INTERPRETATION OF

HYPERSPECTRAL IMAGERY

FOR VEGETATION TYPE AND VIGOR

COMPLETED FOR:
POWDER RIVER COAL COMPANY
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ABSTRACT

Elroi Consulting, Inc., in collaboration with Wintermoon Geotechnologies, Inc., has acquired and interpreted airborne hyperspectral imagery over a portion of the native and reclaimed vegetation areas surrounding the Powder River Coal Company surface mine near Verse, Wyoming. To facilitate this, we conducted a brief field spectrometer survey of the areas to provide 'control' and ground truth during our analysis of the airborne remotely-sensed data. We processed the airborne hyperspectral reflectance values of the vegetation in both areas with identical algorithms to test our ability to identify: 1) vegetation species; and 2) vegetation vigor or health. Our results indicate that, based on spectral reflectance alone, the reclaimed vegetation species populations are very similar in composition to that of the native, undisturbed vegetation that lies due north of the active mine. Vegetation vigor within the reclaimed area appears to vary as a function of the year of seeding. The healthiest vegetation (highest ratio of near IR reflectance to red reflectance) is found in the reclaimed sites that are believed to be part of the year 2001 campaign. All of the revegetated areas that comprise the year 2000 campaign have weaker vigor than our interpreted 2001 revegetation. The 2000 campaign vegetation appears to have very similar vigor to the native area to the north of the mine. All of these results are based solely on our field measurements of reflectance and the airborne remote sensing survey. None of our findings, as yet, have been compared with the biological field work that has been conducted in the survey area.

The processing streams that were most helpful for us included: normalized vegetation index and unsupervised classification. The other technique that also showed significant results is spectral angle mapping using our input control for 'training fields'. Less useful for this project was the minimum noise fraction technique.

In order to integrate these results with the Powder River Coal Company's GIS database, we worked very hard to orthorectify the hyperspectral imagery into the Wyoming East, NAD27 state plane projection. Our efforts were fairly successful, given the current limitations in acquisition techniques, producing a two-image mosaic that has a maximum RMS spatial location error of 50 feet, and is usually within 5 feet. However, future hyperspectral surveying should include inertial models of the sensor, and this will facilitate more accurate and faster orthorectification of the hyperspectral imagery.

This field area, both the native and reclaimed regions, is quite challenging for this kind of hyperspectral vegetation analysis. The arid conditions and the nature of the vegetation cover provide sparse and highly diverse foliage density: grasses and sages mix together plant-by-plant in many areas. In addition, the bare soil is exposed in most of the region as well, since many of the native species do not have broad, thick crowns associated with their mature growth. The airborne sensor used in this study, the Probe I, has a spatial pixel resolution of 5 meters, and a spectral resolution of 128 channels varying in wavelength from 435 to 2500 nm, with a typical bandwidth of 12 to 15 nm. Spectrally, the sensor has excellent resolution for this analysis. Spatially, however, the 5 meter pixel resolution ensures that nearly all of our pixels will be mixed (i.e. more than one species present within the sampling area). This is sub-optimal. Future remote sensing surveys of

the area should strive to attain the same spectral quality with improved (smaller pixel size, say 1 to 2 meters) spatial resolution in order to better map species populations.

Future spectral programs should include the use of a field spectrometer with a broader sampling range. We used the base model, with a range of 350 to 1050 nm. This provided excellent results for the visible and near IR portions of the spectrum. However, the subtle signature differences between grasses and sages in the short-wave infrared (SWIR) were not imaged by this sensor. Any additional field work using spectrometers should employ the reflectance model that samples from 350 nm to 2500 nm, the same range as the Probe I. Future sampling may be conducted not only at ground level, but also from a boom structure located above the field target. Such a 'birds-eye' sampling will more accurately measure the reflectance of a typical 'mixed pixel' that is found within the survey area.

Our conclusions indicate that hyperspectral remote sensing holds promise as a relatively inexpensive technology for monitoring the annual changes in acreage of reclaimed land within a surface mining environment, demonstrating that reclaimed species are approximating the pre-existing natural floral mix in the undisturbed native areas, and quantifying the surface area of 'healthy' native and reclaimed vegetation in and near mined regions. Vegetation vigor parameters that appear to be most influential include: year of seeding and proximity to natural drainage.

Recommendations for modifications in future studies of this type include:

1) Leasing of a field spectrometer with a broader wavelength range;
2) Hiring a field spectrometry acquisition expert to work on-site and lead/oversee the field spectra acquisition;
3) Flying an airborne hyperspectral sensor with finer spatial resolution (1 meter would be ideal);
4) Using a hyperspectral sensor that has well-understood inertial parameters from which an accurate orthorectified image (2 meter RMS error) can be constructed;
5) Designing an overall radiance-to-reflectance model that will have consistent reflectance values among all flight lines (to alleviate any classification 'seams' in the analysis);
6) Close communication with biological team to employ their results as control for our processing, when appropriate.

METHODOLOGY

The primary goal of the study is to assess various remote sensing techniques for their utility in mapping vegetation species (differentiation between grass and sage families) and vegetation vigor in both native, undisturbed regions and reclaimed areas near the Powder River Coal Company surface mine. Our analysis included several phases:

1) Compare available sensors and their utility (use spatial and spectral resolution, as well as cost and timing, as parameters), and arrange and manage the acquisition of the desired imagery;
2) Conduct ground truth and measure plant reflectance in-situ;
3) Orthorectify remote sensing imagery to Wyoming East, NAD27 state plane projection;
4) Perform advanced image processing techniques to extract vegetation classes and vegetation vigor maps from imagery;
5) Make recommendations for a five-year plan;
6) Transfer software and data to Powder River Coal Company office in Gillette, Wyoming.

1) Sensor Selection

We began our analysis by comparing the spatial, spectral, and cost parameters of different sensors available on airborne and satellite platforms. The platforms considered include:

Sensor	Spectral Resolution	Spatial Resolution	Sampling Interval
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

Clearly, there is a trade-off between cost and spectral/spatial resolution. In order to best distinguish among the species in the study area, we decided to focus our effort on the best spectral resolution: the hyperspectral air scan product. In retrospect, we were correct in selecting the sensor with the best spectral detail. However, our results will show that the 5-meter spatial resolution compromised our ability to map individual plant crowns. This may have introduced noise into our effort, as the field area's general vegetation pattern is very patchy, even on a meter-by-meter basis. The hyperspectral acquisition contract was awarded to ESSI of Kalispell, Montana. They flew their survey in two north-south swaths on 22 June 2001 with the Probe I sensor.

The conventional air photo approach would have provided sufficient spatial resolution, but the limitation of only four spectral bands would have made delineation between grass and sage impossible.

2) Ground Truth

In planning the study, we wanted to obtain in-situ reflectance spectra of individual plant species during the time frame of the remote sensing acquisition. We contracted with Analytical Spectral Devices, Inc. in Boulder, CO., to lease their 350nm to 1050 nm field spectrometer for one week. This unit was chosen for several reasons: cost ($1225/week), ease of use, and availability. The alternate unit had a much broader spectral range, from 350 nm to 2500 nm (comparable to that of the hyperspectral sensor we selected), but rents for $10,250 per month and requires more expertise to operate. A third option was to hire an ASD field surveyor ($1000/day) to do the field sampling for us with the 350 nm to 2500 nm unit.

Our field program originally planned to visit pre-selected sites in the native and reclaimed areas. Equipped with GPS, digital camera, and field spectrometer, we were to survey and photograph every site. Greg Jones of Peabody Energy volunteered to spearhead the field work. Michal Ruder, of Wintermoon Geotechnologies, participated in Greg's training with the field spectrometer and joined Greg for one day of field acquisition. In addition, a student assistant provided help for a second day of sampling.

The field campaign diverged from our project plan in several respects. The original plan included sampling at 28 sites, identified in advance from a vintage Landsat-7 image. In actuality, the field conditions were quite different from what we anticipated. There was so much plant mixing and bare soil everywhere that the original 28 sites were non-unique. When we arrived at a scheduled sampling site, we encountered at least four species, plus bare soil, in abundance. As a result, we scrapped our plan and instead acquired as many reflectance spectra from as many different target species and other features that we could obtain. The primary challenges to field acquisition that we had not foreseen were: 1) the paucity of vegetation cover in both the native and 'mature' (greater than one year old) reclaimed areas. Nearly everywhere in the survey area, dirt and bare soil are exposed for 10% to 50% (or even greater) of any area of 5 meters by 5 meters (25 square meters, the spatial resolution or pixel area of the hyperspectral air scan instrument); and 2) the extensive mixing of vegetation types within a typical hyperspectral pixel, with both bull rush grass, cheat grass, and sage present often side-by-side, along with exposed bare soil.

Figures 1 and 2 shows a landscape photograph of a typical native area. Looking at the horizon, the vegetation appears quite lush. Note the great diversity of vegetation, however, including different kinds of grasses and sage.

Figure 1: Landscape photograph of native vegetation. Mixing of different kinds of grass in foreground is evident. Sage bushes of light density are present in the distance.

Figure 2: Landscape photograph of native vegetation. Note dense sage coverage in the distance. The foreground shows strong mixing of red tinted cheat grass with green grass or wheat.

Figures 3 and 4, however, show that a vertical view of the field area reveals large areas of dirt and organic material are exposed within the vegetation cover.

Figure 3: Reclaimed vegetation: grass, dirt, sage. This photograph is near vertical and shows that even in 'densely' vegetated regions of the field area, we have significant bare soil exposure.

Figure 4: Healthy grass still has exposed dirt and organic material easily visible at vertical or near-vertical viewing angle.

Figure 5: Grass and cactus in a native area: note the extensive presence of bare soil when viewed at a near-vertical angle. The shadow of the photographer is the bottom left portion of the photograph. Note the similarity of land cover and condition between Figures 3 and 5, reclaimed vs. native.

The field spectra that we obtained are able to distinguish among many of the plant species present. We show the spectra of several different sages in Figure 6.

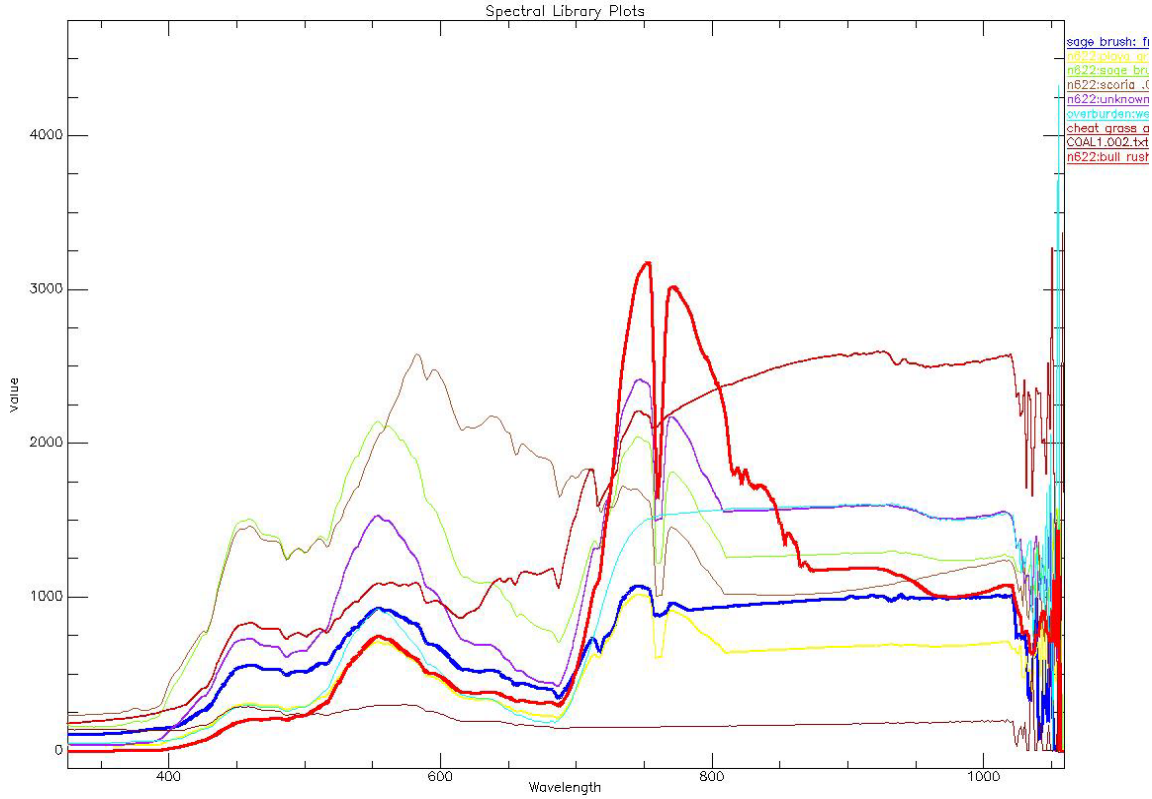


Figure 6: Field spectra of common vegetation in both native and reclaimed areas. Note that beyond 1050 nm, reflectance values are invalid.

The spectra shown in Figure 6 are color-coded by sample:
thick red line = bull rush
thick blue line = fringed sage brush
light green = sage brush
yellow = playa grass
light brown = scoria rocks
purple = unknown vetch
dark brown = coal
thin red = cheat grass

The spectral reflectance curves of the individual field samples show characteristic behaviors. The deep absorption feature at 762 nm is associated with atmospheric water, and is present in all spectra. This is the only feature common to all land cover classes (except coal). The coal signature (dark brown curve) shown very low reflectance at all wavelengths, from the visible (400-700) to the near IR (>700). Scoria (light brown curve) shows high reflectance in the visible range, and decreasing reflectance in the near IR. Since scoria is an earth material devoid of chlorophyll, this signature is consistent

with its composition. Note that the presence of chlorophyll creates a strong positive reflectance in the near IR, and this is the basis for much of our vegetation vigor analysis in the next phase of analysis.

Examination of the various plants show positive reflectance features in visible green (500-600 nm) and near IR (700-800 nm). Significantly, we can distinguish between grass and sage by studying the relative reflectance signatures of the green vs. near IR. In all cases (except for playa grass, where there may be contamination from too much bare soil), grasses have a much stronger signal in the near IR than in the visible green. Sages, however, are nearly equal in green and near IR. This observation holds true not only in this study area, but also in published spectral libraries acquired over sites in other parts of the United States (see the USGS spectral library, for example). Both sages and grasses have an absorption feature in visible red (600-700 nm), with the exception of cheat grass (thin red curve). The red character of cheat, shown in Figures 1 and 2, naturally has an associated positive reflectance anomaly in visible red. Cheat grass is readily distinguished from all other vegetation based on this spectral signature.

Note that when we sampled spectral reflectance for a target, we endeavored to obtain a 'pure' spectrum, i.e. we tried to eliminate any contamination of the spectrum by bare soil, rocks, or other types of plants. We placed the sensor in a field that was completely filled by the target. As a result, our field spectra should be more 'pure' than the spectra acquired by the airborne Probe I, which sampled in 5 meter pixels that contained much more heterogeneity.

As noted earlier, we chose the 350-1050 nm spectrometer because of cost, availability, and ease of use. In retrospect, we would have benefited from sampling the spectral reflectance at wavelengths greater than 1050 nm. There are characteristic positives and negatives in grasses and sage in the short-wave infrared (SWIR) region as well (2200-2500 nm), and these would be important for us to document in-situ. If another acquisition of field spectra is attempted, we strongly urge the use of the spectrometer with the broader range.

Another consideration that may be important is designing a field acquisition program that samples not only the flora leaf reflectance up close, but also a more 'average' reflectance over a typical pixel size. This type of sampling would be more comparable to the airborne sensor, as it samples the true 'mixed pixel' character of the field area. In order to accomplish this, we would require an additional field structure: a boom configuration that would reach out over the 'pixel' and sample the average reflectance of the mixed pixel. The boom's design would have to reach far enough away from the operator to not sample the acquisition staff. These booms are available, but they would add cost and considerable logistical challenges.

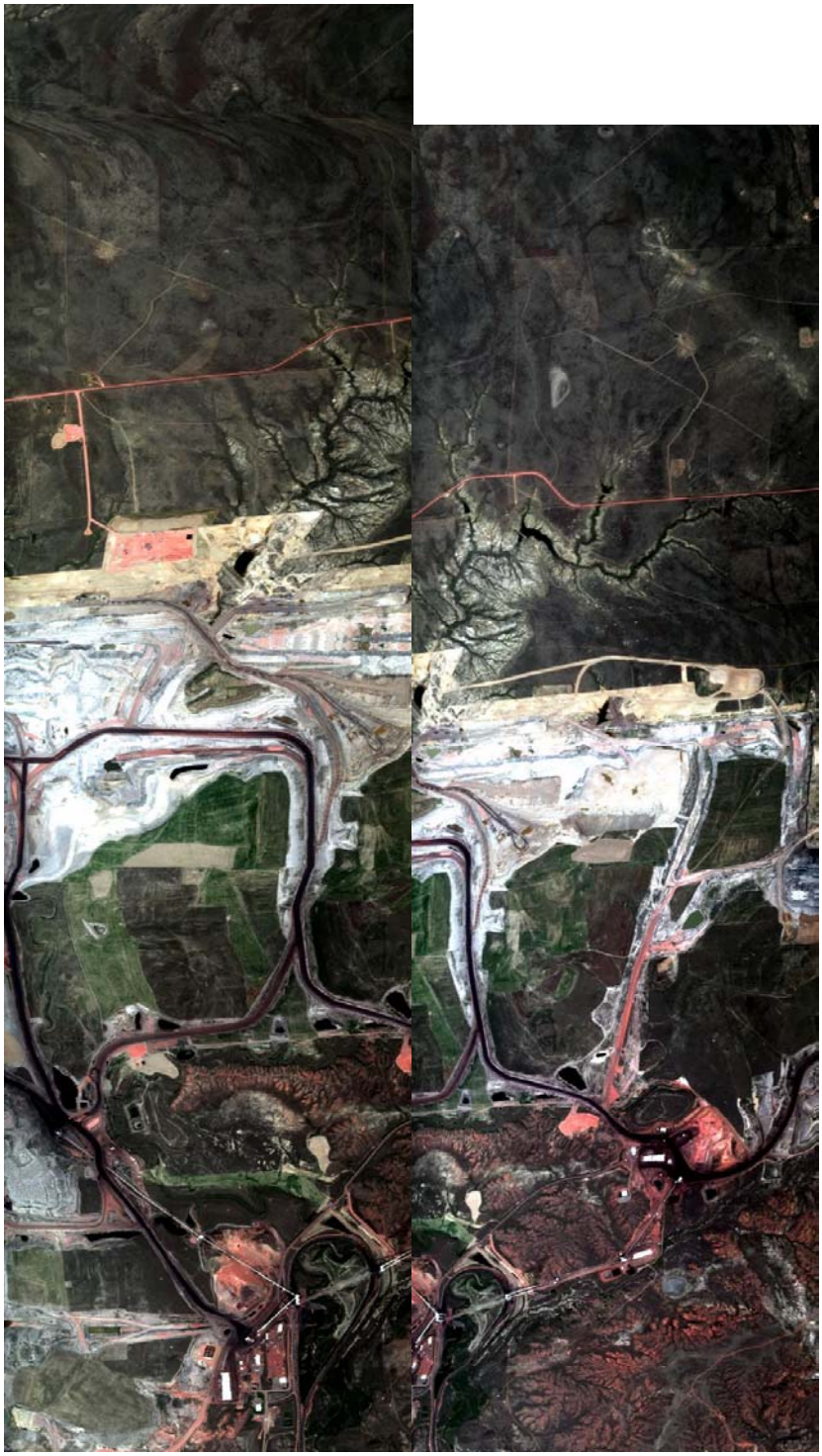
3) Orthorectification of the Airborne Hyperspectral Imagery

The ESSI reflectance scans were delivered to Elroi Consulting in August 2001. At that time, we embarked on our efforts to orthorectify the imagery. The purpose of this step of the analysis is to properly orient the imagery in real-world coordinates. This enables us

to integrate the data into our GIS database and perform constrained analysis and interpretation of the imagery together with our extensive vector GIS database.

The Probe I sensor's reflectance parameters are well-understood. Its geometric features, however, are still under investigation. Apparently, many users of hyperspectral data do not emphasize a tight integration of the raster imagery with vector-based GIS. Our request to ESSI for information on the inertial properties of the sensor required four months to fulfill. This inertial model is required in order to account for the motion and orientation of the sensor as it flies over the topographic surface of the field area. The untimely delay in our receipt of the inertial motion file deleteriously impacted our interpretation effort, as we were keen to complete our analysis on the orthorectified imagery. The inertial model, when finally provided to us, was reasonably good. We were able to orthorectify the western half of each swath very accurately (within 5 feet). The eastern half of each swath, however, was off by up to 50 feet. Clearly, ESSI will continue to refine the sensor's inertial model. In the meantime, however, if further flights are contracted, we must see an example of an organization's correctly orthorecified imagery prior to hiring any hyperspectral imaging firm to fly our survey area again.

The hyperspectral imagery in raw format (not referenced to real-world coordinates) are shown in Figures 7 and 8. Line 5 is the western swath, Figure 7, and Line 3, Figure 8, is the eastern swath. We are displaying a red-green-blue view of both swaths, with channel 15 colored red, channel 8 colored green, and channel 4 colored blue. This is a 'true color' image, much like what our eyes would see from the airplane.



Figures 7 and 8: Probe I image of the eastern and western swaths of the study area. True color image with linear enhancement applied

Both Figures 7 and 8 show significant spatial distortion of readily identifiable features. Note how the northern roads are not oriented east-west: this is due to the effects of the roll, pitch, and yaw of the plane, the rotation of the Probe I scanner as it sweeps through

the acquisition process, and the topographic relief of the study area. In order to render these images useful within a GIS analysis, these artifacts must be removed and the imagery correctly oriented in space.

When attempting the orthorectification in ERMapper and Orthomap, we were unsuccessful. The primary problem was the unknown camera (or scanner) calibration parameter model. Without this model of the scanner's instantaneous motion, the imagery could not be corrected properly by these software packages.

Upon receipt of ESSI's inertial model of the scan line, we were able to employ the IGM georectification routine with ENVI to generate orthorectified imagery. We then produced a composite mosaic of the complete coverage, shown in Figure 9. Note that we honored the swath with best geographic accuracy when constructing the mosaic in order to minimize the distortion of the final mosaic.

Figure 9: Orthorectified mosaic of lines 3 and 5 that cover the study area. Like Figures 7 and 8, this is an enhanced 'true color' image.

4) Image Processing Techniques to Extract Information from the Hyperspectral Imagery

All of our imagery analysis was performed using the ENVI image processing software package. This program was licensed by Peabody Energy specifically for remote sensing interpretation. The license was initially installed at Wintermoon Geotechnologies for the course of this study, and the software will be transferred to its permanent host at the Powder River Coal Company office in Gillette, Wyoming, in December, 2001.

Section 4a: Mean Reflectance Spectra

Our first effort to study the spectral content of hyperspectral mosaic is an analysis of mean reflectance spectra for specific 'training fields' within the survey. To accomplish this, we identified groups of pixels that contain common reflectance profiles, from 400 to 2500 nm. We isolated these training groups and computed an average reflectance spectrum for the entire set of pixels. We identified training fields within the mine works, new vegetation that is part of the reclaimed region, other reclaimed vegetation areas, and native vegetation areas. The spectra of these training fields are shown in Figure 10.

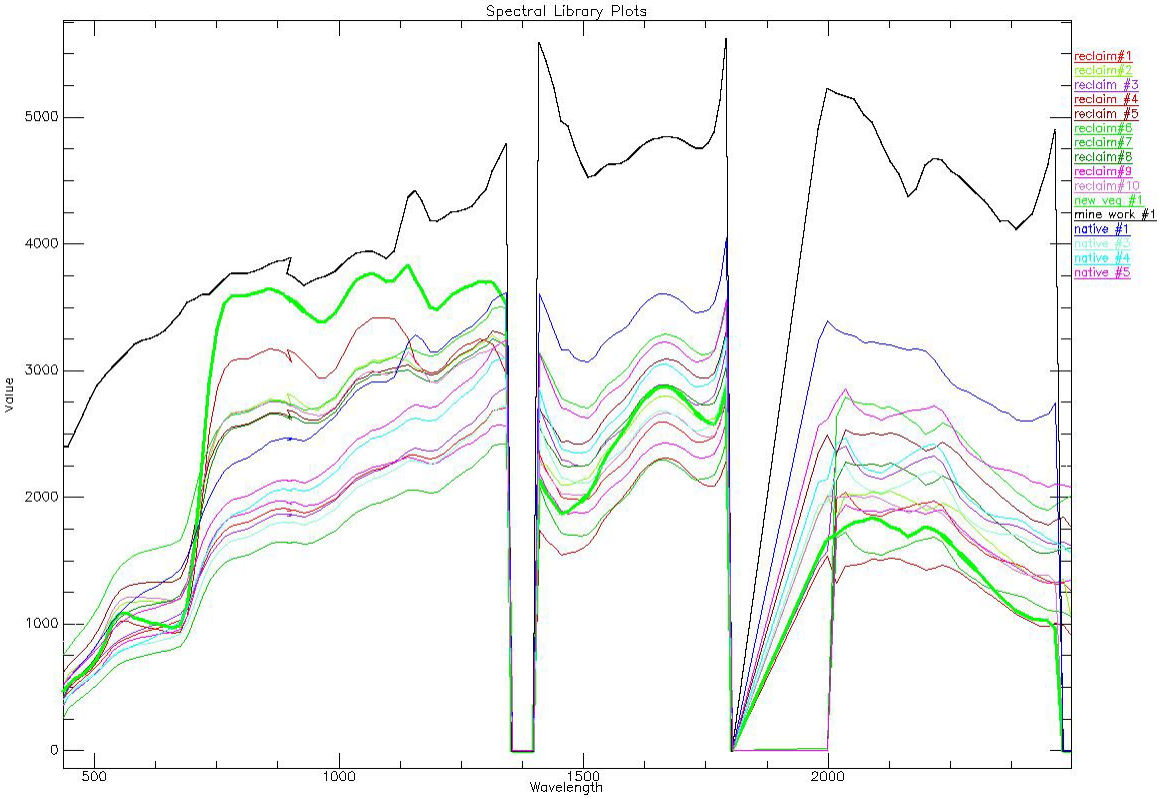


Figure 10: Mean reflectance spectra for training fields in the hyperspectral imagery mosaic.

Most of the curves shown in Figure 10 are for vegetation. This is immediately evident from the dramatic rise in the near IR reflectance (near 750 nm) in the curves. The notable anomaly is the spectral for mine works (thick black) which is quite high in all wavelengths. Another prominent curve is that of new vegetation, the thick green curve.

It has the most dramatic increase in the near IR reflectance, as well as another characteristic peak at 1050 to 1220 nm. Additionally, in the SWIR, this curve peaks again in the 2150 to 2250 range. Note that our field spectrometer did not sample the 1050 and 2150 nm anomalies as they were out of range of the instrument. Comparison of the rate of change of the curve from visible red to near IR with that of our field spectra suggests that the 'new vegetation' training field in the imagery may be something like bull rush grass: relative high reflectance in visible green, low reflectance in red (unlike cheat grass), and very high reflectance in near IR.

The other curves in the reclaimed region (mostly red hues) show less strong positive anomalies in the near IR and the same SWIR positive as the bull rush. These curves may represent species similar to the new vegetation seeding, but there may be more bare soil present, or the blades of grass may be narrower.

Significantly, most of the native areas (bluish hues) have a similar visible and near IR reflectance signature, but the SWIR curve has the opposite sense of relief compared to the new vegetation curve. We believe that this portion of the spectrum is related to the presence of lignum, and this earth material has big impact on the leaf structure of the plant. Quite possibly, a mature sage plant has higher lignum content and will have a lower reflectance in the SWIR. We would like to confirm this finding with the biological team that has been studying the area.

Section 4b: False Color Enhancement of Hyperspectral Data

After reviewing the results of the spectral analysis, we selected a different enhancement for the area: a false-color composite that includes band 108 (2198 nm - SWIR) imaged in red, band 39 (991 nm – near IR) imaged in green, and band 22 (751 nm – visible red) imaged in blue, shown in Figure 11.

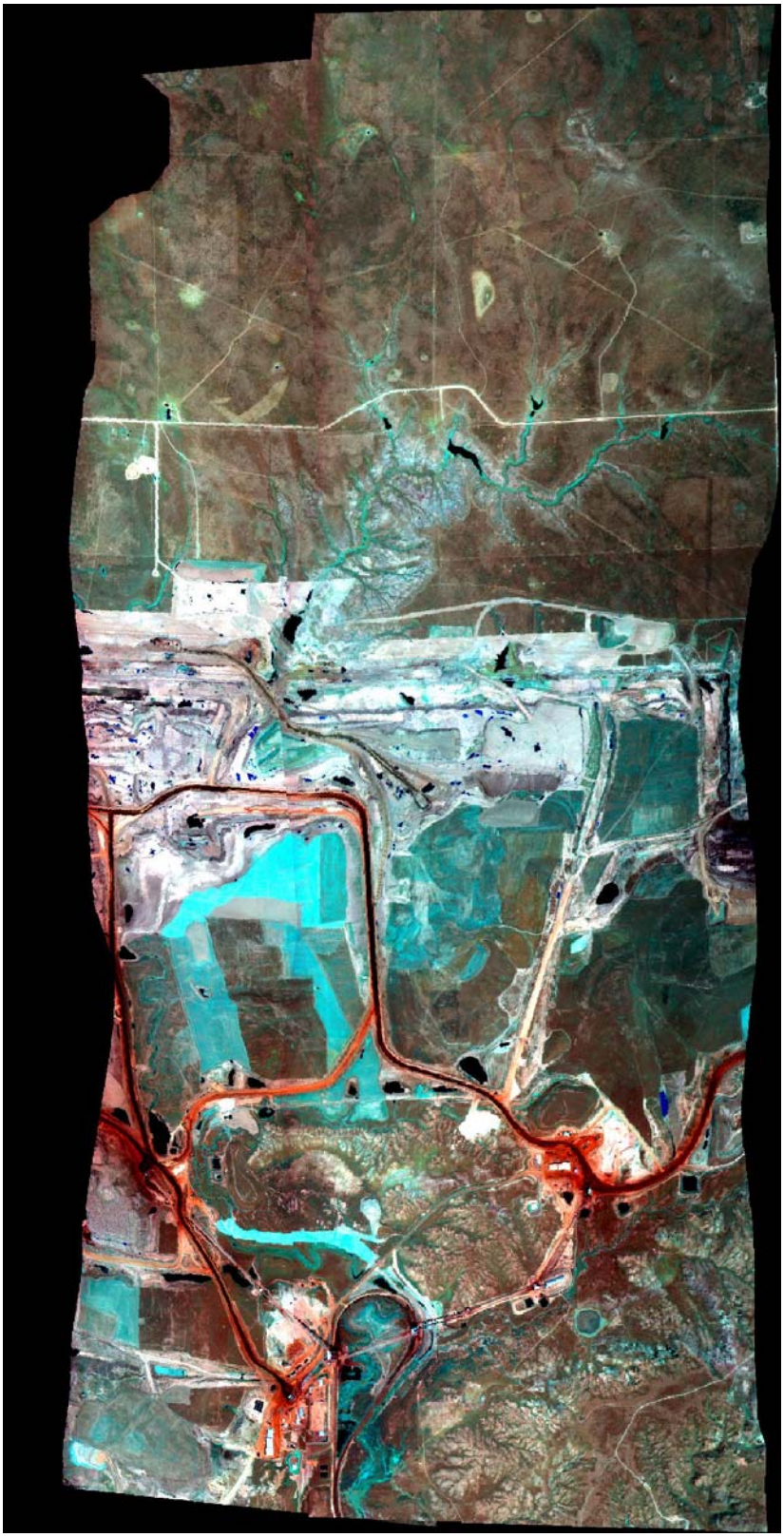


Figure 11: False color mosaic for the study area. Vegetation response is strongest in the cyan hue. Reddish to brownish is believed to correspond to mature sage and/or clay-rich soil.

Section 4c: False Color Enhancement Draped over DEM and Correlation with Year 2000 Reclamation

In order to examine the correlation of vegetation to topography, we draped the hyperspectral mosaic over the digital elevation model (DEM) of the field area. The DEM is shown in Figure 12.

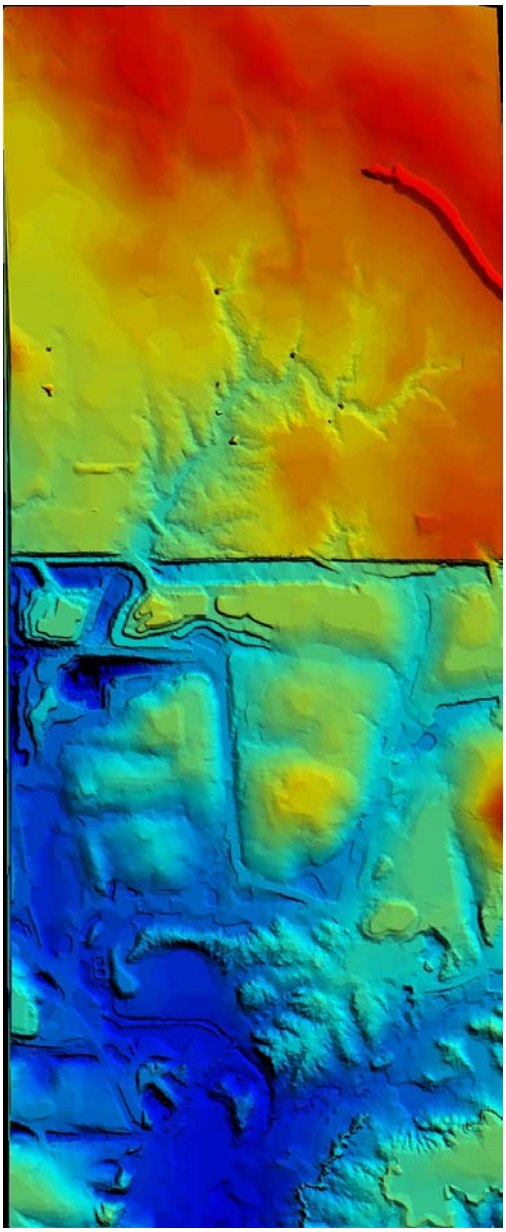


Figure 12: DEM of the field area. The active mine works are clearly visible from the linear contours present in the image. The reclaimed region shows gentle relief, much like that in the native, undisturbed regions. Total relief is 4480 feet above sea level (blue) to 5020 feet above sea level (red).

The drape image in Figure 13 shows reasonably good accuracy of the orthorectified hyperspectral image with topographic relief.

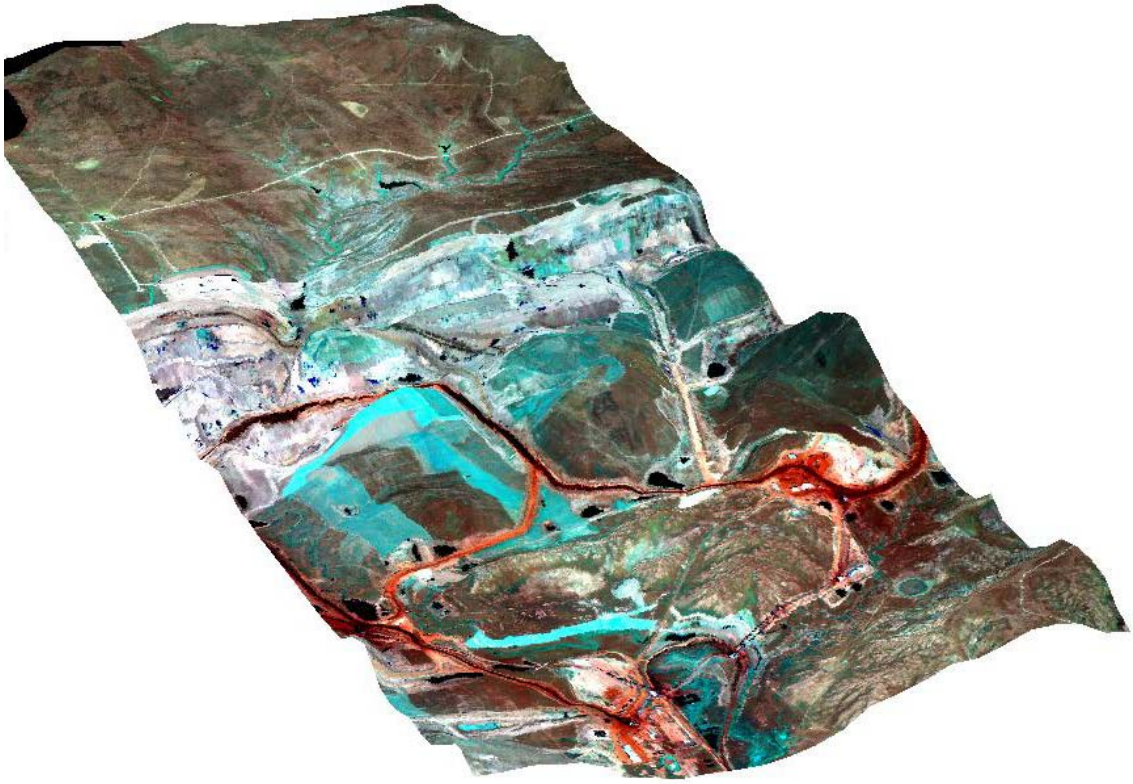


Figure 13: Drape of false-color hyperspectral image over topography. With the exception of (the absence of) drainage, the reconstructed reclaimed regions look very similar to the undisturbed topography.

We were provided with a map of the year 2000 reclamation seeding activity. We overlaid these vectors on the hyperspectral mosaic to identify any direct correlations. The mosaic with the vector overlay is shown in Figure 14.

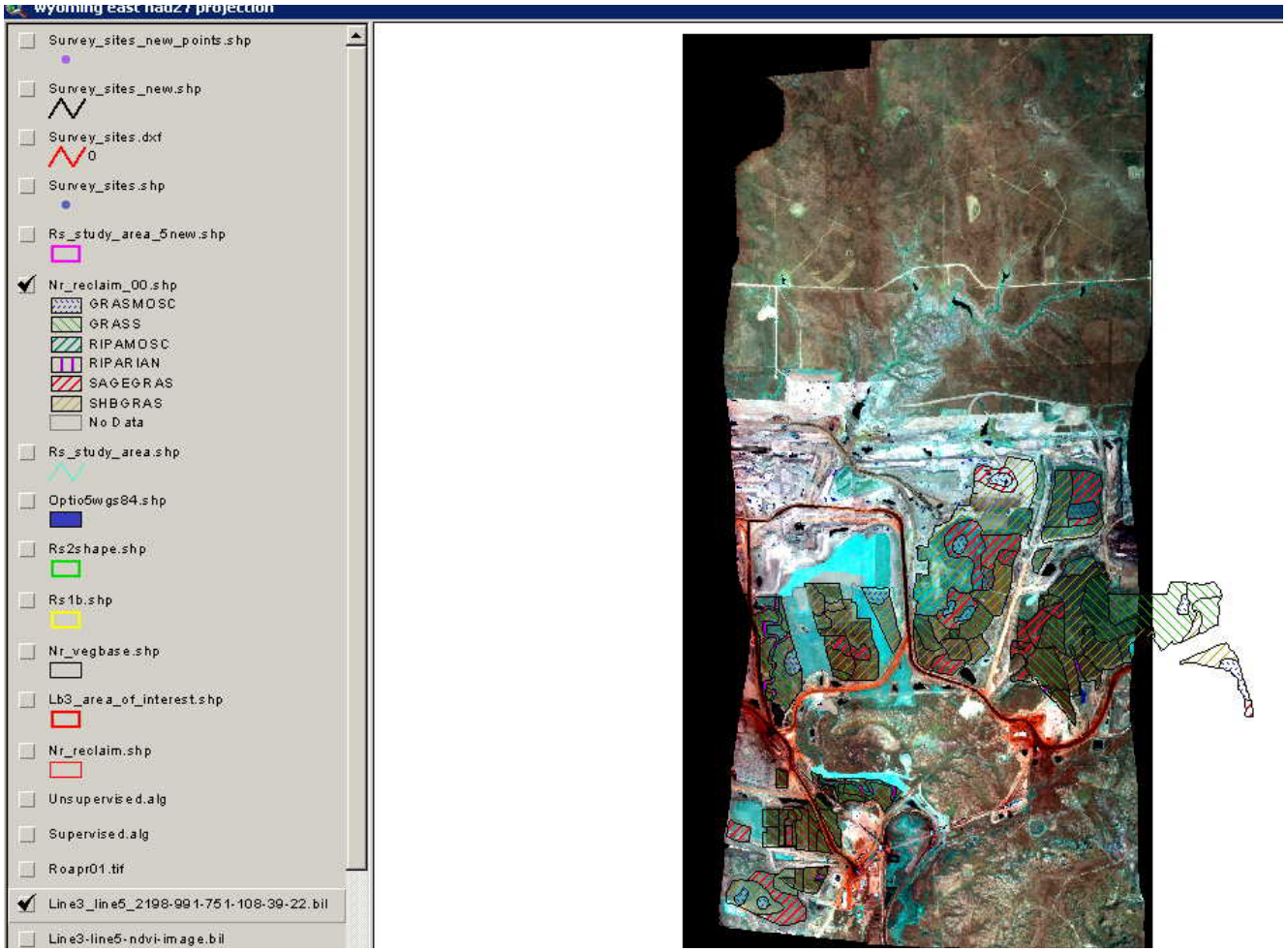


Figure 14: False-color hyperspectral mosaic with year 2000 reclamation seeding regions. Note that there is no clear and consistent correlation between year 2000 planted species and hyperspectral reflectance signatures. In fact, the cyan regions (most ubiquitous vegetation) appear to be part of the year 2001 seeding campaign. There are clear indications of differences in the 2001 regions; we do not know if these are associated with different seed mixes, fertilizers, watering patterns, and/or soils.

Section 4d: Normalized Vegetation Index Analysis

More sophisticated image processing was employed to empirically map vegetation vigor. This computation, the normalized vegetation index, is the ratio of the near IR with the visible red. Regions of extremely healthy, leafy vegetation will have strong positive response. Regions of high visible red reflectance and low chlorophyll content will have a strong negative response. The vegetation index image is shown in Figure 15. We used band 24 (near IR) and band 15 (visible red) to generate this image.

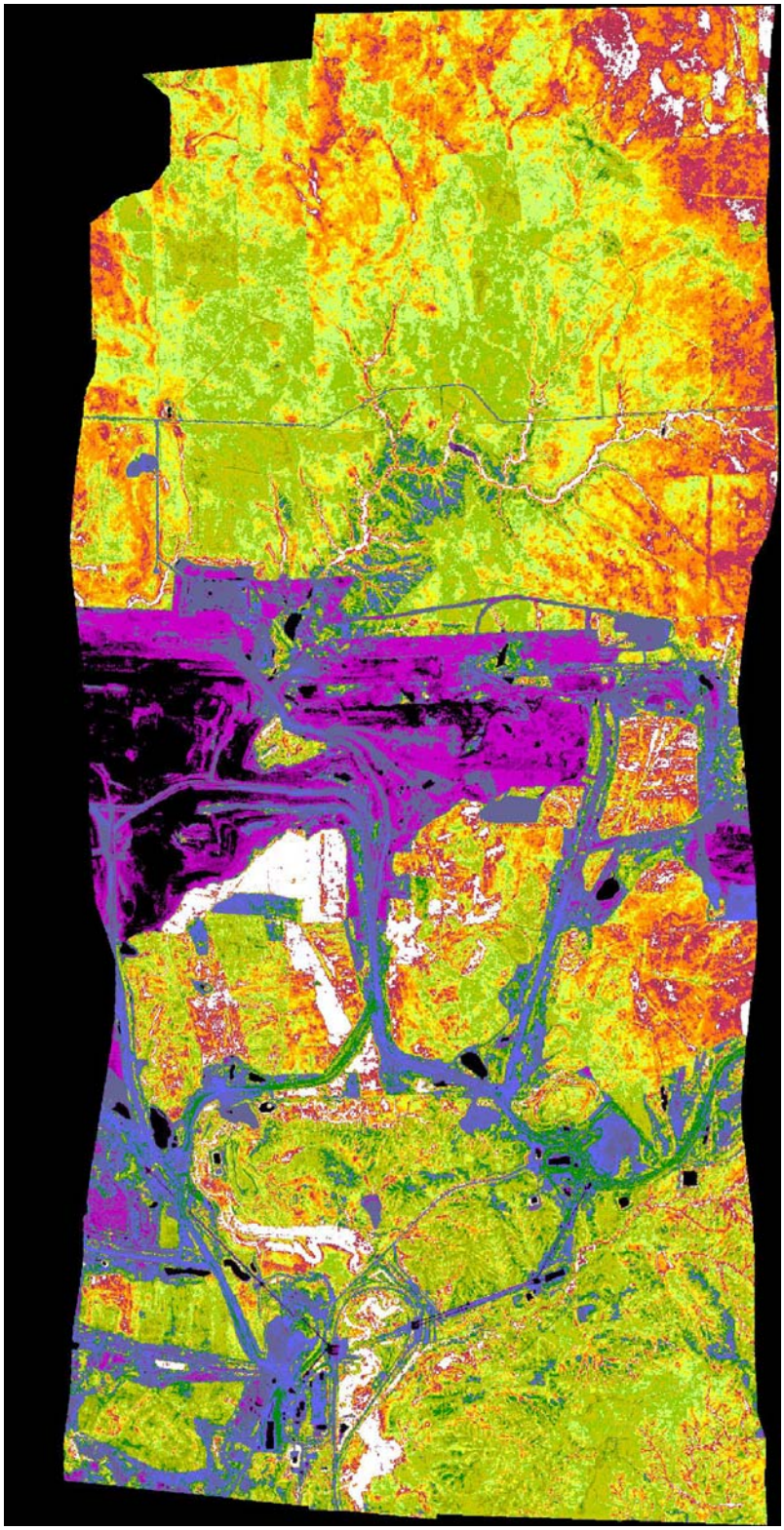


Figure 15: Normalized vegetation index for the hyperspectral mosaic. White and red values have the highest index (healthiest vegetation) . Black, purple, and blue values are devoid of vegetation.

The white pixels in this image are areas of most vigorous vegetation. The white region just south of the primary mine works should correspond to some of the newest seeding in the reclamation area. Other red, green, and yellow regions in Figure 15 show acreage in various degrees of vegetation health and vigor.

An example of the most vigorous vegetation land cover is shown in Figure 16, a field photograph that shows the new vegetation in the foreground on the left, and older reclaimed vegetation in the background on the right.

Figure 16: Reclaimed vegetation of different planting years: new vegetation (left, foreground) and older vegetation (background, right)

We wanted to study the relationship of topography to vegetation vigor, so we draped the vegetation index over the DEM. The result is shown in Figure 17.

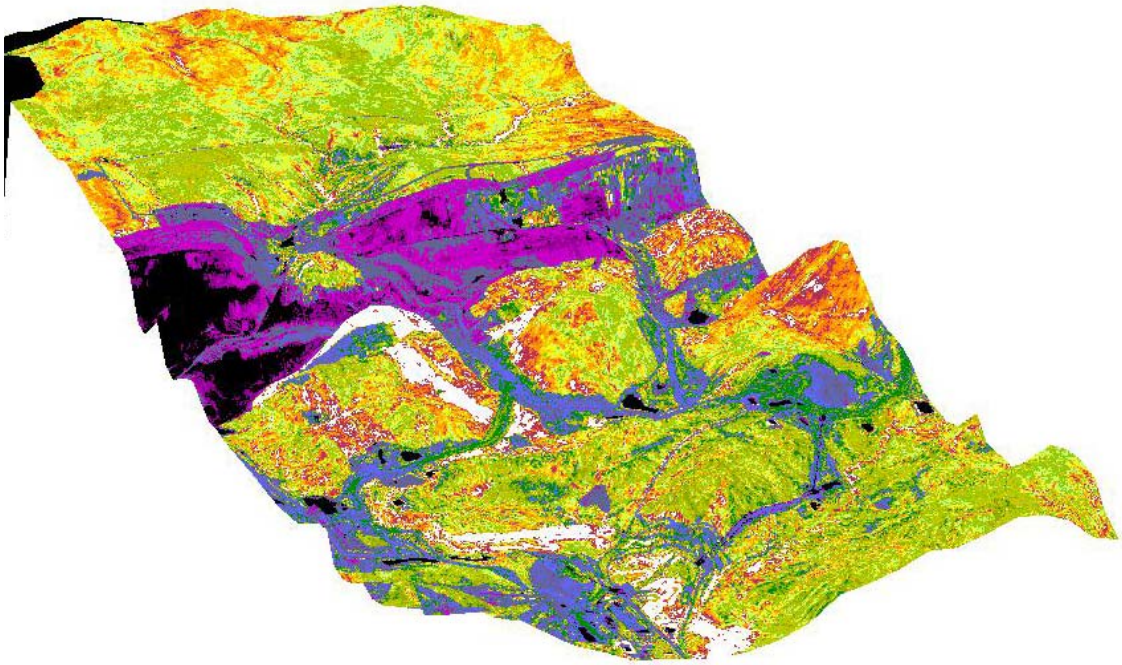


Figure 17: Vegetation index draped over the DEM. Note that the southern exposures do in fact have different vigor from the northern exposures.

Correlating the vegetation index with the 2000 seeding campaign, we overlay the vectors with the raster image in Figure 18.

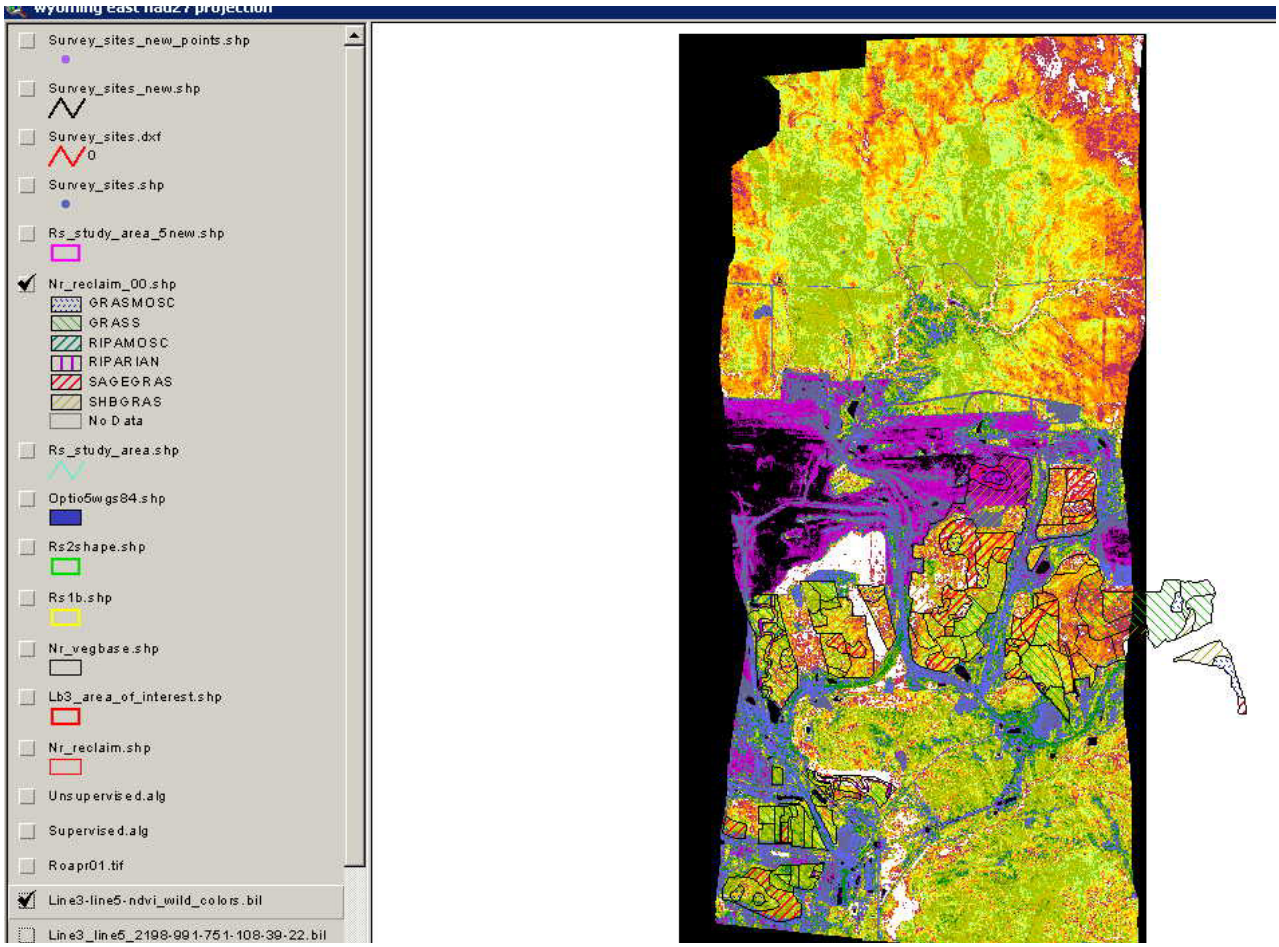


Figure 18: Vegetation index with 2000 reclamation program vectors. It is extremely difficult to correlate vegetation vigor (raster colors) with any particular seeding mix in the vector overlay. This suggests that vegetation vigor may not be due (solely) to seed mixture. There may be other factors that influence the vegetation vigor measure (such as percent of bare soil present within the seeded region one year after planting). At any rate, however, it is clear that the overall vegetation vigor classes in the reclaimed region are very similar to those in the native, undisturbed region.

Section 4e: Unsupervised Classification Analysis

The second technique that we employed with good success is unsupervised classification. This approach capitalizes on the unique spectral qualities associated with specific flora. The algorithm trains itself to identify a predetermined set of unique 'classes' or units of land cover. The user must then identify the actual land cover that corresponds with the output class. The unsupervised classification of the hyperspectral mosaic is shown in Figure 19.

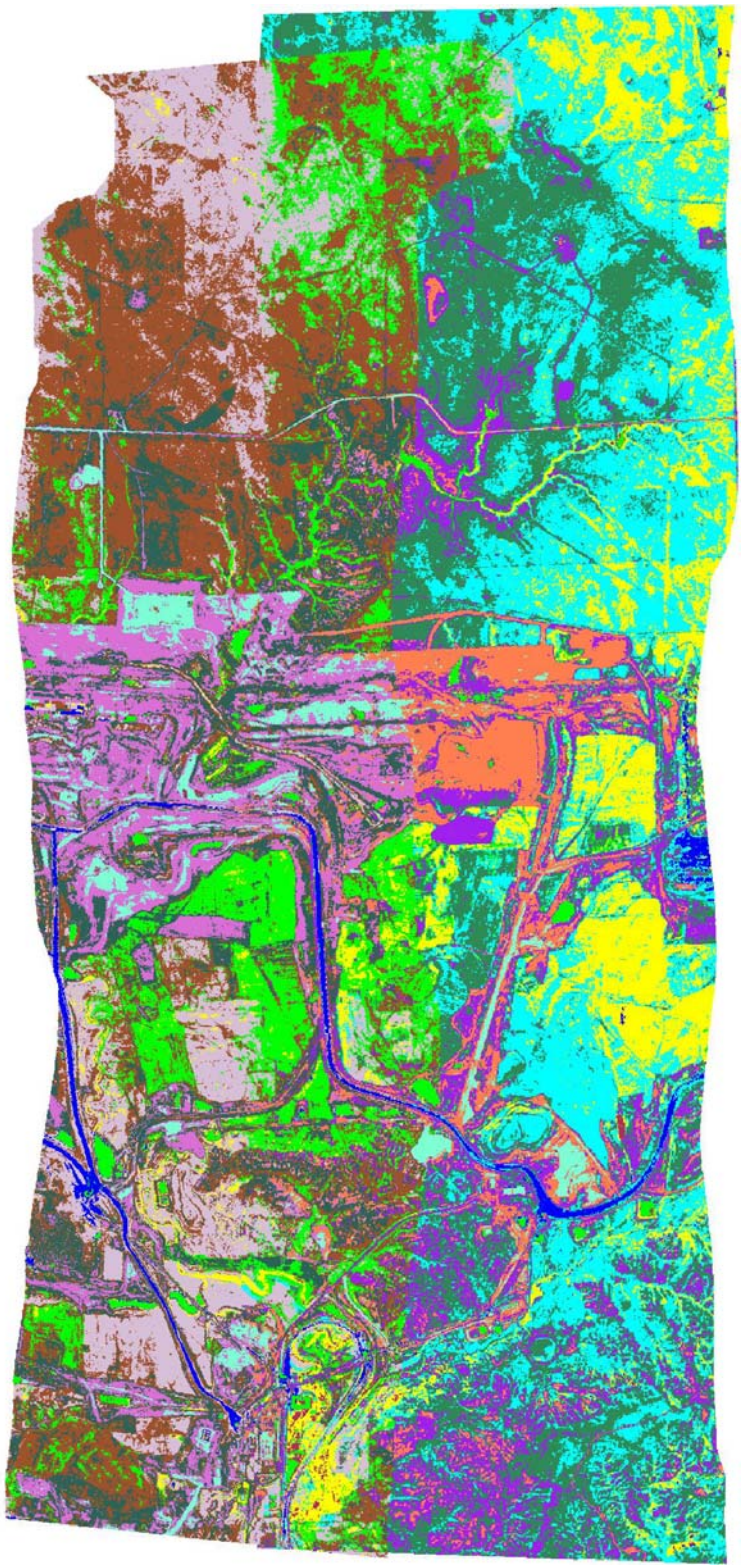


Figure 19: Unsupervised classification of the hyperspectral mosaic. Fifteen output classes have been computed. Note the dramatic variation between the western and eastern portions of the mosaic. We believe this is due to the subtle differences in the spectral character of the two flight paths (different

solar angle, direction of flight, etc.). This contrast makes it very difficult to make consistent classes across the image, and this may be a limiting factor in the utility of the Probe I data for surveying large regions.

Draping the unsupervised classification over the DEM, we obtain Figure 20.

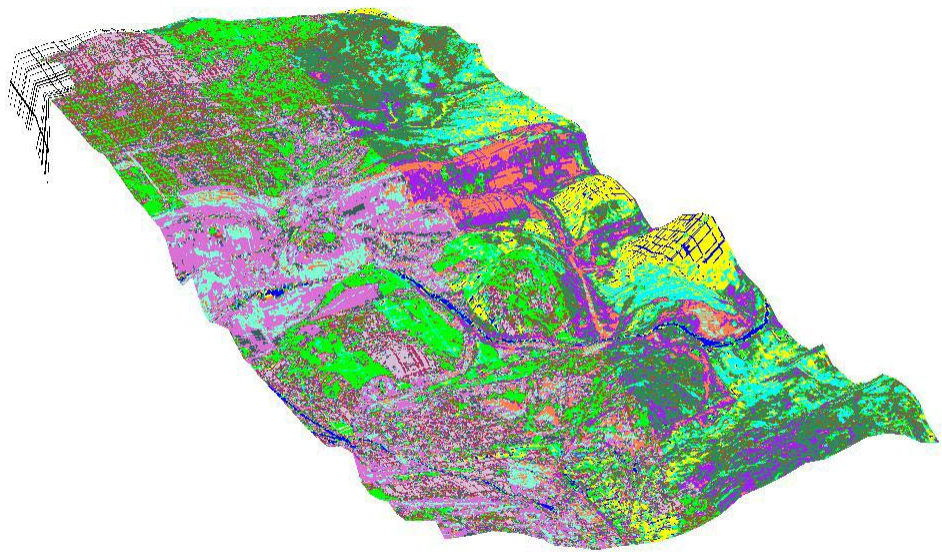


Figure 20: Unsupervised classification draped over the topography. The seam in the data is clearly not an artifact of topography. Some of the output classes appear to have promise of identifying unique vegetation species. Further analysis by the biological team is required in order to obtain definitive confirmation.

Overlaying the year 2000 reclamation program vectors on the unsupervised image, Figure 21, unfortunately does not provide any clear correlation between seed mixtures and output image classes.

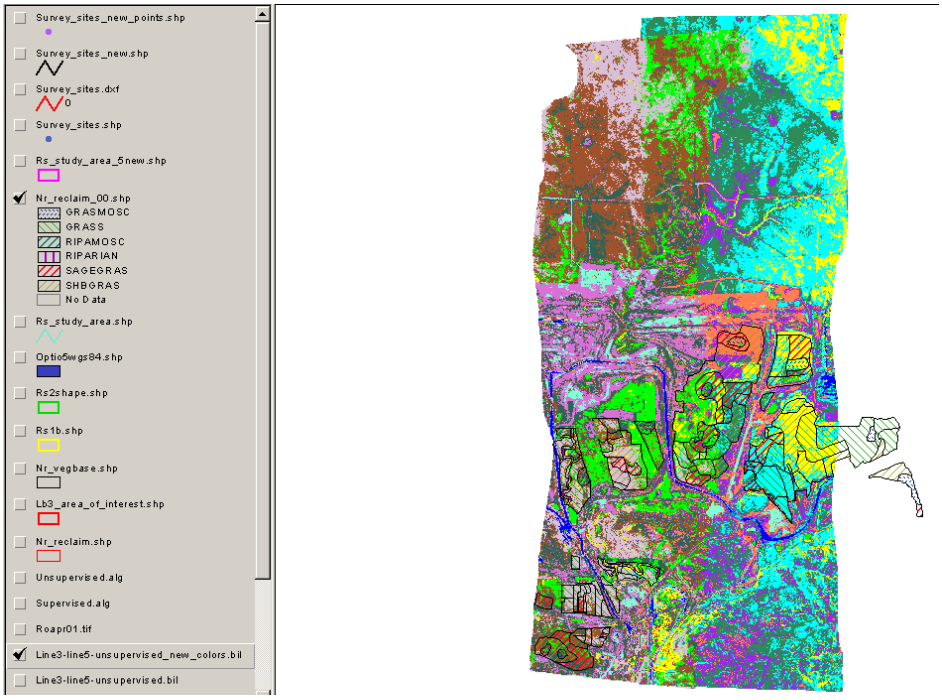


Figure 21: Unsupervised classification with year 2000 reclamation seed mixtures. No obvious correlation can be found that directly relates output classes with seed mixtures. Nonetheless, it is clear that the general class information in the regions that have been reclaimed more than one year prior to surveying is very similar to that of the undisturbed, native areas. This suggests that the reclamation is achieving at least one of its goals: to restore the land to its pre-mining vegetation state.

The other spectral analysis technique that shows promise for land cover mapping is spectral angle mapping. This approach uses the same training fields that we employed to derive our hyperspectral reflectance curves in Figure 10. We can subset pixels that correspond to specific training fields and quantify acreage using this technique. Its main drawback, however, is its non-unique identification of individual classes. This limitation can be quite severe, and as such, the spectral angle mapping technique must be used with extreme caution.

RECOMMENDATIONS FOR FOLLOW-ON WORK AND A FIVE-YEAR PLAN

Our image processing techniques have produced several significant products. Further interpretation of these maps requires additional expertise. Ideally, this would be an opportune time to interface with the biological team that has provided on-site support and monitoring in the field area. The biologists are most familiar with the flora in the region, as well as with the types of seed mixtures that have been used in the historical reclamation efforts over the past several years. Their input as to what types of plants can be found at specific sites in the field area is critical to a more constrained understanding of the field area. In addition, they can provide important details on the variation present in the native, undisturbed region. Also, they may recognize patterns in the hyperspectral mosaic, the vegetation index, and the unsupervised classification that correspond with some of their biological mapping.

Ideally, the biological team, together with the Powder River Coal Company GIS staff, should use the raster imagery in this report as backdrops for further GIS analysis. Planting mixtures, soil types, and other factors can be plotted directly on the hyperspectral basemap. Within GIS software, new polygons can be outlined (using the raster imagery as a guide) to help monitor and quantify the new growth, and to determine ultimately which seed mixtures are most successful, and which areas should be revisited for further reclamation seeding.

Based on the results of the biological integration with the remote sensing data, we will be able to assess the utility of further remote sensing acquisition. Clearly, we can see from the present study that remote sensing presents a very accurate method for mapping the annual reclaimed acreage. We do not, however, have a perfectly unique model for mapping the percent land cover of grass vs. sage from remote sensing. Even with the broader bandwidth field spectrometer, we may not be able to gain much insight into this issue. Due to the coarse hyperspectral spatial resolution (5 meters), we may be averaging the reflectance over too much real estate to obtain accurate mensuration results. In fact, we may need to wait for a new hyperspectral senor that has better spatial resolution in order to obtain more definitive and quantifiable results with respect to the percentage of land cover that is sage vs. grass.

We believe that annual hyperspectral imaging is a worthwhile endeavor, even with current limitations, if the imagery provides a quick and relatively inexpensive method for quantifying the reclaimed acreage on an annual basis. However, until the hyperspectral imagery can be uniquely tied to land cover type by classification techniques, it cannot completely replace field work and ground truth efforts.

TRANSFER OF SOFTWARE AND DATA TO POWDER RIVER COAL COMPANY, GILLETTE, WYOMING

Michal Ruder will visit the Gillette office for two days during the month of December 2001 to install the ENVI image processing software, the hyperspectral datasets, and the field spectral libraries. The basic use of the image processing program will be demonstrated, and construction of ArcView-compatible files will be explained. Michal will review her results with Greg Jones and his staff while on-site.