders.

- **Whiteman Air Force Base Minuteman II Long-Term Stewardship – USAF and MODNR**. The Department has supplied examples of high-resolution imagery collected by ARCHER to the USAF in support of long-term monitoring of former Minuteman II (MMII) ICBM sites. USAF must monitor each site every other year, and many have poor line-of-site from the ground. ARCHER can provide imagery for GIS analysis and archiving. The Department awaits response from USAF regarding a proposal to collect such imagery of MMII sites on a yearly basis.

9. Lessons Learned

The following are process and analysis lessons learned from the HSI projects.

- Project Planning and Field Verification. HSI is a useful tool for project planning and field surveys. Determining the accuracy of HSI analysis depends on extensive field data collection. There are benefits from incorporating an HSI collection and analysis plan as part of project planning, and also benefits from endmember and SAM data for field surveys to gain additional knowledge of sites beyond the traditional site reconnaissance and sampling events.

- Imagery Analysis Steps. Endmember analysis of all or select segments provides spectral maps of project areas, and should be a first step. When displayed on GIS each endmember signature color is a layer that can be displayed separately, making it easier to find matches. SAM analysis should use several signatures from the area of interest, and the analysis conducted with multiple levels of match. GIS also handles the SAM levels as layers allowing the PM to adjust the amount of data for review during planning and in the field. Conduct another SAM analysis after the field survey using areas of confirmed contamination to refine results.

- HSI Data in Field Equipment. Analyzed HSI data, endmember and SAM can be taken to the field on laptop GIS computers and handheld GPS equipment. This allows PMs to go directly to locations of interest without time-consuming map interpretation or physically entering geographic coordinates.

- ARCHER Imagery Processing. ARCHER HSI and HRI are invaluable to emergency responders and environmental PMs, but the data must be processed separately for use beyond the ARCHER ground station. Commercial applications are available that provide the data for GIS and for full HSI analysis. These applications would have the greatest benefit if they resided on the ARCHER ground station so that CAP personnel can replay the flight for users, select appropriate segments and resolutions, and provide the data quickly for use on the customers' systems.

- Mine Waste. Endmember analysis provides a spectral map of the waste revealing multiple signatures for the waste materials. To ensure locating the majority of waste, use multiple signatures from endmember analysis for SAM analysis and field surveys. Use multiple levels of match, exact match, next nearest, etc., for SAM analysis to increase identification. The level of matches displayed can be adjusted on GIS and GPS.

- Airborne Deposition. Conifer, vines and some vegetation appear to retain lead and other heavy metal contaminants from airborne deposition better than deciduous and smooth leaf vegetation. Conifers also provide the best trees for year round detection of zinc uptake and airborne deposition. HSI may be used to detect airborne deposition versus non-impacted trees. The Department has invested a lot of research into this application; however, the process is in need of further refinement.

- Vegetation Stress. False color and VIs provide good indicators of vegetation stress. They are valuable tools when used with other analytical processes to identify contamination. Lead-induced stress in grass has shown promise in USGS studies, and may be the best input for pre-survey planning.

- Lead Levels In Soil. Determining levels of lead contamination in soil, particularly in differing types of soil, may not be feasible. The properties of the soil, not the lead contamination, determines the spectral signature. Based on limited data the project collected, it does not appear HSI analysis of soil will help determine if lead contamination is above clean-up levels.

- Granular Mine Tailings. In several projects, many locations of suspected abandoned or reused mine waste, identified using the signature of chat or chert-like material, were identified as concrete parking areas and roads. The signature of relatively fine mine tailings appears to be similar to the aggregate in concrete. Therefore, the application of using HSI to identify mine tailings results in false positives for concrete and gravel drives.

- Tree Species Differentiation. ARCHER HSI appears to have the spectral resolution to differentiate conifer and deciduous. However, dense canopy, presence of vines, and variety

of species may complicate characterizing species. It does appear to provide some separation between conifer with heavy airborne contamination and those in non-contaminated areas.

- Tree and Soil Contamination Correlation. Limited sampling of conifer needles and soil beneath the trees has identified a correlation between zinc in needles and soil, probably from uptake, and lead in needles and soil, probably from airborne deposition. Juniper trees in SW MO, where zinc levels in mining areas are high and appear to inhibit vegetation growth, appeared to have zinc levels proportional to zinc levels in surrounding soil. Even though lead levels in the soil in the mining areas were high, there was no lead noted in the needles, indicating the trees were taking up zinc but not lead. Project personnel used an Innov-X Field-portable x-ray fluorescence (FPXRF) for testing needles and soil. In SE MO, near a lead smelter and along a haul road, project personnel noted that lead levels in Juniper and pine needles were in proportion to levels in surrounding soil. The levels in soil were below action level indicating that the accumulation was from airborne deposition.

10. Path Forward

Over the past four years the purpose of this project was to mature the technology and create and maintain a network of experts and agencies while developing environmental applications for HSI data. The Department collected and analyzed HSI data, groundtruthed it by performing field sampling, performed vegetation sampling, and provided project reports and individual products to other departmental project managers. The 2009 HSI project will be the last to collect and analyze data as a stand-alone activity evaluating applications. The initiative will continue in 2010, but will focus on formalizing the promising applications for other agencies. The Department will begin supporting other state and federal agencies to develop their ARCHER HSI/HRI programs by implementing Coordination and Knowledge Transfer (CKT). To continue development of this technology at a reduced cost, the following CKT functions are proposed for SFY2010:

1) Coordinate other State and Federal agency use of ARCHER HSI
2) Transfer technical and institutional knowledge to other agencies
3) Maintain and share previously collected ARCHER HSI data with other agencies and individuals
4) Assist others in further development of ARCHER HSI capabilities and environmental applications

These four functions are critical to maintaining and expanding the expertise, data archive, marketing, and the network of stakeholders gained throughout the previous years of the HSI project. Over the past several years, the Department has invested time and funds in this project to mature the technology and application of HSI. This knowledge base and extensive data collection will deteriorate without maintenance and will prove of little use if not marketed.

Several federal agencies and universities are currently working with or have expressed an interest in ARCHER HSI for a variety of projects. Those were identified in previous sections. The AWG has further identified other agencies that are interested in ARCHER. It has also fostered a dialog with HQ CAP on ways to provide ARCHER imagery to consumers for emergency response and environmental analysis, and the work AWG members are currently

doing has provided HQ CAP information to justify continued funding and improvements to ARCHER. The Department will continue to co-chair the AWG and encourage interest and development of ARCHER applications.

The Department will work with current and prospective users on several specific areas in order to improve the validity of imagery analysis and products. These include:

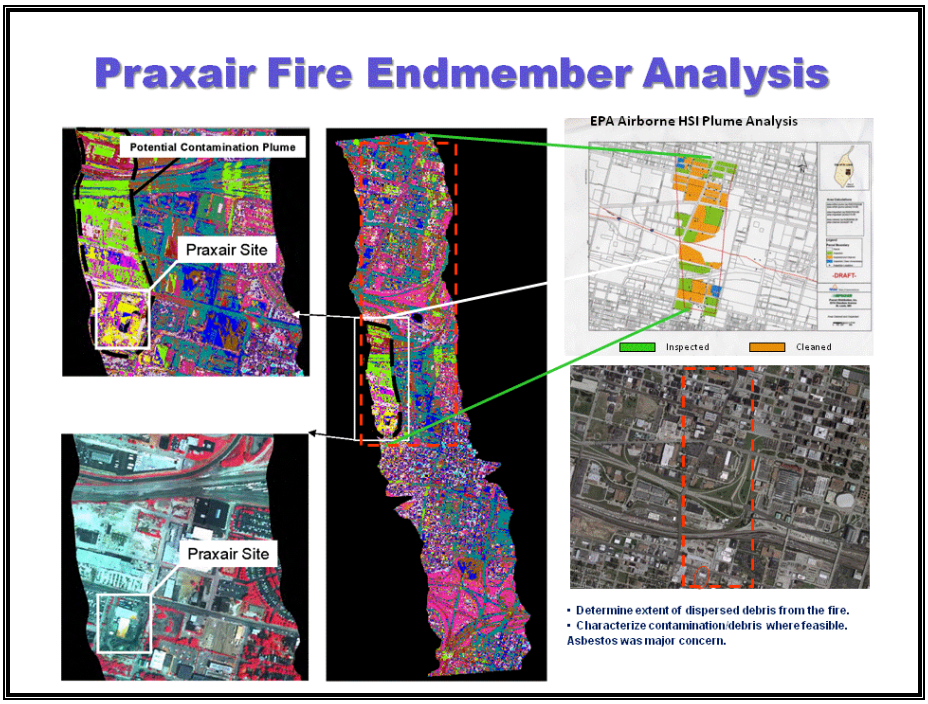
- Developing more in-depth analytical steps. The Department has limited analysis to several basic tools in order to increase timeliness and keep costs within budget. That has resulted in more false positives. USGS and University projects have frequently used other software applications, algorithms and GIS data to reduce false positives and refine output.

- Focusing on more productive applications. The Department has evaluated a variety of applications providing valuable input on those that do not work well and those that have promise. Of the ones that have promise, similar applications to other fields, e.g., agriculture and conservation, may also apply. USGS Denver's use of ARCHER HSI to identify the extent of the pine beetle infestation in CO may also apply to the Emerald Ash Borer in MO and invasive plant monitoring, an initiative of HQ US Army Corp of Engineers (USACE).

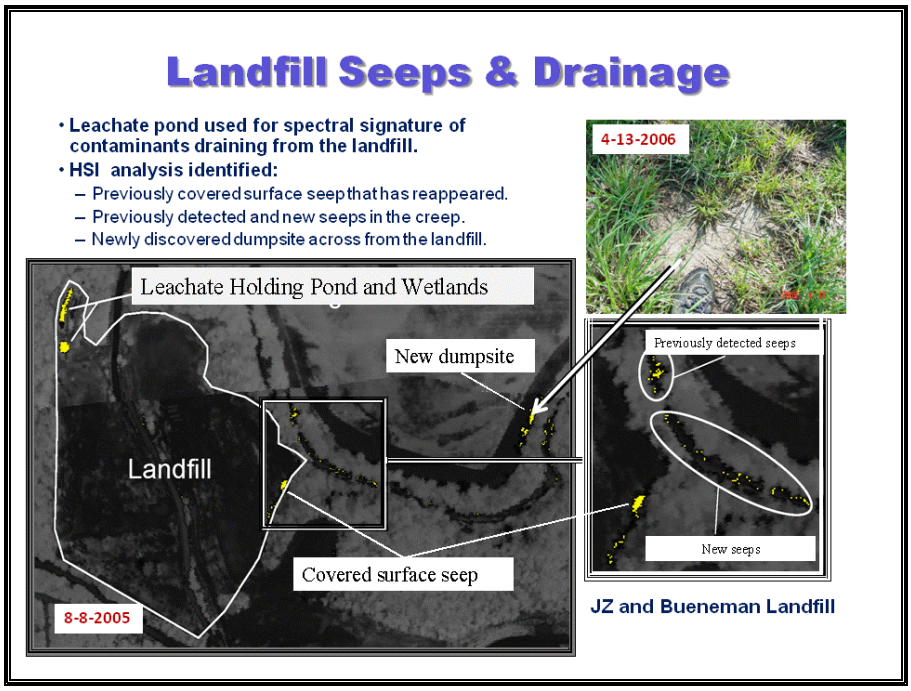
- Expand HSI for monitoring remedies. Neither the Department or many other state and federal agencies have the personnel to adequately monitor sites that have remedies in place. HQ EPA, through USGS Reston, is interested in that application. The landfill analysis from the 2005 Pilot Project shows the hazards of not monitoring remedies and the difficulties of identifying problems over large sites with difficult terrain. ARCHER has the potential to be a PM multiplier, allowing PMs to review the status of more sites from their offices and focusing site inspections with GPS quality data. HSI can provide information on the progress of re-vegetation, and HRI can identify erosion and other remedy deterioration.

- Identify funding for follow-on projects. There are several sources of funding for emergency response and environmental applications of new technology. While HSI is not new technology, commercial HSI has not been cost effective or timely for routine use by most state and federal agencies. ARCHER fits that role. The Department will look for funding opportunities to work collaboratively with AWG partners to make ARCHER support operational.

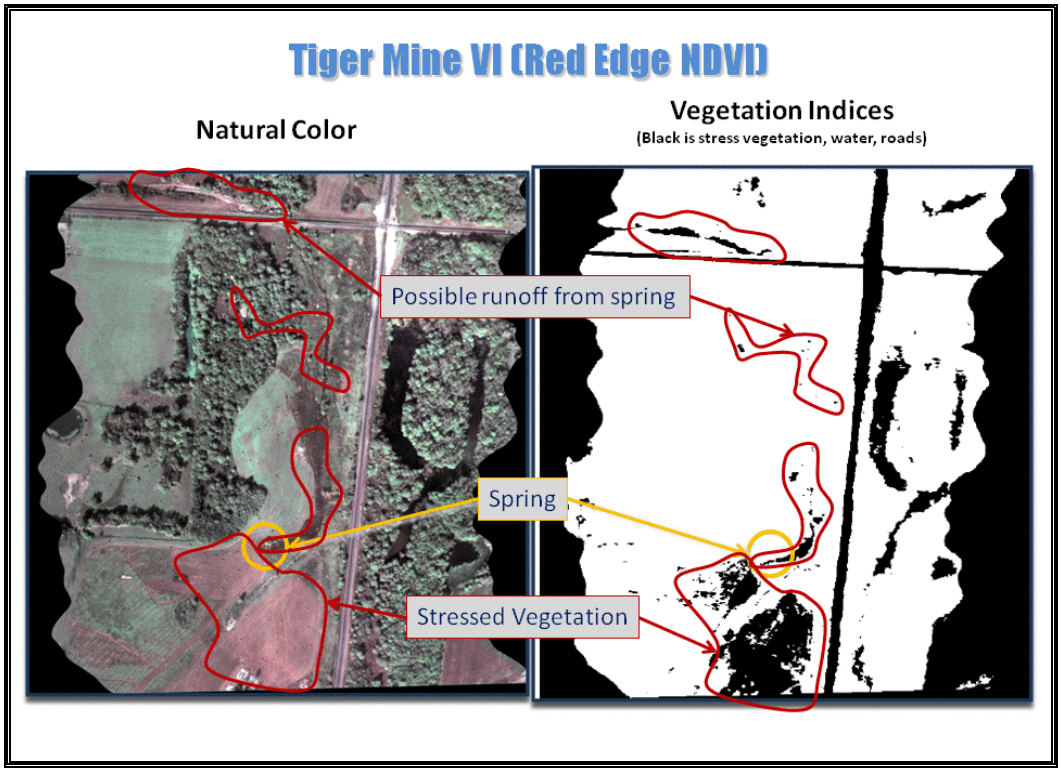
- Expand the use of ARCHER. ARCHER's capabilities are not currently available to most government agencies because of the need for software to process exported data and the requirement for an MOU to facilitate funding and provide aircrew protection. The Department will continue to work with HQ CAP to identify funding to make all ARCHER systems capable of providing usable data, and with government agencies to make them aware of its capabilities.



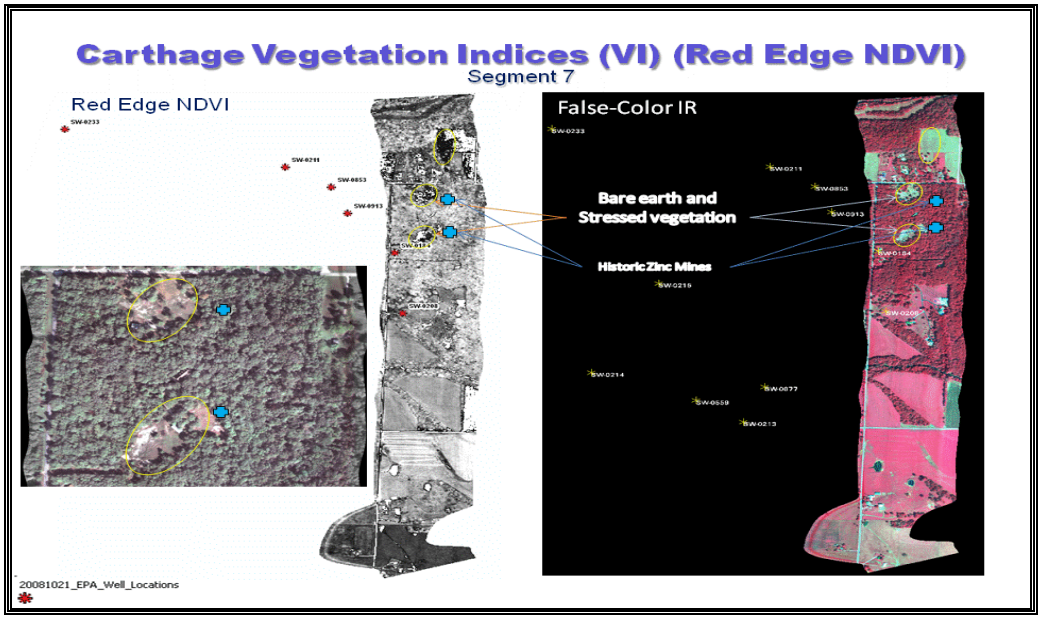
Endmember analysis of the area downwind from the Praxair gas storage facility in St. Louis, less than two months after the fire and with most of the clean-up complete, shows areas where there may still be fire related deposition.



Spectral Angle Mapper (SAM) analysis using the leachate pond as a source signature show numerous seeps along the creek, only one of two wetlands still operational, a surface seep between two landfills that had extra cover had returned, and a previously undetected dumpsite across the creek.

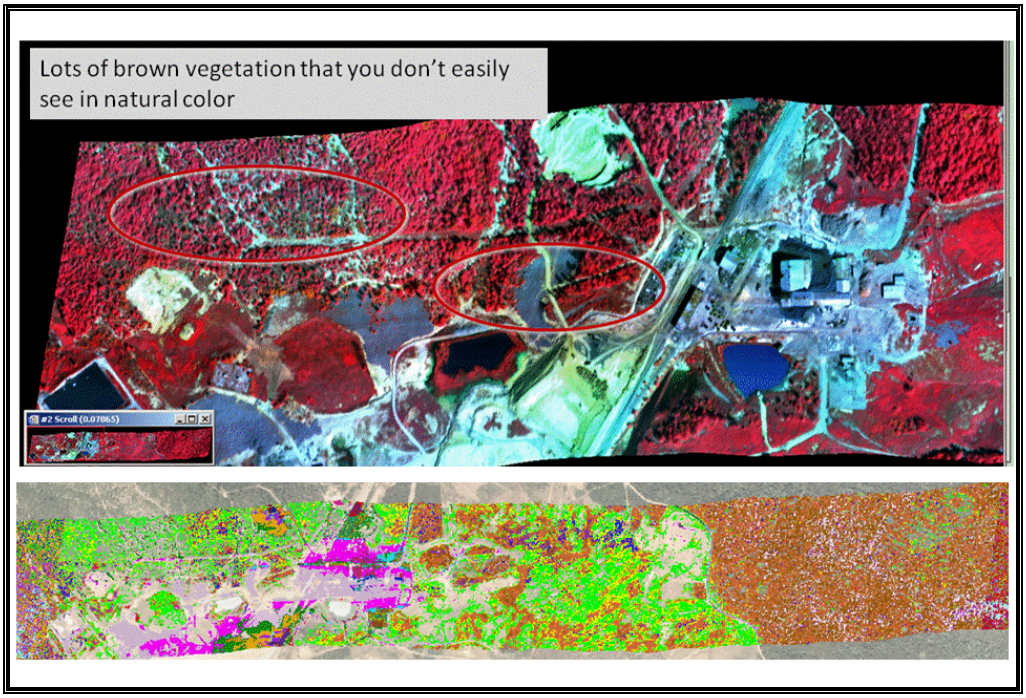


Vegetation analysis of a spring from a subsurface mine shows areas of stressed vegetation that spring runoff may have caused.

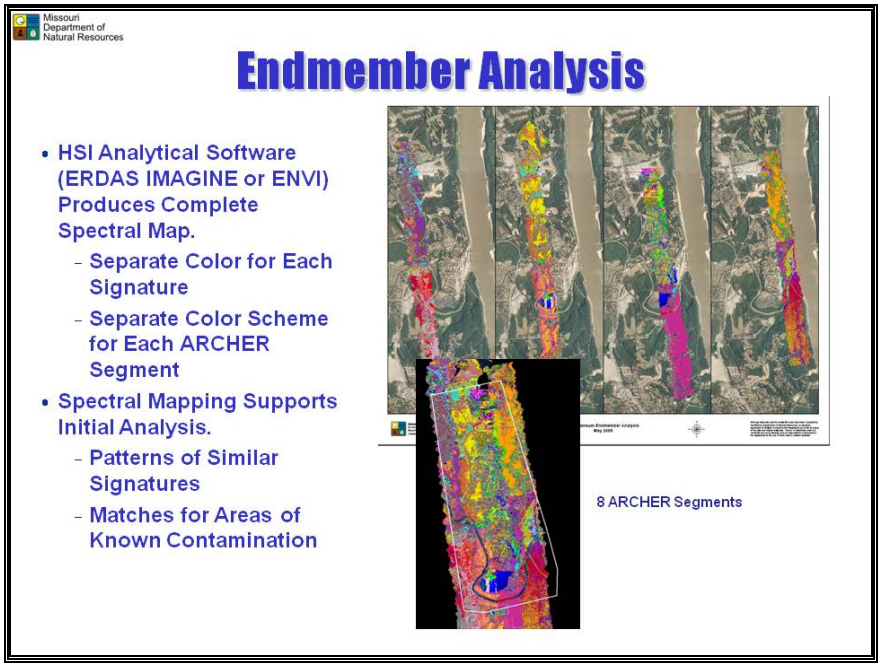


Vegetation analysis shows stressed vegetation near private wells where EPA detected elevated lead levels. The stressed vegetation is also near the sites of former zinc mines. Lead and zinc are frequently found together in southwest MO mining areas.

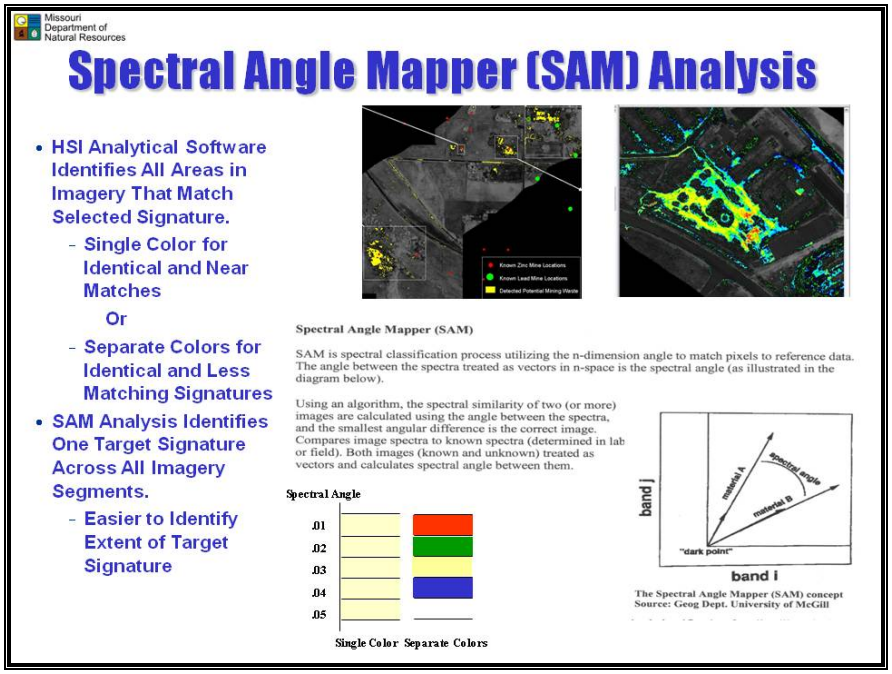
Buick Smelter HSI Segment 29



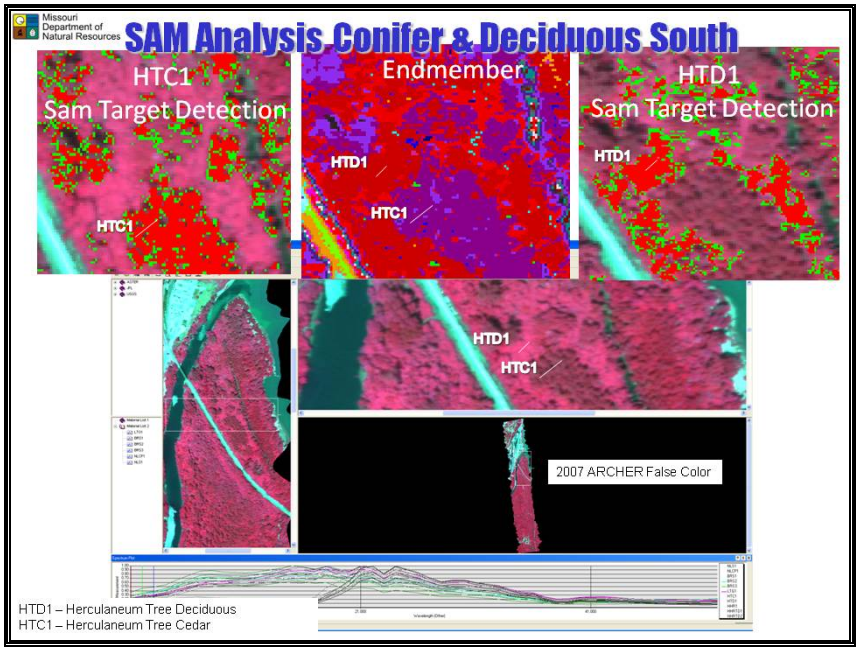
False Color and Endmember analysis of the Buick Lead Smelter show areas of potential vegetation stress from airborne heavy metal deposition. The False Color, which shows stressed vegetation as brown and light red, is particularly evident around the smelter.



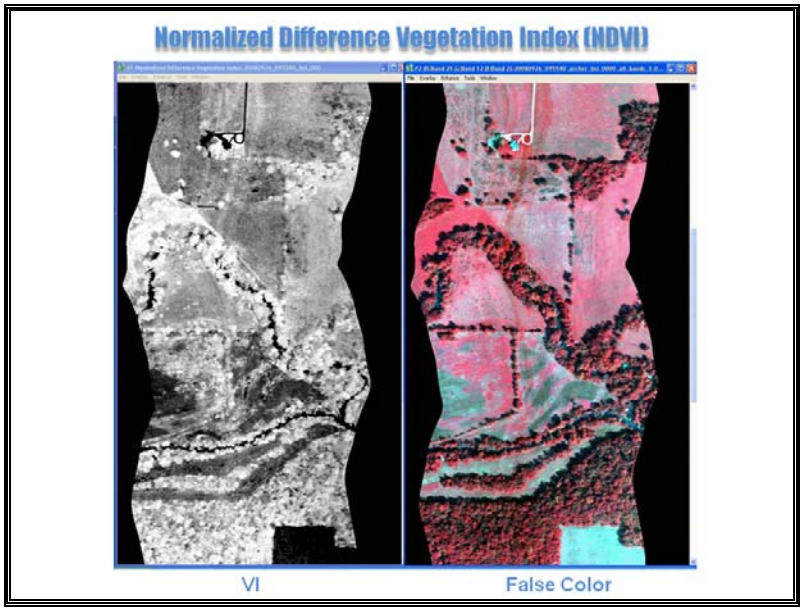
Endmember analysis provides a spectral map of each segment, allowing the Project Manager (PM) to identify locations that match known areas of interest. Unfortunately, the spectral signature-to-color combinations are different for each segment. They can look at segment overlaps to find signature-to-color equivalents.



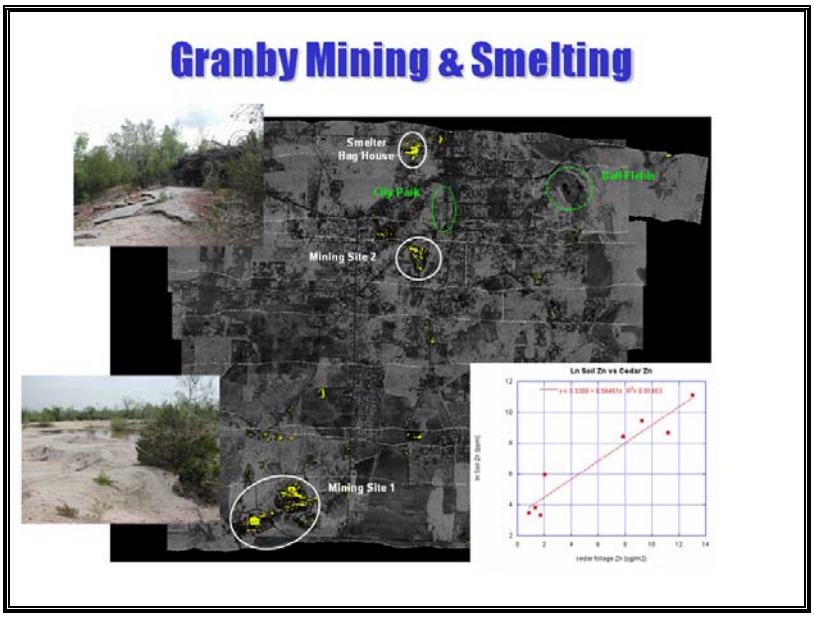
Spectral Angle Mapper (SAM) analysis uses a signature of a material identified by the PM to locate the same or similar signatures in all segments.



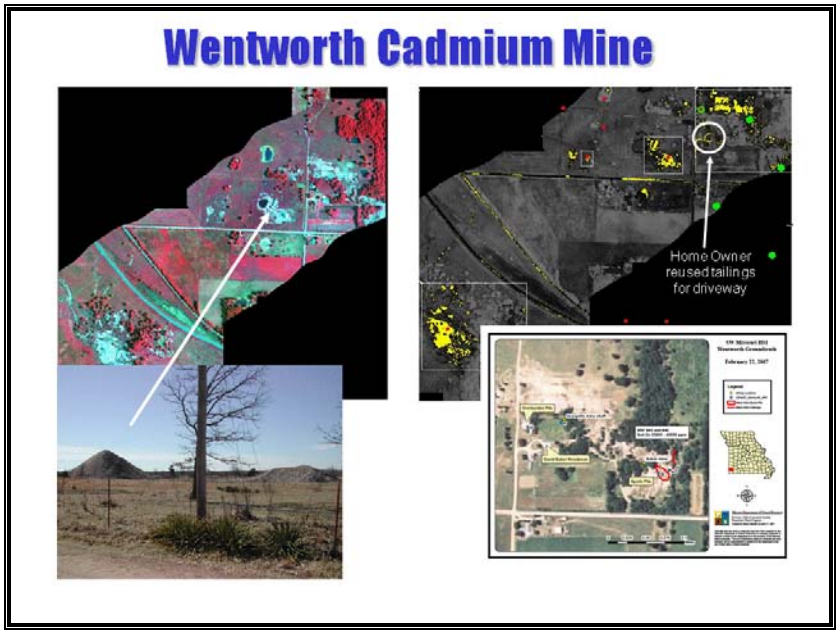
The imagery analyst establishes a Region(s) of Interest (ROI) in the imagery, here represented by white lines HTD1 and HTC1, to cue the application to look for similar signatures in the SAM analysis. The PM identifies the ROIs in the endmember analysis. The graphic shows the selection process and the results of the SAM analysis. Red areas are exact matches and green are next nearest matches for each ROI.



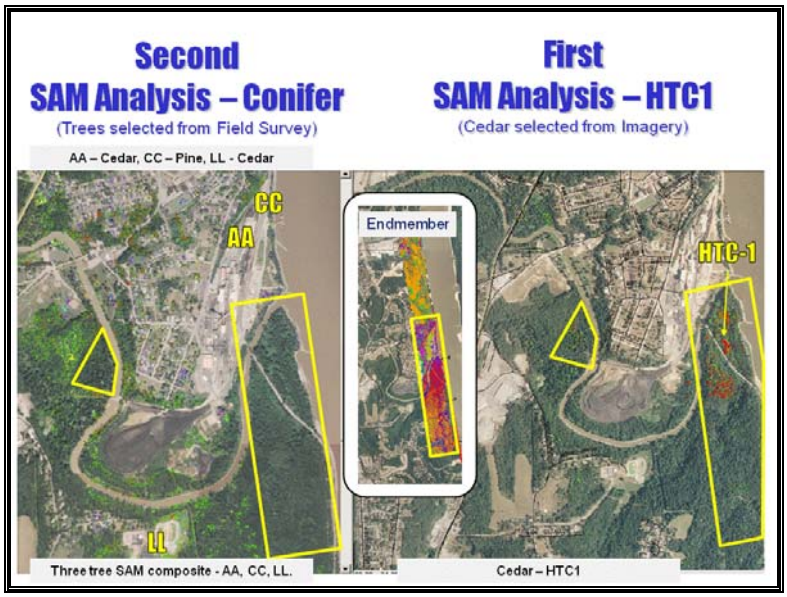
Various Vegetation Indices (VI) show stress from different causes. The project uses the Normalized Difference VI (NDVI), which uses the highest absorption and reflectance regions of chlorophyll and makes it robust over a wide range of stress conditions. Dark areas are stressed vegetation. Light areas are healthy or non-vegetation. The False Color shows stressed vegetation in brown or lighter red.



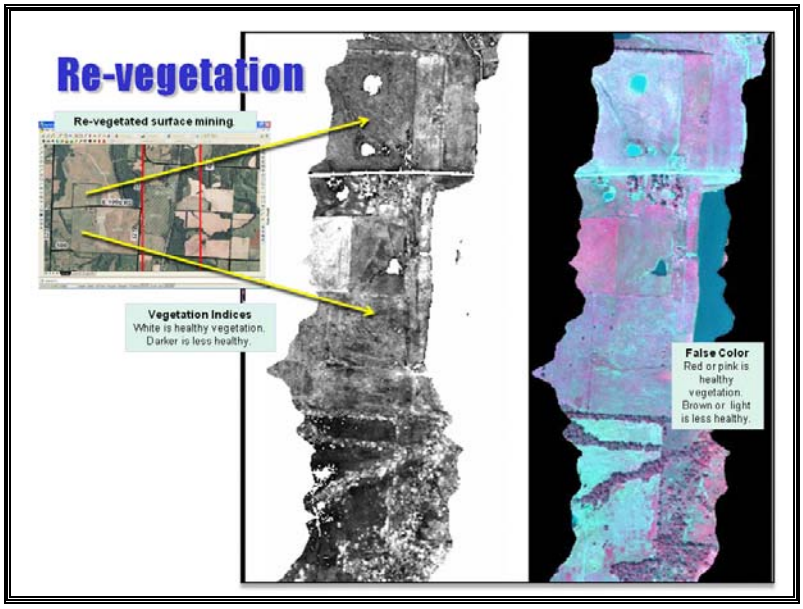
Granby was the site of lead mining and smelting. SAM analysis uses the spectral signature of one known mining site selected by the PM. The analysis results are in yellow, and highlighted the two large known mining sites and the grounds of the former smelter site above the town. Other possible mine waste were noted. Field personnel took samples of cedar needles and soil in mining and residential areas. Sample data showed a strong correlation between zinc in needles and soil. No lead detected in the needles. Zinc levels are high in southwest MO lead mining areas.



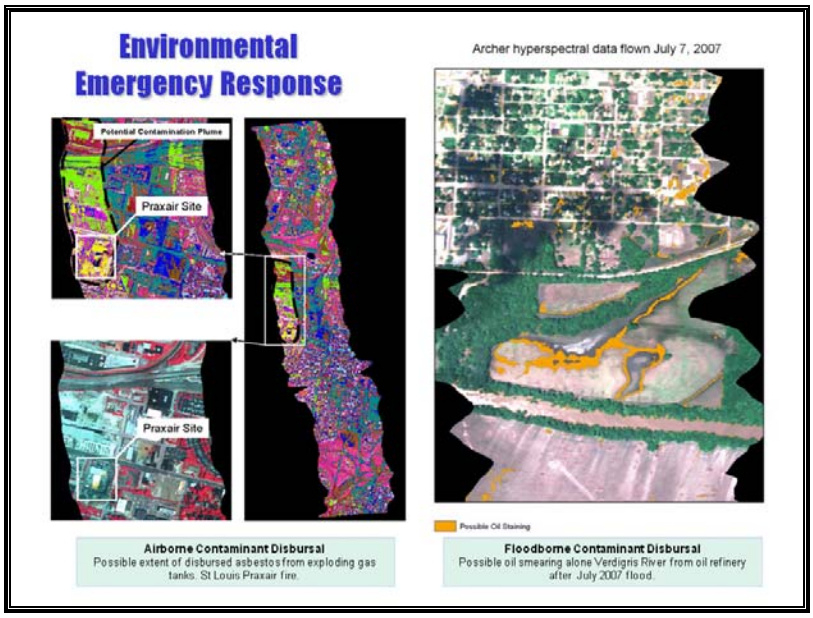
SAM analysis, yellow highlight, of a cadmium mining operation at Wentworth showed mine waste and overburden. Some of the overburden and mine waste could be seen from the road. Analysis also highlighted the driveway of the property owner. The owner advised that he had used mine waste in the driveway.



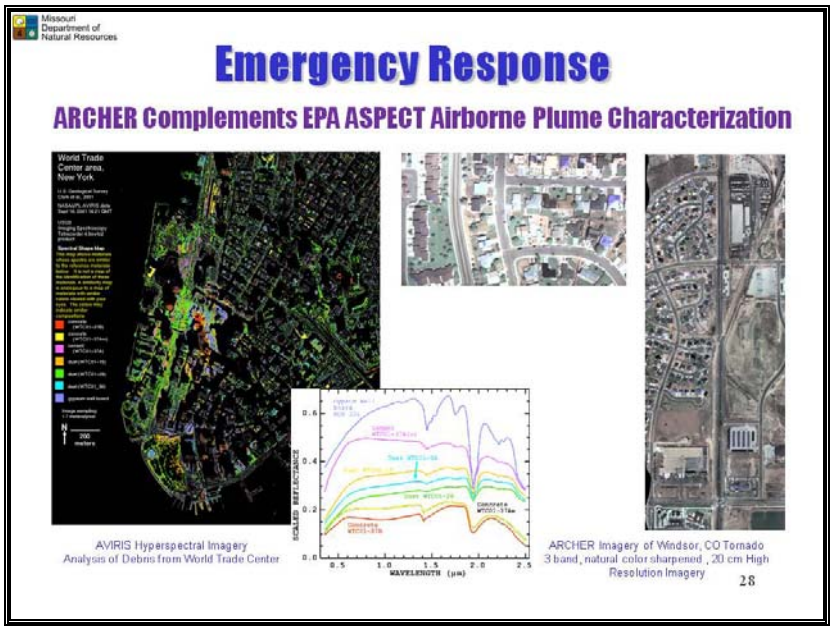
Endmember analysis of ARCHER HSI in the center frame shows a dark red & dark purple area of trees south of the smelter that gradually fades to yellow and orange, possibly showing the extent of airborne deposition from the smelter. The right frame is the result of SAM analysis using the signature of a cedar south of the smelter selected in the imagery. The resultant pattern shows matching cedar primarily limited to the area south of the smelter and a small area west of the smelter. Later SAM analysis using two cedar and a pine north and southwest of the smelter, which had tested positive for lead in the needles, identified other matching conifer around the smelter, but none in the area south of the smelter.



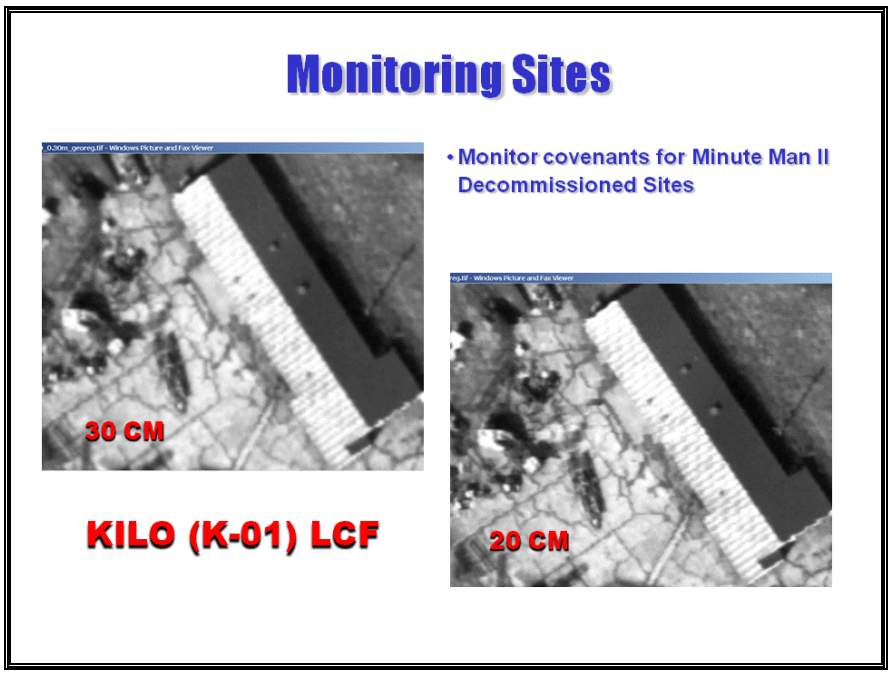
HSI can be used to monitor large area remedies, like landfill covers and re-vegetation of surface mining, in the same way that color and HSI is used in agriculture to monitor crop health. Various VI algorithms detect stress in vegetation brought on by a variety of environmental conditions. False color analysis also provides indications of vegetation health.



As mentioned in Attachment 1, HSI can provide indications of contamination disbursal from fires and other disasters. The EPA Emergency Response team has an Infrared (IR) HSI equipped aircraft that monitors airborne plumes, providing the content and extent of the plume to responders on the ground. After plumes have dissipated, HSI can provide indications of the extent of deposition of materials from the plume. Disbursed chemicals may cause vegetation stress potentially providing an indication of the extent of deposition. USGS Denver used HSI to identify oil smearing along the banks of the Verdigris River after the 2007 flood of an oil refinery in Coffeyville, KS.



Disaster managers used AVIRIS HSI to characterize deposition of several types of debris from the World Trade Center towers collapse. The Colorado WING ARCHER provided high-resolution imagery of Windsor, CO, after a tornado.



Many formerly used defense, superfund, and other remedied sites require monitoring to ensure new owners maintain covenants and other restrictions. Many of these sites are inaccessible for a thorough inspection from the ground. Responsible agencies can use HSI and HRI to monitor a greater number of sites, more frequently. These are former Minuteman II sites.

All CAP aircraft, including ARCHER carry digital cameras for aerial photography. HSI, HRI and aerial photos provide information and orientation not always available from the ground. CAP can also carry PMs on flights, with special permission.