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Advanced Remote Sensing Technologies for Monitoring Postburn Vegetation Trends and Conditions:

A Joint Fire Science Program RFP, 2001—1-Task 4

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Abstract

For the past several decades, prescribed fire has proven to be a valuable tool for managing federal lands. It is an economical and efficient way to reduce accumulated fuel loads resulting from prolonged policies of suppressing wildfires. Prescribed fire helps to control the spread of some exotic species, increase vegetative diversity, and facilitate the regeneration of native grasses and forage for livestock and wildlife. For at least 45 years, natural resource managers have been employing prescribed fire as a range management tool in grassland–shrub ecosystems. Although generally effective for this application, more precise information is needed for comparing the actual response of the ecological landscape to the initial objectives set out in prescribed fire plans. We propose to apply several newly developed remote sensing techniques to accurately describe the temporal dynamics of vegetation community composition in a grassland–shrub ecosystem following prescribed fire treatments. The proposed work is new and innovative but based on a strong fundamental framework. To characterize the outcome of prescribed fires in more detail beyond vegetation classification, there is a need for more accurate geospatial information on vegetation. We seek to apply a recent advance in remote sensing technology, imaging spectroscopy, to estimate both the biomass and moisture content of vegetation canopies, specifically, grassland and shrub fuel types. We propose to develop this state-of-the-art information as input into fire behavior and fire danger rating models such as BEHAVE, FARSITE, and NFDRS.

Introduction

I. Project Justification

Natural resource managers have been unable to statistically monitor the results of prescribed fires in the grassland–shrub environment. Often, only a yearly ocular review of a prescribed fire is practicable. This kind of ocular monitoring may miss critical information and may be misleading in assessing the ecosystem for fire effects, damages, and benefits; evaluating the success or failure of the burn; and determining the return interval for the reintroduction of fire. Natural resource managers and the scientific community need to develop efficient methods for evaluating the results of prescribed fires. Often prescribed fires are proposed and implemented because it is believed that the natural fire regime has been altered and that prescribed fire will restore the land to a healthier state. However, this may not be the case and there is rarely any followup after a prescribed fire to evaluate the results. In this proposal, we suggest that grassland–shrub and sagebrush vegetation communities can be consistently and accurately identified and mapped by using imaging spectroscopy, an advanced remote sensing technique. Imaging spectroscopy offers the benefits of accurate vegetation classification and the opportunity to examine the state of vegetation in more detail than has been possible with more traditional methods of remote sensing. In particular, the relations between plant chlorophyll and plant moisture content and specific absorption features can be used to remotely estimate vegetative biomass (i.e., amount of fuel present), forage production, and moisture content. In essence, this project aims to use spectroscopy-based remote sensing techniques to improve the assessment of the effects of prescribed fire on the environment and ecosystem and produce more detailed fuel inputs for fire fuels models.

The preceding justification is relevant to Task 4 of the Joint Fire Science Program Request for Proposal, 2001-1: *Develop, apply, and validate improved aircraft or satellite-based remote sensing applications for quantifying fuel types, fuel condition and loading, fire hazard, fire behavior, and effects such as fire distribution and severity*. In particular, this proposal employs validation procedures using established field and laboratory measurements and methodologies.

II. Project Objectives

1. Quantify by advanced remote sensing techniques the effect over time of prescribed fire in a grassland–shrub environment to assess its success in accomplishing the goals set forth in the Burn Plan for two study sites. Results will then be used to develop accurate trend data that will determine whether the prescribed fire objectives were met. Remote sensing and field techniques developed and used in this project will be documented in a format understandable to wildland fire managers and publicly distributed through a project Internet site.

2. Test the relations between ground-measured chlorophyll and moisture content with the appropriate absorption features on simultaneously acquired airborne hyperspectral imagery to develop a reliable remote biomass and moisture-content monitoring system. A monitoring system of this type would permit development of multiple levels of burning characteristics for individual fuel types, enhancing inputs to computer-based fire modeling systems such as BEHAVE (Andrews 1984; Andrews and Chase 1989; Burgan and Rothermel 1984) and FARSITE (Finney 1998) beyond present capabilities. Such information may also be used to verify the accuracy of Remote Automatic Weather Station (RAWS) data moisture estimates of nearby fuels, and could be used to provide more accurate information for fuels in areas remote to RAWS data.

III. Background

History and Description of the Study Sites

Two study sites have been selected for this project on the basis of their prescribed fire history, wildfire, and cover of grassland–shrub. We selected these two study sites because they are similar enough to show replication and repeatability of the experimental design.

The Left Hand Creek Study Site

A pilot project was established in 1998 (Goodman et al. 1998, unpublished proposal) to determine the capabilities of remote sensing technologies for accurately mapping vegetation trends after prescribed fires. The site, located 20 miles northwest of Thermopolis, Wyoming, includes a portion of the Left Hand Creek drainage, within the 1:24,000-scale Adam Weiss Peak Quadrangle (Figure 1). The Worland Field Office of BLM manages this site. Because of the mixture of species present, this study site has proven to be a difficult one in which to accurately classify vegetation and to map using multispectral remote sensing analysis techniques employing ADAR Positive Systems and LandSat 7 Thematic Mapper data (Meyer 2000, unpublished report). Preliminary findings in 1999 showed that mountain big sagebrush (*Artemisia tridentata*) regenerated vigorously throughout the study area. The 1999 field sampling showed the vegetation cover to be predominately mountain big sagebrush (*Artemisia tridentata*) mixed with prairie Junegrass (*Koeleria cristata*), Idaho fescue (*Festuca idahoensis*), crested wheatgrass (*Agropyron cristatum*), and green needlegrass (*Nassella viridula*). Limber pine (*Pinus flexilis*) and Rocky Mountain juniper (*Juniperus scopulorum*) are scattered throughout. In the wetter areas of the study site, Rocky Mountain Douglas-fir (*Pseudotsuga menziesii var. glauca*) is found. During the summer of 2000, a portion of the Left Hand Creek study area was burned out to halt the encroaching Enos wildfire.

In 1997, five prescribed fires were executed in the Left Hand Creek study area. Two burn units were completed in spring and three in fall. The goals of the Burn Plan were to (1) increase the amount of available forage in the treatment area for both cattle and elk within 3 years after the completion of the burn, and (2) increase vegetative type diversity, with the postburn landscape consisting of a mixture of timber, grasslands, and sagebrush in the treatment area. The

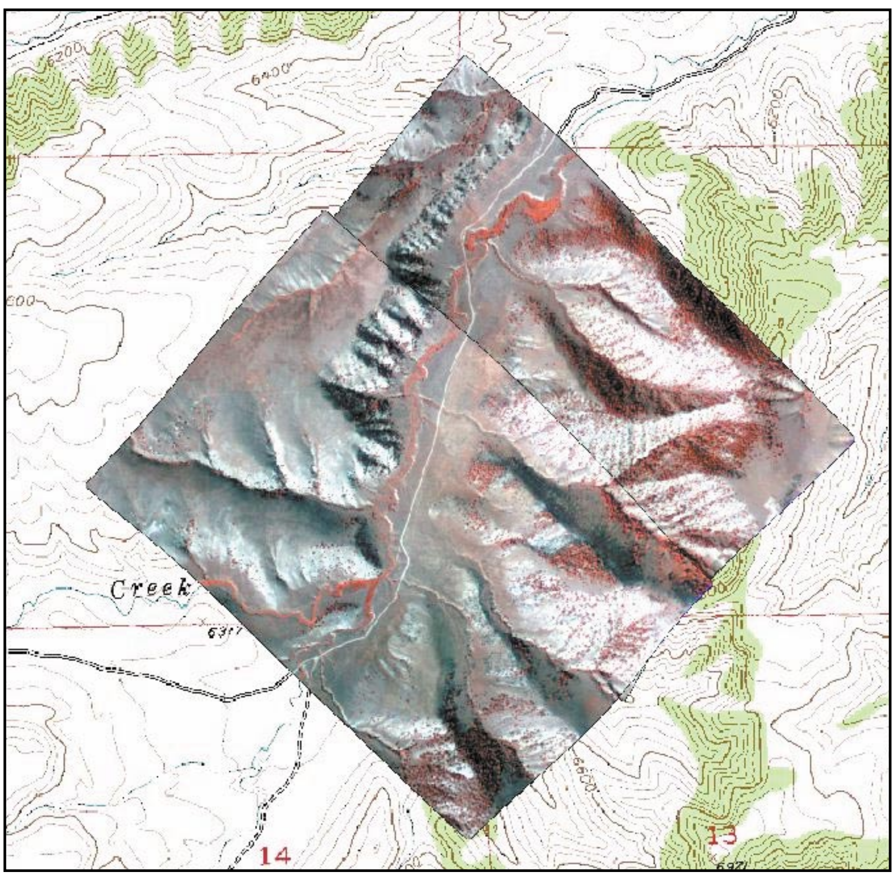

Figure 1: A view of the Left Hand Creek study area (near Thermopolis, Wyoming) using 1999 ADAR Positive System Imagery with Digital Raster Graphic as a backdrop. (*Map courtesy of R. Jackson, 2001*)

direct effects and operational objectives of the fire included (1) accomplish the burn in 5 working days in 1997 with fires that do not exceed line-holding capabilities, (2) burn sagebrush on a total of 900 acres (365 ha) within the treatment area by spring 1998, and (3) create a mosaic burn pattern in the treatment area as follows: (a) leave 60% of sagebrush in the treatment area unburned and (b) burn 40% of the sagebrush in the treatment area. The kill was predicted to vary between 20% and 80% in the individual burn units (Wolf et al. 1997, unpublished report). Figure 2 illustrates the conditions that existed before the prescribed fire and Figure 3 demonstrates the effects of the 1997 fires on the vegetation.

Figure 2. Many species of vegetation are present on the Left Hand Creek study area before the prescribed burns of 1997. (*Photo courtesy of B. Keating, 1999*)

Before the 1997 prescribed fires, site write-up area (SWA) vegetation data were collected from 1978 to 1980. A SWA is the smallest delineation within an ecological site. Rangeland landscapes are divided into ecological sites for the purposes of inventory, evaluation, and management. An ecological site is a distinctive landscape with specific physical characteristics that differs from other landscape in its ability to produce a distinctive kind and amount of vegetation (Butler et al. 1997). Within the Left Hand Creek study area, an ecological site evolved with a characteristic fire regime. Fire frequency and intensity contributed to the characteristic plant communities of this site. The vegetation composition before the 1997 prescribed fires consisted of 20% Kentucky bluegrass (*Poa pratensis L.*), 17% Idaho fescue (*Festuca idahoensis*), 15% mountain big sagebrush (*Artemisia tridentata*), 14% bluebunch wheatgrass (*Agropyron spicatum*), 11% Rocky Mountain Douglas-fir (*Pseudotsuga menziesii var. glauca*), and 10% lemon scurfpea (*Psoralea lanceolata*).

Figure 3. The effects of prescribed burns on vegetation can be seen in this view of the Left Hand Creek study area after 1997. (*Photo courtesy of B. Keating, 1999*)

Catnip Mountain Study Site

The Catnip Mountain study site is located in northwestern Nevada on the Sheldon-Hart Mountain National Wildlife Refuge Complex, 55 miles (88.5 km) southeast of Lakeview, Oregon (Figure 4). The refuge was designated in 1931 for the preservation of the pronghorn (*Antilocapra americana*). The vegetation cover of the study site consists of areas of decadent or dead bitterbrush (*Purshia tridentata*) stands with islands of old mountain mahogany (*Cercocarpus ledifolius*) scattered near the ridges. Mountain big sagebrush (*Artemisia tridentata*) dominates the low elevation areas with grasses and forbs mixed with mountain big sagebrush (*Artemisia tridentata*). Little sagebrush (*Artemisia arbuscula*) dominates the cover of the ridges. Elevations of the site are about 6,000 to 7,000 feet (1,830–2,135 m).

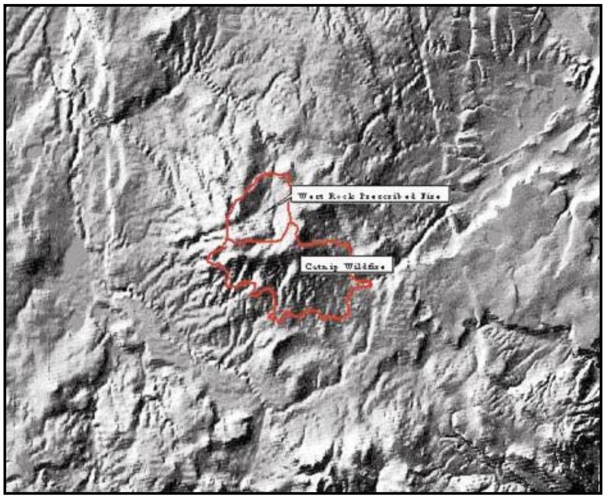

Figure 4: A view of the Catnip Mountain study site (near Lakeview, Oregon) using National Elevation Data as a backdrop. (*Map courtesy of S. Goodman, 2001*)

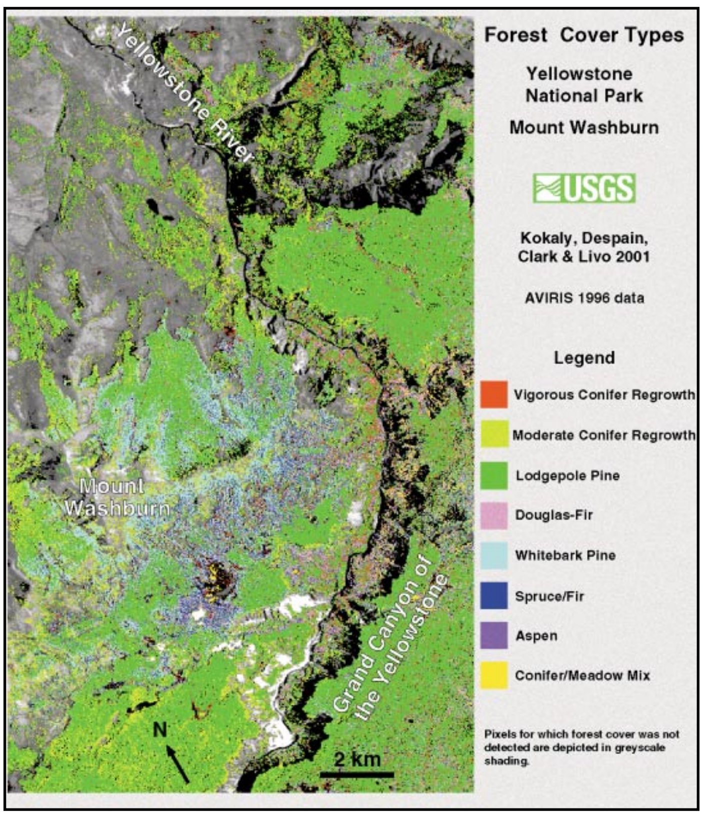

Figure 5. Map of forest cover types for the Mount Washburn area of Yellowstone National Park, derived from AVIRIS data and the USGS Tetracorder algorithm. For clarity, nonforest vegetation was not represented in this image but on another map (Kokaly et al. 1998; Kokaly et al. 2001). (*Map courtesy of R. Kokaly, 2001*).

In fall 1996, a large prescribed fire was initiated on the north side of Catnip Mountain. The resource objectives of the prescribed fire were to (1) improve mule deer (*Odocoileus hemionus*) habitat, (2) remove dead and decadent shrub stands, and (3) increase cover of grasses and forbs. The direct effects and operational objectives of the fire included (1) remove 75% or more of the dead or decadent bitterbrush (*Purshia tridentata*) stands, (2) reduce cover of mountain big sagebrush (*Artemisia tridentata*) by 75%, (3) reseed some areas of bitterbrush (*Purshia tridentata*) to stimulate sprouting, and (4) stimulate bitterbrush (*Purshia tridentata*) sprouting by mechanical disturbance. This prescribed fire turned into a wildfire and burned a total of 8,800 acres (3,560 ha).

In the 1990's, three other prescribed fires were executed in the study site and burned 950 acres (385 ha). Two additional wildfires were extinguished that totaled 605 acres (245 ha). Since 1990, 10,355 acres (4,190 ha) have burned in this 10-km^2 study site.

Background of Imaging Spectroscopy

Imaging spectroscopy, an advanced remote sensing technique also known as hyperspectral remote sensing, has been shown to improve the characterization of vegetation on the landscape (Kokaly et al. 1998; Martin et al. 1998; Roberts et al. 1998; Asner and Lobell 2000; King et al. 2000; and Kokaly 2001). This project will test and verify the ability of imaging spectroscopy to remotely quantify fuel type, fuel condition, and loading. Imaging spectroscopy data are sensitive to the amount of chlorophyll and water concentrations in plants, as well as the total amount of vegetated matter on the land surface. Different vegetation species and, on a smaller scale, different vegetation communities have variable amounts of aboveground biomass and contain variable amounts of chlorophyll and water in their leaves and canopies. These variations in plant composition and water status are observable with imaging spectroscopy data. Kokaly et al. (2001) used this observation to discriminate between forest cover types with varying fire behavior in Yellowstone National Park, Wyoming (Figure 5). This study also demonstrated that nonforest vegetation cover types such as sagebrush, grasslands, and wetland vegetation could be identified and mapped. Furthermore, fine distinctions in the health status of Idaho fescue (*Festuca idahoensis*) grasslands were made.

In addition to identifying cover types on the landscape that have different fire behavior, imaging spectroscopy may be used to determine the biomass and water status of vegetation on the landscape. Field and laboratory reflectance spectra of vegetation reveal the absorption features of chlorophyll and leaf water (Figure 6). Remote sensing data collected by some types of airborne spectrometers have sufficient spectral resolution to analyze these absorption features. Other broader band remote sensing data such as LandSat 7 and IKONOS MSS do not contain enough spectral detail to effectively analyze these plant absorption features.

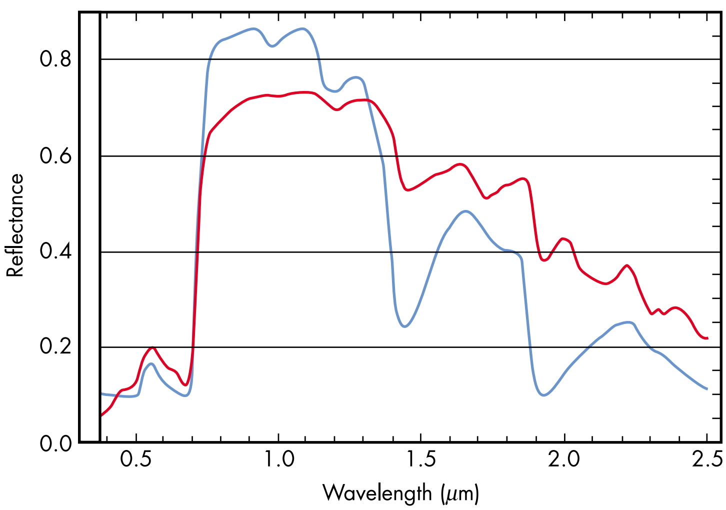

Figure 6. Reflectance spectra of an oak leaf in the fresh state (*blue line*) and the dried state (*red line*). Reflectance in the visible region (0.35 to 0.7 μm) is controlled by plant pigments. In green plant material, the reflectance at longer wavelengths is dominated by leaf water. When the plant material is dry, the longer wavelength absorption features centered at 1.7, 2.1, and 2.3 μm, which arise from protein, lignin, and cellulose, are revealed.

Materials and Methods

Field Data Collection

After discussion with agency foresters, range conservationists, and remote sensing specialists, a combination of techniques from these disciplines was used by the authors to develop methodology for collecting vegetation data for accuracy assessment and validation of the project objectives. Field data and imagery will be collected between June 15 and August 15 near the peak of photosynthesis for this shrub-grassland plant community. At least 30 plots will be selected from stratified random sampling for detailed analysis. Measurements for shrubs and trees will be conducted in fixed 1/100-acre (11.8-feet [3.597-m]) radius plots. Tree height, diameter at breast height (DBH), age, and species will be recorded. Shrub height, width, length, and species will be measured and recorded on hand held computers.

Within the 1/100-acre plot, grasses, forbs, and low-lying shrubs will be measured by using a Daubenmire (20- x 50-cm quadrat) frame method (Coulloudon et al. 1999; Figure 7). Two transects of three Daubenmire frames will originate 30 cm from the center of the plot and each frame will be 30 cm apart from

Figure 7. Range conservationist Ken Stinson takes field measurements using a Daubenmire quadrat frame (Coulloudon et al. 1999). (*Photo courtesy of B. Keating, 1999*)

the next frame. Species and cover class will be measured and recorded on hand-held computers. Percent cover of the dominant species will be estimated.

Four photos of each plot will be taken from each of the four cardinal directions; the focal point will be the center stake of the plot. A Global Positioning System (GPS) measurement will be recorded over the center stake for each plot. Weather readings will be measured from the Left Hand Creek and Catnip Mountain Remote Automated Weather Station (RAWS) during field and imagery collection.

Measurements of spectral reflectance of vegetation in the plots will be obtained by using a field spectrometer (ASD Full Range Field Pro; Figure 8). Reflected solar radiation over the 0.35 to 2.5 μm wavelength range will be measured with respect to a Spectralon white reference standard. These relative reflectance measurements will be converted to absolute reflectance by correcting for the slight absorption of the reference plate. We will collect close-up reflectance measurements from the leaves of the dominant species in the plots and average reflectance signatures from the entire plot area. The reflectance spectra of vegetation species in the plot allow an examination of their reflectance properties. Furthermore, the spectra of these canopy elements may be compared with the average plot reflectance to assess which canopy elements are contributing strongly to the overall reflectance. Field measurements of species and cover will be useful for this determination. In order to characterize the average reflectance signature of the plot, thirty to fifty individual measurements of reflectance will be made with the fiber-optic head of the spectrometer pointed at nadir and at approximately 3 feet (0.9 m) above the canopy while the operator traverses the area of the field. These individual measurements will be averaged to give a representative signature for the plot. We have found very high correspondence between such averaged field measurements and the remotely sensed spectra from airborne spectrometers (R = 0.9999; Kokaly, unpublished data).

Figure 8. Raymond Kokaly (USGS) measures the reflectance of vegetation using a field spectrometer (*Photo courtesy of R. Kokaly*)

In addition to measuring the reflectance signature from leaves of the dominant species, we will also collect samples of these leaves to determine chlorophyll and water content in the laboratory. The cut leaves will be immediately placed on ice to prevent degradation of the chlorophyll before transport to the laboratory. In the laboratory, the leaves will be divided into two subsets, one for chlorophyll determinations and the other for water content analysis. The subset of leaves for the water content analysis will be weighed to determine fresh weight. The leaves will then be dried in an oven for 24 hours at 70° C. After drying, the leaves will be weighed to determine dry weight. The water content will be calculated as the difference between fresh and dry weight. An established wet chemistry procedure for determining chlorophyll *a* and *b* content will be used (Palta 1990). This procedure involves homogenizing the leaves with a solvent in a blender followed by filtering the debris. The absorbance of the resulting filtrate at 645 nm is determined by using a standard laboratory spectrophotometer. This absorbance reading is used with a standard equation (Palta 1990) to calculate the chlorophyll content. The procedure may be validated by using standards of chlorophyll concentration available from the National Institute of Standards and Technology.

Quantifying Prescribed Burn Effects

The first objective of the project is to quantify the effect over time of the prescribed fires in the Left Hand Creek and Catnip Mountain study sites in order to assess the success of the fires in accomplishing the goals set forth in the Prescribed Burn Plans of the study areas.

The first step in this process is to review historical preburn conditions. This will be accomplished by interpreting vegetation community associations within the burn area with historical aerial photography from 1975 to 1994 (Table 1 and Table 2). Postburn conditions will be assessed for each growing season after the burn through the analysis of high-resolution digital panchromatic and multispectral data sets (Table 1). To thoroughly assess current conditions in the 2002 growing season for the Left Hand Creek site and in the 2003 growing season for the Catnip Mountain site, 1:40,000-scale color infrared aerial photography, IKONOS high-resolution digital data, and HyMap 126-band hyperspectral data covering a spectral wavelength range of 0.45–2.48 µm will be acquired over these study areas.

A field crew, equipped with an ASD Field Spec Pro ground spectrometer (which measures radiance in approximately 2-nm wavelength intervals from 0.35 to 2.50 µm), will collect spectra from a nonvegetated calibration site consisting of moderate to high albedo. Integrated reflectance spectra from this ground calibration site, covering at least 30 to 50 HyMap image pixels, will be collected simultaneously with the HyMap mission. Within a few days before or after the HyMap mission, the field crew will also collect field spectra from the 30+ sampling plots in the manner previously described under *"Field Data Collection."*

Table 1. Existing images and scheduled remote sensing data collection for Left Hand Creek Study Site.

Image Type	Scale/Resolution	Date Collected
WWIR color IR	1:38,680	August 1975
NHAP color IR & B&W	1:58,000	Summer 1981
IntraSearch color IR	1:58,000	Summer 1984
NAPP color IR	1:40,000	Summer 1989
WY84BC true color	1:24,000	Summer 1994
NAPP B&W	1:40,000	Summer 1994
DOQQ's B&W	1:12,000	Derived from 1994 NAPP; Used for positional baseline
ADAR (Positive Systems)	1 m multispectral	9/19/98
ADAR (Positive Systems)	1 m multispectral	6/19/99
ADAR (Positive Systems)	1 m multispectral	9/19/99
IKONOS	1 m Pan, 4 m MSS	August 2000
NAPP color IR	1:40,000	Scheduled for summer 2001
IKONOS	1 m Pan, 4 m MSS	Scheduled for summer 2002
HYMAP (hyperspectral)	3 m (0.45–2.48 µm)	Scheduled for summer 2002

Table 2. Existing images and scheduled remote sensing data collection for Catnip Mountain Study Site.

Image Type	Scale / Resolution	Date Collected
DOQQ's B&W	1:40,000	Summer 1994
NAPP B&W	1:40,000	Summer 1994
NAPP B&W	1:40,000	Summer 1999
IKONOS	1 m Pan, 4 m MSS	Scheduled for summer 2003
HYMAP (hyperspectral)	3 m (0.45–2.48 µm)	Scheduled for summer 2003

To achieve the best possible georeferencing of the 2002 data acquisitions for Left Hand Creek and 2003 data acquisitions for Catnip Mountain, IKONOS data will be collected in stereo over these study areas. A custom digital elevation model (DEM) with 5-m "postings" will be produced in the Photogrammmetry Laboratory in the BLM National Science and Technology Center, Denver, Colorado. The IKONOS panchromatic data will be orthorectified using the high-resolution DEM to produce a current and high-resolution baseline map for each of the study areas. Also, the HyMap data will be orthorectified using the high-resolution DEM, providing the necessary level of spatial accuracy to consistently link HyMap spectral responses to the corresponding ground spectra and ground-measured Daubenmire and chlorophyll and plant moisture plots.

The effect of atmospheric gases in the HyMap imagery will be removed by using Atmospheric Correction Now (ACORN) software (Analytical Imaging Geophysics [AIG] 2001), which employs the Modtran 4 radiative transfer model (Berk et al. 1999). The imagery will also be adjusted to surface reflectance by using a ground calibration procedure that involves a multiplicative correction to each image pixel. This correction factor is derived from integrated field spectrometer data obtained over a ground calibration site (Clark et al. 1993; King et al. 2000). This method has been found to result in very well calibrated remote sensing data for which spectra of vegetation closely resemble field measurements (a correlation coefficient of 0.999 was found between field and remote sensing spectra of vegetation using ground calibration; Kokaly unpublished data).

We hypothesize that grass/forb and sagebrush vegetation community associations can be consistently and accurately identified and mapped from the HyMap data by using spectrum matching techniques. Spectrum matching algorithms available in Environment for Visualizing Images (ENVI) software (Research Science Incorportated, 2001) and spectrum matching utilizing continuum removal with the USGS Tetracorder algorithm (Clark et al. 2001) will be used to identify and classify the grass/forb and shrub community associations in the burn areas. Classification accuracies will be quantified through accuracy assessments using information from the measured field plots as ground verification data. Once the accuracy levels are verified using information from the ground sampling plots, spectra (from either the HyMap image or collected in the field) will be convolved to the bandwidths represented by the previously obtained ADAR (Positive Systems) data in the Left Hand Creek site and IKONOS data in both study areas, and analyzed by principal components analysis to verify if the same community associations have sufficient spectral separability to be mapped from the much lower spectral resolution data sets. If this is the case, multispectral image analysis techniques will be applied to the 1998, 1999, and 2000 MSS data to generate community association maps for each of the growing seasons following the prescribed fires. Otherwise, manual image interpretation techniques will be used. Results will then be compared to develop trend data that will be used to determine if the prescribed fire objectives described previously were met.

Remotely Measuring Vegetation Biomass and Chlorophyll and Moisture Content

The strength of a plant absorption feature is directly linked to the concentration of the absorbing material (chlorophyll or water) and the total amount of vegetation on the land surface. The development of techniques for remote estimation of biomass has been the focus of many past investigations. Pearson et al. (1976), Bedard and LaPointe (1987), and Hardisky et al. (1984) established relations between vegetation indices and green biomass. Others such as Waller et al. (1981) and Anderson and Hanson (1992) have reported little or no association. Anderson et al. (1993) failed to find strong relations between vegetation indices and sample estimates of dried green biomass, but did find relations when their data (from semiarid rangelands) were aggregated by greenness strata. More recently, Blackburn (1998), Datt (1998), and Bork et al. (1999) have examined high-resolution spectroscopy for spectral associations with chlorophyll and cover component quantification. Algorithms using specific band ratios were demonstrated to correlate strongly with concentrations per unit area of pigments at the canopy scale.

With the knowledge that these relations exist, this study proposes to compare the response of specific spectral absorption features on calibrated HyMap data with corresponding chlorophyll and plant moisture content measurements. Past studies have repeatedly shown that remote sensing measurements can indicate the amount of chlorophyll and biomass of vegetation. However, these studies used limited traditional multispectral remote sensing data or techniques. A consistent method for mapping biomass has not yet been developed. We propose that more sophisticated analyses of imaging spectroscopy using continuum removal (Clark and Roush 1988) and spectral feature analysis (Clark et al. 2001; Kokaly et al. 2001) will result in more generally applicable algorithms to estimate the biomass distributed over the landscape. Furthermore, we propose that changes in leaf water absorption features observable in imaging spectroscopy data over vegetation will allow for the estimation of plant water status. Such an approach has been taken with respect to determining nitrogen concentrations in plants from their reflectance spectra (Kokaly and Clark 1999; Kokaly 2001) using continuum removed absorption features and stepwise multiple linear regression.

To test the hypothesized relation between specific chlorophyll and plant moisture absorption features and corresponding image spectra, calibrated HyMap data and equivalent field spectra will be compared with the corresponding ground sample plots where chlorophyll and plant moisture measurements were made. The approach that was used by Kokaly and Clark (1999) will be employed to generate empirical equations that estimate the amount of chlorophyll and water in a plant from its spectral reflectance signature. In this procedure, the absorption feature arising from chlorophyll at 0.68 µm will be isolated by using continuum removal applied to each reflectance spectrum (Clark and Roush 1994). The resulting scaled reflectance values for the spectral measurements of vegetation in the field plots will be combined with the corresponding wet chemistry determinations of chlorophyll content in a stepwise multiple linear regression (SMLR). The results of this statistical method are the determination of which wavelengths are highly correlated with the chlorophyll content in the vegetation and a linear equation that uses the scaled reflectance values at these wavelengths to predict the chlorophyll content. We will use two-thirds of the paired field reflectance and chlorophyll content data in the SMLR method to calculate this linear equation. The predictive nature of the regression equation will be validated with the remaining one-third of the paired measurements. This type of procedure has been used repeatedly in accurate estimation of nitrogen contents within plant samples from reflectance data (Card et al. 1988; Marten et al. 1989; Bolster et al. 1996). Although these relations are statistical in nature, Kokaly (2001) has shown that there is a strong underlying physical basis to this approach when the wavelength region is restricted to areas in which the material of interest has a known absorption feature (e.g., the 0.68 µm feature of chlorophyll). The development of an equation to estimate water content in vegetation from reflectance spectra will be conducted in the same manner, using both the 0.98- and 1.20-µm leaf water absorption features.

To scale up to the remote sensing level, two steps will be employed. First, the composite chlorophyll content will be estimated for each plot by using the determinations of chlorophyll content made from each of the major species occurring in the plot weighted by the percent cover of each. This field-derived measure of chlorophyll content will be compared to estimates from the regression equations applied to the average reflectance measured over the plot. The comparison of the two values represents an additional check on the validity of the equations developed from the SMLR method. The same procedure will be used for estimating the water content of the vegetation in the field plots. The second step in scaling these estimations to the remote sensing level will be to perform the same comparison of the composite field measurements of chlorophyll and water to the chlorophyll estimate generated using the empirical equations and the HyMap remote sensing data. This step should have similar results to the first step because of the careful atmospheric correction and calibration methods to surface reflectance that we have proposed to apply to HyMap data. If correlations between these factors are statistically significant, a remote technique for estimating chlorophyll (i.e., linked to biomass and amount of fuel present) and water (indicating fuel moisture condition) will be demonstrated. We propose to link these maps of biomass and plant water status with fire behavior models. Estimating biomass before prescribed burning and in subsequent seasons will also allow for an evaluation of fire management strategies.

A system providing pixel-by-pixel remote estimation of biomass and moisture content would permit the development of site-specific multilevel burning characteristics within individual fuel types, which could be used as enhanced inputs into computerized fuel modeling systems such as BEHAVE or FARSITE. Such a system could also be used to validate interpolated modeling estimates made from data received from Remote Automated Weather Stations and could provide more accurate fuel characteristics in areas that are remote from the stations in this system. Within the next few years, imaging spectrometers will be collecting data from orbital platforms, making such monitoring economically feasible. This research would validate the effectiveness and application of this type of monitoring, in anticipation of immediate application shortly after routine data collections from orbital imaging spectrometers become available. As a result, more detailed and accurate fuel characteristics estimates for individual fuel types would advance the state-of-the-art of information inputs for fire behavior modeling.

Project Duration

The project will be 3 years in duration, from January 2002 to December 2004. In the first year, emphasis of the project will be on the Left Hand Creek site. In the second year, 2003, emphasis will shift to the Catnip Mountain site. In the third year, 2004, both sites will be revisited for accuracy assessment.

Budget

The itemized budget is outlined in the Appendix. The budget includes funding for salary, travel, data collection, supplies, and other miscellaneous expenses.

Deliverables

By December 2004, this project will deliver the following products:

1. Progress reports in January 2003 and January 2004 detailing what data were collected and the corresponding analysis that occurred during the previous year. These reports will then be posted on the Internet site and may be published in an appropriate peer-reviewed scientific journal.

2. A final paper, to be published in an appropriate peer-reviewed scientific journal, describing the project's methodology, results, and recommendations, will be completed by December 2004.

3. A technical procedural manual describing the techniques used will be written in a format understandable to natural resource specialists and wildland fire managers. This will be completed by December 2004.

Technology Transfer

The transfer of technology will be achieved by creating an Internet site. The principal investigators will be responsible for maintaining the Internet site. The site will have the project's budget, proposals, project updates, and results. The site will include annotated visual presentations as they are produced throughout the duration of the project.

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Qualifications of Investigators

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Physical Scientist (Remote Sensing): 01/01–present
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Education

Ph.D., 1974, Remote Sensing of Natural Resources, Colorado State University, Fort Collins, Colorado
M.A., 1969, Geology and Geophysics, Indiana University, Bloomington, Indiana
B.S., 1967, Geology, Allegheny College, Meadville, Pennsylvania

Professional duties and accomplishments in current position since 03/01

Principal Investigator: "The use of Landsat 7 (ETM+) and AVIRIS data to map fuel characteristic classes in western ecosystems." A 3-year study undertaken by scientists from the USGS Western Ecological Science Center, Northern Rocky Mountain Science Center, and Rocky Mountain Mapping Center to develop a method for deriving fuel characteristics class maps from satellite imagery and AVIRIS hyperspectral data and field plots for forest, shrub, and grass fuels. Funded by the National Interagency Fire Center through the Joint Fire Science Program <http://www.nifc.gov> and <http://www.nifc.gov/joint_fire_sci/jointfiresci.html>

Principal Investigator: NASA EO-1 Science Validation Team (Detection and Mapping Of Invasive Leafy Spurge Using Orbital Hyperspectral Imagery from the EO-1 Mission); < http://eo1.gsfc.nasa.gov/Science/>

Principal Investigator: An early detection system for regional delineation of leafy spurge. USDA Agricultural Research Service TEAM Leafy Spurge; < http://www.team.ars.usda.gov/>

Principal Investigator: Detection/mapping of leafy spurge using imaging spectroscopy (NASA AVIRIS); <http://biology.usgs.gov/hwsc/leafsp.htm>

Research on use of temporal/spectral analysis of LandSat imagery for mapping of fire fuels in Yosemite National Park, California

Professional Society Membership

American Society for Photogrammetry and Remote Sensing, 1971–present

Selected Publications

Root, R., and D. Wickland. 2000. Hyperspectral Technology Transfer to the U.S. Department of the Interior: Status and Results of the NASA/Department of the Interior Hyperspectral Technology Transfer project. Proceedings of the Ninth JPL Airborne Earth Science Workshop. Robert Green, editor. NASA JPL Publication 00-18, Pasadena, Calif.

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Nyquist, M., and R. Root. 1997. The USGS Vegetation Mapping Program for the National Park Service: Benchmarking–Preliminary Results. Third International Airborne Remote Sensing Conference and Exhibition, 7–10 July 1997, Copenhagen, Denmark.

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Agee, J. K., and R. R. Root. 1986. The North Cascades Geographic Information System. National Park Service. 1986 Conference on Science in the National Parks, Fort Collins, Colo. n.p.

Root, R. R. 1983. Stratigraphic surveys for site selection of visitor and administration facilities. Florissant Fossil Beds National Monument, Colorado. National Park Service Rocky Mountain Region, Denver, Colo. [This publication includes a map of all Tertiary age volcanic deposits within Florissant Fossil Beds National Monument, and the results of multiple geophysical experiments for remotely detecting buried petrified tree stumps within the monument]

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Education

M.S., Aerospace Engineering, May 1993, University of Colorado at Boulder

B.S., Aerospace Engineering, May 1991, University of Texas at Austin

Professional Position

May 1994–present

Application of imaging spectroscopy (hyperspectral remote sensing) to environmental characterization and vegetation mapping. Algorithm development of advanced spectroscopic methods applied to mapping the forest cover (extent and species composition). Determination of the spectral properties of mineral and biological materials (plants, algae, and bacteria).

Selected Publications

Kokaly, Despain, Clark, and Livo, "Mapping the biology of Yellowstone National Park using imaging spectroscopy." Submitted to Remote Sensing of Environment, February 2001.

Kokaly, "Investigating a physical basis for spectroscopic estimates of leaf nitrogen concentration," Remote Sensing of Environment 75:153–161, January 2001.

Karnieli, Kokaly, West, and Clark, "Remote sensing of biological soil crusts." Book chapter in Biological Soil Crusts: Structure, Function and Managements, Springer. [In preparation]

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Schluessel, Dickinson, Privette, Emery, and Kokaly, "Modeling the bi-directional reflectance distribution function of mixed finite plant canopies and soil." Pages 10577–10600 *in* Journal of Geophysical Research, Vol. 99, No. D5, May 1994.

Professional Organizations

American Geophysical Union American Indian Science & Engineering Society

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Education

M.S., 1991, Natural Resources, Humboldt State University, Arcata, California

B.S., 1985, Forest Management, University of California, Berkeley, California

Professional Position

Ms. Goodman provides technical, scientific and policy leadership in Geographic Information Systems (GIS) in Wildland Fire Management for the Bureau of Land Management, Department of Interior, other agencies, and the public. Her current interests are making GIS more assessable to the wildland fire community, interagency fire perimeter data standards, incorporating a spatial component for all aspects of fire, and finding ways that are more efficient to monitor the results of prescribed fires.

Areas of Interest

Spatially integrating all aspects of wildland fire, vegetation trend analysis, silviculture, data analysis, statistics, and prescribed fire

Job-related Training Courses

- Technical Fire Management—1992
- Fire and Ecosystem Management
- S-490 Advanced Fire Behavior
- S-390 Intermediate Fire Behavior
- S-190 Basic Fire Behavior
- S-130 Basic Firefighting
- Single Resource Crew Boss School
- Fire Statistics
- Fire Economics
- Experimental Design and ANOVA
- Visual Basic

Papers

Goodman, S., B. Keating, A. Konduris, and R. Jackson. Vegetation fuels trend analysis after prescribed fires: *Supplementing Traditional Fire Fuels Mapping Using Multi-Source Imagery* Proposal. October 1998. Work in Progress.

Goodman, S. Debris Prediction Equations for Ponderosa Pine (*Pinus ponderosa*) Plantation. Presented to Technical Fire Management Panel April 1992.

Phillips, S. Regenerating Douglas-fir (*Pseudotosuga menziesii*) on South Facing Slopes in West-Central Montana. Master Thesis, Humboldt State University, Arcata, California, April 1991.

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Education
M.S. Candidate, 2001, GIS/Remote Sensing, Colorado State University, Fort Collins, Colorado
B.S., 1979, Forest Management, Colorado State University, Fort Collins, Colorado

Professional Interests
Ms. Walker provides technical, scientific and project leadership in Remote Sensing and Geographic Information Systems (GIS) in Wildland Fire Management, Hazardous Material Remediation, Abandoned Mine Characterization, Vegetation Classification, and other natural resources concerns for the Bureau of Land Management, Department of Interior, other agencies, and the public. Her current projects include being a cadre member for several GIS courses and hands-on workshops, mapping wildfires with thermal infrared imagery, managing the bureau satellite data archive, and mapping coal-bed methane gases and thermal anomalies using remote sensing technologies.

Areas of Interest
Assessing the affects of wildfires using Landsat Thematic Mapper data, the use of MODIS (Moderate Resolution Imaging Spectroradiometer) for natural resource applications, and providing spatial data sets to the users via the Internet using Arc Internet Map Server.

Job-related Training Courses
- I-443 Infrared Interpreter
- S-390 Intermediate Fire Behavior
- S-190 Basic Fire Behavior
- S-130 Basic Firefighting

Papers
Walker, M. 1996. Granite Butte Elk GIS Project, Proceedings GIS/LIS '96, Denver, Colorado, November 19–21, 1996.

Walker, M., A. Cook, J. Ferguson, and S. Noble. 1996. The Southwest Colorado Vegetation Classification Project: An Example of Interagency Cooperation. Proceedings of the Sixth Forest Service Remote Sensing Applications Conference, Denver, Colorado, April 29–May 3, 1996.

Walker, M. 1987. Is There Life for a Stereoplotter after DMA? Proceedings International Conference and Workshop on Analytical Instrumentation, Phoenix, Arizona, November 2–6, 1987.

Publications
Walker, M., J. Casper, F. Hissong, and E. Rieben. 2000. GIS: A New Way To See. Science and Children, January 2000.

Walker, M., A. Cook, and J. Ferguson. 1999. Integrating Remote Sensing Technologies for Large-scale Vegetation Mapping. Systems and Information Technology Journal, Fall/Winter, 1999.

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Education

M.S., 1995, Forest Ecology, Northern Arizona University, Flagstaff, Arizona

B.S., 1992, Biology, University of North Carolina, Chapel Hill, North Carolina

Professional Position

Ms. McAdams coordinates fire planning activities for all Fish and Wildlife Service facilities in the Pacific Region (CA, HI, ID, NV, OR, WA). She reviews potential ecological impacts of fire management actions, develops and manages the fire effects monitoring program, and ensures compliance of fire activities with the Endangered Species Act, National Environmental Policy Act, and National Historic Preservation Act.

Areas of Interest

Application of ecologically based management objectives for wildland and prescribed fire, including development of a fire effects monitoring program.

Job-related Training Courses

- RX-340: Fire Effects
- Fire Program Management.
- S-390: Intermediate Fire Behavior
- RX-90: Prescribed Fire for Burn Boss
- PFPI: Prescribed Fire Planning and Implementation
- RX-230: Ignition Specialist
- S-212: Power Saws
- S-200: Incident Commander
- S-190: Basic Fire Behavior
- S-130: Basic Firefighter

Publications

McAdams, A. Changes in ponderosa pine forest structure in the Black Hills, South Dakota, 1874–1995. M.S. Thesis, Northern Arizona University, Flagstaff, December 1995.

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Education

B.S., 1977, Geography, Western Illinois University, Macomb, Illinois
Graduate Work, 1980, Geography, San Diego State University, San Diego, California

Professional Position

Mr. Jackson provides technical and scientific leadership in photogrammetry and image processing technologies in support of a variety of Bureau of Land Management programs, including Wildland Fire Management, Visual Resource Management, Oil and Gas, Recreation, Cadastral Boundary Investigations, Wildlife, and Law Enforcement.

Publications

Jackson, “The Inclusion of Photogrammetry in the Resource Assessment Process,” ASPRS/ACSM Annual Convention, 1996.

Jackson, Matthews, "So You Want to Build a Transportation Network." ASPRS Annual Convention, 1998.

Papers

Goodman, Keating, Konduris, and Jackson. Vegetation Fuels Trend Analysis After Prescribed Fires, *Supplementing Traditional Fire Fuels Mapping Using Multi-Source Imagery Proposal*, October 1998. Work in Progress.

Professional Society Membership

American Society of Photogrammetry and Remote Sensing

Professional Certifications

Certified Photogrammetrist–American Society of Photogrammetry and Remote Sensing

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Education
M.S., Watershed Science, August 1998, Colorado State University, Fort Collins
B.A., Geology, May 1977, Hartwick College, Oneonta, New York

Professional Position
May 2001–present
Development of Wildland/Urban Interface data in support of National Fire Plan for the NPS Intermountain Region. Assistance in GIS mapping of fire data and development of attribute standards. Metadata development for fire data throughout the IMR.

Professional Organizations
American Society of Photogrammetry & Remote Sensing
American Water Resources Association
Rocky Mountain Association of Geologists

Proposed Contributions of Collaborators

Russell Jackson–Produce digital elevation models from IKONOS and assist with field work

Bruce Keating–Provide technical expertise in remote sensing and assist with field work

Gretchen Meyer–Provide technical expertise in remote sensing and assist with field work

John Glenn–Provide technical expertise in wildland fire and assist with field work

Ken Stinson–Provide technical expertise in prescribed fire, plant identification, and assist with field work

Jim Wolf–Provide technical expertise in prescribed fire, plant identification, and assist with field work

Andrew Goheen–Provide technical expertise in prescribed fire, plant identification, and assist with field work

Jenny Barnett–Provide technical expertise in plant identification and assist with field work

David Hammond–Provide technical expertise in remote sensing and FARSITE

Appendix: Budget

Itemized Budget, Year 1

Principal Investigators	Hours	Requested Salary	Contributed Salary	Total
PI, Physical Scientist	320		$15,498	$15,498
PI, Fire Management Specialist (BLM)	160		$6,095	$6,095
PI, Fire Management Specialist (FWS)	160		$5,692	$5,692
PI, Geophysicist (*see note 1*)	400	$16,080		$16,080
PI, Remote Sensing Specialist	240		$8,938	$8,938
Sub-Total, Principal Investigators, Year 1	1,280	$16,080	$36,223	$52,303
Collaborators	Hours	Requested Salary	Contributed Salary	Total
USGS-Lab Technician (*see note 1*)	1,560	$46,800		$46,800
BLM–Senior Technical Specialist	80		$3,840	$3,840
BLM–Remote Sensing Specialist	240		$8,160	$8,160
BLM–Photogrammetrist	40		$1,600	$1,600
BLM–State Fire Management Officer	160		$5,597	$5,597
BLM–Prescribed Fire Specialist	80		$2,720	$2,720
BLM–Rangeland Specialist	80		$2,400	$2,400
FWS–Prescribed Fire Specialist	80		$2,384	$2,384
FWS–Biologist	80		$2,692	$2,692
NPS–Fire GIS Specialist	160		$4,000	$4,000
Sub-Total, Collaborators, Year 1	2,560	$46,800	$33,393	$80,193
Indirect Costs, Requested Salary, (15%)		*$9,432*		*$9,432*
Total Hours/Salary, Year 1	**3,840**	**$72,312**	**$69,616**	**$141,928**
Travel	Number of Persons	Requested Cost	Contributed Cost	Total
Team coordination (1 day meeting)	6	$2,500		$2,500
Field data collection (2 weeks)	6	$15,000		$15,000
Annual 3-day PI workshop	5	$5,000		$5,000
Sub-Total, Travel Cost, Year 1		$22,500		$22,500
Data Collection	Area	Requested Cost	Contributed Cost	Total
HyMap Hyperspectral–4m spatial res. BLM site	100 km^2	$20,000		$20,000
IKONOS—Pan + MSS	100 km^2		$8,000	$8,000
2 Field Spectrometers (ASD Field Spec PRO FR)			$10,000	$10,000
Equivalent rental cost (2 weeks ea. & $10,000/mo)				
Sub-Total, Data Collection Costs, Year 1		$20,000	$18,000	$38,000
Supplies/Misc. Expenses		Requested Cost	Contributed Cost	Total
Chlorophyll A/B Lab spectrometer system and scales for plant moisture measurements		$10,000		$10,000
Laboratory supplies (glassware, solutions, etc) for Chlorophyll & moisture content measurements		$5,000		$5,000
4 handheld computers for field data tabulation		$6,000		$6,000
High capacity computer disk storage, r/w DVD's, and media		$5,000		$5,000
Office supplies		$1,000		$1,000
Laboratory facilities (4 sites, .25 year each)		$10,000		$10,000
Sub-Total Supplies/Misc. Year 1		$27,000	$10,000	$37,000
Total Non-salary Costs Year 1		**$69,500**	**$28,000**	**$97,500**
		Requested	**Contributed**	**Total**
GRAND TOTAL, Salary + Costs, Year 1		**$141,812**	**$97,616**	**$239,428**

Itemized Budget, Year 2

Note salaries include 5% inflation increase for year 2.

Principal Investigators	Hours	Requested Salary	Contributed Salary	Total
PI, Physical Scientist	320		$16,272	$16,272
PI, Fire Management Specialist (BLM)	160		$6,400	$6,400
PI, Fire Management Specialist (FWS)	160		$5,976	$5,976
PI, Geophysicist (*see note 1*)	400	$16,880		$16,880
PI, Remote Sensing Specialist	240		$9,385	$9,385
Sub-Total, Principal Investigators, Year 2	1,280	$16,880	$38,033	$54,913
Collaborators	Hours	Requested Salary	Contributed Salary	Total
USGS-Lab Technician (*see note 1*)	1,560	$49,140		$49,140
BLM–Senior Technical Specialist	80		$4,032	$4,032
BLM–Remote Sensing Specialist	240		$8,568	$8,568
BLM–Photogrammetrist	40		$1,680	$1,680
BLM–State Fire Management Officer	160		$5,877	$5,877
BLM–Prescribed Fire Specialist	80		$2,856	$2,856
BLM–Rangeland Specialist	80		$2,520	$2,520
FWS–Prescribed Fire Specialist	80		$2,503	$2,503
FWS–Biologist	80		$2,826	$2,826
NPS–Fire GIS Specialist	160		$4,200	$4,200
Sub-Total, Collaborators, Year 2	2,560	$49,140	$35,062	$84,202
Indirect Costs, Requested Salary, (15%)		*$9,903*		*$9903*
Total Hours/Salary, Year 2	**3,840**	**$75,923**	**$73,095**	**$149,018**
Travel	Number of Persons	Requested Cost	Contributed Cost	Total
Team coordination (1 day meeting)	6	$2,500		$2,500
Field data collection (2 weeks)	6	$15,000		$15,000
Annual 3-day PI workshop	5	$5,000		$5,000
Sub-Total, Travel Cost, Year 2		$22,500		$22,500
Data Collection	Area	Requested Cost	Contributed Cost	Total
HyMap Hyperspectral–4m spatial res. FWS site	100 km^2	$21,000		$21,000
Ikonos–Pan + MSS, terrain corrected	100 km^2	$10,000		$10,000
2 Field Spectrometers (ASD Field Spec PRO FR) Equivalent rental cost (2 weeks ea. & $10,000/mo)			$10,000	$10,000
Sub-Total Data Collection Costs Year 2		$31,000	$10,000	$41,000
Supplies / Misc. Expenses		Requested Cost	Contributed Cost	Total
Laboratory supplies (glassware, solutions, etc) for Chlorophyll & moisture content measurements		$5,000		$5,000
Computer media/office supplies		$2,500		$2,500
Laboratory facilities (4 sites, .25 year each)			$10,000	$10,000
Sub-Total, Supplies/Misc., Year 2		$7,500	$10,000	$17,500
Total Non-salary Costs, Year 2		**$61,000**	**$20,000**	**$81,000**
		Requested	**Contributed**	**Total**
GRAND TOTAL, Salary + costs, Year 2		**$136,923**	**$93,095**	**$230,018**

Itemized Budget, Year 3

Note salaries include 5% inflation increase for year 3.

Principal Investigators	Hours	Requested Salary	Contributed Salary	Total
PI, Physical Scientist	320		$17,085	$17,085
PI, Fire Management Specialist (BLM)	160		$6,720	$6,720
PI, Fire Management Specialist (FWS)	160		$6,275	$6,275
PI, Geophysicist (*see note 1*)	400	$17,720		$17,720
PI, Remote Sensing Specialist	240		$9,854	$9,854
Sub-Total, Principal Investigators, Year 3	1280	$17,720	$39,934	$57,654
Collaborators	Hours	Requested Salary	Contributed Salary	Total
USGS-Lab Technician (*see note 1*)	1,560	$51,597		$51,597
BLM–Senior Technical Specialist	80		$4,234	$4,234
BLM–Remote Sensing Specialist	240		$8,996	$8,996
BLM–Photogrammetrist	40		$1,764	$1,764
BLM–State Fire Management Officer	160		$6,171	$6,171
BLM–Prescribed Fire Specialist	80		$2,999	$2,999
BLM–Rangeland Specialist	80		$2,646	$2,646
FWS–Prescribed Fire Specialist	80		$2,628	$2,628
FWS–Biologist	80		$2,967	$2,967
NPS–Fire GIS Specialist	160		$4,410	$4,410
Sub-Total, Collaborators, Year 3	2,560	$51,597	$36,815	$88,412
Indirect Costs, Requested Salary, (15%)		*$10,398*		*$10,398*
Total Hours/Salary, Year 3	**3,840**	**$79,715**	**$76,749**	**$156,464**
Travel	Number of Persons	Requested Cost	Contributed Cost	Total
Team coordination (1 day meeting)	6	$2,500		$2,500
Field verification measurements (1 week, each site)	6	$12,000		$12,000
Presentation of results at scientific meetings	5	$7,500		$7,500
Annual 3-day PI workshop	5	$5,000		$5,000
Sub-Total, Travel Cost, Year 3		$27,000		$27,000
Data Collection	Area	Requested Cost	Contributed Cost	Total
2 Field Spectrometers (ASD Field Spec PRO FR) Equivalent rental cost (1 week ea. & $10,000/mo)			$5,000	$5,000
Sub-Total Data Collection Costs Year 3			$5,000	$5,000
Supplies / Misc. Expenses		Requested Cost	Contributed Cost	Total
Computer media /office supplies		$2,500		$2,500
Publication costs		$2,500		$2,500
Laboratory facilities (4 sites, 25 year each)		$10,000		$10,000
Sub-Total, Supplies/Misc., Year 3		$5,000	$10,000	$15,000
Total Non-salary Costs, Year 3		**$32,000**	**$15,000**	**$47,000**
		Requested	**Contributed**	**Total**
GRAND TOTAL, Salary + costs, Year 3		**$111,715**	**$91,749**	**$203,464**

Budget Summary, All Years

Principal Investigators	Hours	Requested Salary	Contributed Salary	Total
Sub-Total, Principal Investigators, Year 1	1,280	$16,080	$36,223	$52,303
Sub-Total, Principal Investigators, Year 2	1,280	$16,880	$38,033	$54,913
Sub-Total, Principal Investigators, Year 3	1,280	$17,720	$39,934	$57,654
Sub-Total, Principal Investigators, ALL YEARS	3,840	$50,680	$114,190	$164,870
Collaborators	Hours	Requested Salary	Contributed Salary	Total
Sub-Total, Collaborators, Year 1	2,560	$46,800	$33,393	$80,193
Sub-Total, Collaborators, Year 2	2,560	$49,140	$35,062	$84,202
Sub-Total, Collaborators, Year 3	2,560	$51,597	$36,815	$88,412
Sub-Total, Collaborators, ALL YEARS	7,680	$147,537	$105,270	$252,807
Indirect Salary Costs, ALL YEARS, (15%)		*$29,733*		*$29,733*
Total Hours/Salary, ALL YEARS	**11,520**	**$227,950**	**$219,460**	**$447,410**
Travel	Number of Persons	Requested Cost	Contributed Cost	Total
Sub-Total, Travel Cost, Year 1		$22,500		$22,500
Sub-Total, Travel Cost, Year 2		$22,500		$22,500
Sub-Total, Travel Cost, Year 3		$27,000		$27,000
Sub-Total, Travel Cost, ALL YEARS		$72,000		$72,000
Data Collection	Area	Requested Cost	Contributed Cost	Total
Sub-Total, Data Collection Costs, Year 1		$20,000	$18,000	$38,000
Sub-Total, Data Collection Costs, Year 2		$31,000	$10,000	$41,000
Sub-Total Data Collection Costs, Year 3			$5,000	$5,000
Sub-Total Data Collection Costs, ALL YEARS		$51,000	$33,000	$84,000
Supplies / Misc. Expenses		Requested Cost	Contributed Cost	Total
Sub-Total Supplies/Misc., Year 1		$27,000	$10,000	$37,000
Sub-Total, Supplies/Misc., Year 2		$7,500	$10,000	$17,500
Sub-Total, Supplies/Misc., Year 3		$5,000	$10,000	$15,000
Sub-Total, Supplies/Misc., ALL YEARS		$39,500	$30,000	$69,500
Total Non-salary Costs, ALL YEARS		**$162,500**	**$63,000**	**$225,500**
		Requested	**Contributed**	**Total**
GRAND TOTAL, Salary + costs, ALL YEARS		**$390,450**	**$282,460**	**$672,910**

Justification of Need for Salary Support

The salary funding policy of the Crustal Imaging and Characterization Team, Geologic Discipline of the U.S. Geological Survey, is proposal-based with a full-cost accounting. As a result of this structure, all projects must provide funding for salary time and operating expenses to meet the objectives of the proposed work. The current assignments of *Raymond F. Kokaly* are not within the guidelines of the work outlined in this proposal; therefore, the requested salary support is required and justified.

Certification to the Joint Fire Science Program
Justification of Need for Salary Support

I hereby certify the attached Justification of Need to provide temporary salaries for full-time permanent employee(s) *Raymond F. Kokaly* is necessary and appropriate for enabling him/her/them to fully and directly participate in the proposed project.

I understand that salary funding for this/these employee(s) directly involved in the proposed project is temporary and will not be provided beyond the duration of the proposed project.

Signature ______________________________ Date______________

Victor Labson, Team Chief Scientist
Crustal Imaging and Characterization Team
U.S. Geological Survey