IHI Underground Coal Mine Fire Mitigation: Geophysical Geotechnical evaluation / and Quenching Project, Rifle, CO

By:

Al Amundson
Tara Tafi & Steve Renner

Kanaan Hanna
Steve Hodges & Jim Pfeiffer

COLORADO DIVISION OF RECLAMATION MINING & SAFETY

Abandoned Mines

ZAPATA TRUST · INTEGRITY · QUALITY

GEOHAZARDS IMPACTING TRANSPORTATION IN THE APPALACHIAN REGION

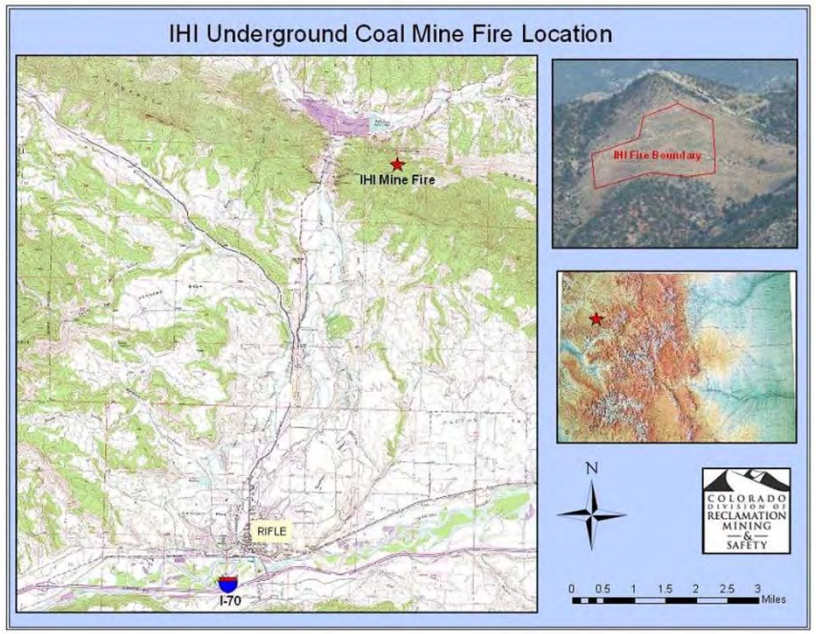
TDOT

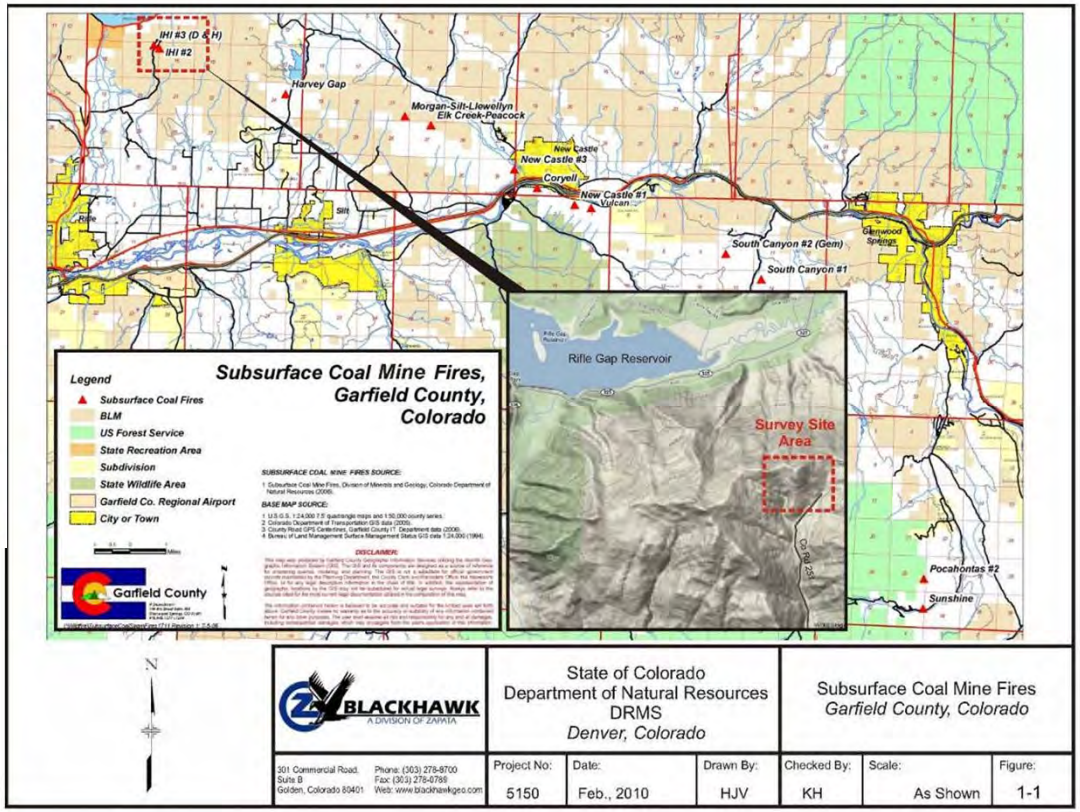
MARSHALL UNIVERSITY.

August 2-4, 2011, Chattanooga, TN

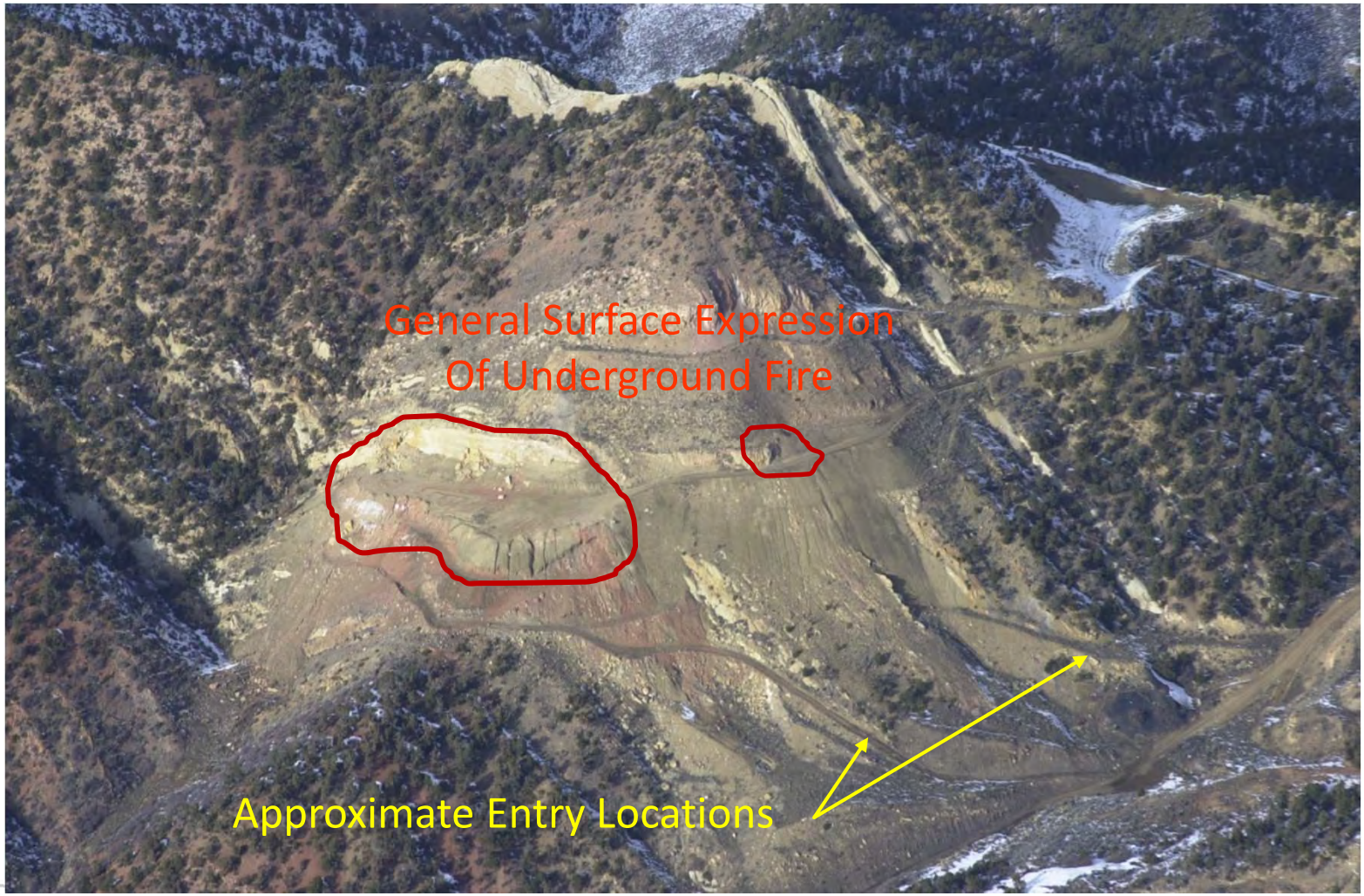
Garfield County Mine Fires…

"13 mine fires burning along Grand Hogback-Garfield County"

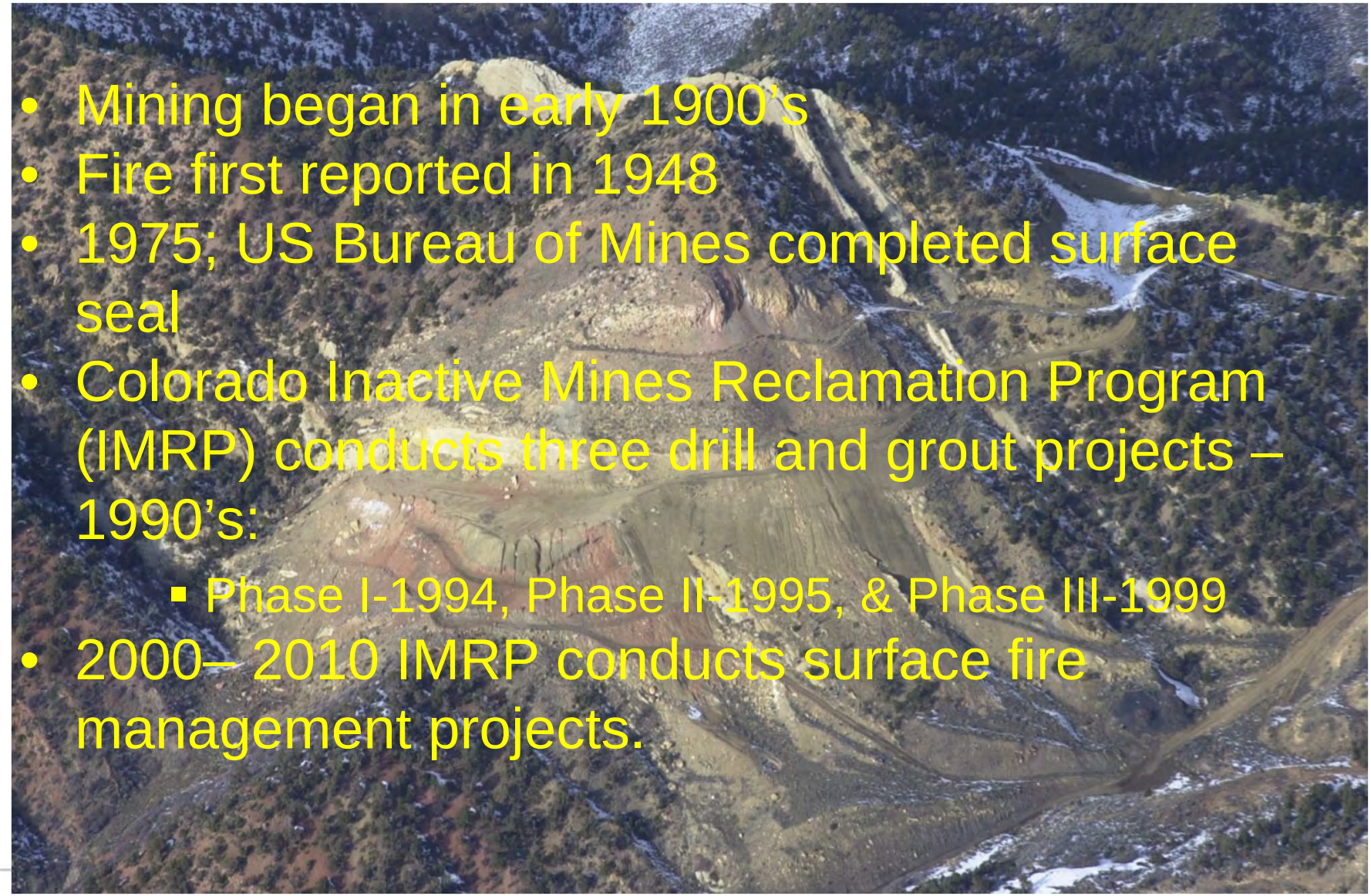




General Site Details



IHI Mine Fire History

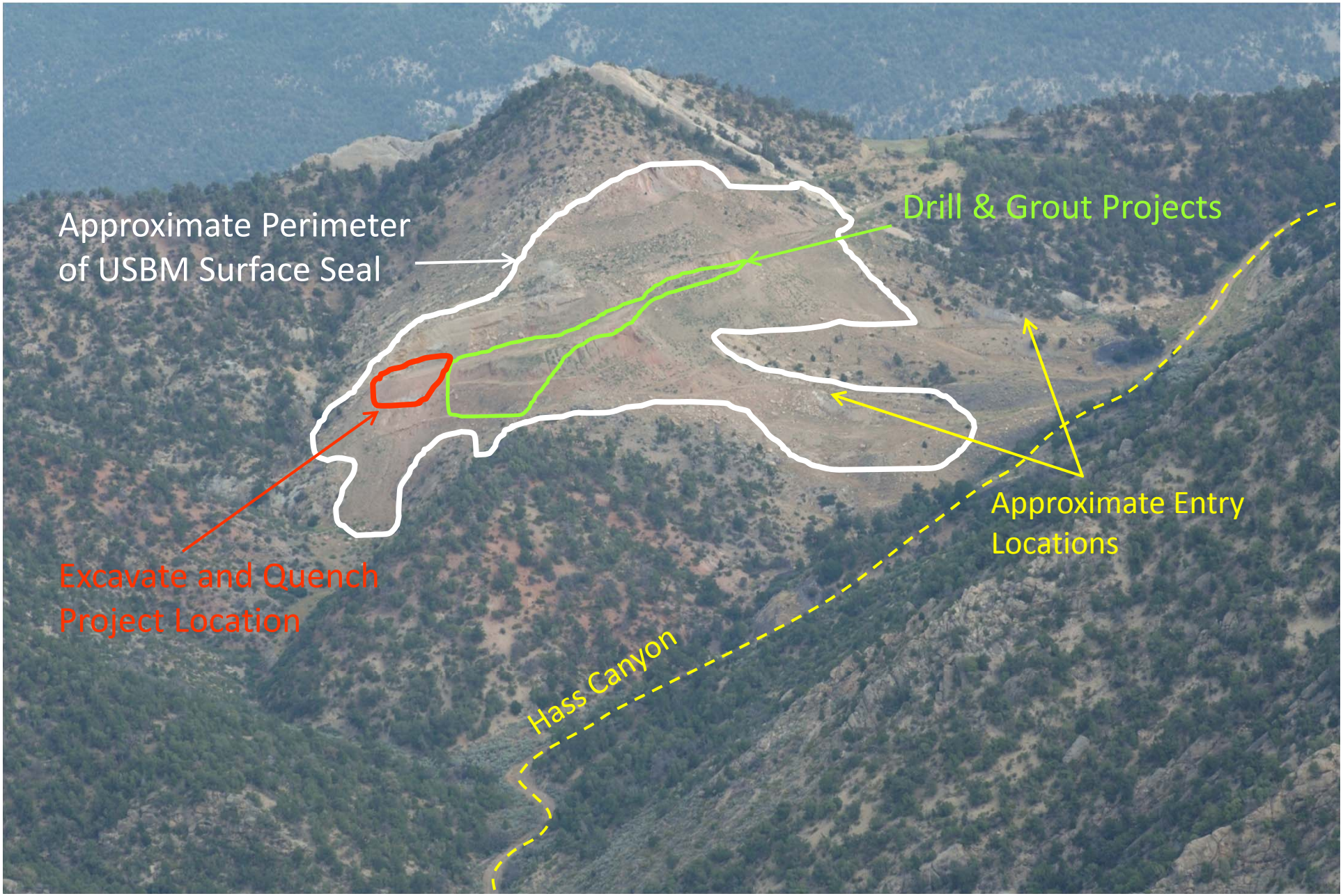


- Mining began in early 1900's
- Fire first reported in 1948
- 1975; US Bureau of Mines completed surface seal
- Colorado Inactive Mines Reclamation Program (IMRP) conducts three drill and grout projects – 1990's:
  - Phase I-1994, Phase II-1995, & Phase III-1999
- 2000– 2010 IMRP conducts surface fire management projects.

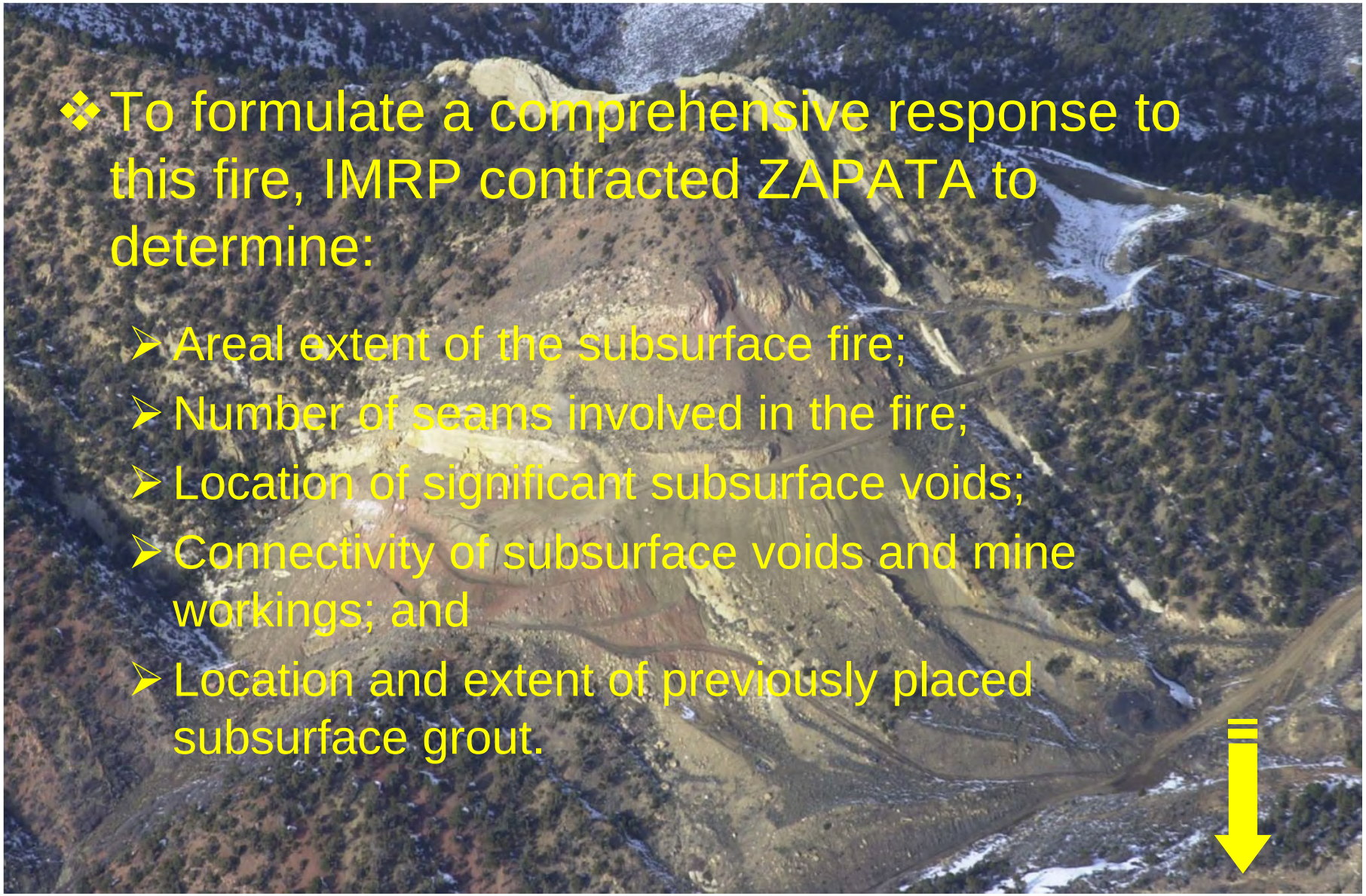
Project Background

- Coal Accessed via entries developed near base of canyon;
- Mining occurred overhead in nearly vertical rooms, or stopes (dip ~ 65° southwest);
- Fire occurs in the vertical stopes and in adjacent, un-mined coal seams;
- Stopes act as chimneys to provide fire ventilation;
- Oxygen likely provided from general area of abandoned entries;
- Fire vents from coal outcrops at or near the former ridge line.

Locations of Site Work



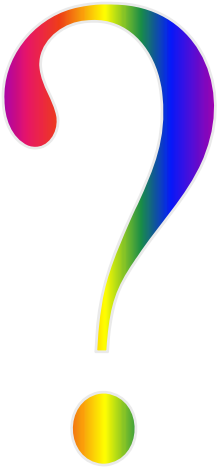
Scope of Geophysical Work



- To formulate a comprehensive response to this fire, IMRP contracted ZAPATA to determine:
  - Areal extent of the subsurface fire;
  - Number of seams involved in the fire;
  - Location of significant subsurface voids;
  - Connectivity of subsurface voids and mine workings; and
  - Location and extent of previously placed subsurface grout.

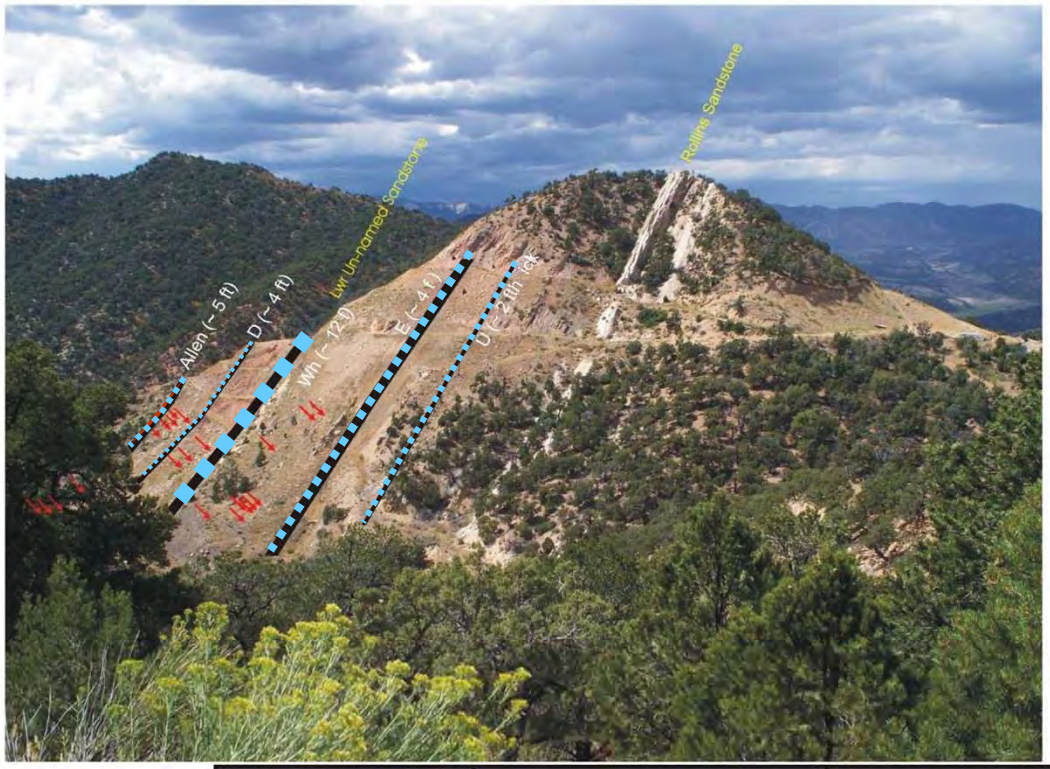
Series of reclamation projects were conducted at the site to control the fire…!

Why the site is so complex to mitigate?



Multi-seams mine workings – Burned & unburned

(looking west along strike showing the subcrob locations of the seams)



Explanation

Coal Seam

Air Intakes

BLACKHAWK
A DIVISION OF ZAPATA

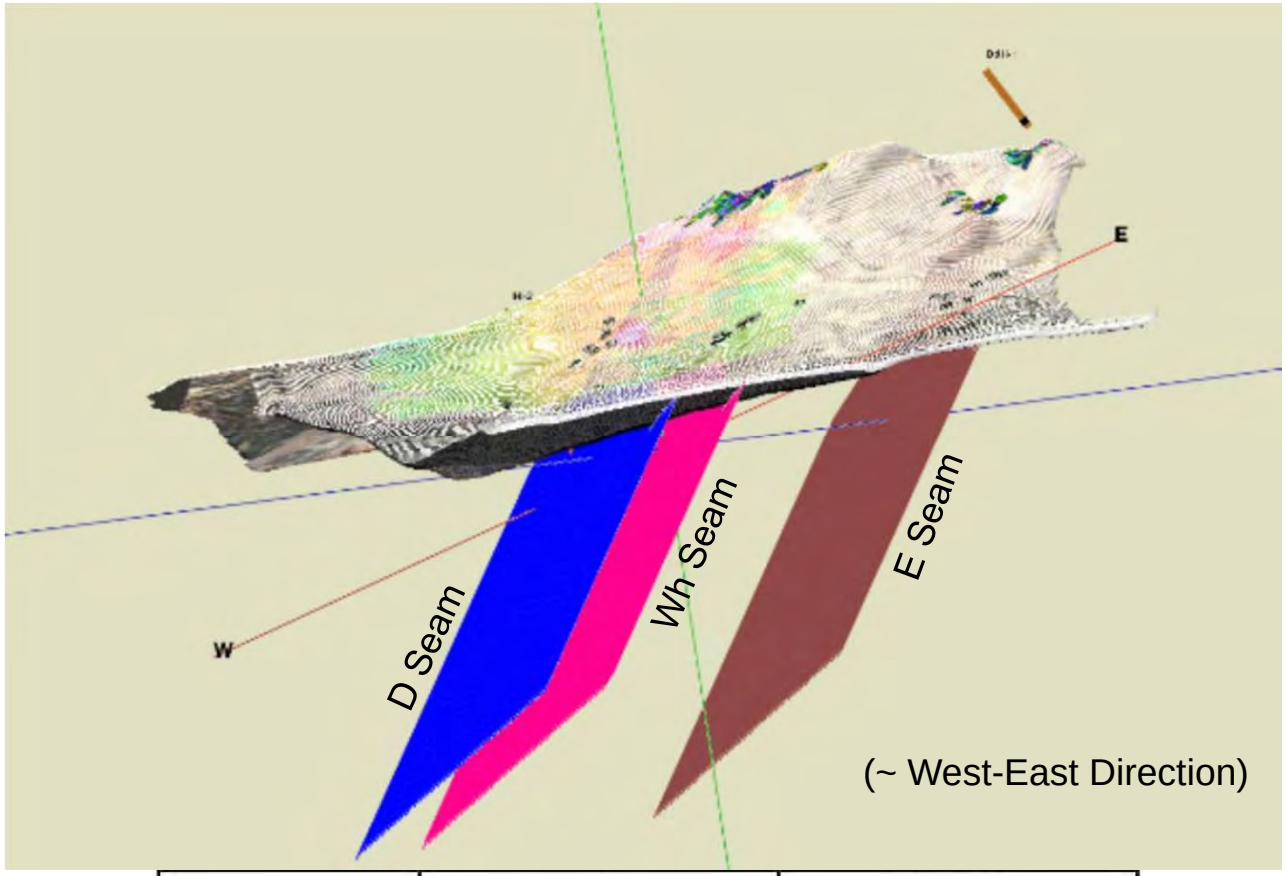
301 Commercial Road, Suite B
Golden, Colorado 80401
Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

State of Colorado
Department of Natural Resources
DRMS
Denver, Colorado

Photo Along Strike
with Coal Seams and Sandstones
IHI Mine Fire
Rifle, Colorado

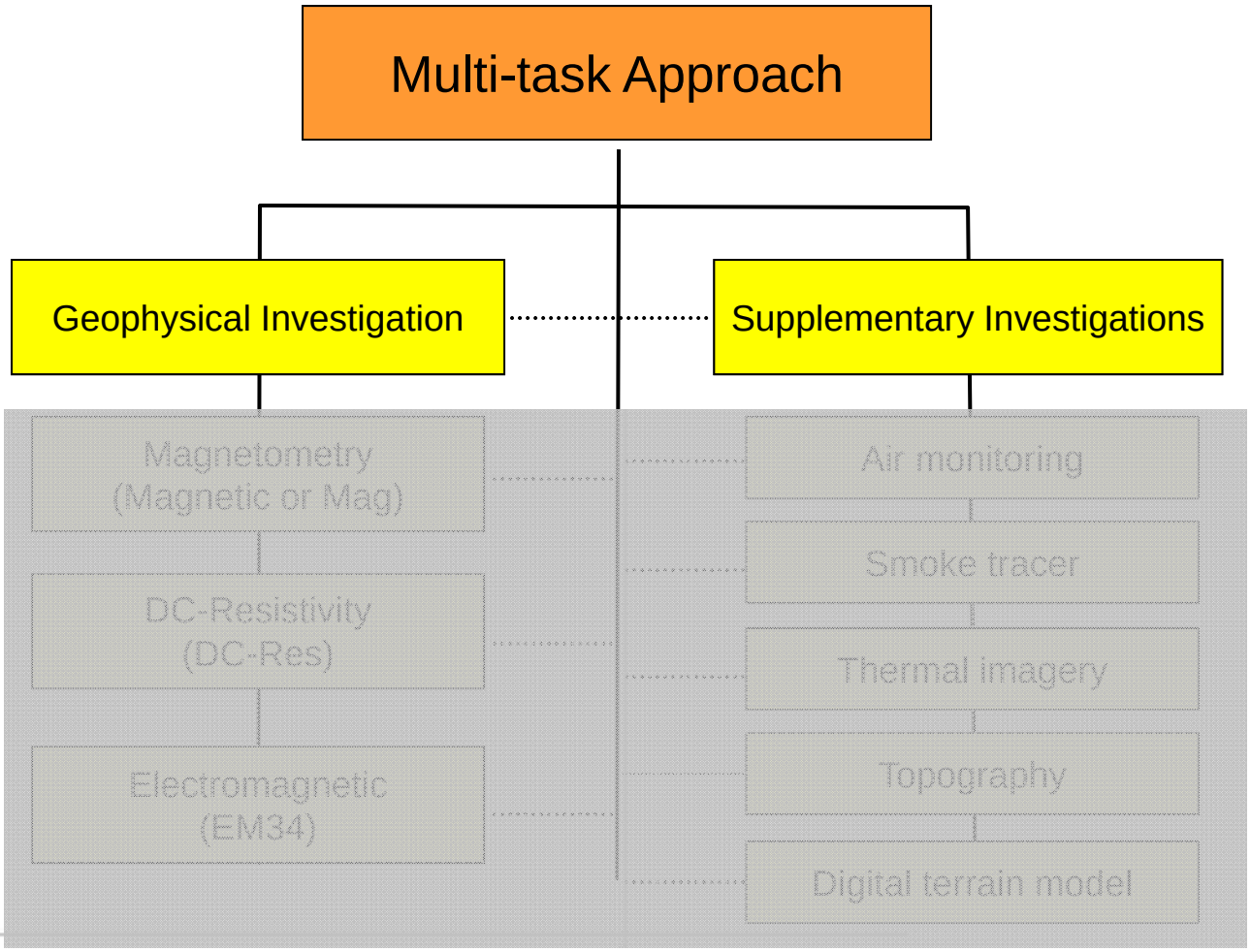
Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5150	Feb., 2010	HJV	KH	As Shown	2-4

3-D Terrain Model using ZAPATA “RockWorks” Software



BLACKHAWK A DIVISION OF ZAPATA	State of Colorado Department of Natural Resources DRMS *Denver, Colorado*			3-D Model (ZAPATA) *IHI Mine Fire* *Rifle,Colorado*		
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5150	Date: Feb., 2010	Drawn By: HJV	Checked By: KH	Scale: As Shown	Figure: 4-9

Geophysical Program Overview

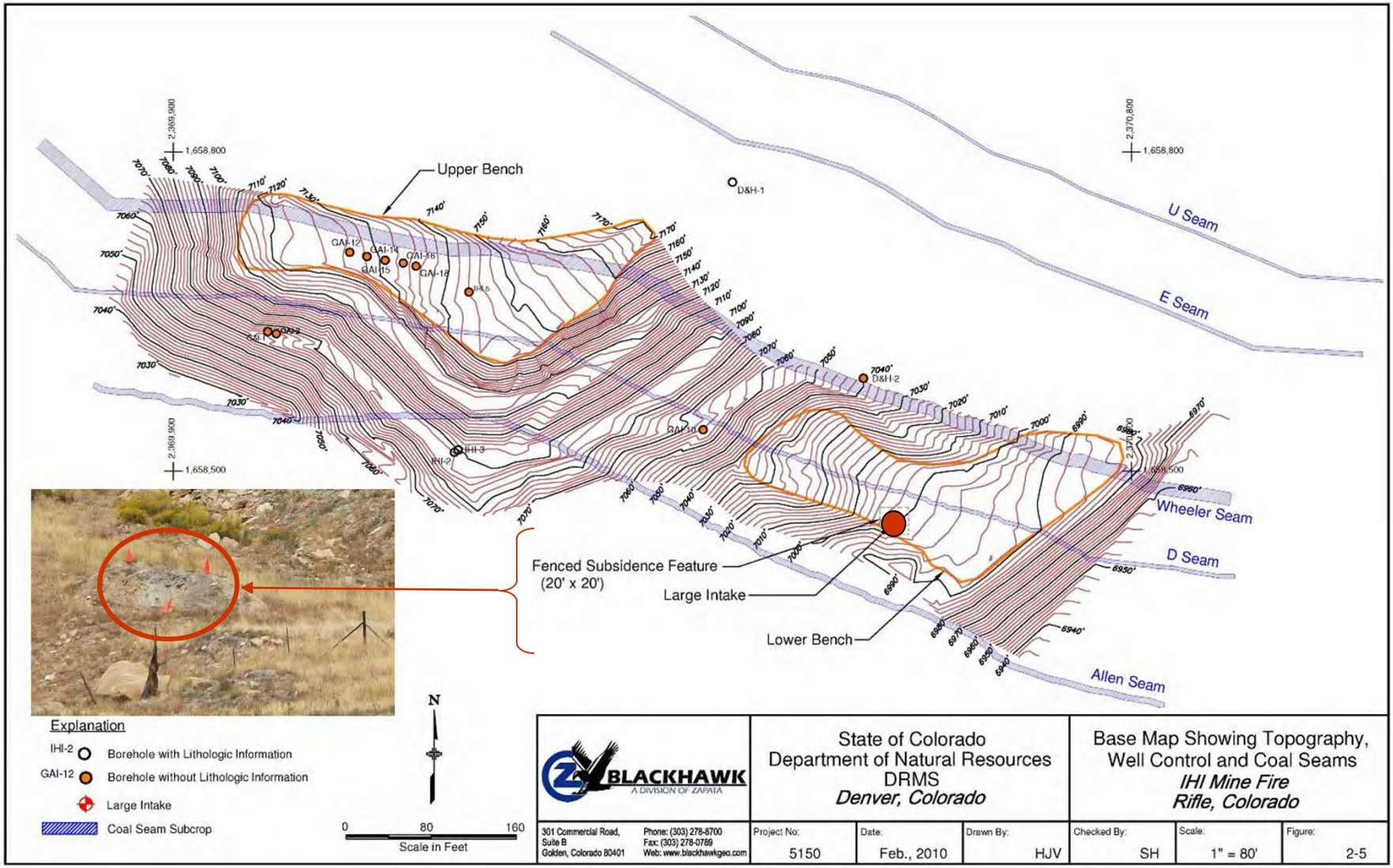


Project location site – aerial photo looking north

BLACKHAWK A DIVISION OF ZAPATA	State of Colorado Department of Natural Resources DRMS *Denver, Colorado*			Aerial Photo Looking North at Area of Investigation *IHI Mine Fire* *Rifle, Colorado*		
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5150	Date: Feb., 2010	Drawn By: HJV	Checked By: KH	Scale: As Shown	Figure: 2-2

Area of Investigation

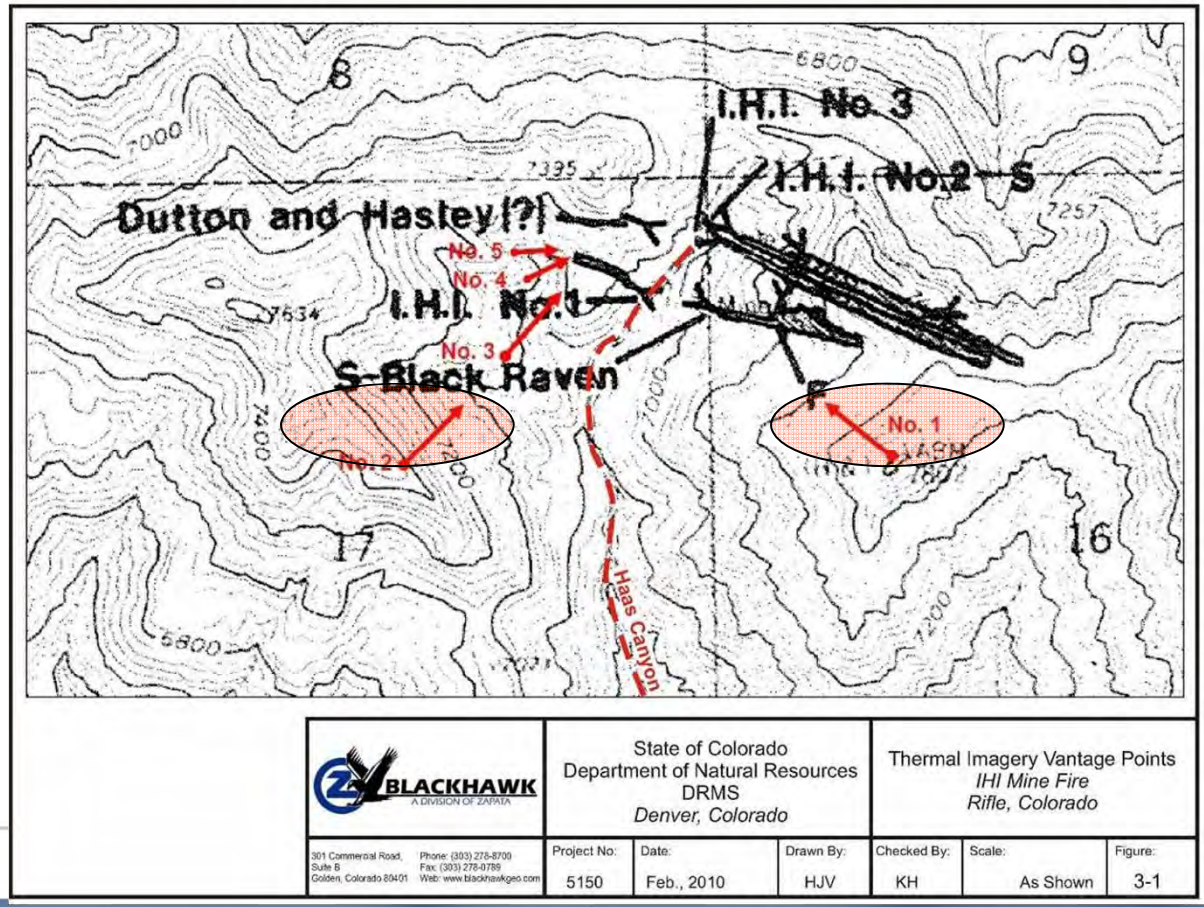
Base map showing topography, well control & coal seams



Thermal Imaging

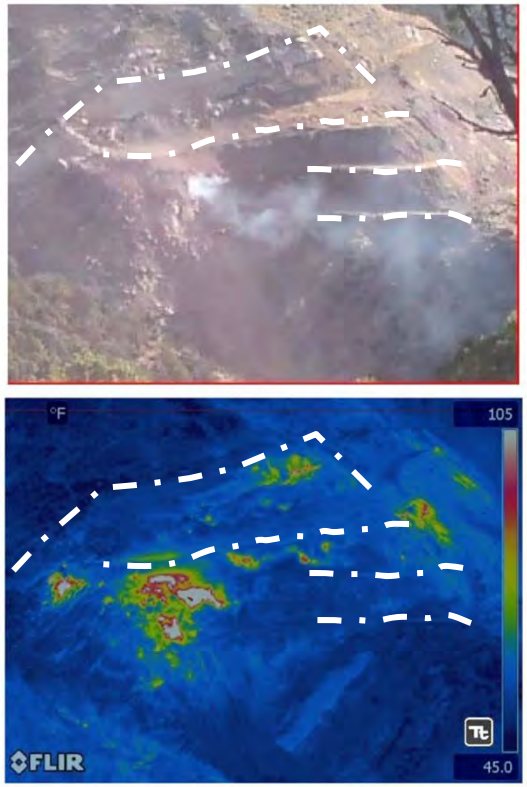
Objective: Determine ground surface temperature (hot exhaust vents) using a FLIR Systems infrared camera (IR)

From various vantage points – No. 1 to No.5



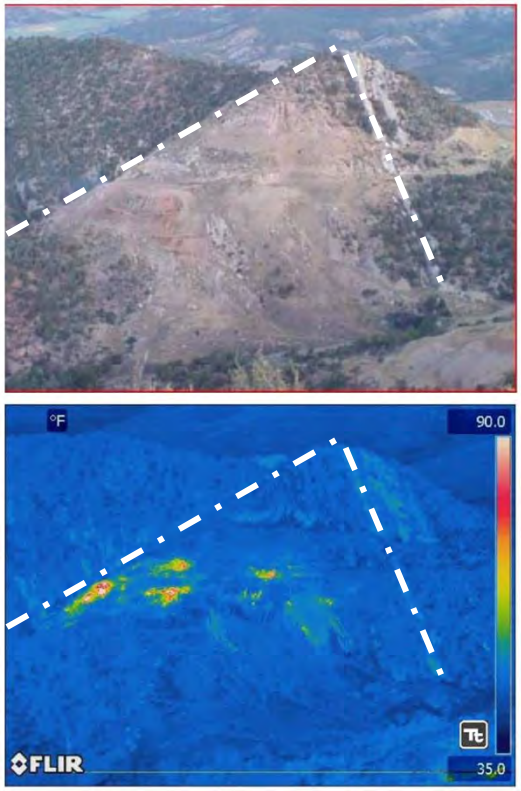
Thermal Imaging Tests (Standard & IR Imagery)

Vantage points – No.2



BLACKHAWK A DIVISION OF ZAPATA	State of Colorado Department of Natural Resources DRMS *Denver, Colorado*		Thermal Image from Vantage 2 *IHI Mine Fire* *Rifle, Colorado*		
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5150	Date: Feb., 2010	Drawn By: HJV	Checked By: KH	Scale: As Shown	Figure: 3-3

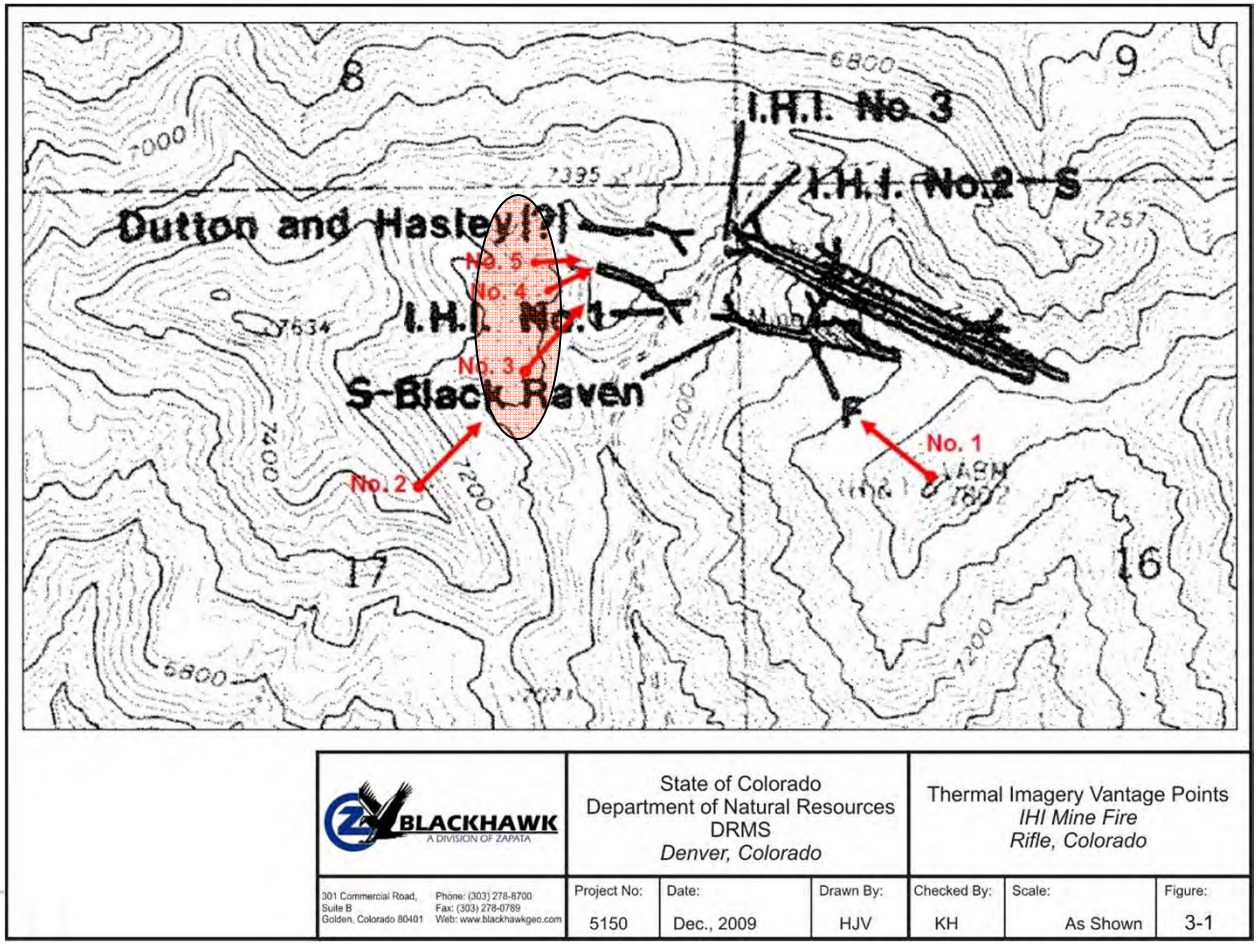
Vantage points – No. 1



BLACKHAWK A DIVISION OF ZAPATA	State of Colorado Department of Natural Resources DRMS *Denver, Colorado*		Thermal Image from Vantage 1 *IHI Mine Fire* *Rifle, Colorado*		
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5150	Date: Feb., 2010	Drawn By: HJV	Checked By: KH	Scale: As Shown	Figure: 3-2

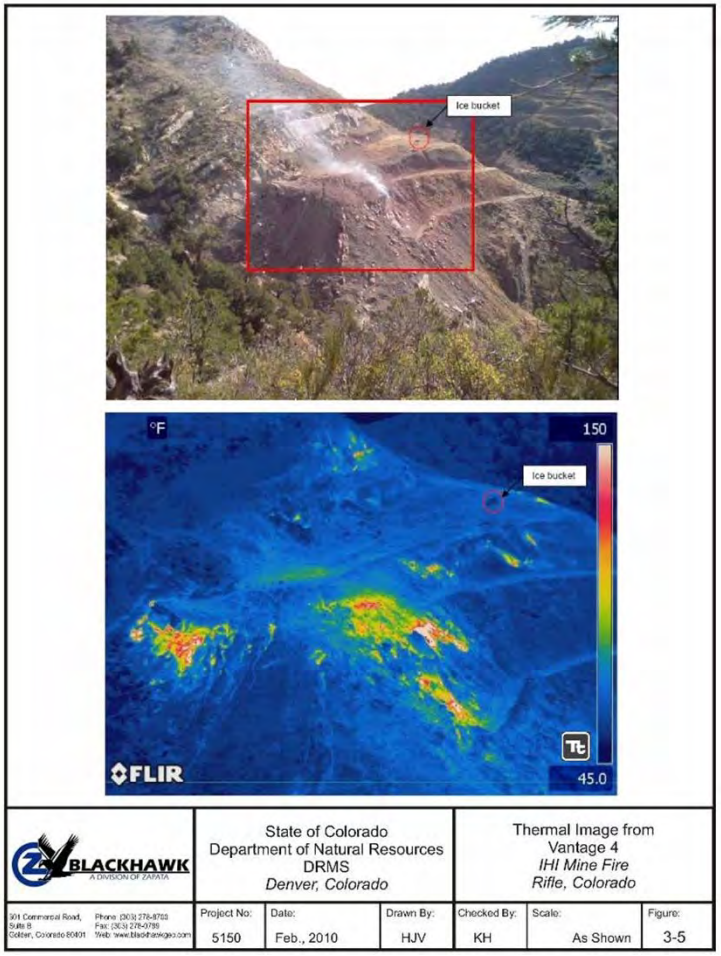
Thermal Imaging Tests (Standard & IR Imagery)

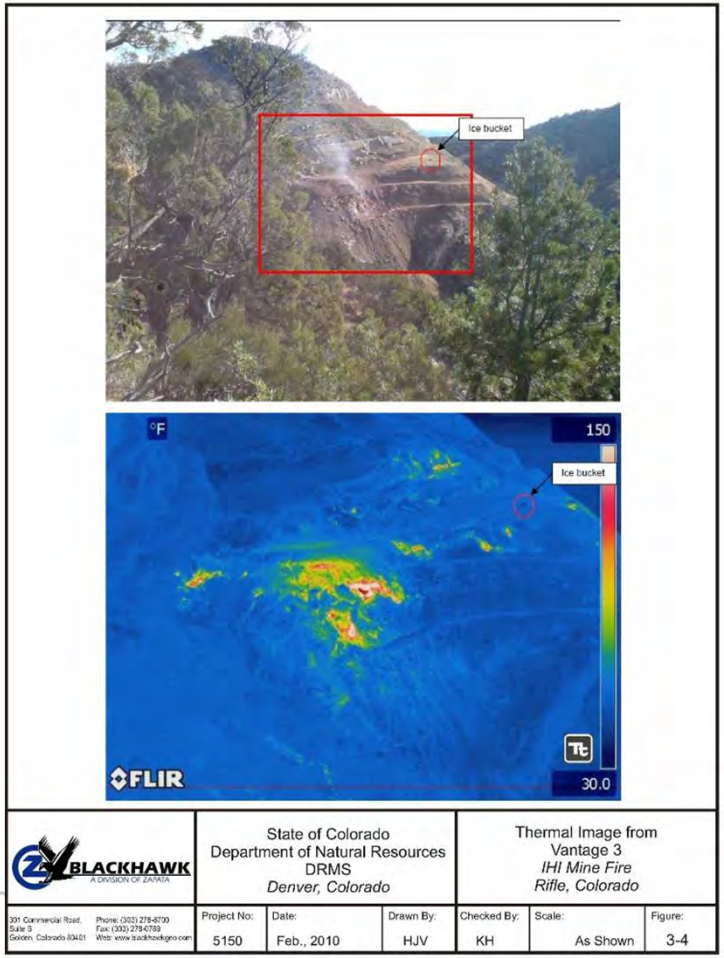
Thermal imagery vantage points – No. 3 to No.5



Thermal Imaging Tests (Standard & IR Imagery)

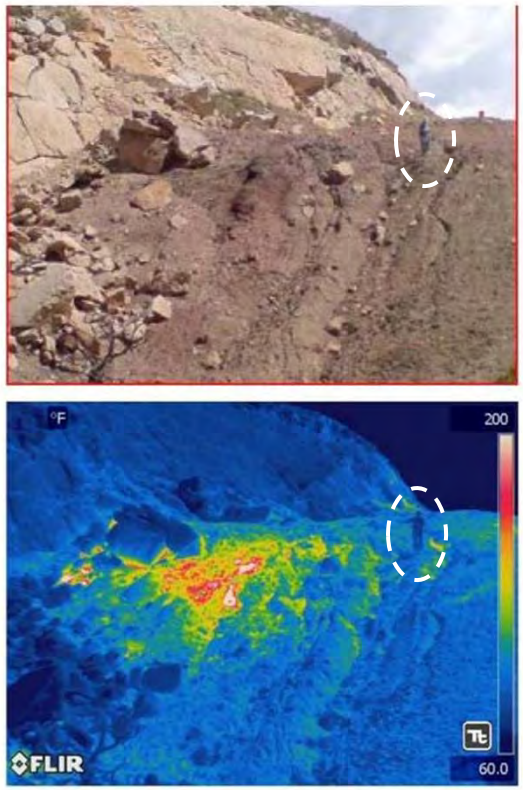
Vantage points – No. 3 & No.4





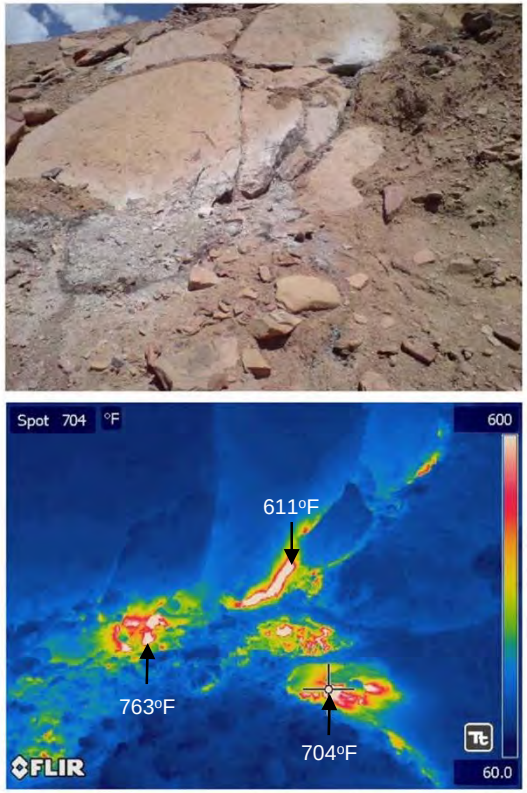
Thermal Imaging Tests (Standard & IR Imagery)

Vantage point 5



BLACKHAWK A DIVISION OF ZAPATA	State of Colorado Department of Natural Resources DRMS *Denver, Colorado*		Thermal Image from Vantage 5 *IHI Mine Fire* *Rifle, Colorado*		
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8786 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5150	Date: Feb., 2010	Drawn By: HJV	Checked By: KH	Scale: As Shown	Figure: 3-6

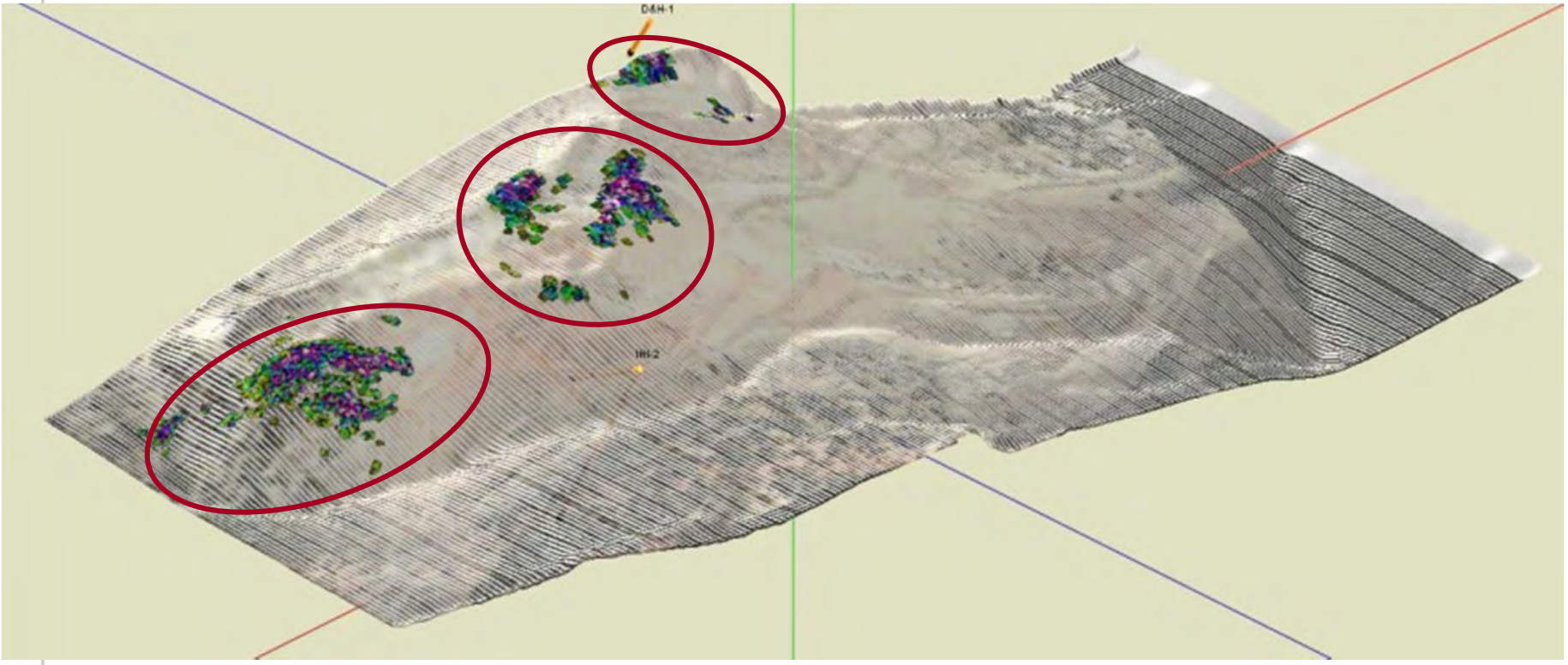
Spot temperature @ main thermal vent (704° F) below upper bench



BLACKHAWK A DIVISION OF ZAPATA	State of Colorado Department of Natural Resources DRMS *Denver, Colorado*		Spot Temperature at Main Thermal Vent (704º F) *IHI Mine Fire* *Rifle, Colorado*		
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8786 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5150	Date: Feb., 2010	Drawn By: HJV	Checked By: KH	Scale: As Shown	Figure: 3-7

Thermal Imaging Results

Hot exhaust vents superimposed on the 3-D terrain model

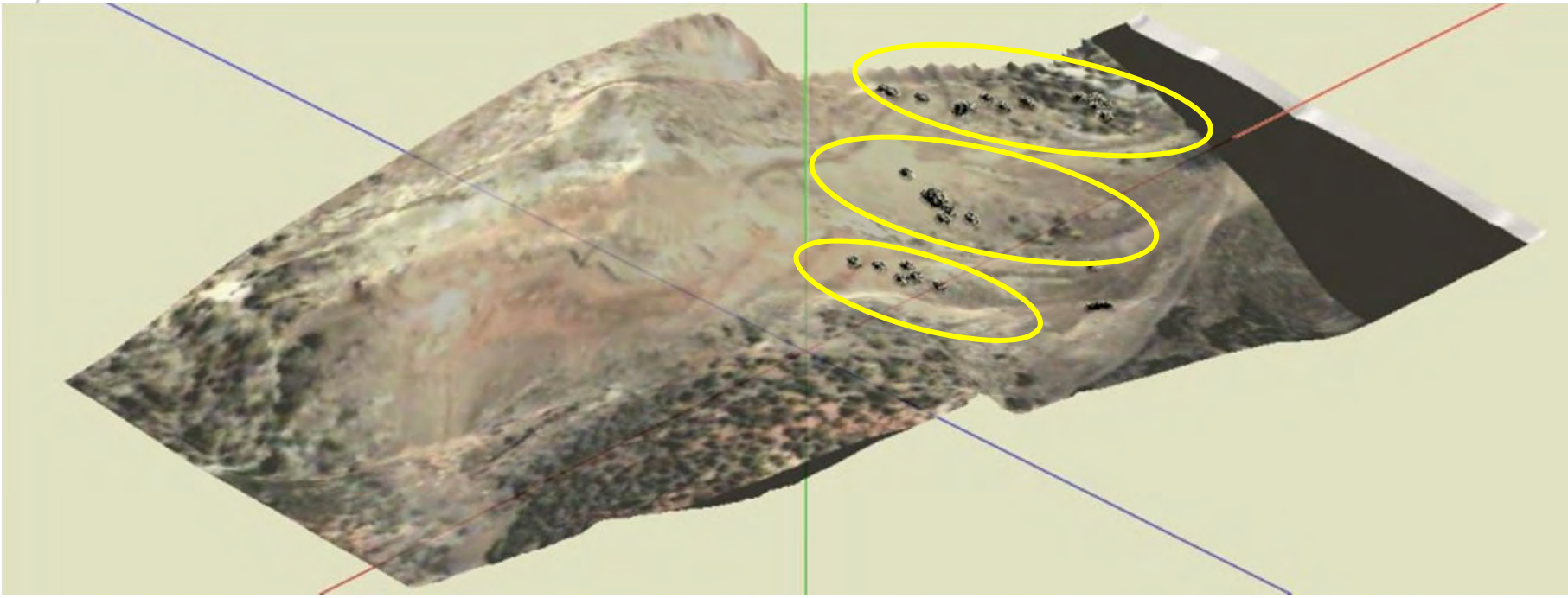


Low spot Hot spot

Smoke Tracer Tests Result (Phases I, II, & III)

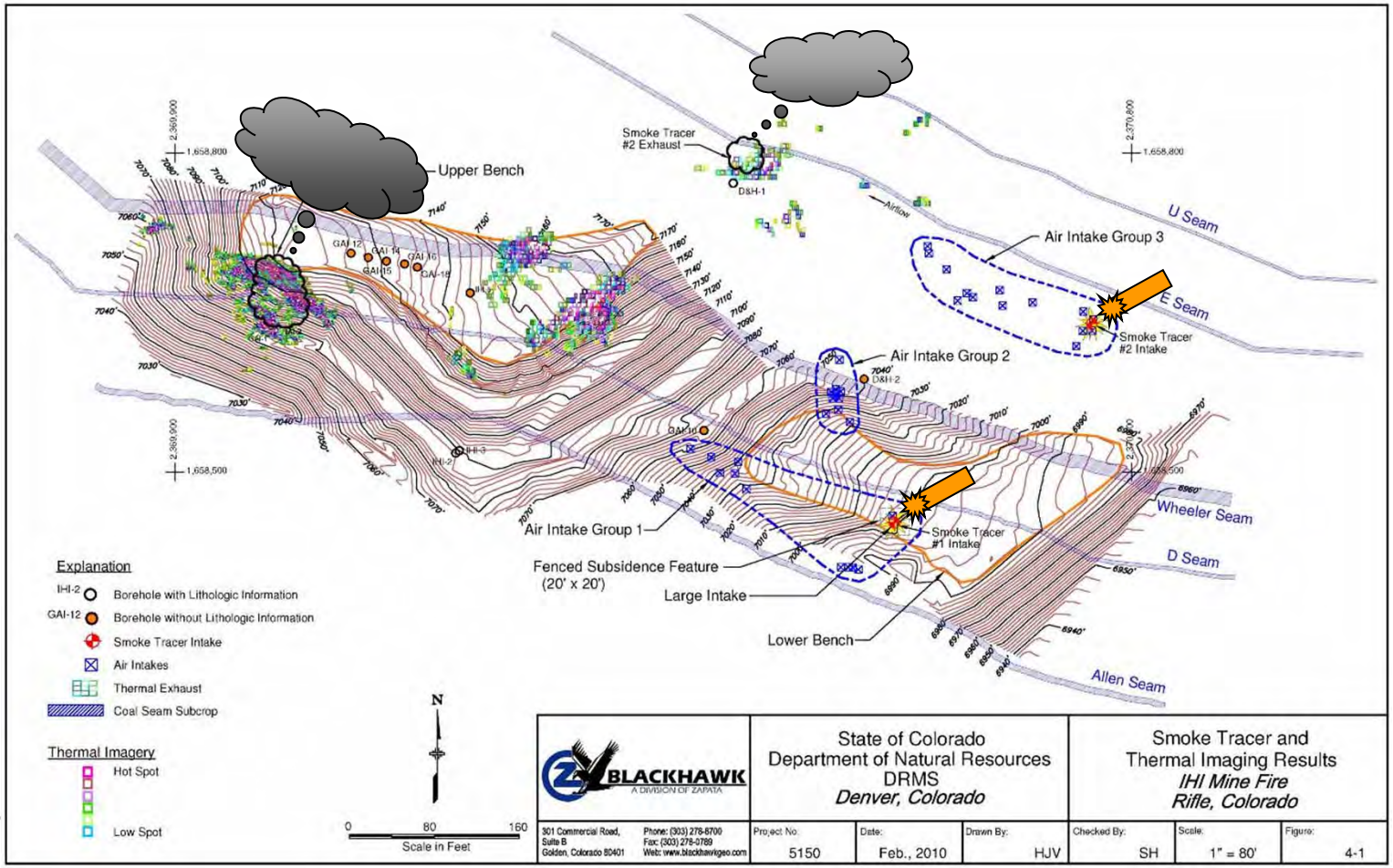
Objective: Determine connectivity between air intakes and exhaust vents

- Phases I & II: Located 36 air intakes using small fireworks
- Phase III: Two tests using large 100K ft^3 smoke canisters to establish *connectivity* between specific *air intakes & exhaust vents*



Smoke Tracer Tests & Thermal Imaging Results

(Phase III: Two smoke tracer tests using large 100K ft^3 gas canister)



Geophysical Survey Methodology

DC-Resistivity and Magnetometry (Mag) Field set up

Geophysical Survey Methodology

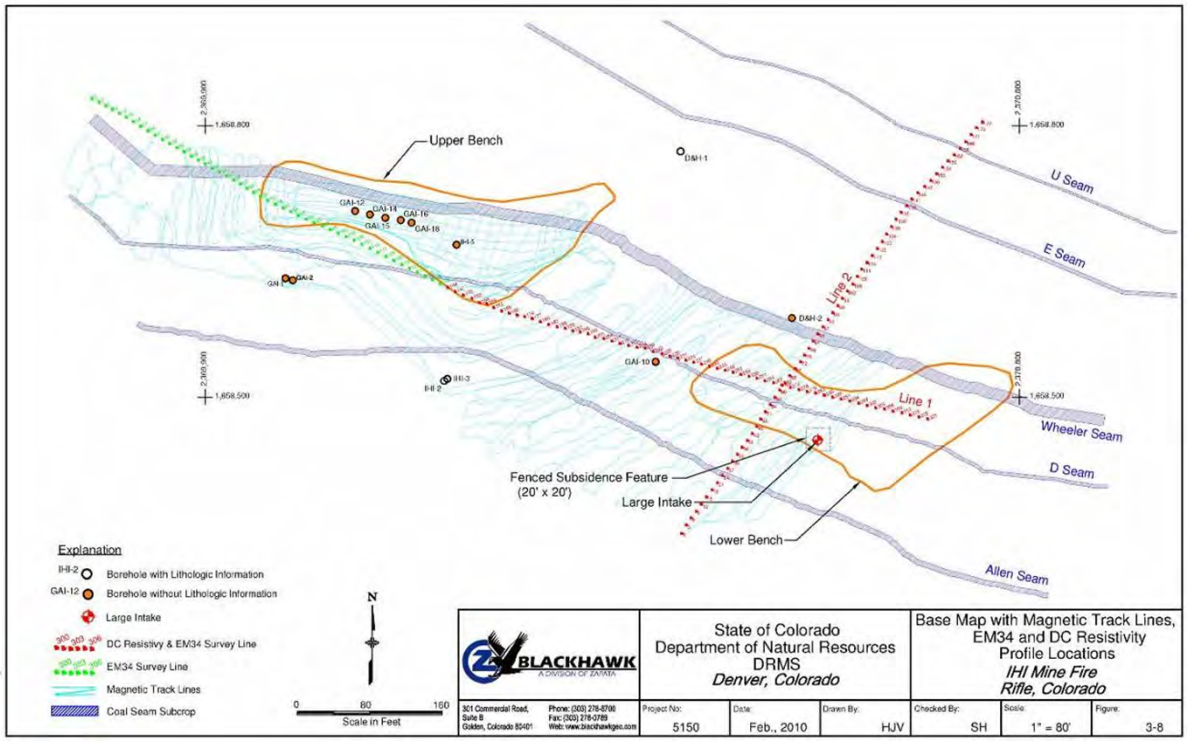
DC-Res, EM34, and Magnetic Profile Locations

DC-Res Objective: Imaging potential voids & hot temperature areas

DC-Res

- Line 1 oriented sub-parallel & down dip of the subcrop of the Wheeler (Wh) seam
- Line 2 oriented sub-perpendicular to the strike of the Wh and other seams
- High temperature problems during data acquisition

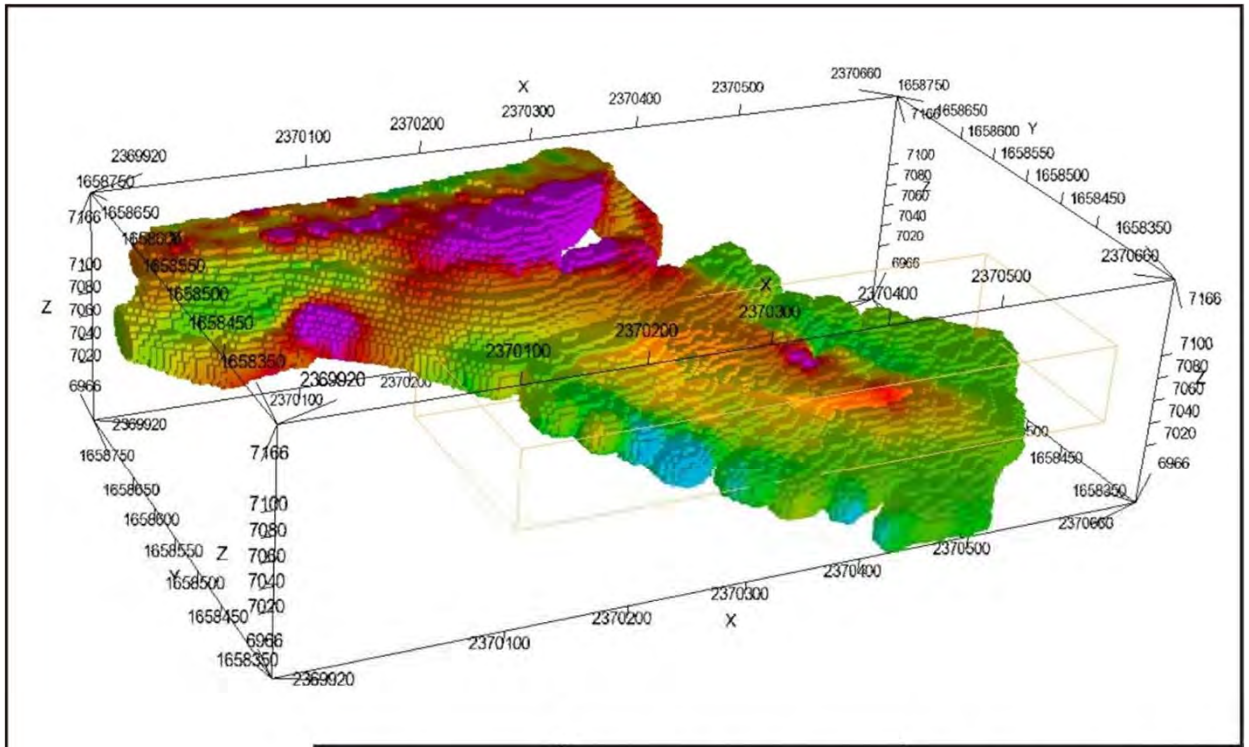
EM34 in areas with high surface temperature



Magnetic Results

Objective: Delineate previously burned areas & active fire zones

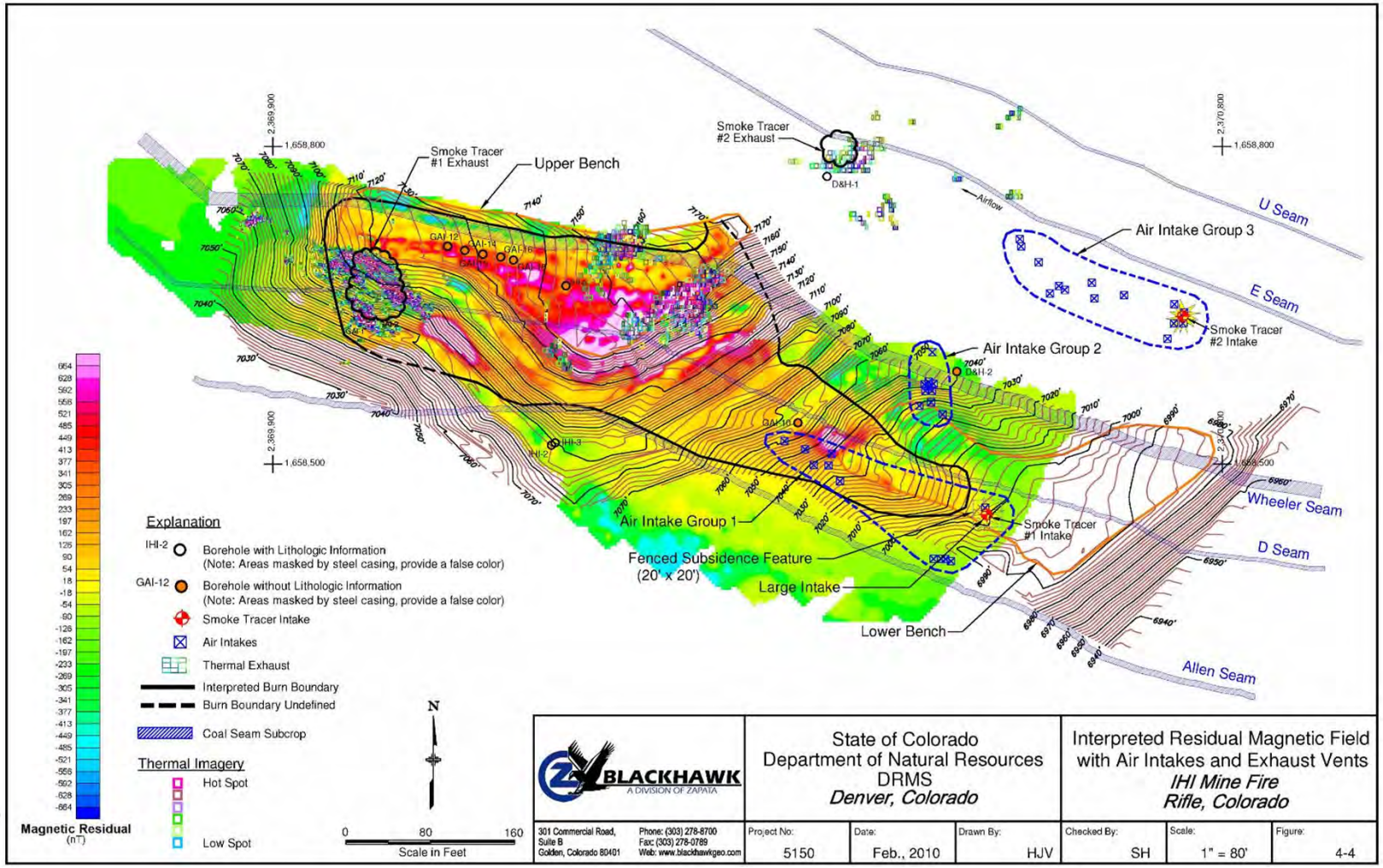
3D representation of residual magnetic field



BLACKHAWK A DIVISION OF ZAPATA	State of Colorado Department of Natural Resources DRMS *Denver, Colorado*			3D Representation of Residual Magnetic Field *IHI Mine Fire* *Rifle, Colorado*		
301 Commercial Road Suite B Golden, Colorado 80401	Phone: (303) 278-8760 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5150	Date: Dec., 2009	Drawn By: HJV	Checked By: KH	Scale: As Shown	Figure: 4-3

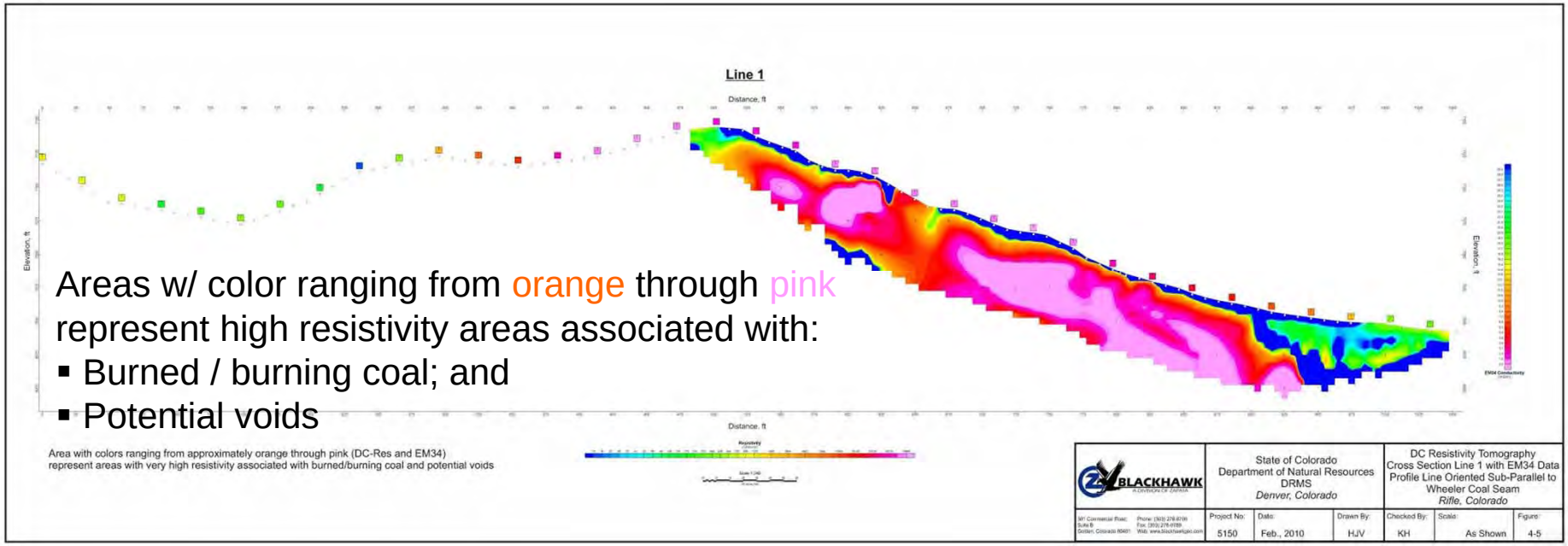
Magnetic Results

Interpreted residual magnetic field with air intakes and exhaust vents



DC-Resistivity Tomography Results

Cross section Line 1 with EM34 data profile
Line oriented sub-parallel to Wheeler seam

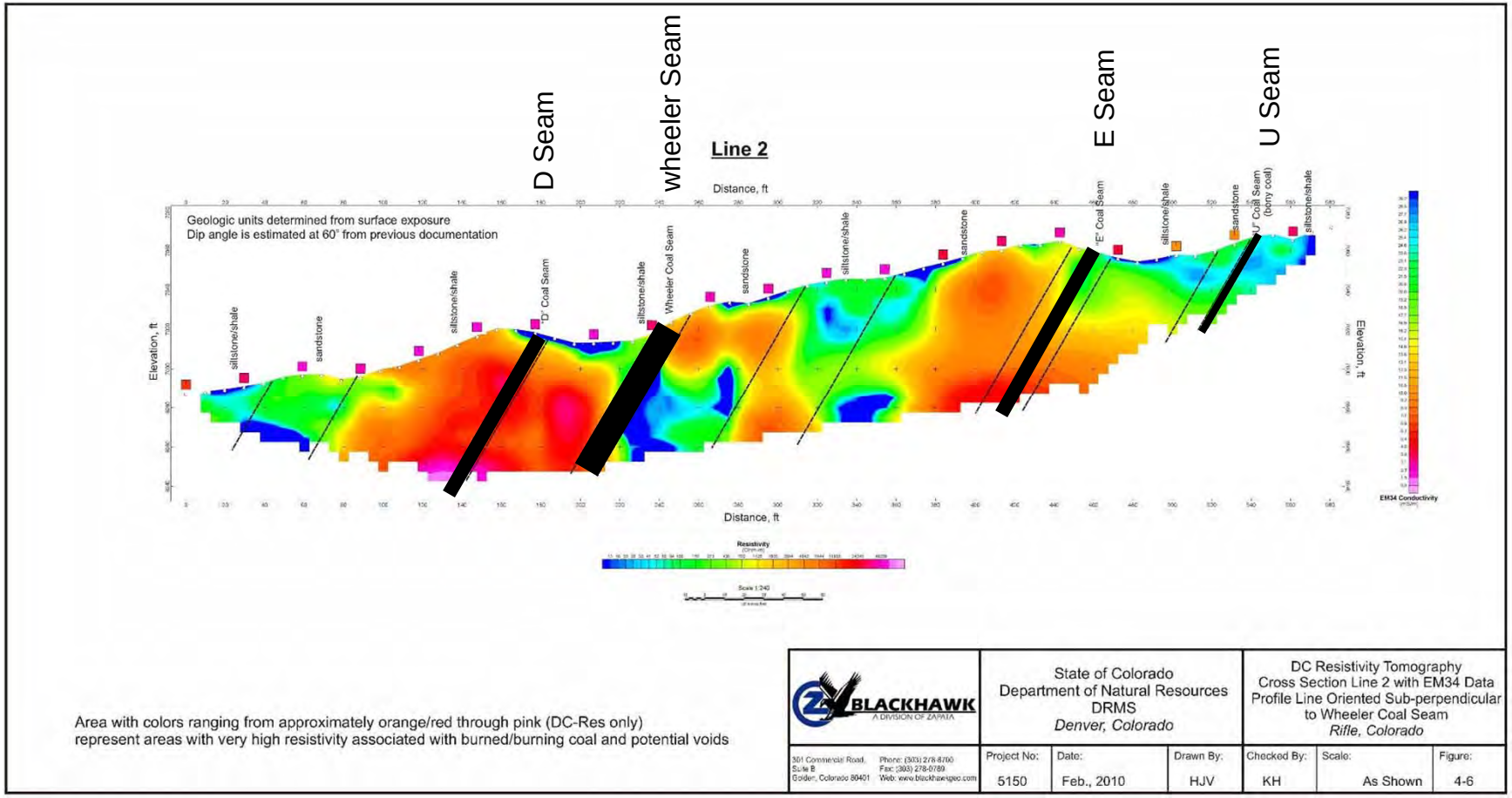


Areas w/ color ranging from orange through pink represent high resistivity areas associated with:

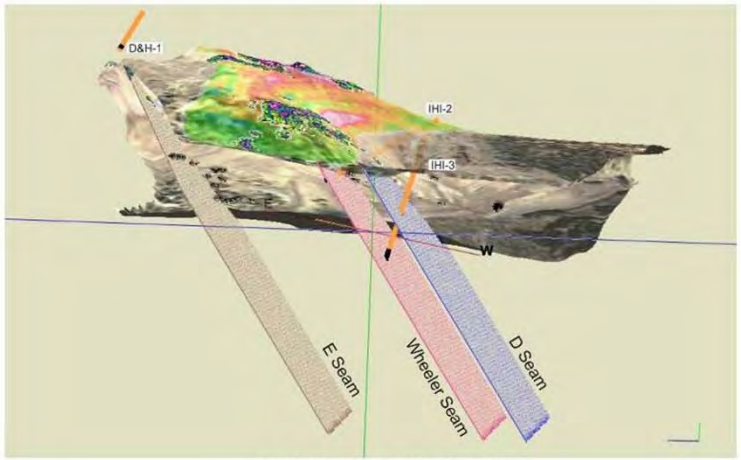
- Burned / burning coal; and
- Potential voids

DC-Resistivity Tomography Results

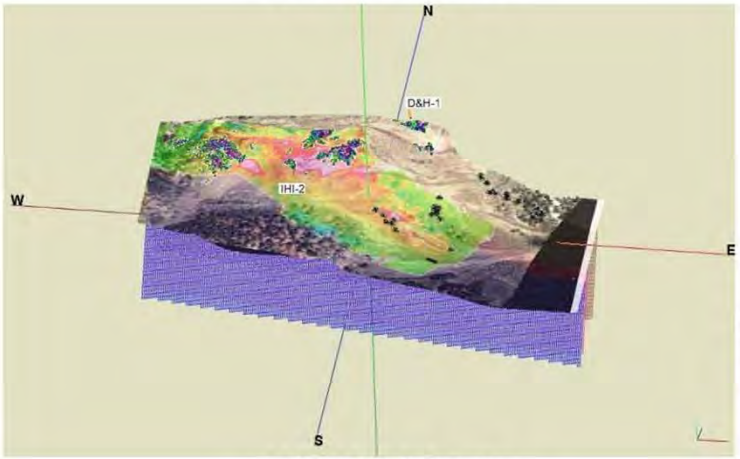
Cross section Line 2 with EM34 data profile
Line oriented sub-perpendicular to Wheeler seam



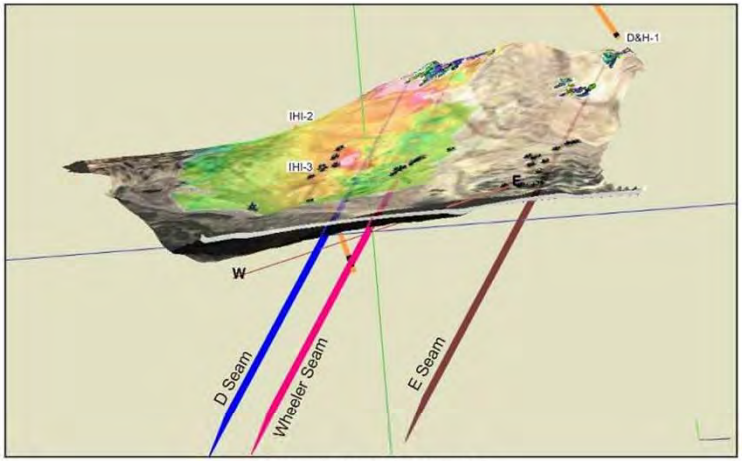
3-D Terrain Model using ZAPATA "RockWorks" Software with View Capabilities



3-D Model, East - West Direction



3-D Model, South-North Direction



3-D Model, West-East Direction

BLACKHAWK A DIVISION OF ZAPATA	State of Colorado Department of Natural Resources DRMS *Denver, Colorado*		3-D Model (ZAPATA) *IHI Mine Fire Rifle, Colorado*		
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5150	Date: Feb., 2010	Drawn By: HJV	Checked By: KH	Scale: As Shown	Figure: 4-9

Conclusions

General…

The area of interest was expanded to better understand:

- The actively burning and non-burning seams, and
- The void connectivity relationship between burning mine workings

Conclusions...(continued)

Smoke Tracer Tests

- Smoke tracer tests identified 36 air intakes w/ the following observations:
  - Large-volume smoke canisters (100K ft^3) were required to establish connectivity relationship between specific air intakes & exhaust vents;
  - Identified three groups of air intakes corresponding with subcrop & hanging walls of E, Wheeler & D seams; and
  - Established connectivity between two large air intakes (lower bench and north of lower bench) and specific exhaust vents.

Conclusions...(continued)

Thermal Imagery Tests

- Mapped hot exhaust vents;
- Located previously unidentified vents; and
- Provided spatial relationships between vents and coal seams.

Conclusions ...(continued)

Magnetometry Survey

- Mognetometry outlined the extent of the area affected by the mine fire with the following observations:
  - Lateral extent of the burned areas were defined;
  - Fire started at the large intake in the D seam and propagated along strike to northwest;
  - Fire propagated into the Wheeler seam from the D seam, by means of fractures and/or unknown mine workings; and
  - Fire does not yet extend into the canyon bottom west of the upper bench.

Conclusions …(continued)

Geophysical Investigation – DC-Resisitivity

- DC-Res identified high-resistivity anomalies
- DC-res as a stand-alone technique could not distinguish between anomalies due to:
  - Voids,
  - High temperature, and
  - or both.
- Large void areas potentially remain
- In-place grout could not be imaged due to:
  - Low strength ~ 75 psi,
  - Low density ` 61 pcf, and the
  - Grout is indistinguishable from rubble or burned coal.

Conclusions

Three-dimensional (3-D) Model

- 3-D model provides a useful visualization tool for:
  - Observing spatial relationship between varying data sets and other supporting information
- Ability to review each data set separately

Recommendations

- The high potential for further subsidence must be addressed (i.e., use of INSAR techniques to monitor subsidence);
- Expand smoke tracer studies to locate all air intakes
  - *Cutting airflow into the mine workings is necessary as an initial step to future reclamation effort…!*
- Reclamation must address all burning seams exhibiting airflow connectivity; and
- Potential drilling locations to be identified for future borings and grouting.

Summary

The geophysical investigation
at the IHI mine fire site has demonstrated
the benefits/effectiveness of the selected techniques….

Mag, DC-Res,
& partially EM34

When

Supplemented by gas tracer and thermal imagery studies combined with engineering practices – to be the most viable approach to investigate complex mine fire problems…

Thank You

Questions ?

COLORADO DIVISION OF RECLAMATION MINING & SAFETY

Abandoned Mines

BLACKHAWK
A DIVISION OF ZAPATA