United States
Environmental Protection
Agency

Imaging Spectroscopy for Determining Rangeland Stressors to Western Watersheds

Pollution Prevention and New Technology

EPA/600/R-01/004
April 2002

Imaging Spectroscopy for Determining Rangeland Stressors to Western Watersheds

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by

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Section 1

Core Task Summary

The Environmental Protection Agency is developing rangeland ecological indicators in twelve western states using advanced remote sensing techniques. Fine spectral resolution (hyperspectral) sensors, or imaging spectrometers, can detect the subtle spectral features that make vegetation and soil discrimination possible. This study will use hyperspectral remote sensing data, such as NASA's Airborne Visible-Infra-Red Imaging Spectrometer (AVIRIS), a system capable of 5 to 20 meter spatial resolution. Airborne and satellite remote sensing will provide vegetation mapping at the species level, soil types and characteristics, and landscape information such as erosional features. Vegetation community structure, spatial distribution, and health can then be determined and combined with climatic data to classify rangeland condition and identify disturbed regions.

Accurate determination of rangeland vegetation and soils is required to establish reliable landscape indicators. Rangelands in the West encompass a range of ecological conditions or states from healthy to at risk to degraded. This gradient of conditions can be quantitatively determined and used to develop landscape indicators. Vegetation communities differ over the gradient of rangeland conditions. Soil attributes such as organic matter content, salinity, moisture, mineralogy, and physical condition influence and are influenced by vegetation cover. The water quality of the watershed is directly impacted by these rangeland variables. Imaging spectroscopy can detect these variables and allows for landscape scale assessment and monitoring of stressors to water resources in the West.

Potential research with the Bureau of Land Management, US Department of Agriculture, and U.S. Geological Survey will correlate remote sensing data with ground measurements. The long-term goal of this work is to develop a methodology using current technologies for use with the forthcoming hyperspectral satellite platforms scheduled for operational service within the next 2 to 3 years.

Section 2

Core Task Narrative

Goals/Objectives

The long-term goal of this research is to institute the use of imaging spectroscopic and radar methods for relating rangeland landscape pattern and biophysical variables to watershed condition. The objectives of this project are to:

- Identify and map at a fine spatial resolution biophysical variables such as vegetation communities at the species level and soil types
- Determine the extremes of rangeland condition using remote sensing and correlate these with ground measurements. Identify and evaluate the gradients that exist between the extremes of rangeland conditions
- Establish landscape ecological indicators that predict the condition of rangelands in the West
- Refine landscape pattern metrics that relate to functioning and degraded watershed conditions

Background/Literature Review

Statement of Problem

Rangelands are valuable natural resources that provide forage for livestock as well as wildlife habitat and recreational opportunities. The nation's rangelands encompass more than 310 million hectares, primarily in the western states. Rangelands regulate the quantity and quality of water for the surrounding watersheds. Rangeland vegetation has the ability to intercept runoff from rain events, and increase water infiltration to the soil allowing for aquifer recharge. Rangeland soils contribute to water quality by immobilizing and transforming nutrients and contaminants and act as a groundwater filter. Rangeland degradation can be caused by overgrazing, drought, improper recreational use, and other anthropogenic and natural stresses. Information on the condition, or state of the nation's rangelands is important for the protection of these resources.

The demands placed upon rangelands are escalating as the populations of the western states increase. Development of land for commercial and residential use can remove areas of rangeland for these purposes, simultaneously increasing the utilization of the remaining rangelands. Rangeland function can be defined as the ability of the rangeland ecosystem to provide commodities such forage and habitat, regulate water quantity and quality, and provide recreational opportunities. Improper rangeland management practices can cause severe degradation that can lead to irreversible changes of the ecosystem. Degradation of these areas can negatively impact the surrounding watersheds through soil erosion and desertification.

There is an urgent need for resource managers to know the state of the nation's rangelands, knowledge that is hampered by lack of reliable and continuous data especially over large regional or watershed scales. Development of data collection systems and ecological assessment methods are required to evaluate and monitor these resources (National Research Council, 1994).

Problem

Livestock overgrazing, climate change, and certain types of land use can lead to a decline in rangeland condition. The recovery process of rangelands to severe degradation may be long, or might never occur (West et al., 1984). Arid and semi-arid ecosystems are especially prone to degradation due to climatic conditions and major population shifts to the western US. The time scales and vegetal dynamics associated with the recovery process is not fully understood for these ecosystems (Anderson and Holte, 1981).

Grazing pressure/intensity: Rangeland ecosystems vary due to the climatic and geologic conditions of the region. Each rangeland ecosystem is a complex combination of vegetation species and soil types. The carrying capacity for each rangeland is unique because of this ecological variability. Grazing pressure or intensity is a way to determine if livestock utilization of a rangeland is proportional to the area's carrying capacity. Grazing pressure is defined as the hypothetical Animal Unit Months (AUM), the amount of forage required to support a cow and calf for one month according to the area's carrying capacity (Mouat et al., 1997). High grazing pressure, as well as several other factors, may lead to loss of desirable or palatable forage species, encroachment of non-palatable species, and topsoil erosion due to overall groundcover loss (Sedgwick and Knopf, 1991).

Long term ecological studies on rangeland vegetation response to grazing practices have shown the changes occurring are not continuous, reversible or consistent (Westoby et al., 1989). Previous ecological theory held that plant communities strive toward a climax condition. Changes in vegetation species and abundance due to disturbance follow a linear path from the climax state to degraded states. This ecological succession model can be applied to rangeland management decisions. Vegetation response due to grazing pressure could then be managed by varying the stocking rate for a particular rangeland site. However, a wealth of evidence from rangeland studies now indicates that the successional theory does not hold, especially for arid and semi-arid ecosystems (Westoby et al., 1989).

Vegetation dynamics are now described by a phase transition model that allows for discrete transitions between a set of states (Westoby et al., 1989). The state and transition theory proposes that 1) plant communities changes may not be reversible to a parent climax state; 2) plant communities may not be in equilibrium with the current climate; and 3) random (stochastic) events may influence changes in vegetation dynamics.

Climate change: Climate is a major controlling factor for vegetation in the western rangelands (Olsen et al., 1985). Drought is the greatest determinant of vegetation change, and trends in vegetative cover can be directly related to climatic fluctuations. Within trends of vegetation change, grazing has a large impact on vegetation resilience and recovery. Native rangeland vegetation has developed under widely varying climatic conditions, and it takes a severe, long-term drought to destroy plant communities in these ecosystems (Cook and Sims, 1975). Rangeland resource managers must be sensitive to climatic fluctuations as well as grazing pressure and stocking rates to maintain rangeland productivity and environmental quality effectively.

Invasive species: Livestock often graze on forage preferentially according to their nutritional needs. This selective grazing tends to reduce relatively homogenous vegetation units into a landscape mosaic of heavily grazed and lightly grazed patches of vegetation (Bakker et al., 1983). Over grazed units are usually characterized by invasive or exotic plant species of little forage value to wildlife and livestock (Hatch and Tainton, 1991). These patches tend to increase in area and number as this type of grazing continues (Fuls, 1992). Overall species diversity is low in the disturbed areas, a situation that may lead to exotic species invasion (Pimm, 1991). However, recent work by Stohlgren et al., (1999) has shown that the richness (or dearth) of species diversity is not always a predictor of exotic invasibility. The invasibility of certain landscapes depends upon variables such as availability of resources, spatial scale, species-specific responses to grazing and other disturbances, and vegetation and biome types. Landscape scale inventorying and monitoring of invasive species along with the study of the effects of invasive species across gradients of resource availability is required to deal with this problem (Stohlgren et al., 1999).

The vegetation communities forming the landscape mosaic are determined by soil types, grazing pressure, and climate. Community composition can be used to identify disturbance and estimate site degradation. Weixelman et al. (1997) identified plant community compositions that corresponded to range condition of the site. A gradient was determined ranging from a grass dominated state being the most desirable, to a grass/forb/shrub state of low productivity.

Overgrazing changes the soil moisture capacity due to the reduction of basal cover (Figure 1). Less vegetative soil cover results in increased evaporation. Absence of plants increases the runoff potential and also decreases the permeability of the soil from lack of plant rooting and soil compaction. More drought tolerant plants such as shrubs displace grass species and the area begins to convert from a grassland to a woodland, and from a stable soil environment to an erosional landscape (Freidel, 1991). The conversion of grassland to a shrub dominated system increases the spatial heterogeneity of water and nutrients in the soil (Fuls, 1992). Such changes are often irreversible in arid and semi-arid ecosystems.

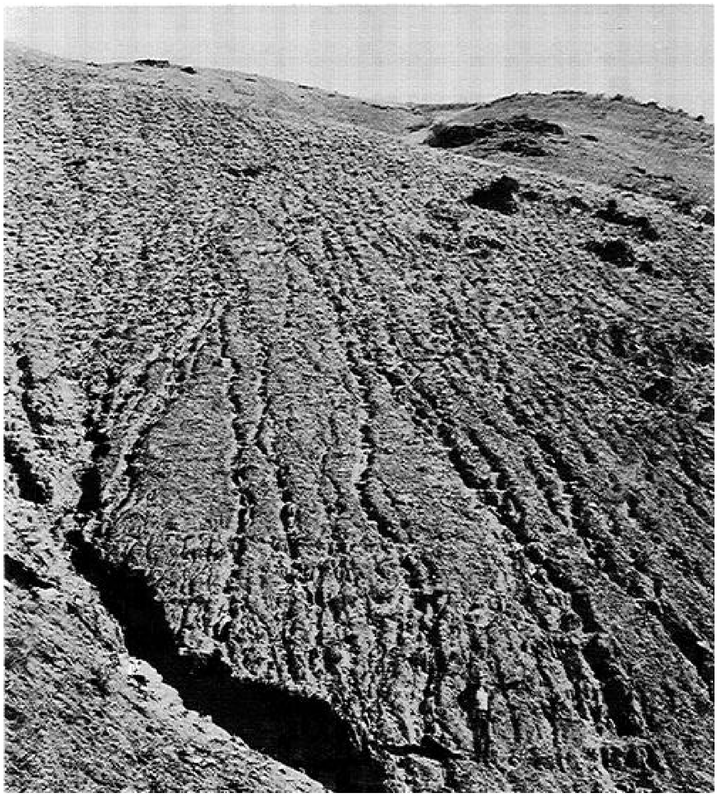

Figure 1. Rill and gully formation due to soil erosion (National Research Council, 1994).

Watershed impacts: Watershed function (soil moisture storage, water table stability, percolation) and water quality is impacted by rangeland topsoil loss and erosion. Streams in arid and semi-arid environments produce the highest sediment yields over the runoff season (Langbein and Schumm, 1958). Infrequent rainfall creates sparse vegetation distributions. This natural lack of vegetation allows for greater runoff and sediment yield in grassland dominated ecosystems than in forested regions. These environments usually have intense rainfall events, which increases the movement of soil particles off the soil surface (Gordon et al., 1992). Soil stability directly influences the condition of rangeland watersheds (Branson et al., 1981). The stability of the soil is determined by the vegetative composition and grazing intensity of the site, and climatic and landscape variables (Fuls, 1992). Denuding of vegetation by overgrazing exposes the soil to increased solar radiation and erosion by wind and water. Erosion removes the surface horizon of the soil, along with most of the soil organic matter and nutrients. Without the plant canopy, the high incident solar radiation increases the temperature of the soil. Soil denitrification occurs as the ability of nitrogen oxidizing bacteria declines at soil surface temperatures above 40°C (Van Wambeke, 1992). Loss of the surface horizon and organic matter causes a crusting of the soil surface, preventing water infiltration and seed germination (Brady, 1990).

Streambank erosion is a natural and continuous process in stream evolution. The banks of streams can become unstable if the annual amounts of sediment and organic debris are reduced. Periods of greatly increased sediment input can alter stream morphology and instream biotic ecology. Streams in semi-arid regions have greater variation in sediment loads than streams in humid environments (Nordin, 1985). Excessive erosion produces sediment in quantities that can severely impact the environmental quality of the receiving waters. Sediment particles contain nutrients that may cause eutrophication of downstream water bodies. The eutrophication may be less of a problem waters receiving sediments from nutrient poor soils of the arid and semi-arid western US. The sedimentation of streams and lakes results in increased turbidity, streambed blanketing, habitat destruction, and other deleterious impacts (Pierzynski et al., 1994). High turbidity reduces the photosynthetic ability of aquatic plants, disturbing the energy flow of the system. Voluminous sediments irritate fish gills, blanket spawning beds, and reduce visibility (Rabeni and Smale, 1995). Long term accumulation of sediment can foul water supply intakes and fill in navigable waterways.

Development of Ecological Indicators to Assess Rangeland Condition

Need: The National Research Council in 1994 determined that all attempts at national-level assessment revealed that significant degradation is occurring on a majority of rangelands in the United States. The council also determined that despite the evidence of historical and current rangeland degradation, inadequate data on current rangeland conditions exist. To add to the problem, there is no consensus between managing agencies on how to assess and monitor the status and health of these resources (National Research Council, 1994). Further, the ability to measure rangeland health reliably and efficiently, and in a systematic manner, over the western U.S. is currently lacking. Extensive monitoring of rangeland condition is inhibited by several factors; debates over the methods employed for rangeland assessment, the cost of large scale measurements and research, and a lack of proven technology for variable quantification.

A coordinated federal effort is required to develop, test, and standardize indicators and methods for inventorying and monitoring rangeland health (National Research Council, 1994). This effort should be coordinated with the federal environmental and agricultural programs to:

1. Develop a set of indicators for a minimum dataset for inventorying and monitoring rangeland health.

2. Standardize methods of measuring indicators and categorizing rangelands as healthy, at risk, or unhealthy
3. Validate the indicators and methods selected by field testing
4. Quantify the correlation between measures of rangeland health and condition

Indicators: Determination of rangeland condition is a complex task, a mixture of judgement and quantification that requires an interdisciplinary approach to solve. The ecological processes controlling degradation and recovery are numerous and not fully understood (Teuller, 1973, Glenn-Lewin and van der Maarel, 1992). Ecological indicators relating to rangeland condition can be measured and used to understand the status or health of the ecosystem. Proper selection and measurement of indicators can tell the manager whether an ecosystem is healthy, at risk of deterioration, or unhealthy. Defining rangeland condition this way requires the determination of boundaries between healthy, at risk, and unhealthy. Selected ecological indicators are used to assess the state of a rangeland, and long term monitoring will tell if the system is deteriorating to a lower state, or recovering to a higher state. By understanding the relationship between the ecological indicators and the state of the ecosystem, thresholds can be developed to define the boundary between at risk and unhealthy conditions. These boundaries are significant since they represent a possible irreversible shift to a state of lowest productivity and environmental quality (National Research Council, 1994).

Indicators recognized by the National Research Council (1994) are established around three criteria; 1) soil stability and watershed function, 2) nutrient cycling and energy flow, and 3) recovery mechanisms. These criteria encompass a host of indicators relating to the overall condition of a given rangeland (Table 1). All three criteria are interconnected, and one by itself cannot be used to determine an area's ecological status.

Table 1. Criteria and Indicators of Rangeland Health (Adapted from National Research Council, 1994)

Criteria	Indicators
Soil Stability and Watershed Function	A-horizon present Rills and gullies Pedestaling Scour or sheet erosion Sedimentation of dunes
nutrient cycling and energy flow	Distribution of plants Litter distribution Rooting depth Photosynthetic period
recovery mechanisms	Plant age-class distribution Plant vigor Germination and presence of microsites

Use of Remote Sensing to Develop Rangeland Ecological Indicators

Satellite and airborne remote sensing has been a powerful tool for the analysis of earth features. Remote sensing data has been used to solve complex environmental problems, investigate the impacts for global change, identify archeological sites, and solve geopolitical-political problems (Lillesand and Kiefer, 1994). Ecological and environmental applications often involve point or plot measurements taken in the field. Many resources vary in space and time, and sampling these variations is difficult (Lyon et al., 1992). Remote sensing affords the user the opportunity to sample multiple dates and extrapolate point measurements collected in the field over large spatial scales (Lyon and McCarthy, 1995, Vincent, 1997).

There have been many uses of remote sensing to inventory and assess rangelands (Tueller, 1992). Landsat TM imagery has been used to estimate rangeland plant productivity, monitor change, and identify disease and pest outbreaks (Haas, 1992). Airborne multispectral video has been successfully employed to distinguish plant communities and species and detect drought stress, grazing intensity, and burned areas (Everitt and Escobar, 1992).

The use of remote sensing data as input to an ecological model is an important next step for rangeland assessment and monitoring. Landscape ecological models require spatially-intensive data (Lobo et al., 1998). Remote sensing provides this information, often at the fine spatial resolution and large areal extents needed for most landscape studies (Frohn, 1997).

Remote sensing systems: Remote sensing systems operate by observing the interactions of electromagnetic (EM) radiation with materials on the surface of the earth (Figure 2) (Vincent, 1997). These systems work by either passively collecting light energy reflected or emitted off the earth's surface, or by actively transmitting EM radiation and collecting the reflected or scattered energy from the source. Both active and passive systems record different information regarding the physical and chemical properties of a material. These systems can complement each other greatly by simply gathering more information on a material than one system could do alone.

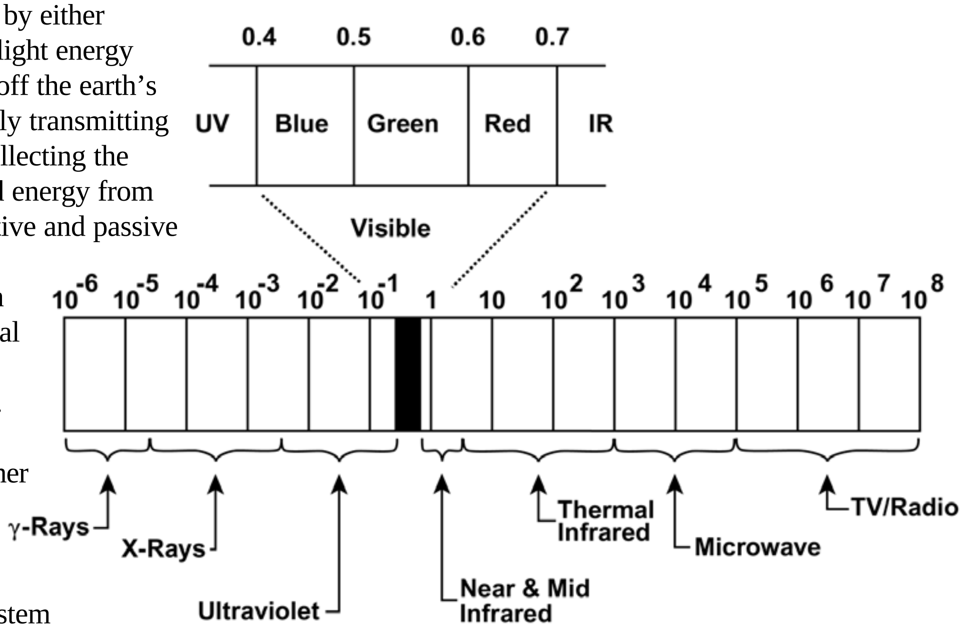

Figure 2. The electromagnetic spectrum. Scale in micrometers (μm).

Section 3

Imaging Spectroscopy

Materials such as minerals, vegetation, and man-made substances have characteristic reflectance spectra caused by the absorption and emission of impinging EM energy. Multispectral systems are not designed to sample a large portion of the EM spectrum at a fine detail, and may miss important information contained in the non-sampled bands. Diagnostic absorption features that characterize materials often occur over a small portion of the spectrum (Clark, 1999). The large, noncontinuous bands of sensors such as Landsat, SPOT, ASTER, and others are not able to detect these subtle features.

Hyperspectral sensors are designed to sample, or image a large segment to the EM spectrum, usually visible to near Infra-Red (NIR) at a fine spectral resolution (Green et al., 1990). These systems are termed imaging spectrometers since they collect data in ways similar to laboratory reflectance spectrometers. Imaging spectrometers can see absorption bands not detectable by other systems, making them the preferred sensor for accurate material identification (Clark, 1997).

Spectral reflectance of vegetation: Vegetation has a very characteristic spectral reflectance, or signature caused by chlorophyll absorption of a segment of the EM spectrum known as photosynthetic active radiation (PAR). The two chlorophyll types, a and b, absorb light energy at 0.43 - 0.66 µm and 0.45 - 0.64 µm respectively (Schanda, 1986). Leaf chemistry also produces spectral features that can vary according to plant species and health. Absorption features associated with foliar nitrogen, lignin, and cellulose concentration can be diagnostic (Martin et al., 1998). Water is a strong absorbent of light and these absorption bands can be related to leaf moisture content (Goetz, 1983).

Discrimination of plant species using imaging spectroscopy: Vegetation species can be characterized by plant and leaf structure and foliar chemical composition. These components affect the absorption of light in various ways (Figure 3). The physical properties of the plant canopy, such as leaf size (leaf area index), orientation (leaf angle distribution), and woody stem abundance relates to overall canopy spectral reflectance (Ramsey and Jenson, 1995). These properties, together with leaf chemistry, create a spectral “fingerprint” which is used to identify plant species and physiology (Martin et al., 1998).

The diagnostic spectral features produced by the physical and chemical properties of vegetation occur over discrete wavelengths. These features can be resolved by removal of the continuum in the spectra (Clark and Roush, 1984). Two components make up the diffuse reflectance spectrum; the continuum and the actual absorption features. The continuum can be thought of as the background. Features of interest are superimposed onto this background absorption (Kokaly and Clark, 1999). The diffuse reflectance spectrum of a sample generally has an increasing slope due to a number of effects such as scattering, the additive effect of optical constants, and Beers Law (Clark et al., 1990, Clark, 1981, Morris et al., 1982). Removal of the continuum isolates the absorption band center and allows for these features to be easily compared with other diffuse reflectance spectra (Figure 4). Imaging spectroscopy can detect these subtle features, which allows for vegetation species mapping, determination of plant health, and by collecting this type of data over a long period of time, detection of environmental change (Kokaly and Clark, 1999).

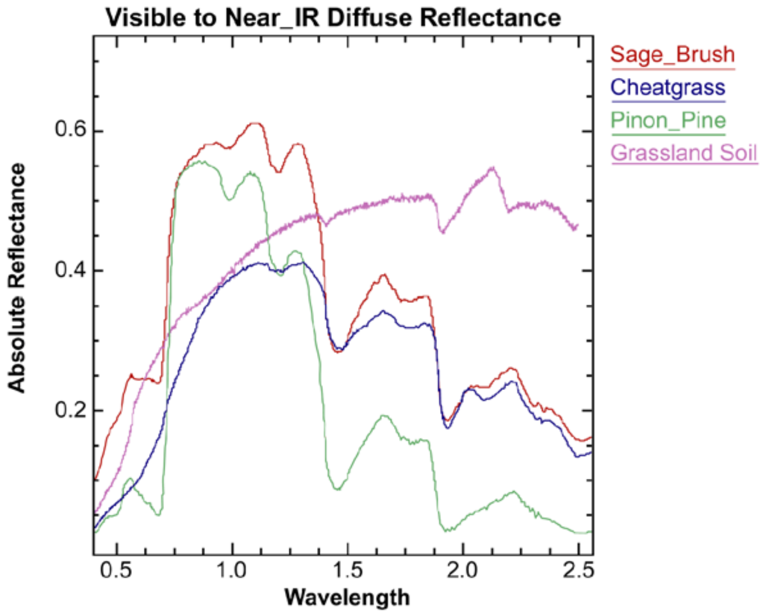

Figure 3. Spectral reflectance of common rangeland vegetation and soils. Data courtesy of USGS Speclab.

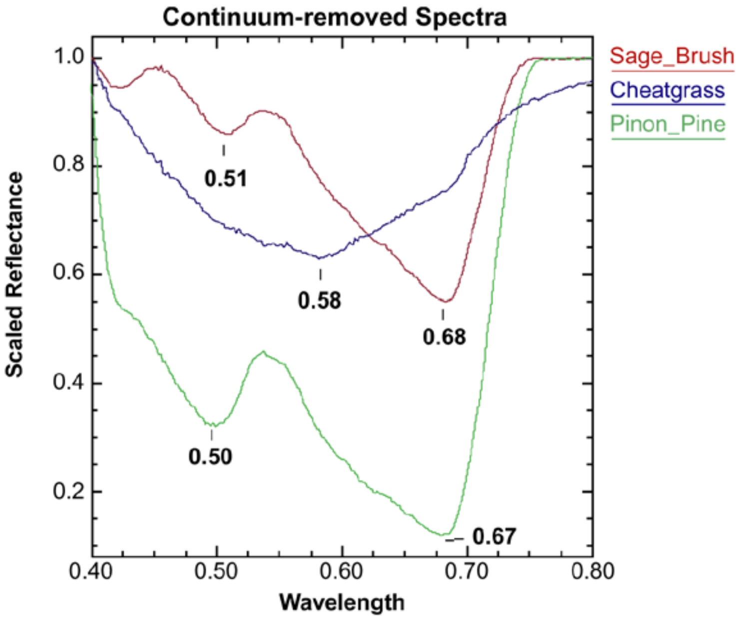

Figure 4. Comparison of vegetation species by band center analysis.

Remote sensing of vegetation in arid and semi-arid regions has proven to be challenging due to the effect of soil-vegetation mixtures within pixels (Huete et al., 1985). The low vegetation cover of these ecosystems together with the high spectral variability of the soils creates problems when trying to employ standard image analysis techniques such as vegetation indices (Elvidge and Chen, 1995). The spectral signature of these mixed pixels is so complex as to require the use of data of high spectral dimensionality to accurately determine the components occurring within the mixtures (Okin et al., 1998). Spectral unmixing techniques can be applied to hyperspectral data to analyze multiple component pixels. Methods such as linear spectral mixture analysis use spectral end-members, common components occurring within the scene that account for most of the image's spectral variability. The assumption is that most of the pixels in the scene contain some proportion of these end-members (Mustard and Sunshine, 1999). The mixed spectrum in a pixel is a linear combination of the "pure" end-member spectra, weighted for their fractional abundance within the pixel (Kruze, 1999). Mixture modeling has been successfully used to map sparse vegetation, soils, and minerals in arid and semi-arid environments (Drake et al., 1999; Okin et al., 1998; Roberts et al., 1993).

Section 4

Imaging Radar

Advanced radar systems have great promise for use in ecological studies (Kasischke, 1997). Radar systems interact with the earth's surface differently than sensors that work in the visible and NIR spectral region. Radar systems actively illuminate a scene with microwave energy and collect the reflected and scattered return of this energy (Lillesand and Kiefer, 1994). Microwave radiation is scattered according to the sensor's wavelength of operation. Objects whose height is greater than ⅛ cos 1 (where 1 is the angle between the sensor and the target) of the operating wavelength are diffuse reflectors to radar and are able to scatter energy back to the sensor. The information collected by radar systems relate to earth surface texture and dielectric variations caused by the interaction of microwave energy with conductive and resistive materials (Ulaby et al., 1982).

Traditional radar systems transmit and receive in one wavelength only. Advanced systems, such as AIRSAR can work in 3 frequencies, and thus image more of the EM spectrum than single frequency sensors. Microwave radiation is transmitted in a linear polarized wave. Most systems transmit and receive in a single specific polarization, either vertical or horizontal. AIRSAR works in a quad polarization mode by transmitting and receiving in both vertical and horizontal polarizations (Van Zyl et al., 1992). More information regarding surface characteristics can be collected in this mode. Mathematical models can be employed to analyze multifrequency polarimetric radar data to estimate a materials physical properties (Van Zyl, 1992).

Development of Landscape Ecological Indicators Using Fine Spectral and Spatial Resolution Sensors

The National Research Council (1994) recommended the development of landscape indicators for the evaluation of rangeland condition. These indicators are to be adopted by agencies responsible for the management of public and private rangelands to create a uniform assessment and monitoring system. Remote sensing is aptly suited for the identification of the components related to rangeland indicators (Haas et al., 1983). Specifically, the use of imaging spectrometry and radar can be used to accurately and reliably identify these components and, through the use of GIS, develop the rangeland ecological indicators necessary for efficient and robust assessments (Kasischke et al., 1997; Smith et al., 1995).

Determination of ecological indicators: Vegetation community structure, ecological change, and landscape pattern can be determined using various landscape metrics (Washington-Allen, 1999). The use of hyperspectral data for the derivation of landscape metrics will an innovative use of this technology. The vegetation community structure for a rangeland can be related to the area's disturbances, such as grazing, drought, fire (Fuls, 1992). Invasion of weedy species changes the community structure of a system and can indicate site degradation (Mouat et al., 1997). The ratio of perennial versus annual species, or native versus introduced species as a percent of the total vegetative coverage of an area is an important indicator of rangeland condition (Mouat et al., 1997). The fragmentation, or patchiness of an area caused by the introduction of weedy plants can be determined using landscape metrics (Frohn, 1997). The fine spatial resolution of the AVIRIS low altitude deployment can provide vegetation mapping at a resolution desirable for landscape metric analysis.

Soil mapping and soil assessment: Soils form a continuum across the landscape and do not occur as discrete homogenous units (Odeh et al., 1992). Remote sensing can provide various levels of information concerning soil properties depending on spatial scale and spectral resolution of the system (Wessman, 1990). For many decades the USDA Natural Resource Conservation Agency's Soil Survey has used aerial photography to aid in mapping soils (Soil Survey Staff, 1951). However, the use of multispectral image classification to map soils is problematic due to the complexity of the soil mixtures (Huete, 1986). Hyperspectral data can be used to evaluate these complex signatures. The relative contributions of different soil physical and chemical properties can be analyzed using mixture modeling (Boardman et al., 1995). Ahn, (1999) used linear unmixing analysis of hyperspectral imagery together with geostatistics and fuzzy clustering to create boundary maps showing delineations between soil class memberships. These soil pattern maps can be integrated using a GIS with other spatial ancillary data to create true soil maps. A comprehensive collection of soil spectra has been created by Stoner and Baumgardner (1980, 1981).

Soil classification: Soils are three-dimensional components of the landscape (Buol et al., 1989). Soil classification is the grouping of soils according to a set objective. This grouping relies on the soil's morphology, or the specific characteristics of a soil's horizons (Soil Survey Staff, 1975). Most soils, except those which are newly formed, are made up of distinct horizons that extend from the surface to often greater than 3 meters below the surface (Brady, 1994). Remote sensing is capable of imaging only the surface horizon of a soil, but useful information can be derived from this component of the soil profile. In healthy soils, the greatest amount of biological activity occurs in the surface, or A horizon of the soil profile. In the arid and semi-arid western regions of the country, the A-horizon is often very low in organic matter or is absent due to erosion or intense weathering. Soil groups, or orders (see Buol et al., 1989 for descriptions of soil orders) can be identified in part by the presence or absence of a unique surface horizon called an epipedon. Soil properties such mineralogy, structure, and organic matter content are elements of a soil's surface horizon or epipedon. These components can be quantified using remote sensing. In areas with an absent A-horizon, the surface presentation of a high clay B-horizon might be an indicator of the reduction or elimination of the overlying A-horizon.

Soil mineralogy: Soils are a matrix of clay minerals and other geologic and organic materials. Some of the most common soil minerals are silicates, carbonates, and iron oxides (Brady, 1994). A great deal of work has been done to characterize the reflectance spectra of minerals (Hunt, 1971a,b). The matrix can be a simple linear mixture or a complex combination (Clark, 1999). The complexity of material such as soils requires an imaging spectroscopy approach to properly characterize these materials (Kruse et al., 1993).

Soil organic matter: Soil organic matter (OM), a complex carbon-rich material characterized by several organic acids, is important to soil biological productivity and health (Sposito, 1989). Wessman (1991) discusses the effect of soil organic matter on the spectral response of soils. Organic materials have diagnostic absorption bands caused by the presence of specific functional groups (Weyer, 1985). Soils having high organic matter content appear dark due to these absorptions, and spectrometers are sensitive to these features (Bigham, 1995). The almost negligible concentrations of OM in arid and semi-arid soils still may be detectable using imaging spectroscopy due to the significant influence OM has on a soil's spectral response (Stoner and Baumgardner, 1981).

Relating soil parameters to vegetation: The soils of an area has an influence on the occurring vegetation. Soils parameters such as OM, texture, cation exchange capacity favor one type of vegetation over another (Buol et al., 1989). Vegetation, in turn, influences the always evolving formation of a soil. In areas where vegetation has been rapidly removed, the soils of that area can change rapidly as well due to wind and water erosion, reduction in soil OM, and decreased biological activity. The type of soil can then be linked to the types of resident vegetation. By accurately mapping soil types predictions of vegetation occurrence can be done. The information is valuable for areas that have vegetation in abundances, as a proportion of a pixel relative to the soil background, too small to be accurately detected using remote sensing. In areas where the vegetation obscures the soil, information on the linkage between soil and vegetation coverage may be useful for estimation of the underlying soils.

Salinization: Soil with high salinity can be toxic to vegetation and is an indicator of soil degradation (Logan, 1992). Areas receiving irrigation water are prone to salinization due to the high electrolytic concentration of groundwater. Through evaporation, the salts present in the irrigation water are deposited in the soil where it accumulates. The presence of salt minerals have an influence on the spectra of the soil (Csillag et al., 1993). In addition, the unique dielectric properties of salts are detectable using imaging radar (Kierein-Young, 1997).

Soil crusting: The absence of vegetative cover increases the oxidation of soil organic matter and leads to topsoil loss. Crusting occurs when the topmost layer of soil, when dry, becomes harder than the layer beneath it. Soil crust formation is caused by the loss of fine soil particles under the impact of raindrops (van Wambeke, 1992). The surface layer becomes aggregated and impenetrable to moisture and plant seedlings. Re-vegetation of the area becomes difficult without intervention. This condition can lead to severe erosion and site degradation. The textural variation between crust formations and the surrounding soils may be detectable by imaging radar and spectroscopy.

Biological soil crusts: Cryptobiotic soil crusts provide improved surface stability, water infiltration, and fertility in arid ecosystems. These fragile biological crusts are composed of cyanobacteria, lichens and mosses and are easily disturbed by human, animal and mechanized trampling (Belnap and Gardner, 1993). Disturbance of these biotic crusts can cause accelerated soil erosion and degradation. The characteristically long recovery time of arid ecosystems make disruption to these crusts a near irreversible process. These soil crusts have a characteristic dark color that make them identifiable using remote sensing instruments. Mapping of microbiotic soils has been accomplished for an area along the Colorado Plateau using imaging spectroscopy (Kokaly et al., 1994).

Stability: Erosional features indicate the lack of soil stability. Rills and gullies are conduits for sediment transport, while scouring or sheet erosion indicate large scale soil loss. Sedimentation and dune formation indicate mass soil movement and site degradation. The drainage patterns formed by rills and gullies can be interpreted from remote sensing imagery. Radar systems can detect these patterns by topographical differences and the soil dielectric variations caused by the increased soil moisture present in these depressions (Ulaby et al., 1982).

Ancillary Data

The inclusion of non-remote sensing data, or supporting datasets, improve landscape ecological analysis and landcover mapping (Mouat et al., 1997). Ancillary data can be used to assist in the image classification procedure and are used as inputs to spatial models (Williams et al., 1999; Vogelmann, 1998). Riparian habitat was characterized for a watershed in Arizona using a combination of satellite imagery with water level data, and temperature and precipitation maps (Lee and Marsh, 1995).

Climate: Climate determines the characteristic vegetation communities for an ecosystem (Bailey, 1983). Vegetation change cannot be understood without knowledge of the climatic context in which a community evolved. The perceived anthropogenic disturbance may in fact be of natural causes, an example being the effect of drought on grass dominated regions. Classification of range condition is outlined by the National Research Council (1994) by mapping and correlating soil and climatic information with a sites vegetation community. A vegetation species occurring out of its climatic context may be an indicator of site degradation. Introduced, or invasive weedy species are such candidates.

Ground measurements: Field measurements are essential to ecological indicator development (Ringrose et al., 1994). Range research stations provide long-term measurements of important ecological variables which can be used with remote sensing data (Washington-Allen et al., 1999). Field based spectral measurements of rangeland vegetation cover is essential for determination of the vegetative components using overhead imagery (Bork et al., 1999a). Ground spectral measurements are required for several steps in the image processing procedure, especially when imaging spectroscopy data is calibrated (Clark, et al., 1999). Field based measurements are also used to establish a gradient of conditions to test ecological indicator and remote sensor sensitivity.

Grazing plot intensity, duration and season of use records and other land use data: Information on grazing area intensity of use, duration of use, and season of use are important in determining grazing pressure. This type of data can be used similar to census data to aid in regional assessments. Experimental rangelands and watershed stations often have long-term stocking rate, livestock type, and season of use records that can be used for site specific and regional studies.

Topography: The topography of the landscape influences the vegetation community structure (Bailey, 1983). Mouat (1997) used slope length along with soil morphology and erodibility as components of an erosion hazard indicator. Slope, aspect, and elevation are important attributes of soil formation as well (Buol, 1992).

Hypothesis

The observations described above lead to the following hypotheses:

1. Arid and semi-arid shrub, forb and graminoid vegetation have distinct and separate chemical and morphological features that can be detected using imaging spectroscopy and radar. These features allow for accurate vegetation mapping at the species level.
2. Landscape erosional features such as gullies and scouring can be detected using spectral and microwave remote sensing, especially systems having fine spatial resolutions.

3. Soil properties such as mineralogy, organic matter content, texture, surface horizon determination, and other features can be determined using imaging spectroscopy and radar. Basic soil mapping is possible.
4. Ancillary spatial and non-spatial data can be used with remote sensing data to reduce the uncertainty as well as enhance image classification and provide modifier variables in model development. Degraded, disturbed and functioning systems can be identified by modeling the interactions between these variables.
5. Rangeland ecological indicators can be determined using remote sensing allowing for large scale assessments of resource conditions.

Conceptual Basis for Hypothesis

The following is a listing of the rangeland indicators that are predicted to be collected using remote sensing. The model to be developed will use this evaluation matrix as its structure. The model's equations will use various indicators as variables and weighting factors (Table 2).

Table 2. Indicator Development Adapted from the Rangeland Health Evaluation Matrix (National Research Council, 1994)

Indicator	Component to be Measured	Sensor
Soil Stability and Watershed Function		IS = imaging spectroscopy IR = imaging radar
Soil A horizon	Soil organic matter	IS imagery to determine soil organic matter content and mineralogy
	Texture	IR to estimate soil texture
	Mineralogy	IR to determine erosional features
Rills and gullies	Landscape drainage patterns	IS for drainage pattern characterization
Scouring or sheet erosion	Elimination of soil surface horizon	IS to identify presence/absence of soil horizination
Sedimentation	Soil accumulation, dune formation	IS/IR to identify sediment deposits
Distribution of Nutrient Cycling and Energy Flow		
Distribution of plants	Landscape fragmentation using pattern metrics	IS/IR to map plant species
Litter distribution and incorporation	Above ground detrital biomass	IS for leaf litter estimation
Recovery Systems		
Age-class distribution	Plant species identification and age estimation	IS/IR to determine plant species and height for age estimation
Plant vigor	Determine photosynthetic efficiency	IS to determine plant chlorophyll absorption
Germination	Soil crust formation and areas of soil translocation	IS/IR to identify soil organic matter depletion and crusting

Technical Approach

Methodology

General approach: The complex nature of rangeland ecological research requires an interdisciplinary approach. Multiple agencies involved in research and management of rangelands such as USGS, BLM, and USDA will be asked to enlist in this effort. Accessing the considerable knowledge of these groups will help ensure a better understanding of the nature of the ecological interactions occurring in these ecosystems and identify gradients in ecological condition. Cooperation with pertinent field research stations and scientific personnel will be important to this study. The research will consist of field data collection, laboratory analysis of collected samples, and remote sensing data collection of hyperspectral and polarimetric radar imagery (Bork et al., 1999b; Smith et al., 1995). Ancillary data such as climatic information, animal stocking rates, and spatial data (DEM's, DLG's) will be merged with the remote sensing data products. Modeling of data will be done in a GIS framework in order to develop the landscape indicators required for rangeland assessments and monitoring.

This research will be conducted in a two-phase approach. A pilot study will be done on several areas that have recent and historical imagery. Sites may be part of or adjacent to field research stations or part of a research study such as the US EPA's Environmental Monitoring and Assessment Program (EMAP). The mission of EMAP is to provide documentation on the current condition of the Nation's ecological resources, why that condition exists, and predict future ecological conditions (EPA, 1990). This will allow for the collection of good representative data and will provide assistance in the data analysis effort. Sites to be included in the study will encompass a range of ecological conditions or rangeland states from healthy to at risk to degraded. Landscape indicators will then be developed across this gradient of rangeland conditions using remote sensing data and existing data and knowledge that will be obtained from other rangeland management agencies.

The second phase will be an extrapolation of the pilot study to a larger area of the western United States. Subsets of the imagery collected during normal operations by government and commercial data vendors will be added to the study. This imagery will be analyzed according to the methods developed in the pilot study to evaluate the effectiveness of the model over a wide range of ecological conditions. It is hoped that near the end of this phase there will be an operational space borne hyperspectral satellite. This will provide the final segment of this studies objectives, to use advanced remote sensing systems for large scale assessments of this nation's rangelands.

Subtask 1: The pilot study will be done on two long-term rangeland research sites: the Walnut Gulch Experimental Watershed, Tombstone, Arizona, and the Sevilleta National Wildlife Refuge, Socorro, New Mexico. Field data collection will consist of reflectance measurements of soils and vegetation using EPIC's ASD FR field spectrometer. Soil samples will be collected and analyzed for mineralogy (using x-ray diffraction [XRD], infra-red spectroscopy [FTIR], and chemical procedures), texture, organic carbon, major cations and anions, moisture content and other parameters such as dielectric constants and particle size using published methodologies (Klute, 1986). Additional laboratory soil and vegetation reflectance measurements will be obtained using a suite of spectrometers available at the USGS Spectroscopy labs in Reston, Virginia and Denver, Colorado. If a soil survey of the site has not previously been accomplished, then one will be conducted to determine the soil orders and other landscape information occurring at the site. Vegetation species identification will be accomplished by range scientists. Plant chlorophyll measurements will also be taken. Topographic, climatic, census, and other ancillary data will be compiled for each site. The remote sensing datasets will be correlated with ground measurements obtained at the study sites. Model development will be accomplished in this phase using spatial and nonspatial statistical methods.

Remote sensing data for the study sites will be obtained using current and historical sources. The HyVista HyMap system will be the primary system and the NASA/JPL AVIRIS and AIRSAR sensors will be used if available. Other aerial photography, airborne video such as Digital MultiSpectral Video (DSMV), and medium and high resolution multispectral imagery (Landsat, SPOT, and IKONOS) will be obtained as necessary. An accuracy assessment of the remote sensing derived products will be accomplished using the methodologies outlined in Congalton and Green (1998).

Subtask 2: This phase of the study will test the rangeland assessment model's accuracy and seek to develop additional model parameters using two-three other long-term rangeland research sites in the southwestern United States, the Muleshoe Ranch Cooperative Management Area, Willcox, Arizona, the Jornada Experimental Range, Las Cruces, New Mexico, and the Desert Experimental Range in Pine Valley, Utah. Other sites may be added if resources permit. These sites are the Amenderas Ranch, Truth or Consequences, New Mexico and Vermejo Park Ranch near Raton, New Mexico and the Desert Ranch in Utah. Selected study sites in this phase will be characterized using the methods developed in subtask 1. Rigorous model calibration and testing using these additional study sites will occur in this phase.

The rangeland ecological indicators developed in subtask 1 and 2 will be applied over a gradient of conditions in many additional areas as remote sensing data for these regions becomes available. The landscape indicator model for these areas will rely on remote sensing data primarily. Collection of field data will be used for solely for accuracy assessment purposes. This final iteration of the model will set the stage for an operational methodology for rangeland assessments using the forthcoming hyperspectral satellites due near the end of this research study.

Data Acquisition and Planning

Hyperspectral data will acquired for the pilot study using the HyMap system obtained under a group shoot scenario where the mobilization costs are shared by multiply federal, and university entities. NASA AVIRIS data collection will be obtained if resources permit. The pilot study sites are long term ecological research (LTER) stations and the federal agencies and universities in charge of the site have obtained AVIRIS data. Collaborative arrangements have been set up with these partners for data sharing and cooperative research. Planning for hyperspectral data acquisition, whether AVIRIS or HyMap must be done several years in advance. Strategic plans are in place to coordinate airborne and ground based data collections for the pilot and follow-on study areas.

Data Analysis and Interpretation

Imaging spectroscopy data will be analyzed using techniques outlined by Clark (1997), Boardman (1995) and others (see reference list). Surface reflectance calibration of the imaging spectrometer data will be accomplished using the steps outlined in Clark (1999). Briefly, a radiative transfer algorithm is applied to the data to remove atmospheric absorptions and Rayleigh and aerosol scattering from the data. Next, ground spectral measurements using a portable field spectrometer of areas imaged by the sensor is used to correct the overflight data. Highly reflective and spectrally uniform areas occurring within the flightlines of the sensor are used as ground calibration sites. The spectra of these sites are collected by the field spectrometer and are compared to the imagery and corrections to the image data are made through the use of multipliers to achieve accurate reflectance signatures of materials in the image.

Materials of interest such as soils, minerals, and vegetation will be identified and mapped by comparing the imaging spectrometer reflectance data to *in situ* ground measurements, standards contained in spectral libraries, and field samples analyzed using laboratory spectrometers. Multiple endmember analysis techniques will be applied to the imagery to detect and map whole pixel and sub-pixel occurrences of target materials (Okin et al., 1998). The steps in the image processing and analysis are as follows (Kruse, 1999); 1) imaging spectrometer data reduction using a minimum noise fraction (MNF) transformation; 2) spatial data reduction using a pixel purity index (PPI); 3) endmember extraction using n-dimensional visualization; 4) spectral identification of target materials by comparison of the image derived reflectance data to *in situ* measurements and known standards; 5) mapping of materials using the mixture tuned matched filtering (MTMF) method (Boardman, 1998; Kruze, 1996).

Analysis of soil and vegetation interactions will be accomplished using spectral and GIS modeling. The soil/vegetation spectra will be analyzed by testing linear and non-linear models and accuracy assessing the results. Probabilistic maps of vegetation will be generated using soil information derived from remotely sensed data, field data, and historical ecological information. Pixel in the hyperspectral imagery having mixed spectra will be compared to the vegetation probability maps to assist in the image classification process. This will allow for the identification of possible vegetation species occurring in the pixel. Once the species is estimated, its spectral contribution to the whole pixel spectra can be determined. The vegetation spectra can then be de-convolved from the whole pixel signature and the abundance of vegetation in the pixel can be calculated (Huguenin et al., 1997).

Software tools such as ENVI, Grams32, Tetracorder, SpecPR will be used to process imagery and map target materials. Landscape metrics will be developed using GIS tools such as ESRI ARC/INFO and ArcView Spatial Analyst, and Erdas Imagine. Modeling of data to develop landscape indicators will be accomplished using SAS and Systat statistical software packages.

Radar imagery will be processed and analyzed using an approach developed by van Zyl (1989). Radar backscatter modeling will be accomplished using the methods outlined in Taylor et al. (1996), Kierein-Young (1993) and Kierein-Young and Kruse (1997). Radar fusion with hyperspectral imagery will use the method described in Kierein-Young (1997).

Section 5

Potential for Reducing Uncertainty in Exposure Assessments and Importance to the Milestones and Program Area Goals

This research reduces uncertainty in conducting assessments of rangeland ecological conditions by coordinating research efforts with agencies responsible for rangeland management with EPA scientific and field personnel. The influence of healthy, at risk, or degraded rangelands on the water quality of the rangeland watersheds can be more accurately determined. This approach allows remotely sensed measurements to be compared against field samples measured with state-of-the-art analytical methods that are, by law, designed to withstand legal scrutiny. Further, when spectra of known chemicals or vegetation species are obtained, they will be compared against existing library spectra as a method of reducing uncertainty in assessments. This is central to milestones of this research effort. By coordinating closely with site-specific operations, especially *in situ* sample analysis, this research can enjoy a level of quality control and reduction of uncertainty that driven by operational requirements.

The EPA, to better account for the success of its actions, has developed a cascading set of goals, objectives, subobjectives, milestones, measures, tasks, and products in compliance with the Government Performance Results Act (GPRA). There are currently ten longer-term goals for the EPA under the GPRA. Goal 8, "Provide sound science to improve the understanding of environmental risk, and develop and implement innovative approaches for current and future environmental problems" serves as the foundation, or core of the ORD's Ecological Research Program. The specific objective associated with ORD's ecological research under this "Sound Science" goal is to provide the scientific understanding to measure, model, maintain, or restore, at multiple scales the integrity and sustainability of ecosystems now, and in the future.

In addition, the ORD's "Ecological Research Strategy" identifies major objectives, sub-objectives and products associated with its core research program areas of:

- Ecosystem monitoring research
- Ecological processes and modeling research
- Ecological risk assessment research
- Ecosystem risk management restoration research

A shorter-term accounting of success is accomplished by establishing, and monitoring the response to the annual performance goals (APGs) and measures (APMs) under GPRA and progress toward completion of any additional critical research products identified in the ORD's "Ecological Research Strategy" and its subsequent updates. These goals and measures provide the "why" and the "what" of our research tasks and projects. This document, as a technical research plan addresses not only the “why” and the “what,” but also the “how” -- the approach to providing products that satisfy the specific performance goals associated with this activity. Those specific annual performance goals and measures are:

- Review Article: Rangeland ecological indicator development using advanced remote sensing technologies
- Field Data Collection, Number of Sites Visited
- Hyperspectral Remote Sensing Imagery Acquired
- Reports, Papers, Journal Articles

Section 6

Quality Assurance Statement

This research will be conducted in accordance with the Quality Management Plan for the Environmental Sciences Division (ESD), National Exposure Research Laboratory, Las Vegas. A Quality Assurance (QA) Project Plan will be prepared prior to the initiation of field activities and data processing. The QA Project Plan will document: (1) questions to be answered or decisions to be made based upon study data; (2) The nature, number and quality of data points needed to achieve a selected level of confidence in those decisions; (3) the experimental design and methods necessary to meet those data objectives (EPA 1999).

Also, the Environmental Photographic Interpretation Center (EPIC) has a Master Quality Assurance Project Plan in place and has developed a full set of 53 Standard Operating Procedures (SOP) for many aspects of photographic and digital imagery acquisition, scanning, processing, analysis, and graphics (Lockheed 1999). Specific quality assurance measures for this research include:

1) The use of the manufacturers calibration systems and reports for field spectrometer data collection (Beal, 1997).
2) The Use of a Spectralon Standard white reference for field spectrometer data collection (ASD 1997).
3) The averaging of multiple spectral measurements for all field data collection (Clark et al., 1999).
4) Comparison of collected spectra with that of known spectra from existing spectral libraries as developed by USGS, NASA and others.
5) The use of accepted calibration and atmospheric removal algorithms for all hyperspectral remote sensing data (Clark et al., 1999).
6) The comparison of field and remote sensing spectra with *in situ* samples collected and analyzed by conventional analytical chemistry methods.
7) The publication of all significant results in peer-reviewed scientific journals.

Anticipated Results/Milestones

A standardized, effective, and accurate method for determining the state of this nation’s rangelands is needed. This research will provide rangeland managers with the tools they need to assess and monitor these resources. The long-term goal of this work is to develop a methodology using current technologies for use with the forthcoming hyperspectral satellites due in the next 2 to 3 years.

This research will enhance other ESD research efforts that deal with the development of landscape indicators and those that deal with ecosystem assessments in the western EMAP regions. Specifically, the results of this work are directly related to GPRA goal 8.1.1, Development of Landscape Indicators for Use in Regional Risk Assessments and its following subtasks: H - EMAP Western Landscape Pilot and J - Quantification of Landscape Indicators/Watershed Conditions Relationships in a Semiarid Watershed.

Results and reporting: The proposed working relationship with rangeland management agencies will allow for the dissemination of results and model improvements. All results will be reported through a series of internal EPA reports, symposium poster presentations and proceedings, and journal articles in peer-reviewed scientific journals.

Milestones

1. Research Plan: A fully developed and peer-reviewed research plan will be developed and in place by 12/01/00.
2. Literature Review: A literature review of the use of imaging spectroscopy and radar for rangeland assessments will be completed by 3/01/01.
3. Field Data: Selected sites will be visited and spectral data Spectral data will be collected with EPIC's ASD FR Spectrometer. Ongoing.
4. Remote Sensing Data Collection: Working with NASA and commercial vendors, hyperspectral and radar imagery will be acquired over many of the study areas. Ongoing.
5. Research Partnerships: Developing cooperative partnerships with Federal Agencies responsible for rangeland management and research. Also, developing cooperative partnerships with Federal Agencies and commercial remote sensing providers for the acquisition and analysis of hyperspectral data for environmental issues. Ongoing.
6. Research Results: Developed on a site by site basis, research results will be reported as internal reports, symposium papers and peer-reviewed journal articles. As needed.

Deliverables

1. Preliminary guide to the development of landscape indicators of rangeland condition utilizing remote sensing, primarily imaging spectroscopy or hyperspectral data, and ancillary data.
2. GIS model for determining rangeland condition using indicators derived from research results. This model would run on ArcView and let users choose data layers such as soil types, vegetation species, areas of soil erosion. Users may also assign weights to the layers for statistical analysis. Developed indicators may also be chosen and operated upon using statistical weights. These indicators include; vegetation patch metrics, exotic vs. native vegetation ratios, percent grass/forb/shrub species per unit area (area units to be determined).
3. Regional assessments using the GIS model. Rangeland scientists involved in the project will be accomplishing the analysis and deriving the results. The regions used in the assessments first be the areas in the subtasks. Additional regions will be accomplished as more hyperspectral data becomes available.

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Proposed Staffing

		Percent Time		
Name	**Duties**	**FY99**	**FY00**	**FY01**
David J. Williams	Investigator/Physical Scientist	50%	50%	50%
William G. Kepner	Co-Investigator/Landscape Ecologist	10%	10%	10%

Description of Facilities

All data potentially acquired under this proposal will be analyzed by EPA image processing scientists at the image processing laboratory of the Environmental Photographic Interpretation Center (EPIC) in Reston, Virginia. The EPA/EPIC laboratory is currently outfitted with three Unix workstations (two SUN Ultra 30, one SGI Indigo 2) and one Windows NT workstation. Included is an ASD Full-Range field Spectrometer for field data collection. Software in the EPIC IP lab includes two copies of Arc/Info (GIS), five copies of ARCVIEW, three copies of ENVI, one copy each of ERDAS Imagine and PCI (image processing). Spectral processing software includes GRAMS32, and ATREM. Also, under Interagency Agreement with USGS, EPA scientists have access to the USGS reflectance Spectroscopy lab and their Specpr and Tetracorder spectral analysis software.

Appendix A

Description of Potential Study Sites

Descriptive text courtesy of the USFS, USDA, USGS-BRD, and Utah State University.

Pilot Study Sites

Sevilleta National Wildlife Refuge, Socorro, New Mexico. The University of New Mexico's Sevilleta Long-Term Ecological Research Program (LTER) in the central Rio Grande Basin is one of the U.S. National Science Foundation's LTER Network sites. The Sevilleta LTER Program is located primarily on the Sevilleta National Wildlife Refuge in Socorro County, NM. Varied study sites include a wide range of ecosystem types, including Chihuahuan Desert, Great Plains Grassland, Great Basin Shrub-Steppe, Piñon-Juniper Woodland, Bosque Riparian Forests and Wetlands, Ponderosa Pine Forests, Mixed-Conifer Montane Forests, and Sub-alpine Forests and Meadows.

Walnut Gulch Experimental Watershed, Tombstone, Arizona. Located in SE Arizona surrounding the historic city of Tombstone, the 150 sq. km. Walnut Gulch Experimental Watershed was established in the early 1950's to study the role of watershed treatments on downstream water yield. The site was deemed typical of the black grama grass-brush dominated areas of southern New Mexico and Arizona. Beginning in 1954, a network of recording precipitation gages was established. Since then, the network of recording precipitation gages has grown to the nearly 100 gages currently maintained by SWRC staff. Complementary to the precipitation gages, 25 flumes and weirs have been established within the Walnut Gulch Experimental Watershed defining subwatersheds ranging in size from 112 sq. km. to 0.3 sq. km.

Follow-on Study Sites

Jornada Experimental Range, Las Cruces, New Mexico. The Jornada Experimental Range is a 193,394 acre (78,325 hectare) research facility established in 1912. The Range is located in the northern portion (the Trans Pecos region) of the Chihuahuan Desert, the largest desert in North America. The mission of the Range is to develop new knowledge of ecosystem processes as a basis for management and remediation of desert rangelands. AVIRIS data has been collected for the range in 1998 and a current overflight for the area and supporting ground measurements is planned in October, 1999.

Desert Experimental Range. The Desert Experimental Range is in Pine Valley approximately 70 km (43 miles) west of Milford, Utah. It is geographically and floristically representative of approximately 200,000 km^2 (77,220 $miles^2$) of the Great Basin, an arid region of the Western United States comprising a series of north-and south-aligned ranges and closed basins. AVIRIS data has been collected for regions adjacent to the range.

Great Basin Experimental Range, Ephraim, Utah. The Great Basin Experimental Range is on the south portion of the Ephraim or Cottonwood Creek drainage on the west front of the Wasatch Plateau about 8 km (5 miles) east of Ephraim, Utah, on the Manti-LaSal National Forest. AVIRIS data has been collected for adjacent areas in 1998.

Appendix B

Personnel

David James Williams

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Education

Ph.D. (In progress) Computational Sciences and Informatics, Earth Observing and Remote Sensing, George Mason University

M.S. Environmental Science: Soil Physical Chemistry, 1998. The Ohio State University

B.S. (cum laude) Natural Resources, 1996. The Ohio State University

Research Interests

Remote sensing with an emphasis on hyperspectral data analysis or imaging spectroscopy and computational techniques; evaluation of current and future remote sensing systems; reflectance spectroscopy of organic and inorganic contaminates in soils and sediments; chemistry and mineralogy of sediments from mining and industrial effluents; spatial analysis of environmental data including the development of landscape ecological indicators; GIS and spatial statistics. Scientific background in analytical and physical chemistry, geochemistry, hydrogeology, and pedology.

Professional Memberships

American Society for Photogrammetry and Remote Sensing

IEEE Geoscience and Remote Sensing Society

Honorary Societies: Phi Kappa Phi, Gamma Sigma Delta

Employment

1998 - Present:	Research Physical Scientist, USEPA National Exposure Research Lab, Environmental Photographic Interpretation Center, Reston, Virginia.
1997 - 1998:	Image Analyst, Ohio Environmental Protection Agency, Division of Surface Water, Columbus, Ohio.
1996 - 1998:	Graduate Fellow, Environmental Science Graduate Program, The Ohio State Univ. Columbus, Ohio.

1993 - 1996: Research Assistant, Soil Characterization Lab, School of Natural Resources, The Ohio State Univ. Columbus, Ohio.

Scholarships and Awards

1999: USEPA Office of Research and Development Honor Award: Exceptional ORD Technical Assistance to the Regions or Program Offices

1996: U.S. Department of Defense Environmental Restoration Fellowship

1995: Ohio State University, School of Natural Resources Undergraduate Research Scholarship

Selected Publications

Williams, D.J., J.M. Bigham, and S.J. Traina. 2000. Assessing mine drainage water quality form the color and spectral reflectance of chemical precipitates. Applied Geochemistry (submitted).

Williams, D.J., and S., Norton. 2000. Determining impervious surfaces in satellite imagery using digital orthophotography. Proc. of the Am. Soc. for Photogrammetry and Remote Sens. Annual Conference, Washington, DC.

Williams, D.J., D.A. White, and A. Engelmann. 1999. Riparian characterization using sub-pixel analysis in an ecological risk framework. Proc. of the Am. Soc. for Photogrammetry and Remote Sens. Annual Conference, Portland, OR. May 21st 1999.

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Education

M.S. Zoology, Arizona State Univ., 1982

B.S. Biology, Univ. of Arizona, 1975

A.A. Biology, Phoenix College, 1973

Professional Registration

Certified Wildlife Biologist, The Wildlife Society, 1983

Certified Fisheries Scientist, American Fisheries Society, 1982

Certificate in Business Management, UNLV College of Business and Economics, Department of Management in cooperation with the American Management Association, 1995

Experience

1990-Present:	Research Ecologist: U.S. Environmental Protection Agency, National Exposure Research Laboratory, Las Vegas, Nevada
1984-1990:	Environmental Contaminant Specialist: U.S. Fish and Wildlife Service, Phoenix, Arizona
1978-1984:	Wildlife Biologist: U.S. Bureau of Land Management, Phoenix, Arizona
1977-1978:	Research Assistant: Lower Colorado River Basin Research Laboratory, Arizona State University, Tempe, Arizona
1997:	Hydrologist: U.S. Forest Service, Apache-Sitgreaves National Forests, Springerville, Arizona

Selected Publications

Mouat, D.A., J. Lancaster, T. Wade, J. Wickham, C. Fox, W.G. Kepner, and T. Ball. 1997. Desertification Evaluated Using an Integrated Environmental Assessment Model. Environmental Monitoring and Assessment 48:139-156.

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Wade, T.G., J.D. Wickham, and W.G. Kepner. 1995. Using GIS and a Graphical User Interface to Model Land Degradation. Geo Info Systems. Pp. 38-42.

Kepner, W.G. 1995. Environmental Monitoring and Assessment Program: A Landscape Approach to Environmental Assessment: Application to Neotropical Migratory Bird Issues. Partners in Flight, 4(2). National Fish and Wildlife Foundation, Washington, D.C.

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EPA/600/R-01/004
April 2002