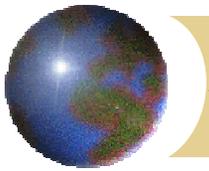


***HYPERSPECTRAL REMOTE SENSING
AND ITS APPLICATION TO VEGETATION
MAPPING
NORTH ROCHELLE/ANTELOPE MINE
COMPLEX***

POWDER RIVER COAL COMPANY

MICHAL RUDER
ELROI CONSULTING AND
WINTERMOON GEOTECHNOLOGIES

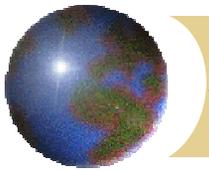
7 DEC 2001



PURPOSE OF THE STUDY

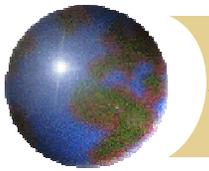
- ✚ EXPLORE THE UTILITY OF AIRBORNE HYPERSPECTRAL IMAGERY FOR MAPPING:
 - ✚ VEGETATION TYPE
 - SPECIES
 - COMMUNITY
 - ✚ VEGETATION PRODUCTIVITY
 - ✚ VEGETATION COVER

- ✚ CAN REMOTE SENSING PROVIDE AN ACCURATE AND INEXPENSIVE SOLUTION FOR MONITORING RECLAMATION AND ASSESSING CONDITIONS THAT MEET BOND RELEASE?



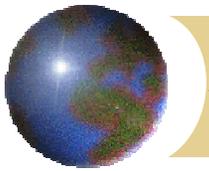
APPROACH

- ➊ IDENTIFY APPROPRIATE AIRBORNE SENSOR TO IMAGE THE SURVEY AREA
- ➋ FLY THE SURVEY
- ➌ ACQUIRE 'GROUND TRUTH': MEASURE SPECTRAL REFLECTANCE OF EARTH MATERIALS IN-SITU
- ➍ ORTHORECTIFY THE AIRBORNE IMAGERY
- ➎ APPLY ADVANCED IMAGE PROCESSING TECHNIQUES TO ENHANCE THE IMAGERY AND MAP VEGETATION



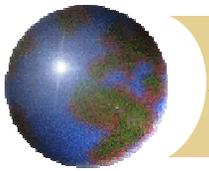
RESULTS

- THE 128-CHANNEL PROBE-1 HYPERSPECTRAL AIRBORNE SENSOR HAS THE SPECTRAL RESOLUTION REQUIRED TO SURVEY THE REGION, BUT ITS SPATIAL RESOLUTION IS PROBABLY TOO COARSE FOR MAPPING INDIVIDUAL STANDS OF SPECIES
- THE FIELD AREA IS EXTREMELY DIVERSE: THERE ARE NO 'PURE' PIXELS FOR THE SENSOR TO DETECT. IN ADDITION, BARE SOIL IS PRESENT TO SOME EXTENT IN ALL PIXELS
- OUR PROCESSING DETECTS VEGETATION VIGOR VARIATIONS THROUGHOUT THE STUDY AREA, IN BOTH NATIVE AND RECLAIMED REGIONS
- OUR PROCESSING HAS IDENTIFIED NUMEROUS (>10) DISTINCT CLASSES OF LAND COVER IN BOTH REGIONS. THESE MAY BE RELATED TO A COMBINATION OF FACTORS WHICH INCLUDE: VEGETATION SPECIES, SOIL CHEMISTRY, VEGETATION PRODUCTION, AND/OR VEGETATION COVER



RECOMMENDATIONS FOR FUTURE WORK

- THESE FINDINGS REQUIRE FURTHER FIELD VERIFICATION BY THE PRCC EXPERT BIOLOGICAL TEAM. THE TEAM SHOULD VISIT THE UNIQUE SITES IDENTIFIED IN THE IMAGERY AND ASSESS THE FACTORS PRESENT (COVER, PRODUCTIVITY, SPECIES, SOIL CHEMISTRY)
- BASED ON THE RESULTS OF THE BIOLOGICAL TEAM, WE SHOULD PLAN TO RE-SURVEY THE AREA WITH A HYPERSPECTRAL SENSOR NEXT GROWING SEASON AND MAP THE CHANGE IN VEGETATION FROM 2001 TO 2002.
- A MORE AGGRESSIVE FIELD GROUND TRUTH SPECTROMETER SURVEY SHOULD BE PLANNED FOR THE NEXT GROWING SEASON TO BETTER IMAGE THE MIXED PIXELS. THIS COULD INCLUDE A BOOM SAMPLING CONFIGURATION AND A SPECTROMETER WITH A BROADER WAVELENGTH RANGE OF MEASUREMENT



SELECTION OF AIRBORNE SENSOR

<u>Sensor</u>	<u>Spectral Resolution</u>	<u>Spatial Resolution</u>	<u>Sampling Interval</u>
Landsat-7	7 bands	30 meters	14-day revisit
Ikonos	4 bands	4 meters	60-day lead time for first image acquisition
Conventional air photo	4 bands	1 meter	3-day lead time
Hyperspectral air scan	128 bands	5 meters	3-day lead time

Relative cost of the sensors:

Landsat = \$605

Ikonos = \$6000

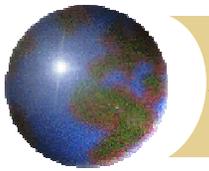
Conventional air photo = \$14,500

Hyperspectral air scan = \$18,000

THE HYPERSPECTRAL AIR SCAN SOLUTION MET OUR NEEDS FOR SPECTRAL RESOLUTION AND TIMING.

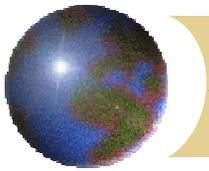
SPECTRAL SAMPLING RANGE FROM 350 NM TO 2500 NM.

BETTER SPATIAL RESOLUTION WOULD BE IDEAL.



FIELD WORK: GROUND TRUTH SPECTRAL MEASUREMENTS OF INDIVIDUAL SPECIES IN-SITU

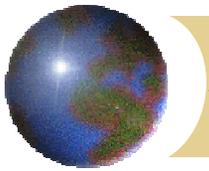
- LEASE OF ASD SPECTROMETER, CAPABLE OF MEASURING REFLECTANCE FROM 350 NM TO 1000 NM
 - SAMPLED THE CRITICAL VISIBLE AND NEAR-IR BANDS, BUT NOT THE SHORT-WAVE IR BANDS
 - COST WAS VERY REASONABLE (10% OF THE BROADER RANGE SPECTROMETER)
 - METER WAS AVAILABLE IN THE TIME-FRAME WE REQUIRED
 - MEASUREMENTS OF FLORAL SPECTRA WERE COMPLETED USING THE 2.5° SAMPLING CONE: A 'PURE' PIXEL OF THE SAMPLE WAS RECORDED AT CLOSE RANGE. LITTLE, IF ANY, CONTAMINATION FROM BARE SOIL WAS INCURRED.



GROUND TRUTH SAMPLING SITES

- ⊕ EXTREME DIVERSITY IN PLANT SPECIES
- ⊕ MIXED PRODUCTION AND COVER CONDITIONS

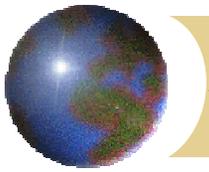




VERTICAL IMAGING OF THE STUDY AREA SHOWS SIGNIFICANT EXPOSURE OF BARE SOIL

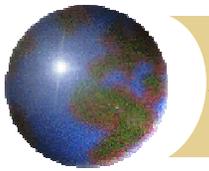
- PRESENT IN BOTH NATIVE AND RECLAIMED AREAS





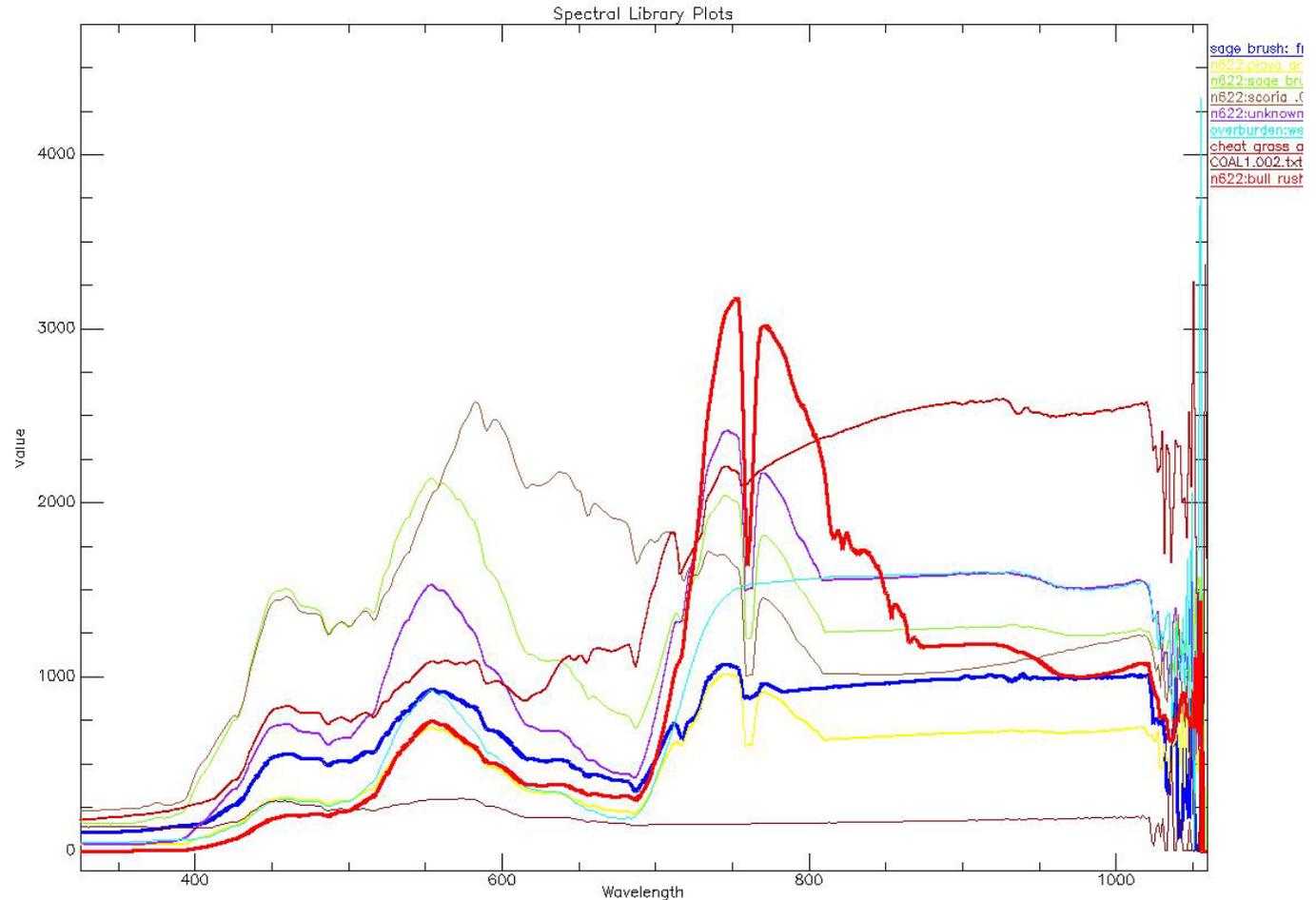
WITHIN THE RECLAIMED REGION, NEW VEGETATION IS EASILY RECOGNIZED

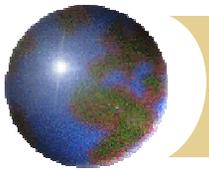




FIELD SPECTRA OF COMMON LAND COVER TYPES

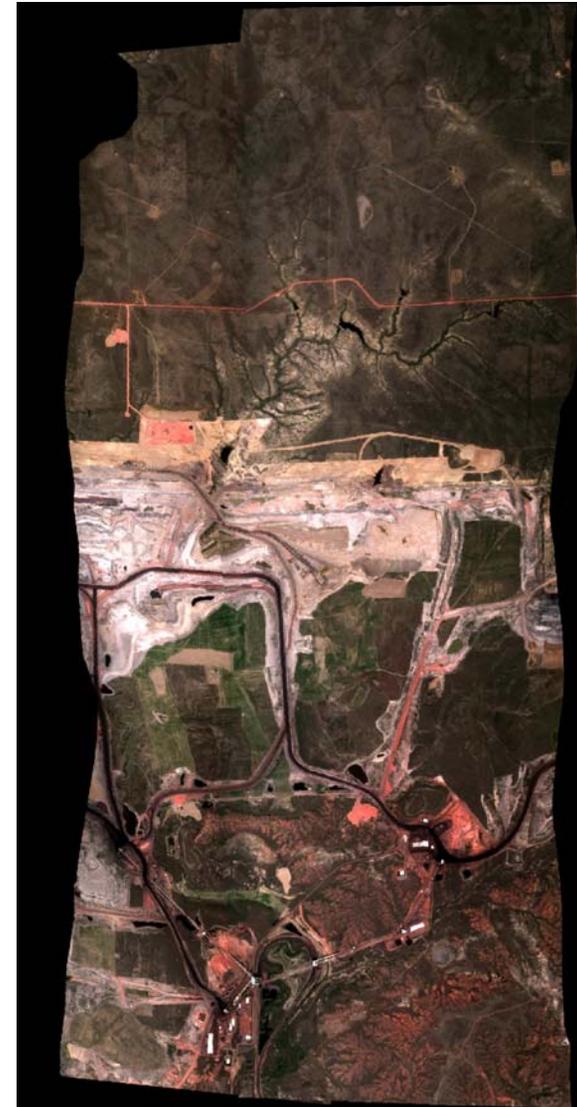
THESE ARE 'PURE'
SAMPLES,
UNCONTAMINATED
BY OTHER SPECIES
AND BARE SOIL

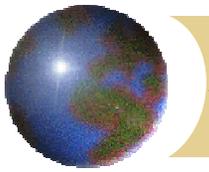




HYPERSPECTRAL IMAGERY

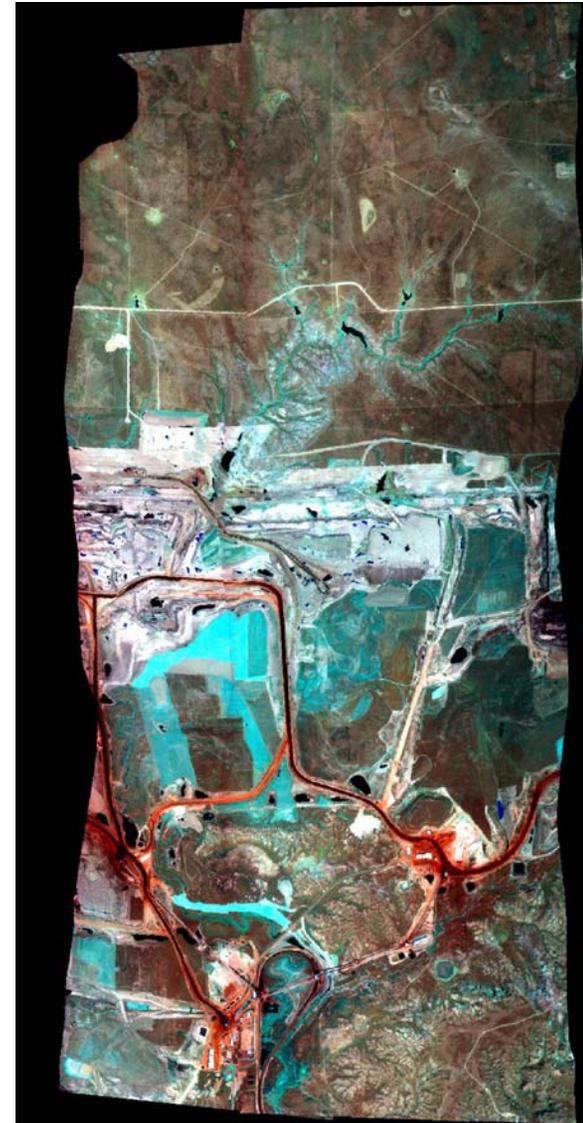
- ❖ 'TRUE COLOR' IMAGE OF THE SURVEY AREA
- ❖ TWO FLIGHT SWATHS REQUIRED TO COMPLETE THE SURVEY
- ❖ ORTHORECTIFIED TO WITHIN 50 FEET (NEEDS TO BE BETTER!); CONTRACTOR IS STILL DESIGNING THE SENSOR'S INERTIAL PARAMETERS

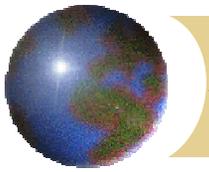




HYPERSPECTRAL IMAGERY

- ➊ 'FALSE COLOR' IMAGE OF THE SURVEY AREA
- ➋ RED = Band 108 (2198 nm – SWIR)
- ➌ GREEN = Band 39 (991 nm – mid IR)
- ➍ BLUE = Band 22 (751 nm – near IR)



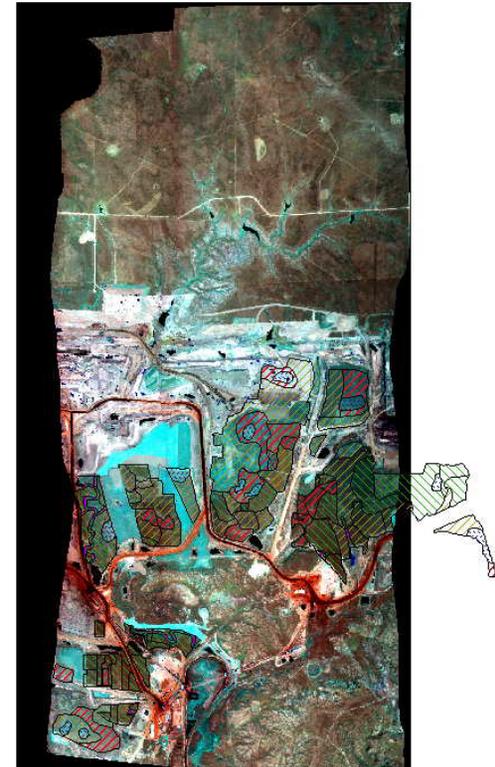


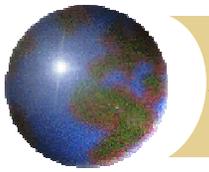
INTEGRATION OF VECTOR DATA WITH RASTER IMAGERY

WE CAN MERGE/OVERLAY ALL GIS COVERAGES ON WITH THE HYPERSPECTRAL IMAGERY

VEGETATION TYPE, SOIL TYPE, RECLAMATION SEEDING PROGRAM, ETC.

THE POTENTIAL BENEFITS FROM THIS APPROACH ARE ENORMOUS





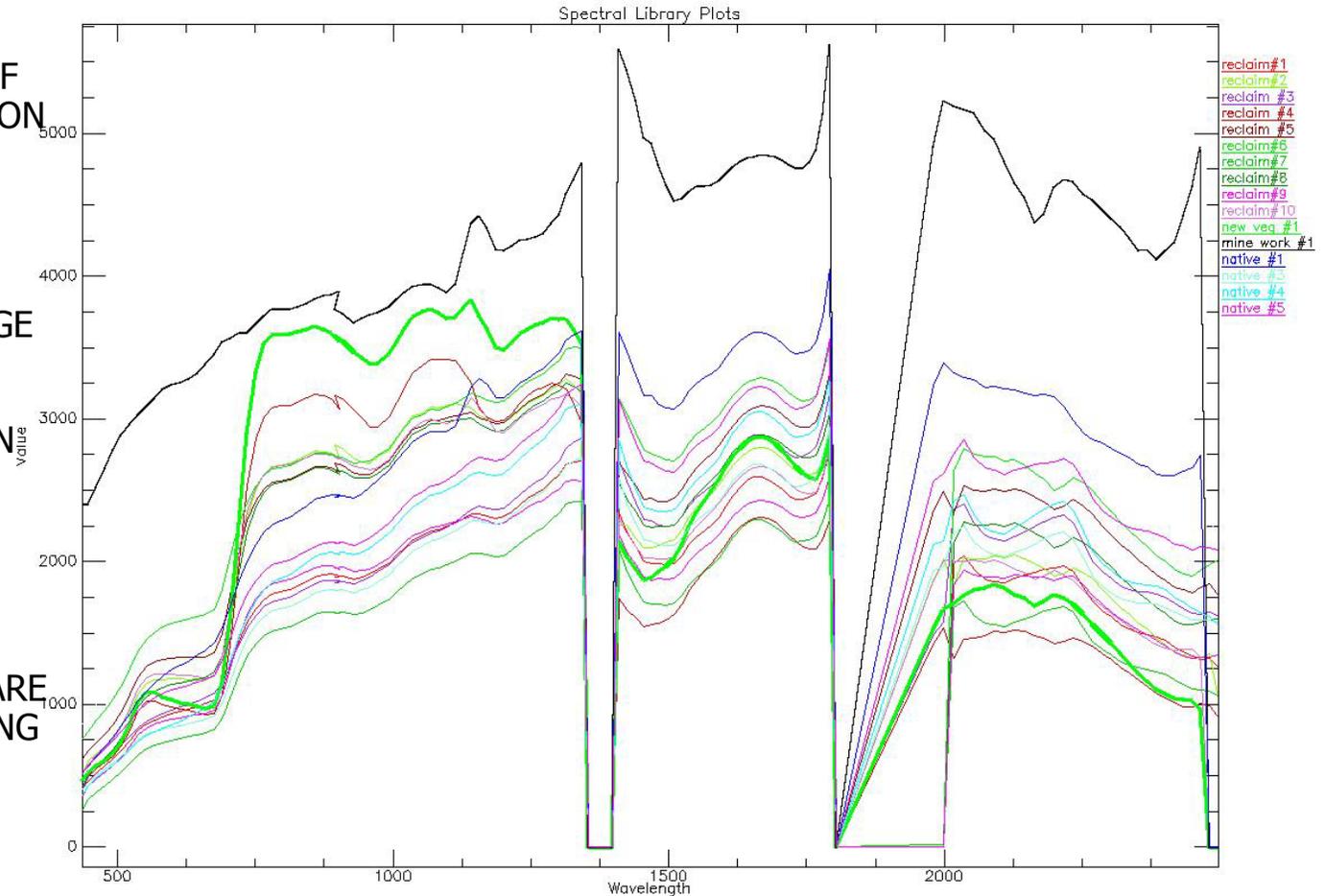
AIRBORNE SPECTRA OF COMMON LAND COVER TYPES

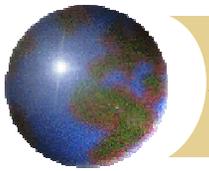
THESE ARE OUR BEST ASSESSMENT OF 'PURE' PIXELS, I.E. REGIONS OF CONSISTENT VEGETATION TYPE, COVER, AND PRODUCTIVITY.

HOWEVER, MOST PORTIONS OF THE IMAGE CONSIST OF 'MIXED' SAMPLES, WHOSE REFLECTANCE HAS BEEN AVERAGED OVER 5 x 5 METERS.

THERE MAY BE SIGNIFICANT CONTAMINATION OF BARE SOIL, AS WELL AS MIXING OF SPECIES

NOTE THE SWIR DATA PRESENT





ADVANCED IMAGE PROCESSING TECHNIQUES HAVE BEEN EMPLOYED TO MEASURE VARIATION IN VIGOR, LAND COVER

✿ NDVI: NORMALIZED VEGETATION INDEX:

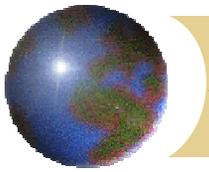
- ✚ IR REFLECTANCE/RED REFLECTANCE
- ✚ RESULTS ARE VERY PROMISING

✿ UNSUPERVISED CLASSIFICATION

- ✚ CLASSES ARE CLEARLY IDENTIFIED, BUT WHAT ARE THE FACTORS THAT DISTINGUISH THEM?

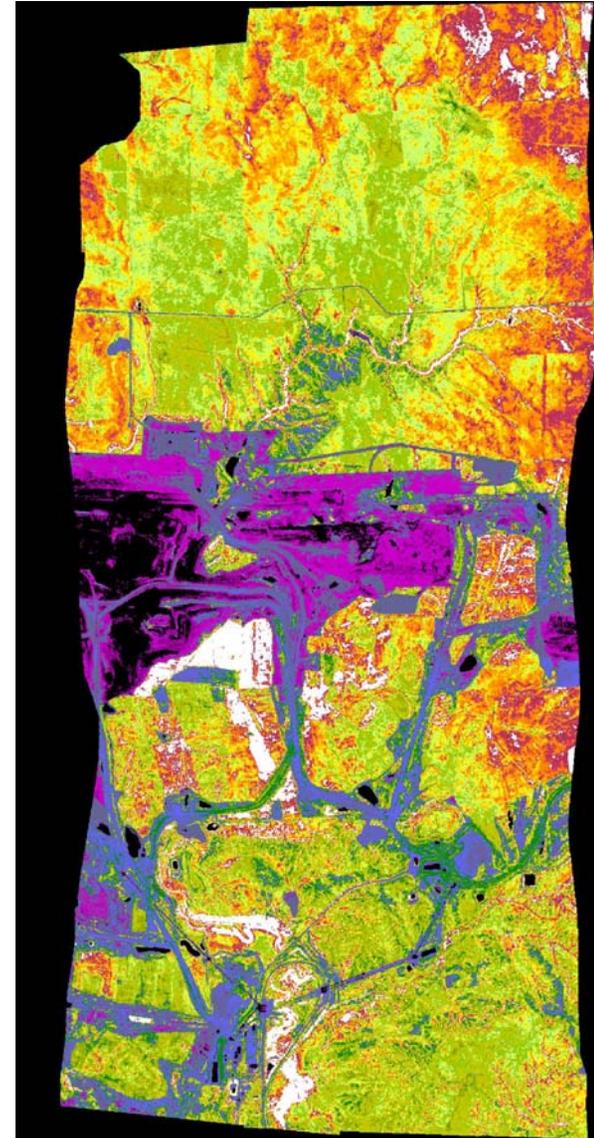
VEG TYPE, PRODUCTIVITY, COVER, SOIL CHEMISTRY, ETC.?

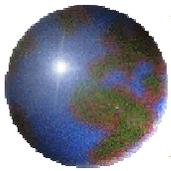
- ✚ PROBLEM: THE TWO FLIGHT SWATHS HAVE GENERATED TWO 'DIFFERENT' CLASSES WHERE THERE SHOULD ONLY BE ONE. THIS NEEDS TO BE ADDRESSED IN FUTURE SURVEYS



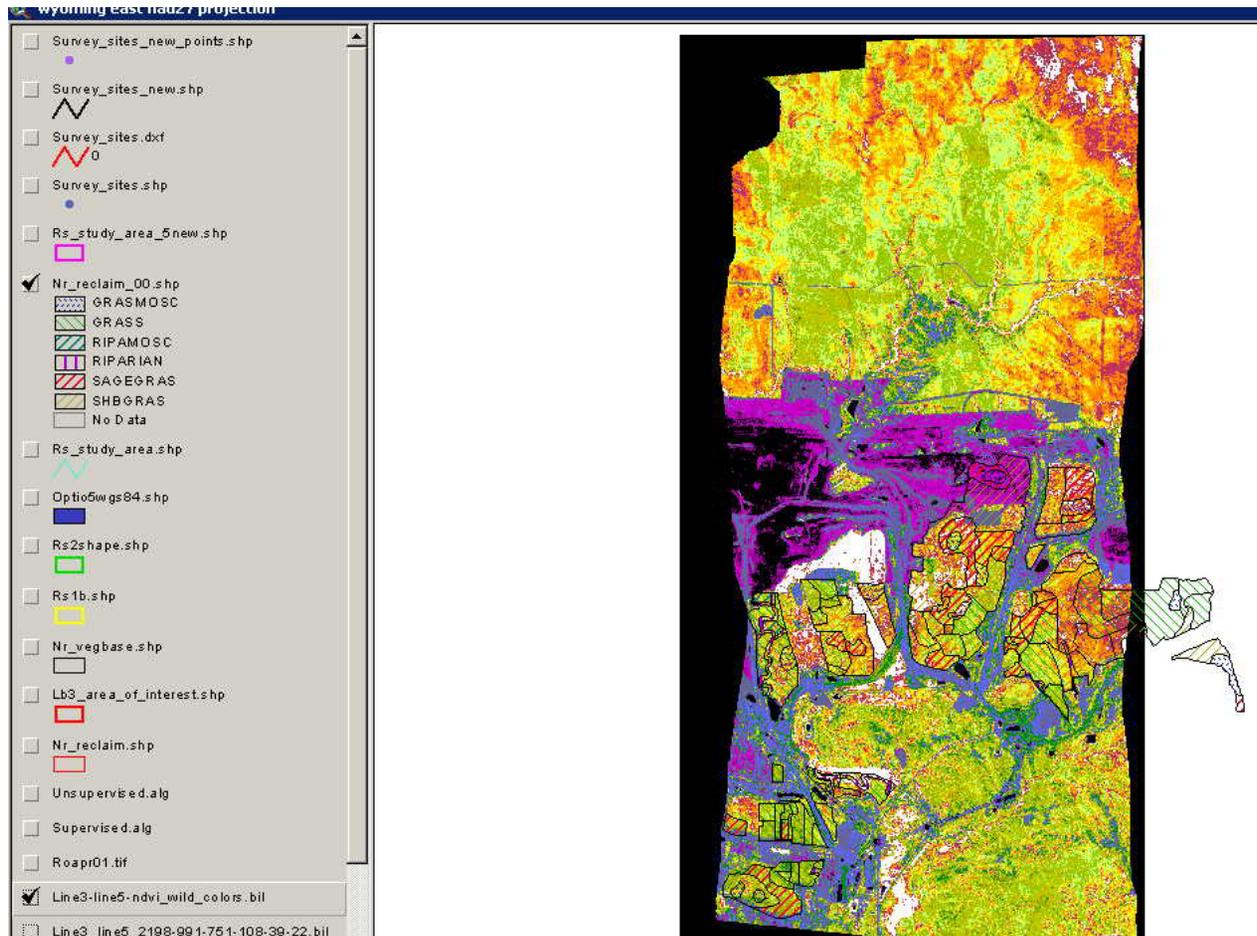
VEGETATION VIGOR: NDVI

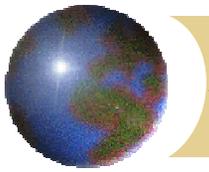
- ❊ WARM COLORS (WHITE, REDS, ORANGE, YELLOW) INDICATE STRONG VIGOR
- ❊ TEPID COLORS (YELLOWS, GREENS) INDICATE MODERATE VIGOR
- ❊ COOL COLORS (BLUES, PURPLES, BLACK) INDICATE NO VEGETATION





VEGETATION VIGOR: NDVI WITH YEAR 2001 RECLAMATION PROGRAM

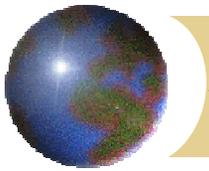




UNSUPERVISED CLASSIFICATION

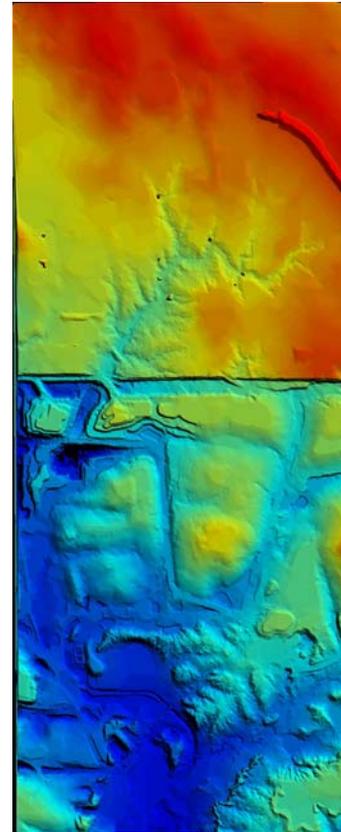
- INDIVIDUAL CLASSES ARE IDENTIFIED BY UNIQUE COLORS
 - CLASSES COMMON TO BOTH FLIGHTS APPEAR TO BE 'DIFFERENT'. THIS ISSUE MUST BE RECTIFIED IN FUTURE SURVEYS

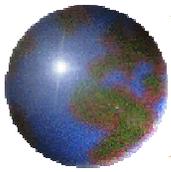




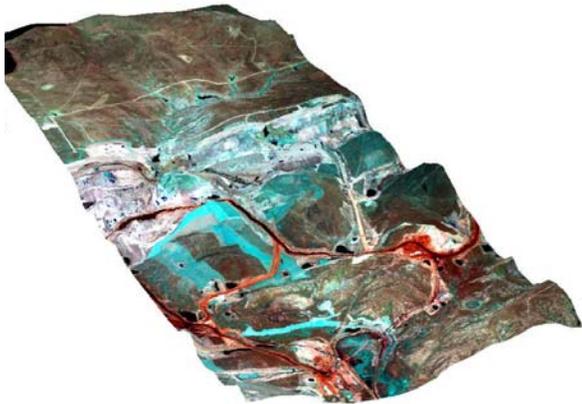
OTHER FACTORS THAT MAY IMPACT VEGETATION: EXAMPLE OF TOPOGRAPHY

- ✚ WE CONSTRUCTED A FIVE-METER RESOLUTION DIGITAL ELEVATION MODEL (DEM) OF THE LAND SURFACE
- ✚ THIS DEM CAN BE USED TO MODEL THE IMPACT OF SLOPE AND ASPECT ON VEGETATION VIGOR AND CLASS

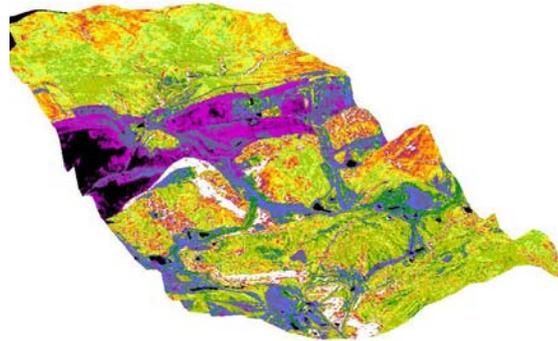




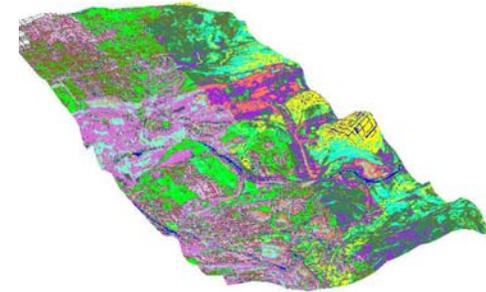
FALSE COLOR IMAGERY, VIGOR AND CLASSIFICATION, DRAPED ON TOPOGRAPHY



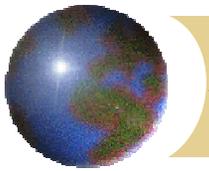
**FALSE
COLOR**



VIGOR



**UNSUPERVISED
CLASSIFICATION**



CONCLUSIONS

- WE HAVE DEMONSTRATED THAT EVEN COARSE SPATIAL RESOLUTION HYPERSPECTRAL IMAGERY CAN DISCERN AMONG DIFFERENT LAND COVERS IN THE NATIVE AND RECLAIMED AREAS
- EXPERT BIOLOGICAL GROUND TRUTH IS WARRANTED TO QUANTIFY AND VALIDATE OUR RESULTS
- THIS TECHNOLOGY BEARS GREAT PROMISE FOR COST-EFFECTIVE MONITORING OF RECLAMATION
- PRCC SHOULD ACQUIRE BASELINE HYPERSPECTRAL DATA FOR LEASE PROPERTIES PRIOR TO COMMENCEMENT OF MINING ACTIVITY
- ELROI/WINTERMOON WOULD BE HAPPY TO FACILITATE FURTHER WORK (WITH PUBLIC AND/OR PRIVATE FUNDING)