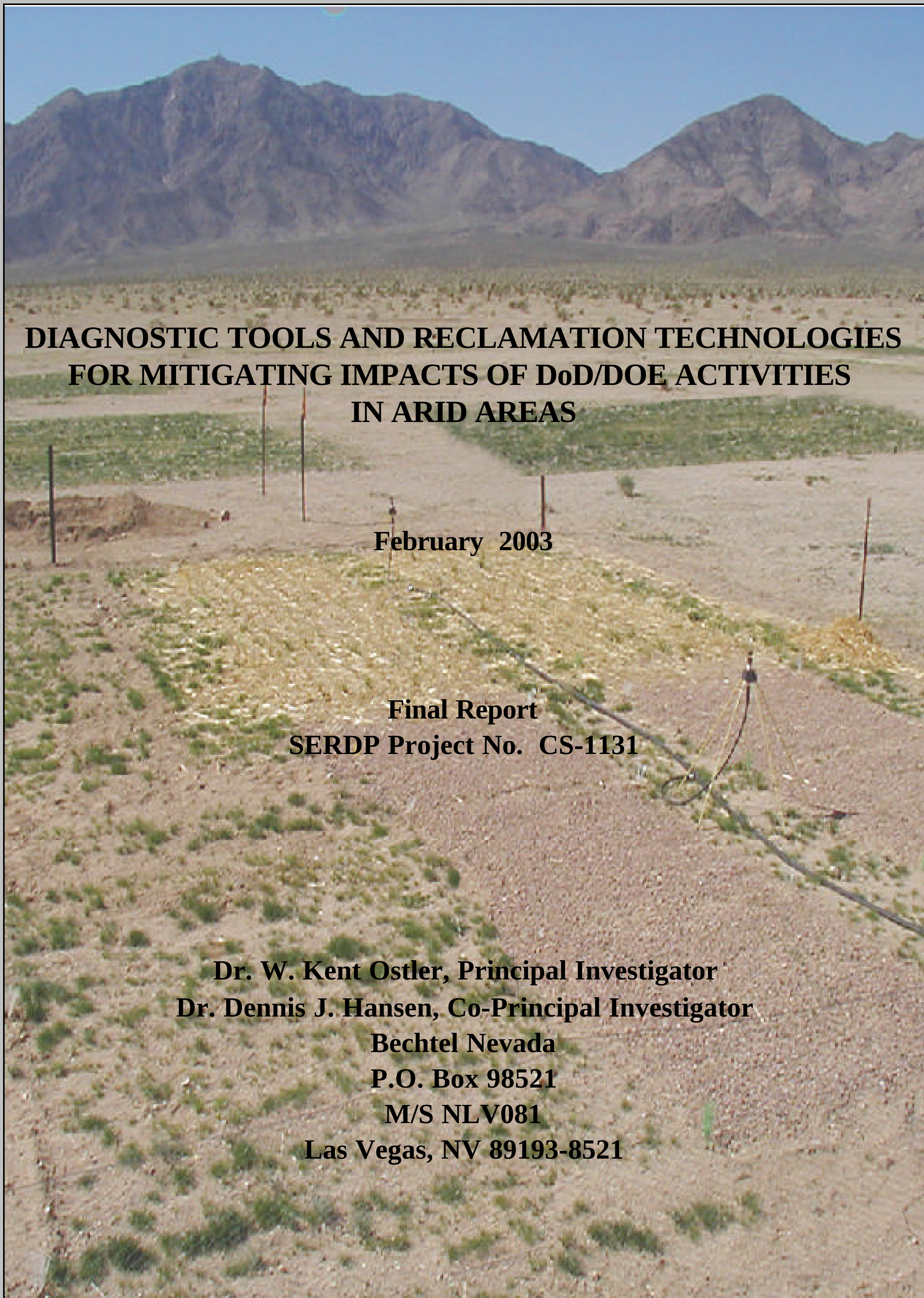

# DIAGNOSTIC TOOLS AND RECLAMATION TECHNOLOGIES FOR MITIGATING IMPACTS OF DoD/DOE ACTIVITIES IN ARID AREAS

**February 2003**

**Final Report**
**SERDP Project No. CS-1131**


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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AES | Applied Ecological Services, Inc |
| ANOVA | Analysis of variance |
| AOI | Area of Interest |
| ATTACC | Army Training and Testing Area Carrying Capacity |
| BN | Bechtel Nevada |
| C | Centigrade |
| cm | centimeter |
| CSU | Colorado State University |
| CSUDH | California State University – Dominguez Hills |
| DoD | U.S. Department of Defense |
| DOE | U.S. Department of Energy |
| ERDC | Engineer Research and Development Center |
| ESA | Ecological Society of America |
| GIS | Geographic Information System |
| GPS | Global Positioning Satellites |
| ITAM | Integrated Training Area Management |
| LCTA | Land Condition Trend Analysis |
| LIFI | Laser-Induced Fluorescence Imagery |
| LIFS | Laser-Induced Fluorescence Spectroscopy |
| LRAM | Land Rehabilitation and Maintenance |
| m | meter |
| NTC | National Training Center |
| NTS | Nevada Test Site |
| NV | U.S. Department of Energy/Nevada Operations Office |
| p | probability |
| SAIC | Science Application International Corporation |
| SERDP | Strategic Environmental Research Development Program |
| SPOT | Satellite pour L'Observation de la Terre |
| STL | Special Technologies Laboratory (BN) |
| TIFF | Tagged Image File Format |
| TM | thematic mapper |
| TMSES | Terrain Modeling and Soil Erosion Simulation |
| USACERL | U.S. Army Construction Engineers Research Laboratory |
| USDA | U.S. Department of Agriculture |

# EXECUTIVE SUMMARY

Approximately 70 percent of all U.S. military training lands are located in arid and semi-arid areas. Training activities in such areas frequently adversely affect vegetation, damaging plants and reducing the resilience of vegetation to recover once disturbed. Fugitive dust resulting from a loss of vegetation creates additional problems for human health, increasing accidents due to decreased visibility, and increasing maintenance costs for roads, vehicles, and equipment. Diagnostic techniques are needed to identify thresholds of sustainable military use. Under conventional technologies to mitigate these impacts, it is estimated that up to 35 percent of revegetation projects in arid areas will fail due to unpredictable natural environmental conditions, such as drought, and reclamation techniques that were inadequate to restore vegetative cover in a timely and cost-effective manner. A cooperative effort among the U.S. Department of Energy (DOE), U.S. Department of Defense (DoD), and selected university scientists was undertaken in 1999 to focus on developing new techniques for monitoring and mitigating military impacts in arid lands (SERDP Project No. CS-1131).

This report summarizes goals and objectives of the project, project coordination and planning, accomplishments, research findings, and transfer of technology of newly developed techniques to installation users. This report contains appendices with supporting data, publications, research findings, and workshop presentations. It also contains two user's manuals (bound separately) that describe the most important aspects of this research project. Additionally, this final report includes two CD ROMs that contain a digital version of this final report and two user's manuals with all the Microsoft® Power Point presentations that were given at a project workshop held on October 22-23, 2002 in Las Vegas, Nevada for the purpose of introducing newly-developed techniques as described in the user's manuals and to facilitate technology transfer. A summary follows of these two user's manuals.

**Vegetation Change Analyses User's Manual**

This attached manual, *Vegetation Change Analysis, User's Manual* (Hansen and Ostler, 2002) focuses on the development of new monitoring techniques that have been implemented at the U.S. Army's National Training Center (NTC), Fort Irwin, California. This user's manual was designed to address diagnostic capabilities needed to distinguish between various degrees of sustainable and nonsustainable impacts due to military training and testing and habitat-disturbing activities in desert ecosystems. Techniques described in this manual focus on the use of high-resolution imagery and the application of image-processing techniques developed primarily for medical research used to measure vegetation in arid lands.

The manual provides discussions about the measurement of plant biomass and shrub canopy cover in arid lands using conventional methods. Both semi-quantitative methods and quantitative methods are

discussed and reference to current literature is provided. A background about the use of digital imagery to measure vegetation is presented. Image-capturing techniques using cameras mounted on tripods and hand-held poles, kites, blimps and balloons, helicopters, fixed-wing aircraft, and satellites are discussed. The pros and cons of using various types of cameras and lenses, films, and digital recording media are reviewed and evaluated.

Image processing using various approaches are described in detail with links to useful Web sites including the use of commercial image-processing software. Screen captures of key procedures of selected software are shown and described. Digital image formats are discussed. Classes of image-processing software include: (1) image editing and enhancing (e.g., Picture Window Pro® and Adobe Photoshop®), and (2) georeferencing software (e.g., MrSID® , DIME®). The historical background of measuring plant cover by digital techniques is presented. Several types of image-processing software are described. These include ImageTool, Sigma Scan Pro®, and Image Pro Plus®. A detailed description of the steps required to successfully measure shrub canopy cover is provided, including tips from experienced users, user precautions, and alternate approaches.

A discussion is also provided about image-mapping software such as Surfer® gridding and mapping software. An image conversion program written for this project is described and provided to users to convert TIF (tagged image file) images to Surfer® XYZ tabular grid files. Procedures are described to assist users in exporting maps to rectified shapefiles that can be used in geographic information systems for the purpose of shrub-cover change detection and the presentation of areas at various thresholds of use. Using these thematic layers permits managers to estimate cost for mitigation and establish priorities for future mitigation efforts.

Appendices of the manual are provided that describe (1) application of techniques used at the NTC at Fort Irwin, California, to evaluate changes in vegetative cover using the new techniques described in this report; (2) a plant-damage assessment technique for evaluating military vehicular impacts to vegetation in the Mojave Desert; and (3) pertinent World Wide Web Internet Web sites and links to other related SERDP projects and government sites that focus on remote-sensing techniques for monitoring and mitigating training impacts.

**New Technologies to Reclaim Arid Lands User's Manual**

The purpose of this attached manual *New Technologies to Reclaim Arid Lands User's Manual* (Ostler et al., 2002) is to assist land managers in recognizing thresholds associated with habitat degradation and to provide reclamation planning and techniques that can reduce the costs of mitigation for these impacted lands to ensure sustainable use of these lands. This user's manual focuses on the development of new reclamation techniques that have been implemented at the NTC at Fort Irwin, California, but are applicable to most arid land reclamation efforts. As arid lands are impacted due to DoD and DOE activities, biological and soil resources are gradually lost and the habitat is altered. A conceptual model of that change in habitat quality is described for varying levels of disturbance in the Mojave Desert. As the habitat quality degrades and more biological and physical resources are lost from training areas, greater costs are required to return the land to sustainable levels. New reclamation and restoration techniques are needed in desert ranges to help mitigate the adverse effects of military training and other activities to arid-land environments.

The importance of reclamation planning is described in this manual with suggestions about establishing project objectives, scheduling, budgeting, and selecting cost-effective techniques. Reclamation techniques include sections describing: (1) erosion control (physical, chemical, and biological), (2) site preparation, (3) soil amendments, (4) seeding, (5) planting, (6) grazing and weed control, (7) mulching, (8) irrigation, and (9) site protection. Each section states the objectives of the technique, the principles, an in-depth look at the techniques, and any special considerations as it relates to DoD or DOE lands.

The need for monitoring and remediation is described to guide users in monitoring reclamation efforts to evaluate their cost-effectiveness. Costs are provided for the proposed techniques for the major deserts of the southwestern U.S. showing the average and range of costs. A set of decision tools are provided in the form of a flow diagram and table to guide users in selecting effective reclamation techniques to achieve mitigation objectives.

Recommendations are provided to help summarize key reclamation principles and to assist users in developing a successful program that contributes to sustainable uses of DoD and DOE lands. The users manual is helpful to managers in communicating to installation management the needs and consequences of training decisions and the costs required to achieve successful levels of sustainable use.

Appendices of the manual are provided that describe native plant species that are well suited to reclamation in arid lands of the Southwest. An in-depth paper describing reclamation costs is provided, a post-closure monitoring checklist is included, and links to selected World Wide Web Internet Web sites are provided.

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# 1.0 INTRODUCTION

This report documents research and activities of SERDP Project No. CS-1131, "Diagnostic Tools and Reclamation Technologies for Mitigating Impacts of DoD/DOE Activities in Arid Areas." Innovative technologies developed by this research provide valuable tools to ensure continuation of military testing and training currently threatened by deteriorating site conditions and reduce the cost of mitigating adverse impacts. Techniques developed in this project will decrease the risk of violating particulate standards of the Clean Air Act, that could potentially restrict or reduce testing and training exercises.

## 1.1 BACKGROUND

Approximately 70 percent of all U.S. military training lands are located in arid and semi-arid areas. Training activities may adversely affect vegetation, damaging plants and reducing the resilience of vegetation to recover once disturbed. The cumulative impacts result in a loss of plant cover, species diversity, plant reproduction, and soil resources such as organic matter and soil microorganisms needed to recycle soil nutrients. Fugitive dust resulting from a loss of vegetation creates additional problems for human health, increasing accidents due to decreased visibility and increasing maintenance costs for roads, vehicles, and equipment. Under conventional technologies to mitigate these impacts, it is estimated that up to 35 percent of revegetation projects in arid areas will fail due to unpredictable natural environmental conditions and because of reclamation techniques that were inadequate to restore vegetative cover in a timely and cost-effective manner.

It is difficult to detect and monitor impacts to vegetation from military training in desert areas using conventional remote sensing techniques that rely on low-resolution satellite imagery. This is because the pixel sizes of satellite images are large (e.g., 10 to 30 square meters per pixel) while the shrub sizes are small (0.25 to 3 square meters in area). Vegetation cover in arid landscapes varies substantially with seasonal changes in climate. Cover is normally low, usually less than 25 percent in undisturbed areas and frequently less than 5 percent in heavily used areas. Sun light reflecting from soils in these desert areas masks the smaller amount and quality of light that is reflected by vegetation making it impossible to accurately measure changes in vegetation cover. New diagnostic techniques are needed to identify thresholds of sustainable military use, and to accurately measure plant canopy cover in arid-land environments.

In 1999, a cooperative effort among U.S. Department of Energy (DOE), U.S. Department of Defense (DoD), and selected university scientists was undertaken to focus on mitigating military impacts in arid lands. Bechtel Nevada (BN) assembled a team of scientists to address these problems. The research team included researchers and advisors from government, universities, and private industry. Collaborators include DOE National Nuclear Security Administration Nevada Operations Office (formerly known as DOE Nevada Operations Office [DOE/NV]) BN; DoD–Fort Irwin, Center for

Ecological Management of Military Lands at Colorado State University; U.S. Army Construction Engineers Research Laboratory (USACERL), California State University–Dominguez Hills; and Weber State University–Applied Ecological Services, Inc. Fort Irwin, the U.S. Army's National Training Center (NTC) located near Barstow, California, in the Mojave Desert, was selected as the primary test site for development of new technologies. The approach focuses on specific problems at the NTC, but is suitable for other DoD and DOE facilities located in arid and semiarid areas. Diagnostic tools and reclamation technologies developed by this program may also be applicable to wetter areas of the United States.

Data developed as part of this research will provide users of models such as the Army Training and Testing Area Carrying Capacity (ATTACC) and other models used in Land Condition Trend Analysis (LCTA), and the Terrain Modeling and Soil Erosion Simulation (TMSES) programs, with the means to bridge the gap between deficiencies common to remote sensing using satellite imagery and the high cost and time associated with detailed ground surveys. New rehabilitation and restoration techniques will find immediate application for Integrated Training Area Management (ITAM) personnel located at military facilities in the western U.S. where ecosystem sustainability for training and testing is at risk.

# 2.0 GOALS AND OBJECTIVES

This project was designed to overcome gaps in diagnostic capabilities needed to distinguish between various degrees of sustainable and nonsustainable impacts due to military training and testing or earth-disturbing activities in desert ecosystems. The project also focused on developing and evaluating new and cost-effective techniques for rehabilitation and restoration of such disturbed habitats. These new tools will enable management to maximize utilization of limited training environs and thus increase operational readiness.

Technical objectives of the project were to:

(1) Develop and test image collection and image processing diagnostic techniques for rapidly characterizing vegetative parameters needed to distinguish between sustainable and nonsustainable impacts of military training and testing.

(2) Reduce the amount of downtime and off-limit areas imposed by rehabilitation/mitigation activities by identifying critical stages of habitat degradation and focusing resources to extend resiliency of training areas for longer periods of time.

(3) Develop and evaluate the cost effectiveness of new rehabilitation and restoration techniques for short-term and long-term sustainment needs in desert ranges.

(4) Demonstrate diagnostic and emerging restoration technologies at Fort Irwin that will reduce the life-cycle costs and time for rehabilitation, and ensure compliance with federal environmental regulations.

(5) Provide a suite of diagnostic and restoration tools applicable to military testing and training in other desert locations and nondesert ranges and to facilitate models currently in use or under development.

The technologies being evaluated and tested were divided into two principal areas: (1) diagnostics and (2) restoration techniques.

# 3.0 PROJECT COORDINATION AND PLANNING

## 3.1 Technical Team

The research team included researchers and advisors from government, universities, and private industry. Collaborators included DOE/Nevada Operations Office (NV), Bechtel Nevada (BN), DoD – Fort Irwin, Center for Ecological Management of Military Lands at Colorado State University (CSU), U.S. Army Construction Engineers Research Laboratory (USACERL), California State University – Dominguez Hills (CSUDH), and Applied Ecological Services, Inc. (AES). Key investigators included:

**Dr. Kent Ostler** of BN served as the Co-Principal Investigator for the Project. He has over 20 years of experience in the field of reclamation and arid land ecology. He has designed and implemented numerous reclamation projects and evaluated reclamation techniques throughout western North America. He has been the project manager for DOE/NV's ecological monitoring and compliance programs on the Nevada Test Site (NTS) for the past nine years. He has directed research work on reclamation at NTS and other DOE sites in Nevada and California, and has authored numerous reports from these studies. His responsibility was to coordinate the various participants and advisory groups.

**Dr. Dennis Hansen** is a plant ecologist with BN who served as Co-Principal Investigator for the project. He developed and evaluated rapid assessment of vegetation structure using digital images and remote sensing techniques with applications of digital image processing software. He has extensive experience as a remote sensing and revegetation specialist. He has prepared a number of user's guides for revegetation of disturbed lands, including projects for the Office of Technology Assessment (U.S. Congress). He has organized and conducted several international workshops in revegetation and trained federal and state government organizations in monitoring and revegetation techniques. He has a working knowledge of the ecology of many vegetation types in the United States, having worked in more than 18 states from the arctic to the tropics.

**Dr. David Anderson** is a reclamation specialist with BN and has extensive experience in implementing large-scale (200 to 1,000 acres) reclamation projects (e.g., revegetation of lands disturbed by oil and gas development activities on the Naval Petroleum Reserves in California) in low-rainfall (< 5 inches/year) areas. He has also designed and established numerous reclamation trial plots. He was responsible for the implementation of various restoration technologies that were tested at Fort Irwin. Dr. Anderson has been involved in the reclamation of disturbed lands at either a research or operational level for the past three decades. Research has focused on establishment of plant species in harsh growing conditions, effects of various revegetation techniques on plant performance, irrigation strategies for remote locations, reestablishment of biotic soil crusts, and control of fugitive dust using chemical soil stabilizers as part of the reclamation process.

**Dr. Steve Warren** with the Center for Ecological Management of Military Lands at CSU provided support in linking LCTA and erosion control models with data derived from the restoration tests conducted during this effort. Dr. Warren is one of the original developers of the Army's LCTA program. He was instrumental in developing the links between the LCTA program and the erosion models that form the basis of ATTACC model. His participation in the proposed project helped ensure that the data derived from the monitoring techniques were compatible with existing erosion models and those currently developed under with the Strategic Environmental Research Development Program (SERDP) funding at the USACERL. Dr. Warren was also one of the primary developers of the Land Rehabilitation and Maintenance (LRAM) component of the Army's ITAM program. He is the Project Leader of the Arid Land Management Capability Package and was involved in cutting-edge research regarding the reestablishment of cryptogamic soil crusts that are critical components of many arid ecosystems. This knowledge and experience has contributed to the development of restoration techniques and model applications.

**Dr. Christopher Lee** was an Associate Professor and Chair of Earth Sciences at CSUDH and an adjunct Assistant Research Scientist at the University of Arizona. He has specialized in remote sensing and Geographic Information System (GIS) applications in arid environments for the past 14 years and was a former Fulbright Senior Research Scholar to Egypt. Dr. Lee has been working at Fort Irwin for the past several years developing techniques to map disturbance using satellite data. He has also collected extensive ground truth data from various locations at Fort Irwin. He coordinated satellite data with the new diagnostic tools developed during this project.

**Dr. Gene Capelle** with BN's Special Technologies Laboratory (STL) in Santa Barbara, California, was responsible for the testing of the Laser-Induced Fluorescence Imagery (LIFI) technology. Dr. Capelle's specialty is lasers and spectroscopy, specifically as applied to remote sensing problems. Since 1995, he has been a principal investigator of research investigating plant vitality as monitored through optical signatures from the plants to assess the presence or absence of certain nutrients or contaminants. Under this project, measurements were made to characterize the reflected light from various plant species, including those that had been damaged by wheeled and tracked vehicles during military training and testing. From this information, optical remote measurement techniques were identified and developed.

**Ruth Sparks**, with Charis Corporation, is located at Fort Irwin and directs the ITAM program at the Army's NTC. As the LRAM and ITAM coordinator, her efforts have been directed toward the management of military training lands. Since March 1996, fifteen erosion control and revegetation projects have been implemented to repair damage caused by training activities and promote a safe training environment. She is currently responsible for developing plans for integrating long-term biological monitoring data, remote sensing, soils maps, training scenarios, and other data layers within a GIS framework to direct LRAM and ITAM activities. Ms. Sparks provided coordination for plot location, maintenance activities, and field work in relation to military training activities for the demonstrations and studies conducted at the NTC.

**Mickey Quillman** is with the Directorate of Public Works at Fort Irwin and was the principal contact for activities that occurred at the NTC. He has been at Fort Irwin for the past decade, where he serves as Natural Resources Manager, with responsibilities for Threatened and Endangered Species, Pest Management, and Natural and Cultural Resource Compliance.

## 3.2 Technical Advisory Team

**Dr. Cyrus McKell** is currently President of AES. He is the former Dean of the school of Biology at Weber State University; Committee Chair, National Academy of Sciences (Revegetation Semi-Arid and Marginal Lands); and Director of the Institute for Land Rehabilitation at Utah State University. Dr. McKell has extensive reclamation experience in deserts of the world and has worked at numerous military ranges evaluating revegetation problems. He is author of several textbooks on the biology and utilization of shrubs (McKell, 1989) and technical publications setting industry standards for many revegetation techniques used in the western United States. Dr. McKell was responsible for chairing the Technical Advisory Team of restoration specialists and the Reclamation Workshop.

Six other specialists in the areas of remote sensing, reclamation, and arid land ecology were identified and invited to serve as technical advisors for the project. Dr. Merrill Ridd from the University of Utah and Dr. Charles Hutchinson from the University of Arizona's Office of Arid Land Studies are both well-known experts in remote sensing, particularly in satellite images. Dr. Kathyn Thomas with the University of Northern Arizona has done vegetation sampling and mapping in the Mojave Desert using both aerial and satellite images. Dr. Von Winkel, (formerly with Science Applications International Corporation, the Management and Operations contractor the DOE's Yucca Mountain Project), assisted in coordinating the first reclamation workshop and served on the Technical Advisory Team. Dr. Winkel is currently serving on the Mojave Desert Land Reclamation Task Force. He was formerly in charge of the reclamation program at DOE's Yucca Mountain Project and has done numerous reclamation trials in the Mojave Desert. Steven Monsen, with the U.S. Forest Service Shrub Science Laboratory, has been conducting reclamation research throughout the western U.S. for the past 30 years. He is a recognized expert in the area of reclamation. Dr. Richard Gebhardt with the USACERL in Champaign, Illinois, is familiar with the ITAM program and vegetation parameters that are needed as input to models developed for that program. He also has numerous contacts with other defense facilities and has been helpful with the transfer of technology developed during this project. A project organization chart (Figure 1) outlines the various project tasks and identifies key responsibilities.

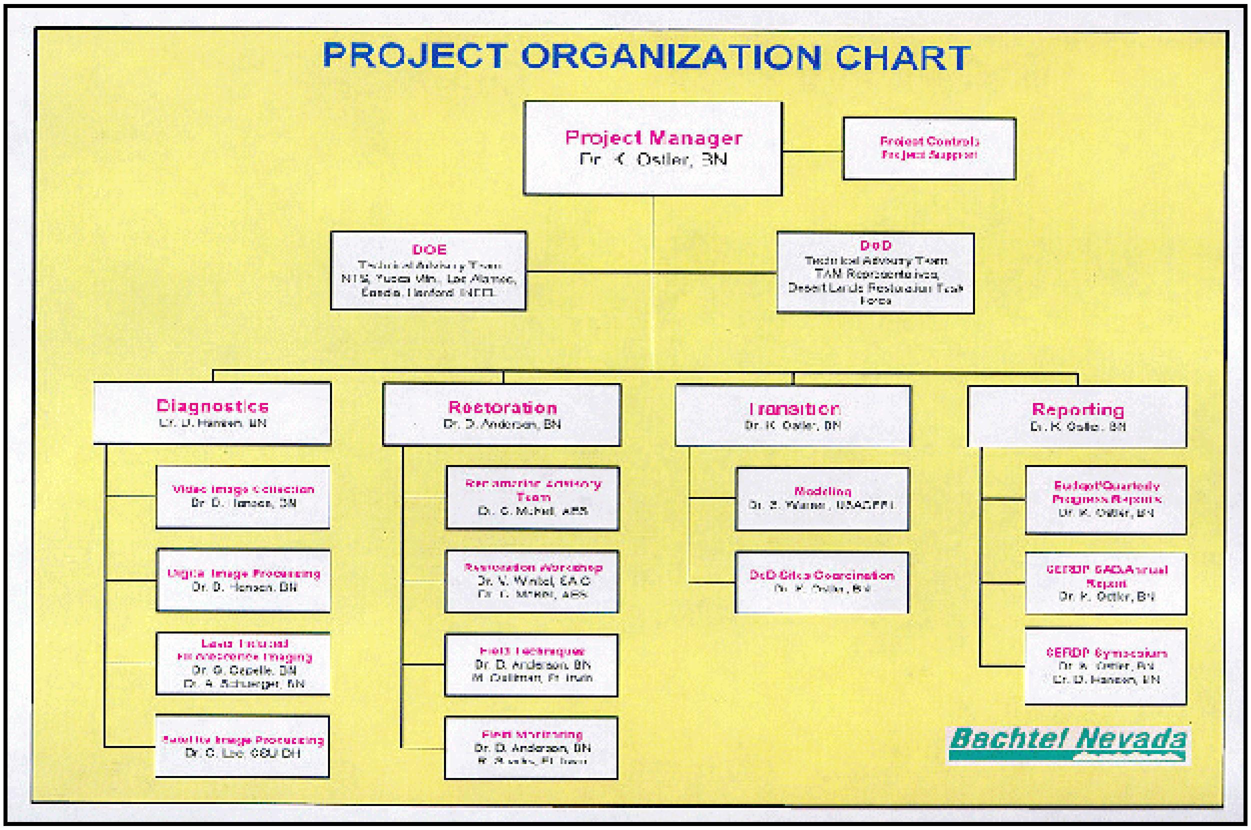



**Figure 1. Project Organization Chart**

## 3.3 Management Plan

A management plan was developed and published in 1999 at the start of the project. This document described the goals, objectives, tasks, subtasks, schedules, milestones, and budgets of the project . It was written to help facilitate the establishment of subcontracts and to facilitate the coordination and management of the project. Major tasks were identified for the project and task goals, objectives, subtasks, schedules, and milestones were developed. These data were used as input values into Microsoft Project 98® and schedules and milestones were provided to create yearly schedules and milestones as well as an overall project schedule. The schedules were updated yearly or as needed. Changes in schedules were needed as some efforts became unnecessary and work was redirected. Redirection was coordinated with our Technical Advisory Team and SERDP managers at the annual internal project reviews.

# 4.0 DIAGNOSTIC TOOLS

This section of the final report describes project activities and accomplishments in support of achieving the objective of developing and testing image collection and image processing diagnostic techniques for rapidly characterizing vegetative parameters needed to distinguish between sustainable and nonsustainable impacts of military training and testing. The greater part of these activities are described in detail in the user's manual: *Vegetation Change Analysis User's Manual.* Dennis J. Hansen and W. Kent Ostler. 2002. DoD/DOE/NV/11718-729, Bechtel Nevada, Ecological Services, Las Vegas, NV 89193 (Appendix A.2).

Activities that were not described in the user's manual included procedures that were tested but yielded unacceptable progress in meeting the desired objective. Some of these procedures are described here in this final report and are included in the appendixes to document what was done, especially if these activities were considered worthy of discussion and related to the stated objective. Other activities were not included because their discussion would not contribute meaningful information and may distract the reader from pertinent information related to the goals and objectives of the project. Examples of activities not described included were those dealing with antiquated software, hardware, and procedures that are no longer used because improved alternatives are currently available and it is unlikely that such equipment or procedures will be used in the future. Other activities not described are those that are considered beyond this project's scope of work (e.g., information that may have been collected or developing during the project, but later is considered to be only marginally related to the goals and objectives of the project and who's discussion might be best served in a separate future report or publication perhaps directed to a different audience).

## 4.1 Background

An essential component of monitoring to determine the spatial extent and degree of military impact is the ability to accurately assess site changes through time as training areas undergo normal use under varying climatic conditions. Historically, monitoring techniques have been primarily limited to expensive, labor-intensive ground collection of data such as plant canopy cover by line-point or line-intersect methods, and plant density by quadrant sampling techniques. Additionally, accessibility to the range by field biologists has been limited at many sites to only one week each month because of intensive military training exercises, making it difficult to obtain sufficient field data during narrow windows of opportunity.

Alternatives to ground-based monitoring techniques are those that focus on remote sensing. Traditionally, these techniques have used satellite imagery as a means of capturing and assessing vegetation conditions at a landscape-size area or scale. Information such as the intensity of a particular wavelength of light or ratio of wavelengths from individual area units of the satellite image (known as pixels) are then statistically correlated with data taken on the ground (e.g., canopy cover or plant density). Pixel size for most satellite images ranges from 10 meters (m) x 10 m to 30 m x 30 m (328 feet [ft] x 328 feet to 2,953 ft x 2,953 ft), which further restricts the usefulness of this technique because most shrubs are often less than 1 square meter ($m^2$) (11 square feet [$ft^2$]) in size. The use of remote sensing using such large pixel elements is useful in areas where ground cover of vegetation is relatively high (e.g., > 30 percent cover) and impacts to the vegetation result in spectral changes that are detectable in the digital images (Falkner, 1995). Such conditions are common for agricultural lands, grasslands, and forest areas, but are less useful in desert areas where plant canopy cover is often less than 10 percent and may be as low as 1 to 2 percent following intensive training impacts such as encampment.

Large-scale ecoregion management approaches have relied upon satellite imagery such as LANDSAT multispectral and thematic mapper (TM), and SPOT (Satellite pour L'Observation de la Terre) panchromatic/multispectral images (Plumb and Pillsbury, 1986). For example, at Fort Irwin, California, the use of this approach has been successful in identifying broad disturbance patterns attributed to military training impacts over time (Lee, 1995). Fort Irwin was selected for development of new diagnostic tools because it is one of the largest training facilities and it is where previous studies have provided a sound foundation of biological, modeling, and remote sensing information, thereby providing a foundation of existing site information.

Despite the usefulness of conventional remote sensing techniques, data deficiencies still exist in applying these techniques to assess the sustainability of training impacts. The deficiencies are associated with the inability to obtain additional levels of detail needed to determine essential characteristics of the vegetation such as shrub cover, density, and species composition. These parameters are needed to establish recovery thresholds where increasing costs and rest-rotational use patterns may restrict short-term use in order to sustain long-term testing and training.

Because training impacts are ongoing at most military training areas and precise location of these impacts are somewhat unpredictable, a method for rapidly monitoring condition of soils and vegetation was needed to determine the condition of vegetation, assess its resiliency to training impacts, assess impact severity, and to direct maintenance activities. A method for rapid capture of field data was required. Such rapid detection methods were developed as part of this project using aerial photography and hand-held digital cameras to record selected ground details. These techniques can utilize permanent transects or photo points to assess year-to-year trends and to be compatible with current sampling formats in LCTA. The focus of our research was to develop techniques that bridge the gap between the labor-intensive and costly ground collection techniques and remote sensing techniques using satellite imagery which is less expensive, yet less precise in detecting vegetation change.

## 4.2 Image Collection and Processing

Information about vegetation, soils, and desert pavements on the ground can be captured by photographic imaging techniques, most commonly done using standard photographic methods such as aerial photographs taken from an airplane. Various cameras and films are used to enhance photographic details. Fast camera lenses that permit rapid capture of images reduce blurring from aircraft movement, and chemically coated lenses reduce scattering of photons of light or wavelength changes. Integration with global positioning satellites (GPSs) and aircraft instrumentation also enable post-image processing to correct for aircraft movement between frames for georectification. Film speed, wavelength sensitivity, and emulsion grain-size influence the quality of the resulting image. The constant improvement in cameras, lenses, and films provide a means of improving image collection techniques.

Film may be processed as positive or negative images. The advantage of positive images is that they can be more readily interpreted by the technicians without a loss in image quality. Negative film is often printed as positive photographs and suffers slight degradation in the enlargement process. The degree of degradation depends on the quality of the lens of the enlarger and the photosensitive quality of the photographic paper used to print the image. Fortunately, considerable research has occurred during the past 50 years to minimize image degradation.

Photographic images either as positives, negatives, or paper prints can be scanned using flatbed scanners to create digital images that can be stored, manipulated, and analyzed. Scanners use a light sensor head that measures information about light wavelength (usually red, green, blue or cyan, yellow, and magenta) at predetermined units of area referred to as pixels. Image size or resolution is usually reported as the number of pixels per square inch. Generally speaking, the higher the number of pixels per square inch, the greater the mechanical resolution of the digital image. It is also possible to alter the number of pixels by interpolation. This is a mathematical method of increasing or decreasing the number of pixels in an image in a process called “resampling.” Large numbers of pixels require more storage space and processing time than small numbers of pixels in an image. It is usually advantageous to limit the number of pixels to the minimum needed to properly resolve the details needed for photo-interpretation.

### 4.2.1 Satellite Imagery

Satellite imagery does not use photographs like conventional aerial photography, but rather consists of remotely sensed data from light sensors and filters that scan a precise area on the earth’s surface and store the data as numerical data. Data can subsequently be printed as an image or manipulated and analyzed mathematically. The U.S. satellite LANDSAT and the French satellite SPOT are the two most commonly used satellite images. They have data in multiple bands or wavelengths, consisting of panchromatic (black and white, mainly for resolution) and multispectral (color for image composition) bands. The major limitation in the use of the imagery is in the very large pixel size. Pixel sizes are usually 30 m × 30 m (98 ft × 98 ft) for color bands and 10 m × 10 m (33 ft × 33 ft) for black and white bands (SPOT data only). Satellite imagery is relatively inexpensive, but has limited time intervals and scale, and may have reduced value because of cloud cover. Such imagery is used in research involving landscapes and is usually considered to be a relatively low-resolution image compared to aerial photography taken by fixed-wing aircraft.

The analyses of SPOT satellite imagery data was based on previous work at Fort Irwin, California. Research to develop disruption classification techniques at Fort Irwin was conducted by CSUDH from 1994 to 1996 (Prigge and others, 1998). They used LANDSAT TM images to give a preliminary statistical measure of disruption assessment. Their goal was to apply disruption classification techniques of their 1994 research to more recent 1996 imagery, thereby permitting comparison of disruption levels for the years 1993 and 1996. In addition, the 1996 classified imagery gave a more recent product for accuracy assessment for mapped disruption levels through field checking.

The goal of CSUDH's past research (1997) was to refine the 1996 disruption classification through ground-based checks against 1996 disruption maps. Albedo maps were produced and attempts to appraise the usefulness of the technique for future statistical and temporal analysis was reported. The map was generated using prepublished pre-launch gains and offsets to convert TM digital numbers to exoatmospheric reflectance in percent. This function used the satellite digital counts (from 0 to 255) to approximate at-satellite reflectances of individual image picture elements (pixels) by correcting for sensor gains and offsets, solar irradiance, and solar zenith angles.

Correlation of shrub cover data collected from satellite imagery and compared with aerial photography data taken from 68 ground plots measuring 500 m x 500 m in size (located in four transects across the valley floor in Central Corridor at Fort Irwin, California) were analyzed for statistical and spatial correlation. Results indicated very low statistical linear or curilinear correlations (low $R^2$ values). Ground observations of these plots and prints from both image types indicated that spectral values taken from SPOT satellite imagery that were considered to indicate vegetation were more often than not indicative of dark shadows, roadcuts, and other artifacts than they were of actual shrubs. The satellite imagery was good at detecting larger roads and scrapes, but were inadequate at detecting shrubs. Imagery from high resolution aerial imagery, on the other hand, indicated good correlations with both bare areas as well as shrubs. It was concluded that the primary reason for the poor correlation between the image types was the difference in resolutions. The SPOT satellite imagery had too large of a pixel to adequately detect shrubs. More recent use of IKONOS imagery with a 1m x 1m pixel size was much more correlated, although the resolution of low-level aerial photography was still superior to satellite imagery because of the higher resolution.

Newer and higher-resolution satellite imagery became available during the past two fiscal years. The IKONOS 2 was launched successfully on September 24, 1999, and provides a 1-m (3-ft) resolution panchromatic sensor and a 4-m (13-ft) resolution multispectral sensor, the highest spatial resolution available from a commercial imaging satellite. Three panchromatic images of Mojave Desert areas at the U.S. Marine Corps Air Ground Combat Center in Twentynine Palms, California were provided by Dr. Paul Tueller with funding provided by another SERDP Project. Most of our research during the FY 2001 and 2002 focused on the use of this new high resolution imagery and correlation of satellite pixel data with higher-resolution ground data. The lack of good correlation of small-scale satellite imagery with shrub cover directed most of our research to the use of higher resolution aerial photography to achieve our goals and objectives.

### 4.2.2 Aerial Photography

The first analyses of aerial photographs were made on images scanned from films, prints, or directly from digital cameras. Camera types used included Nikon 35 mm, Hasselblad, and two digital cameras, a Nikon body with 6 megapixel back, and a Kodak 1- megapixel camera. Aerial photographs were taken from a helicopter (handheld) at 150 ft, 250 ft, 350 ft, and 500 ft altitudes above the ground approximate 3/4 mile southeast of Bechtel Nevada’s Remote Sensing Laboratory at Nellis Air Force Base in Las Vegas, Nevada. The ground vegetation at this location consisted of creosote bush along a moisture gradient on dry thin soils to wetter deep soils, thereby providing a range of vegetation cover. These films were scanned using a flatbed scanner and film scanner at a range of dots per inch (dpi) from 150 to 1200 dpi. These images provided a series of test images for further analyses. Images taken closer than 150 ft from the ground created winds from the helicopter rotor blades that were excessive which caused moving of shrub branches and the optical resolution targets. Altitudes greater than 500 ft were considered to be in the range that could be captured more effectively with fixed-wing aircraft (camera movement is a problem at lower altitudes). Results of these test indicated that 35 mm film images using Kodak Royal Gold® film produced the highest resolution images (even better than Hasselblad using conventional film).

Aerial photographs were taken of Fort Irwin during 1997, 1999, and 2001 (1:24000 scale) for the purpose of performing retrospective analyses and documenting changes in site conditions (e.g., comparisons of changes detected in photographs taken in 1997, 1999, and 2001). The most recent photos were taken in August 2001 and conversion of the imagery to binary file formats has now been accomplished and is being analyzed by technicians at Fort Irwin. This analysis has recently been postponed due to changes in site personnel. It is anticipated that further image analyses will be made during FY2003. Images taken in 1997 were processed and a map showing vegetative cover at Fort Irwin was produced by trained scientists at Fort Irwin using the new photo analyses techniques developed by this project and incorporated into their geographic information system.

Sample digital imagery (Camis imagery with resolutions of 0.5 m, 1.0 m and 2.0 m) were provided by the U.S. Army Corps of Engineers (ERDC-CERL), in Champaign, Illinois of Mojave Desert vegetation at U.S. Marine Corps Air Ground Combat Center in Twentynine Palms California. Plant cover estimates (Figure 4-1) for these images inflated slightly with decreasing resolution (e.g., 12.7% cover for 0.5 m resolution, 13.7% cover for 1.0 m resolution, and 14.8% for 2.0 m resolution.). The reason for the increase in cover is because at lower resolutions there are more mixed pixels which contain light photons from vegetation and soil. These pixels contain light reflected by soils. These mixed pixels tend to be classified as vegetation (darker) when the threshold is set at lower light reflected from vegetation (black) and greater light (higher albedo) from light colored are at or near threshold values for the soil (light). For example, mixed pixels that are gray get classified as vegetation (black) when the threshold is set near values associated with soils (white). It was concluded from these analyses that higher resolution imagery is more accurate and preferred over lower resolution imagery. The measure of error was documented.

Aerial photographs of Jornada Experimental Range in New Mexico were obtained at a scale of 1:12000 and processed in 2001 using several image software packages to estimate the percent cover of shrubs in an arid land environment dominated by mesquite and creosote bush shrubs. Sample imagery from a mosaic of plant communities were processed to show shrub silhouettes and results shared with scientists working at the Agricultural Research Service in Las Cruces, New Mexico. The photographic scale appeared to provide sufficient detail to identify most large shrubs with percent cover ranging from 0.8% to 14.9% for different scenes (usually containing different plant communities).

From the image analyses using several software packages, an error was detected in the cover calculation algorithm of Sigma Scan Pro® software. The current version (Version 5.0) apparently under estimates cover (e.g., 4.93%) compared to values calculated with other software (e.g., 14.9% using ImagePro Plus™) when large numbers of pixels (tens of thousands) are selected while processing large images (2,500 pixels wide by 2,500 pixels high).

No errors were detected using smaller images (e.g., 300 pixels x 300 pixels) with hundreds of objects thresholded. However, threshold masks produced by Sigma Scan Pro® were accurate. Caution should be exercised using Sigma Scan Pro® to ensure that accurate cover estimates are obtained. Additionally, error messages obtained while writing measurement data to the internal spreadsheet should be taken as a sign of unreliable cover estimates.

### 4.2.3 Ground Level High-Resolution Imagery

Handheld digital images of ground-level shrubs were taken with a white bed sheet draped behind them to estimate foliar density needed for modeling wind erosion at Fort Irwin. Images were 1,280 pixels wide by 960 pixels high. Images were take in the Langford Impact Zone and the John Wayne Hill (very heavily disturbed site) near the "Tip of the Whale," to provide

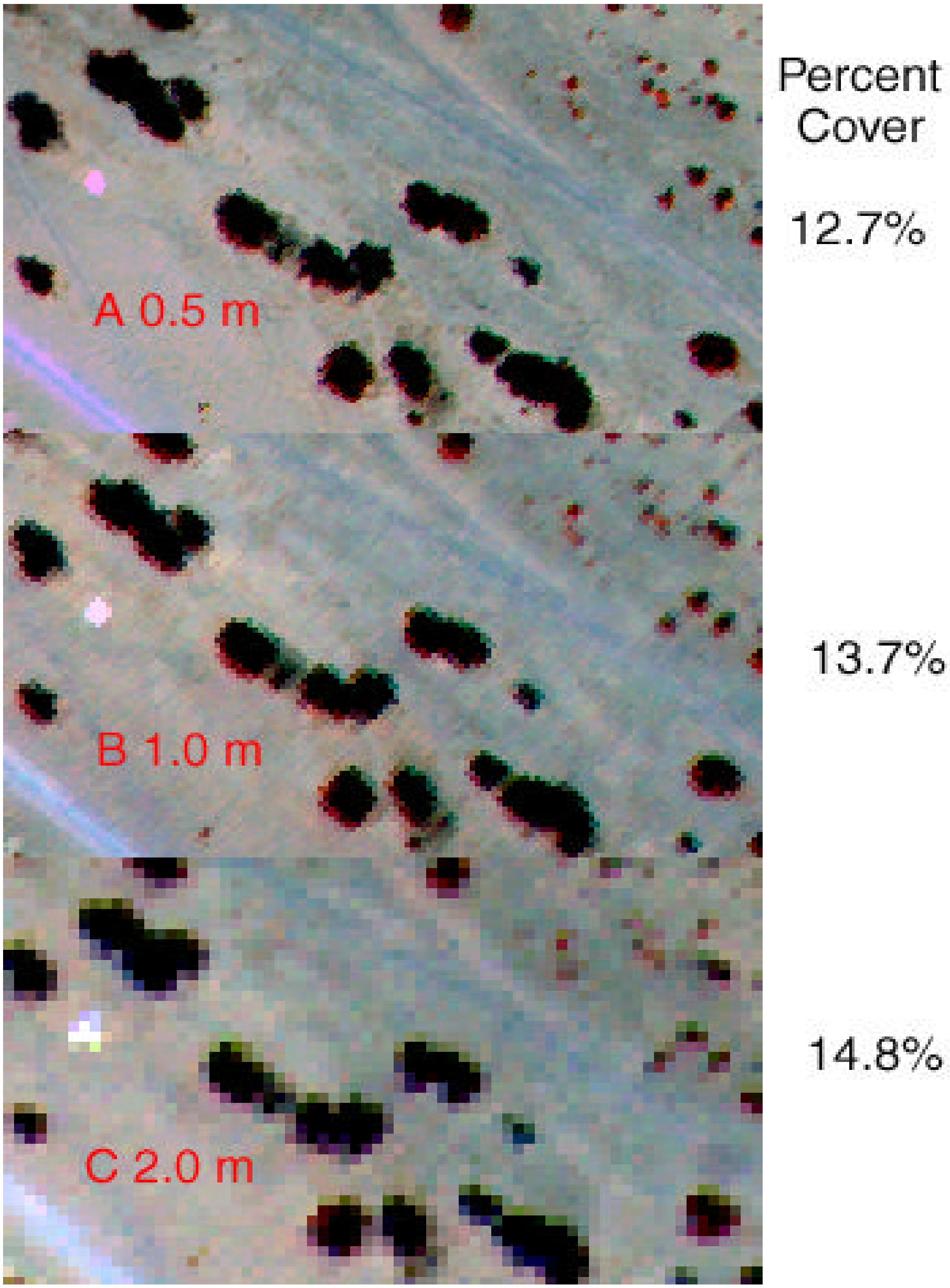



**Figure 4-1. Camis imagery at scales of 0.5 m, 1.0 m, and 2.0 m per pixel showing estimated percent plant cover.**

approximately 12 images in areas considered lightly disturbed, 9 images in areas considered moderately disturbed and 15 images considered heavily disturbed. Images were analyzed using Image-Pro Plus™. The outline of the shrub (green line) was digitized using the Area of Interest (AOI) freehand tool. The AOI was measured to estimate the percentage of the area that was considered to have foliage (Figure 4-2).

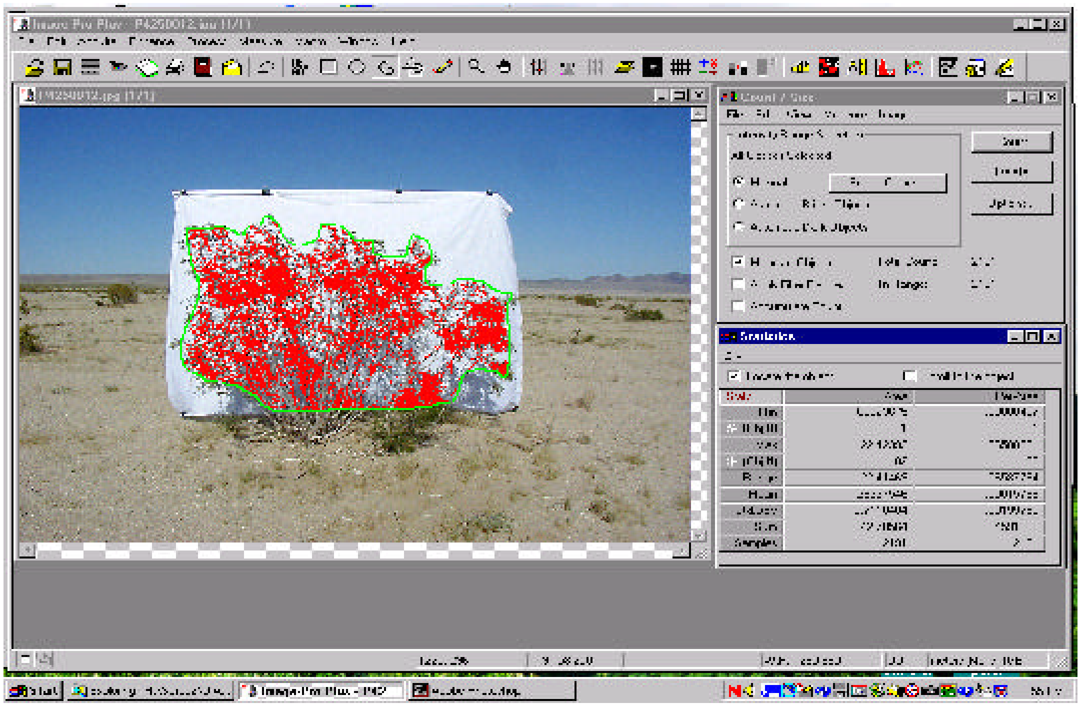


**Figure 4-2. Example of screen capture of Image-Pro Plus showing percent cover (per area) of Area of Interest (green line) for creosote brush at Fort Irwin in a heavily disturbed site.**

The mean foliar densities for shrubs in three disruption levels are shown in Figure 4-3. The percent mean foliar density was observed to increase with increase in disturbance level due to military training. This can be explained simply. When plants are only lightly disturbed the plants are so infrequently run over that branches extend considerable distances from the plant crown allowing a more open canopy with less dense foliage. As plants are increasingly impacted more branches are broken off and more sprouting occurs near the base of the plant crown and from resprouting branches. Under heavy disturbance plants are regularly "pruned" and cut back resulting in a more compact and foliar-dense plant. Because the impacts are more or less random the variance of foliar density is large under the high disruption levels of training. A few plants are reduced to small resprouts while other plants are rarely

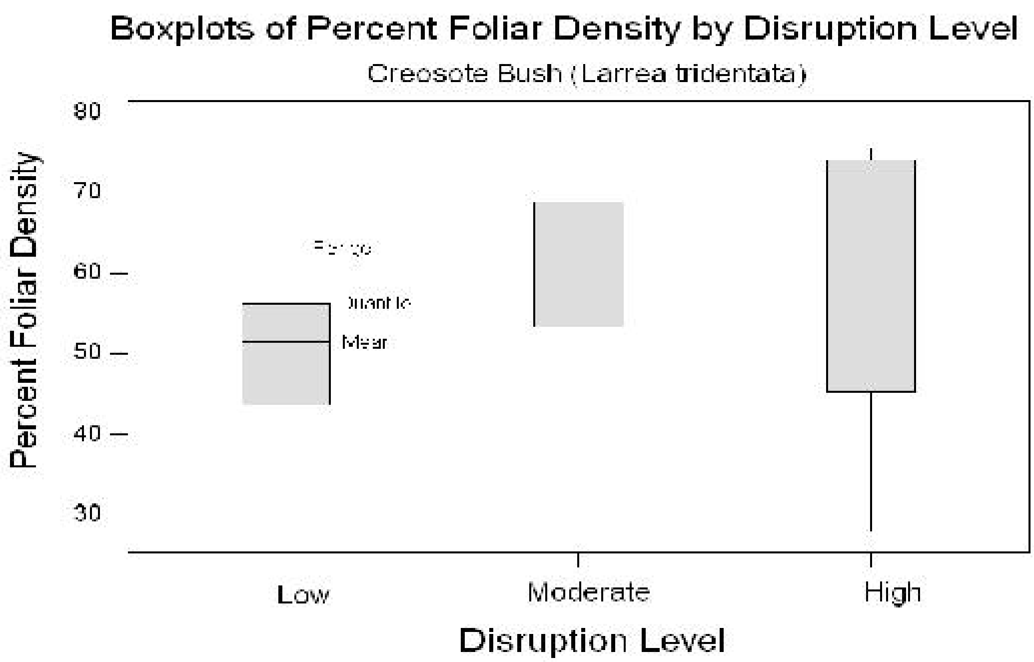



**Figure 4-3. Percent mean foliar density of creosote shrubs (*Larrea tridentata*) shrubs located in three levels of disturbance due to prior military training.**

impacted resulting in a large range of percent foliar density.

## 4.2.4 Videography

The use of ground-level videography was evaluated as a source of imagery. It was determined that the older analog form of video was not suitable for use in photo processing as resulting images lacked detail. This form of imagery relies on filling in scan lines with every other frame and produces acceptable moving images (30 frames per second), but poor still images. Some of the newer, high-resolution digital camcorders are suitable for use and are comparable to digital imagery taken with a digital still-shot camera. An important characteristics is image quality which rapidly deteriorates with video camera motion and was found to lack detail needed to differentiate details of the vegetation. Camera motion also prevented the camera from focusing precisely on the vegetation. Proper exposure was often difficult to achieve in the bright arid landscape (e.g., images were washed out). In short, digital cameras were found to be less expensive and more reliable than digital camcorders for digital imagery that could be processed for measurement of shrub cover.

## 4.2.5 Image Processing Software

A number of image editing, image enhancing, and image processing software packages were evaluated. These software packages were primarily used for medical image-processing (light-microscopy images) as contrasted with GIS image-processing software. The former software was found to have better features to manipulate high resolution images that could be used to created GIS themes and maps. No GIS software was found to have the same ability to distinguish shrub cover in arid lands as well as did the medical imaging software. However, the medical imaging software lacked geospatial coordinates needed to use them in GIS systems and they required geological mapping software to create maps that could be imported into GIS software. Results of these evaluations are described in Appendix A and newly developed techniques form the basis for the attached user's manual.

This technique, although somewhat complicated in that it requires several steps, was the only way that was identified to produce site-wide installation maps of very large areas. The technique was described in several workshops including the 18$^{th}$ Biennial Workshop on Color Photography and Videography in Resource Assessment, held in Amherst, MA on October 16-18, 2001 (Hansen and Ostler, 2001), and A Workshop: New Technologies to Assess Vegetation Change and Reclaim Arid Lands, held in Las Vegas, Nevada on October 22-23, 2002 (Hansen and Ostler, 2002). It provides an economical means of mapping large DoD and DOE installations within relatively short periods of time and is currently being used at several government arid land installations. Development of this technique is considered a significant improvement over ground-based techniques for acquiring vegetation cover data.

Requirements of the technique include digital imagery at a scales of 1:50 (photo units: ground units) to 1: 24000 with 1:2000 to 1:4000 being considered ideal for most arid lands. At smaller scales (e.g., 1:24000 scale) the technique provides only a cover index as many small shrubs are not detected. Identification of individual species was only possible on plant species with unique sizes or non-overlapping spectral image properties; at best only three to four dominant species can be identified and quantified. Plants are best sampled in the spring when vegetation is green and at its peak growing period for the year. Vegetation that was dry (tan or gray in color) was often difficult to differentiate from the background soils with similar color. Shadows and rocks frequently gave false signals at smaller scales of images, but could be detected and separated from the true vegetation cover at higher resolutions (e.g., 1:2000 scale). Grasses, particularly if dry, were the most difficult species to measure because their color blended in so well with the color of the soil.

It is apparent that commercial software is developing each year and new features are being added to improve the performance of image processing software, both in the GIS image processing software as well as the medical image type of image processing software, and that new develops and improvement should be anticipated in the future. Increases in resolution are also expected in satellite imagery which will make coverage more affordable, dependable, and accurate.

### 4.2.6 Plant Damage Assessment Technique Development

Research efforts to correlate image processing techniques to field conditions led to the need to develop a quick technique of assessing plant damage from different types of vehicles. Adverse impacts caused by vehicles operating in non-arid land areas are significantly less than those associated with arid lands. In grasslands, for example, plants may tolerate many (e.g., 12-24) passes of a vehicle before extensive damage is done. In arid lands, by contrast, up to 70% of the plant may be killed by a single pass of a vehicle and resprouting and recovery may be slow or non-existent during periods of drought. A technique was developed to assess plant damage for evaluating military vehicular impacts to vegetation in the Mojave Desert. A copy of this report is found in the appendix (Appendix B) of the user's manual (Appendix A.2 of this final report) (Hansen and Ostler, 2002).

### 4.2.7 Software Development

A need was identified during the evaluation of image processing techniques for creating spatial maps showing distribution of shrub cover over large areas that could be converted into GIS coverage (themes). Most of the commercially available GIS software did not have the statistical power needed to develop maps at varying scales of detail. A few GIS software packages provide simplified kriging but, lack more sophisticated features that are found in geological mapping software such as Surfer® that is designed to permit the user to map mineral composition and geological features with powerful statistical functions and other sophisticated graphing techniques. However, such software requires the use of tabular data sets with values associated with X and Y (number of pixels) coordinates (e.g., x = 1, y = 4, and z = 0.35). Therefore, new software was developed to convert shrub silhouette images into tabular data. This software, named "SERDP TIFF Conversion Software" was designed to read in a black and white TIFF image, establish a user-defined grid size (large number of pixels per grid cell [e.g., 100 x 100 pixels] for low resolution maps, and low number of pixels per grid cell [e.g., 10 x 10 pixels] for high resolution maps) and sample the grid cell, calculating the percentage of the grid that was comprised of dark pixels and return a percent cover value with the grid coordinates expressed as the number of grid cells from the graph origin in the horizontal direction (e.g., 1), the number of the grid cells from the graph origin in the vertical direction (e.g., 4), and the percent shrub cover (e.g., 0.35) . The software was designed using Microsoft's Windows Visual Basic and a copy of the software is included in the attached CD.

### 4.2.8 Laser-Induced Fluoroscopy Imagery and Spectroscopy

Laser induced fluorescence imagery (LIFI) and laser induced fluorescence spectroscopy (LIFS) experiments were conducted on vegetation at the National Training Center at Fort Irwin, California (Figure 4-4). The field equipment was refined in FY2000 and FY2001, making it smaller and easier to use. The purpose of the experiments was twofold: (1) to determine if stressed plants could be distinguished from unstressed plants using LIFI/LIFS signatures, and (2) to determine if species differentiation or identification could be achieved.

The use of LIFI/LIFS shows promise for detection of plant stress, but is not considered cost-effective because other less expensive methods have been developed under this program (e.g., rapid assessment of vegetative cover using image analysis software to measure plant cover) to detect reductions in vegetation vigor and cover. These latter alternative methods also provide larger areas of coverage that can be more readily incorporated into Geographic Information Systems which is the preferred way to document changes due to training impacts. Spectral qualitites of stressed *Larrea tridentata* (creosote bush) plants were readily distinguished using LIFS spectra. *Senna armata* and *Psorothamnus fremontii* also have rather unique spectra that can be used to distinguish them from other species. Differentiation between stressed and unstressed plants of other species was not as definitive. The ability to differentiate between species based on their LIFI/LIFS signatures was possible under limited conditions. For example, creosote bush, when stressed, was readily differentiated between other

species, but unstressed creosote bush was not. Results of these experiments are described in Appendix B.1.

**Figure 4-4. Example of equipment used to measure laser induced fluorescence imagery and spectroscopy at Fort Irwin, California.**

# 5.0 RECLAMATION TECHNIQUES

This section of the final report describes project activities and accomplishments in support of achieving the objective of developing and testing cost-effective techniques for rehabilitation and restoration of disturbed habitats. The greater part of these activities are described in detail in the user's manual: *New Technologies to Reclaim Arid Lands User's Manual.* W. Kent Ostler, David C. Anderson, Derek Hall, and Dennis J. Hansen. 2002. DOE/NV/11718—731, Bechtel Nevada, Ecological Services, Las Vegas, NV 89193. (Appendix A.3).

Activities that were not described in the user's manual included procedures that were tested but yielded unacceptable progress in meeting the desired objectives. Some of these procedures are described here in this final report and are included in the appendixes to document what was done, especially if these activities were considered worthy of discussion and related to the stated objective. Other activities were not included because their discussion would not contribute meaningful information and may distract the reader from pertinent information related to the goals and objectives of the project. Examples of activities not described included were those dealing with germination or planting techniques that did not work are not likely to be used in the future.

## 5.1 Background

The resiliency of a site to training exercises depends on the frequency and nature of the impacts, as well as the site potential for restoration. Such things as plant species present, seed bank, soil moisture, soil texture, and available nutrients determine the site potential for restoration. At some sites, a shift in the plant community composition may also occur, with more sensitive species being replaced by plants more resistant to training impacts. Recovery may occur naturally and keep pace with the level of disturbance at some sites, depending on the nature and frequency of the disturbance, however in arid environments sites usually require selected restoration techniques to recover from adverse training impacts before sustainable restoration is achieved.

Project personnel have used several revegetation techniques to accelerate the recovery process in desert environments. Combinations of innovative revegetation techniques developed at the NTS and other disturbed sites in the Mojave Desert were applied to disturbed lands at Fort Irwin. Reclamation equipment to implement these treatments was provided by the DOE. The primary questions to be answered are: (1) At what degree of disturbance and vegetative condition is a site no longer capable of regenerating itself ? ( 2) What are the costs, time, and techniques needed to return a site to a sustaining usable condition given various degrees of site degradation?

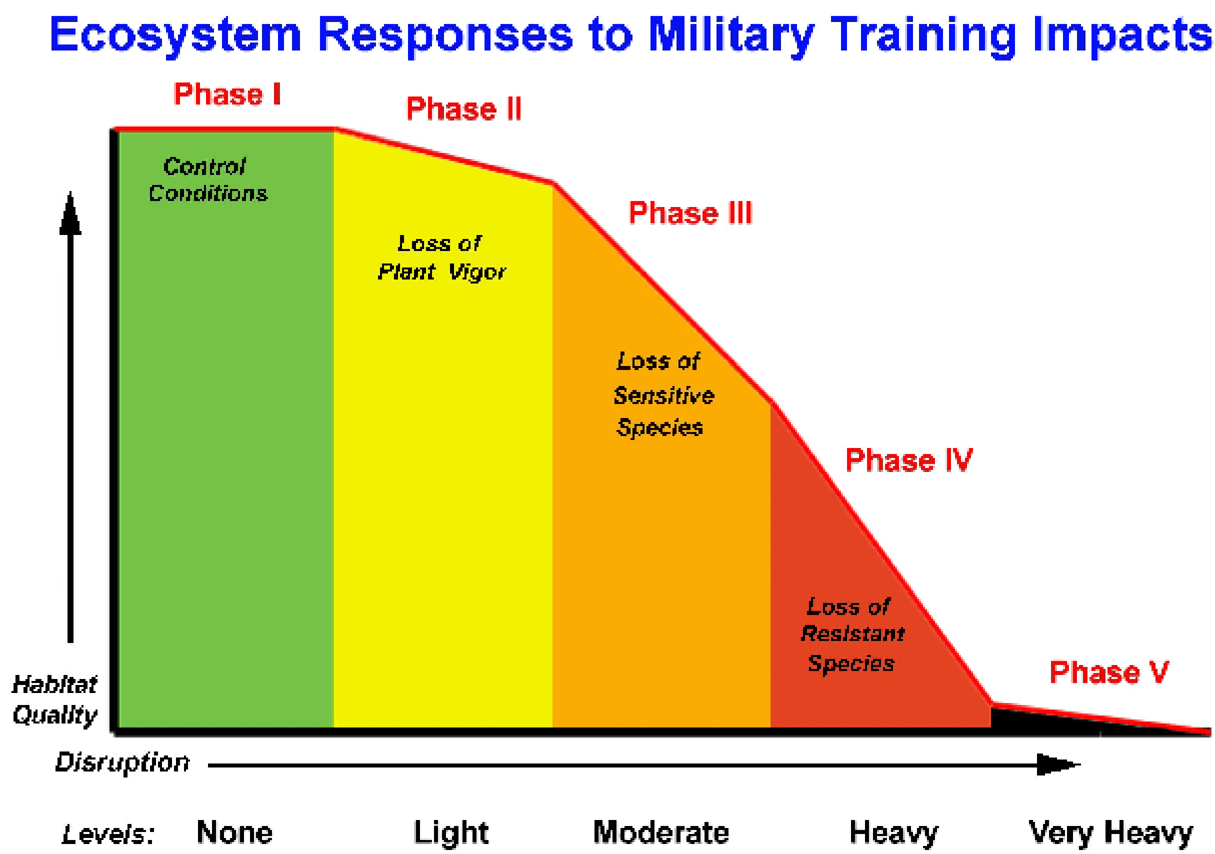
## 5.2 Threshold Levels

The impacts of military training include such things as mechanical damage to plants, compaction of soils that restrict root growth and the establishment of new seedlings, loss of soil structure that inhibits infiltration of precipitation, loss of soil nutrients and organic matter that accelerate erosion and sandblasting of young plants, and loss of beneficial soil microorganisms that provide nutrients to plants and bind soil particles together (biotic crusts). Under severely disturbed conditions, mature plants capable of producing seed are lost and the soil seed bank becomes depleted. Valuable resources such as topsoil and nutrients may be lost. Soils under further degradation may become hydrophobic with increased temperature and salinity that may inhibit germination and growth of new plants.

Figure 5-1 shows the key phases of habitat degradation that result under increasing disruption from military training. Phase I represents habitat in relatively undisturbed conditions with a full complement of plant species and undisturbed community structure and composition. As light disruption begins, there is usually a loss of plant vigor of sensitive species categorized as Phase II. Under moderate disruption levels (Phase III), there is a loss of sensitive species. During heavy disruption levels (Phase IV), there is a loss of not only the sensitive species, but also the resistant species. During very heavy disruption levels, even resistant species lose vigor until little or no seed or plants remain. Soil resources such as nutrients, organic matter, soil microorganisms, and even topsoil are lost by wind and water erosion. The few plants that do become established are severely challenged by increased evapotranspiration and damage from insects such as ants and small mammals.

The lack of water in arid and semiarid military ranges is perhaps the most limiting factor in the growth and resiliency of vegetation to withstand training impacts (Wallace and others, 1980; Verma and Thames, 1978). In desert areas, the cost of recovery, risk of failure, and time needed for recovery increase dramatically and curvilinearly with the severity of impact (Figure 5-2). In moist environments, costs and associated restoration requirements increase only slightly with increase in level of disruption because there are fewer limiting factors in moist environments and recovery is more dependant on the vegetative growth rate. In arid ranges, the impacts to vegetation become increasingly severe as training impacts increase in frequency and duration at rates that are disproportionate to early stages of disturbance. Even under natural conditions, severely disturbed sites in the Mojave Desert are projected to take up to 200 years to restore vegetation comparable to pre-disturbance conditions (Figure 5-3) (Angerer and others, 1995; Vasik, 1980; Webb and Wilshire, 1980). Lands that have been drastically disturbed in deserts create serious challenges to revegetation. Frequent and continued impacts require new restoration techniques to increase cost efficiency of mitigation efforts and to enhance natural plant establishment in synchrony with natural, often unpredictable climatic patterns.

In the User's Manual, Appendix A.3, we have presented a flow diagram (see Figure 6-1 in Appendix A.3) that provides assistance in determining when a site should be revegetated or protected from



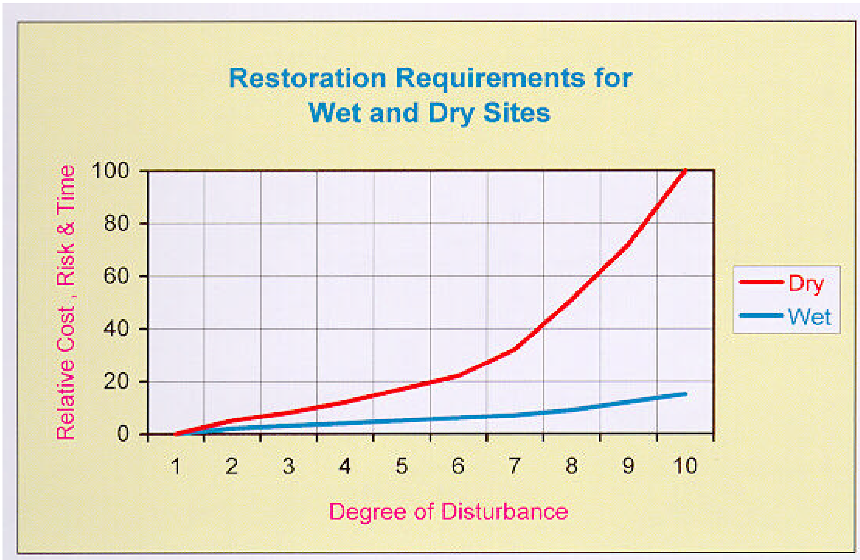

erosion. At Fort Irwin, California, a site is heavily disturbed if vegetation cover is under 6 percent or if the site is losing the resistant species, creosote bush, white bursage, and **Figure 5-1. A conceptual model of thresholds in a Mojave Desert Ecosystem.**

desert senna. This represents phase IV in the conceptual model and steps should be taken to protect these sites from further degradation. It is imperative that these resistant species are not lost from a site or the site will quickly degrade losing soil resources that can not be replaced without tremendous cost and money. We observed from our reclamation trials that standard practices (including limited irrigation) were not adequate to recover highly disturbed sites. These sites would first have to be stabilized and soil resources added before revegetation could occur. On the other hand sites could recover well if protected and provided adequate water either naturally or through irrigation (Figure 5-4).

## 5.3 Literature Review and Data Gathering Efforts

Project team personnel used Internet access to conduct a search for current information regarding

Mojave Desert and arid-land restoration techniques. One hundred eighty-six individual references with pertinent information were found and documented in Appendix C.



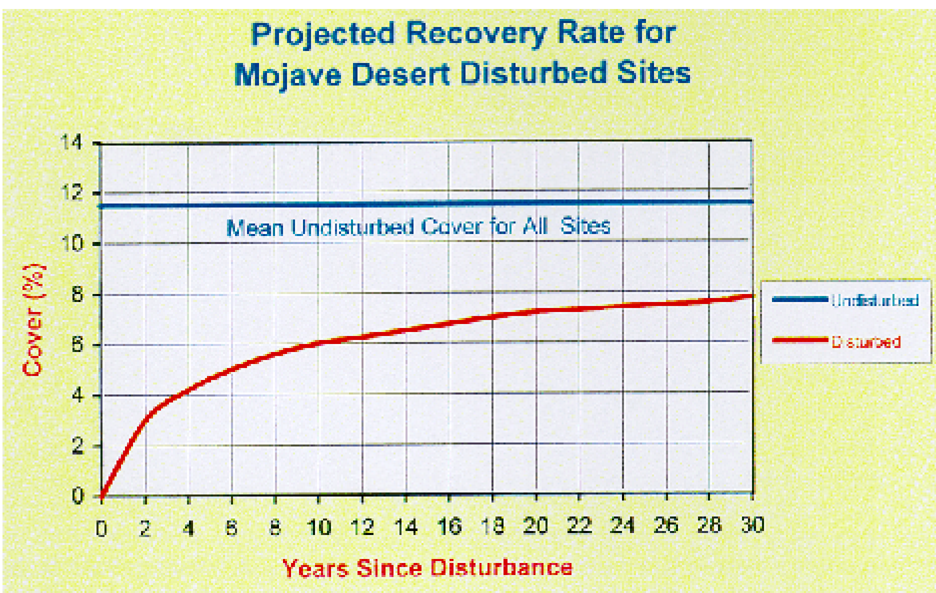




**Figure 5-2. Restoration requirements of different sites.**

**Figure 5-3. Recovery rates of disturbed sites in the Mojave Desert.**

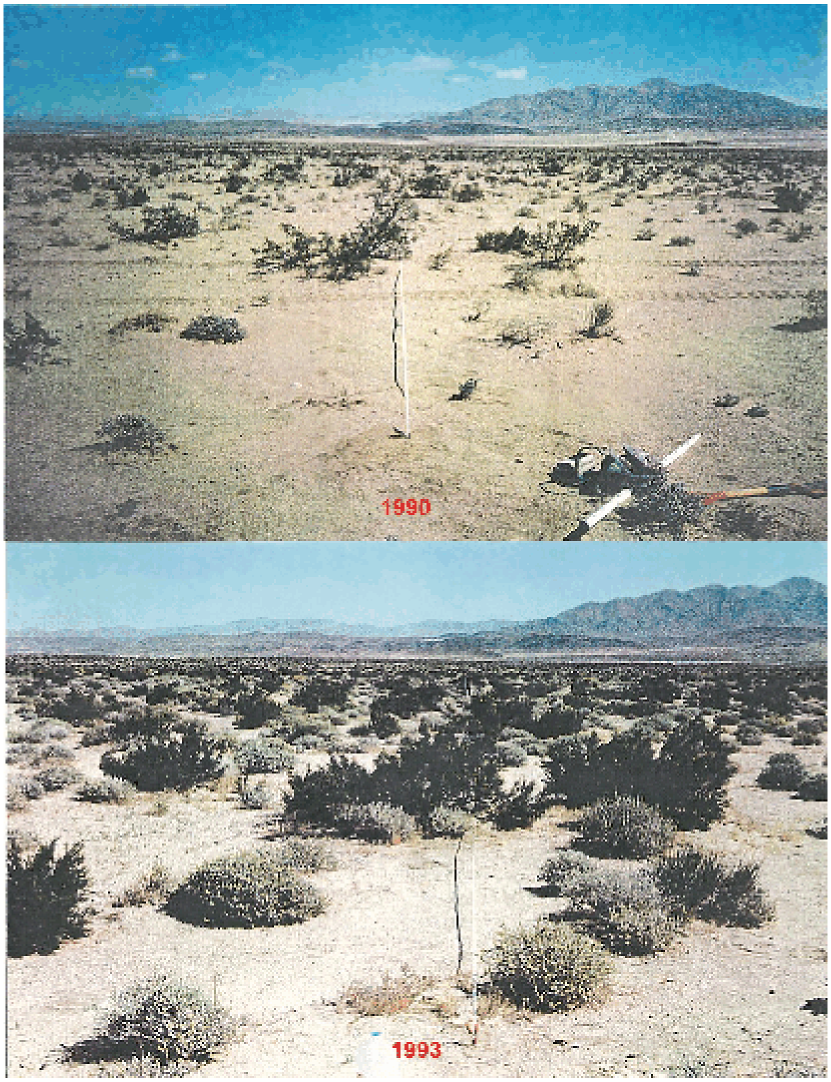



**Figure 5-4. Site recovery in 1993 at Fort Irwin from a headily disturbed area (1990) after three years of good precipitation.**

Most information found consisted of traditional reclamation techniques and methods such as . seeding, transplanting, irrigation, and mulches. Other, less traditional methods described (which reportedly improve reclamation success) included soil pitting, vertical mulch, imprinting, synthetic soil amendments, and inoculation of the seedbed with mycorrhizal fungi

In addition to the Internet search, 18 individuals who specialize in arid-land restoration were contacted by phone. These individuals were requested to provide information pertaining to current (1995-1999) restoration projects and research in the Mojave Desert and surrounding areas, with a particular interest in unpublished and/or difficult-to-find literature. Verbal information of restoration-related work was also recorded from each phone conversation.

Managers generally reported use of traditional arid-land reclamation techniques and methods consisting primarily of transplanting and seeding operations. Native species were used in most current projects, although some introduced species were still being utilized in others. The reported success of these restoration projects was highly variable.

## 5.4 Initial Workshop

A workshop was planned as an initial activity for this project as a way to get input and support from recognized experts in arid land reclamation. Planning for the workshop was conducted by BN staff in concert with specialists contracted from other organizations. The Workshop Coordinator was Dr. Cy McKell, President of AES and former Dean of Science at Weber State University. Dr. McKell and Dr. Von Winkel, Senior Scientist, SAIC, served as moderators of the various sessions of the workshop. The time chosen for the workshop was soon after the project was initiated not only to gain the input of the technical community, but also to be at a time when participants were available before they initiated fall field activities and academic duties at universities. Fort Irwin, California, was the general location of reference for the workshop, but areas of similar climate, vegetation, soils, and type of use by DoD and DOE were considered in the planning, presentations, and discussions.

The main purpose of the workshop was to obtain the recognition, review, and input of technical and scientific specialists involved in remote sensing of land conditions and in arid land revegetation. By inviting recognized specialists in remote sensing and revegetation to present their work on topics of current interest, the project benefitted by hearing up-to-date presentations and discussions of work that are highly relevant to the project. The workshop also provided an opportunity for review and comment on several project field activities planned for the fall/winter season of 1999 and 2000.

Invitations to attend the workshop were sent to more than 90 remote sensing/GIS and revegetation specialists in military units, government agencies, universities, and private industry. Previously, lists of attendees at workshops, conferences, and technical training sessions were screened by project staff to develop the mailing list for the workshop. The number of people invited to attend was intentionally kept modest to have the number of people attending the workshop at a workable size that would facilitate comments and discussions and involve a high proportion of the audience in a classroom setting. A high proportion of those invited accepted the invitation to attend; some sent regrets that they were involved in other meetings and did not have the date available. More than 55 specialists attended the workshop, giving it a balanced composition of experience and research in problems common to the arid and semi-arid environmental setting chosen for the workshop.

The workshop program was designed to obtain presentations of current work and to stimulate discussion and review of topic areas. The schedule of topics and names of presenters are shown in Appendix C.1. Presenters were encouraged to highlight recent progress in techniques and materials, as well as areas of their disciplines where gaps in knowledge and more field testing is needed. Prior to the workshop, each person presenting a topic provided an abstract containing highlights of the topic covered. All abstracts were photocopied and provided to attendees as they registered for the workshop. After each group of presentations, 30 minutes were scheduled for questions and discussion, led by a moderator.

The workshop began with a brief welcome and introductions, followed by a discussion by Dr. Ostler of workshop objectives. Two presentations described some of the needs and problems in remote sensing analysis of vegetation/ land condition to provide a background for understanding how remote sensing and analysis were important to the whole problem of site analysis and revegetation. Subsequently, three topics on diagnostic tools and techniques, five topics on applications, and three topics on new diagnostic techniques were presented and discussed. At the end of the day, a poster session of eight poster boards were displayed to allow those in attendance to view the work and to have informal visiting time.

On the second workshop day, the focus was on arid land revegetation methods and materials. Five presentations outlined reclamation needs, followed by four topics on plant materials for reclamation. The afternoon session consisted of five presentations on reclamation techniques. The day concluded with a presentation of experimental designs for three field experiments planned for the fall/winter period and the environmental constraints of working on an active training site (Fort Irwin). The general consensus on the experimental design was that it contained too many factors and too many levels within factors, which would cause the experiments to be too large and costly. Suggestions were made to use past experience and research to omit or limit the number of factors/levels within factors. Several suggestions were offered on possible soil amendments, particularly those that enhanced soil microbial action and nutrient cycling. A general discussion was conducted at the end of the workshop to summarize reclamation tools. Appendix C provides a summary of the workshop presentations and discussions.

## 5.5 Reclamation Trials

### 5.5.1 Selection of Restoration Trial Sites

The resiliency of a site to training exercises depends on the frequency and nature of the impacts, as well as the site potential for restoration. The site potential for restoration is determined by such things as plant species present, seed bank, soil moisture, soil texture, and available nutrients. At some sites, a shift in the plant community composition may also occur, with more sensitive species being replaced by plants more resistant to training impacts. Recovery may occur naturally and keep pace with the level of disturbance at some sites, depending on the nature and frequency of the disturbance, or it may require selected restoration techniques to recover from adverse training impacts before sustainable restoration is achieved.

The proposed approach included the establishment of study plots representing three classes or degrees of disturbance ranging from moderate disturbance (Phase III in the conceptual model) to very heavily disturbed sites (Phase V). Reclamation treatments and the number and size of plots were presented at the workshop. This experimental design was then refined using input from other reclamation experts during the reclamation workshop. The experimental design was then reviewed by a BN statistician to ensure that proper analyses could be conducted. The design consists of a set of treatments that is unique for each of the three levels of disturbance (moderate, heavy, and very heavy) that are being reclaimed. Thus, there were really three separate experiments that were conducted and they were analyzed separately.

Because soils play such an important role in the effectiveness of recovery treatments, it was decided that from three to five separate locations representing the major soil types at Fort Irwin were needed to adequately evaluate the impact of soils on recovery of desert vegetation. Soil samples taken from prospective locations showed that the soils were very sandy, which means they would hold very little moisture for plant use, and they contained very low levels of nutrients including negligible amounts of organic matter.

The other critical factor that was recognized during the workshop was the need for water for both new seedling establishment and for recovery of damaged plants. Irrigation would be applied to the three disturbance level plots, but the actual amounts and timing would vary with the particular objective for the disturbance level. For example, irrigation at moderate disturbance plots would consist of larger amounts of water applied at fewer periods to encourage movement of water deeper into the soil profile which stimulates established plants (McDonald and others, 1999). Supplemental water was particularly important for short-term experiments such as this that could not wait for natural rainfall. A third factor, seeding of native species adapted to site conditions, was identified and agreed upon as being sufficiently important that it should be tested at all disturbance levels.

Other treatments were selected to address the specific needs of each disturbance level. For example, on the very heavy disturbance sites, compaction of the soil was very evident. These sites would require ripping to relieve that condition and enhance plant growth. Other treatments that will be tested in the very heavy sites include the addition of organic matter/nutrients to stimulate soil microorganisms and reestablish nutrient cycling, and surface stabilizers (straw and chemical) to control surface soil erosion until plants can become established. Treatments in the heavily disturbed sites included the addition of micro-nutrients and low levels of macro-nutrients to enhance seedling growth, as well as to stimulate existing plants on these sites. Ripping to relieve compaction and surface stabilization with straw was to be applied to all plots within this disturbance level. Treatments within the moderately disturbed sites included various levels of micro and macronutrient additions. Irrigation application was designed to enhance growth and reproduction of established plants and not necessarily to establish new seedlings. Control treatments were also identified to determine what would happen with no active revegetation efforts.

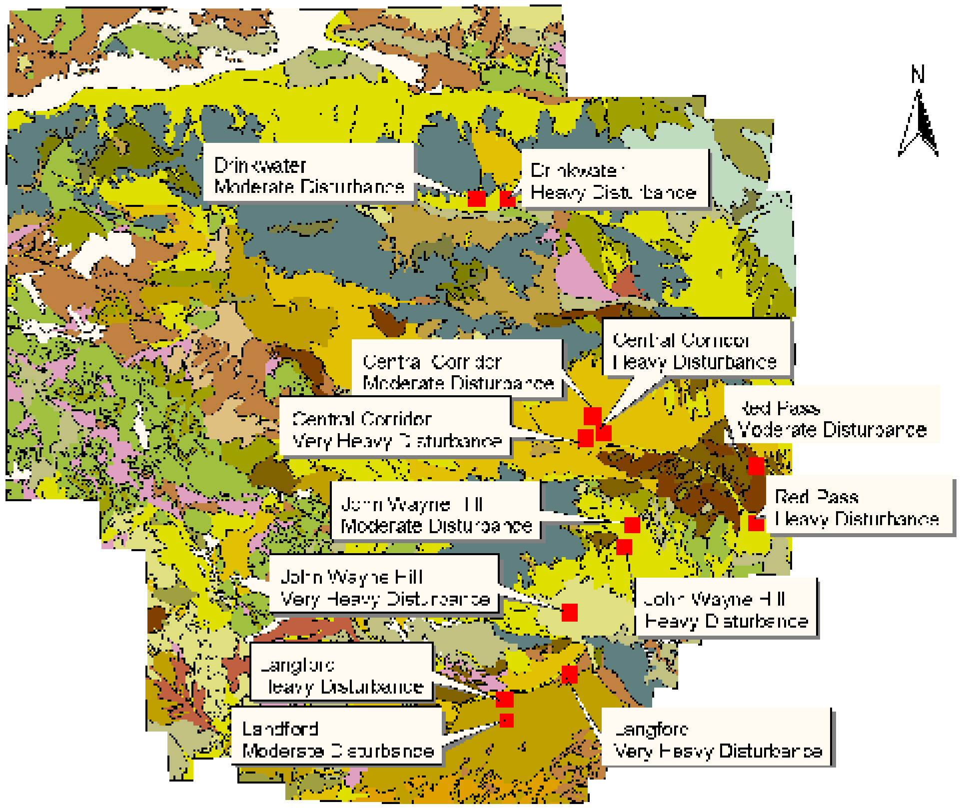
Thirteen potential sites or areas varying in size from 1 to 4 hectares (100 m x 100 m to 200 m x 200 m) were identified with the aid of Fort Irwin staff and soils and vegetation data from Fort Irwin. Potential sites were placed in areas of typical use. Areas in the western and northern portions of Fort Irwin were excluded because of access restrictions. It was anticipated that some of these areas may not be available for our use because of military training needs or conflicts. Once these sites were approved for use, they were placed on maps within the Fort Irwin GIS and identified as exclusion zones. Protection of these plots was enhanced by marking the boundaries in the field with fence posts and siebert stakes. Even with these protection efforts, some disturbances occurred. Those disturbed portions within plots were excluded from future sampling or analysis.

### 5.5.2 Establishing 1999 Restoration Trials

In December of 1999, a series of reclamation trials were established at 13 locations throughout Fort Irwin. The trial locations are shown in Figure 5-5. In December 1999, implement of treatments (except irrigation) on the 13 trial sites was completed. All plots at each site were flagged with chaser stakes at each corner that were color coded to designate the treatments to be applied. Germination was recorded on the trial sites in April of 2000. Most of these trials were sampled again in 2001 to evaluate if changes had occurred. No additional treatments had been implemented on these sites since the initial treatments.

From May 14 to 16, 2001, the plots at the 12 study sites were sampled. All of the severely and heavily disturbed sites were sampled and four of the moderately disturbed sites were sampled. Sampling designs were developed for each level of disturbance, severe, heavy and moderate. At the severe and heavy sites, ten one-meter square quadrats were placed at randomly selected locations in each plot. Counts of all seedlings by species were recorded within these ten quadrats. Total ground cover by living plants or litter was also recorded. Results from this sampling were used to assess first year survival and any additional germination that may have occurred.

At the moderately disturbed sites two additional parameters were measured. Since the objective of these treatments was to enhance existing species growth, leader lengths from 10 individuals of white




Reclamation Study Areas at Fort Irwin

bursage, a dominant species at each site were measured. Each plant was divided into four quadrants and a leader was measured from each quadrant and recorded. This generated 40 leader length measurements at each plot. These were then averaged to obtain an average leader length for each species from each plot. In addition at the sites, inflorescence lengths of white bursage were measured. Twenty individuals from each plot where randomly selected and the longest inflorescence was measured. These were then entered into a database and average **Figure 5-5. Location of 13 reclamation study areas (red boxes) at Fort Irwin. (Colored polygons indicate soil types.)**

inflorescence lengths of white bursage for each plot were obtained. These data were then analyzed using ANOVA and other descriptive techniques to identify difference among the various treatments within each disturbance level. Results of this sampling are reported in three categories summarized by the level of disturbance.

### 5.5.2.1 Severely Disturbed Sites

The experimental design for the severely disturbed sites included four main factors: soils, soil stabilization techniques, soil amendments, and irrigation. Three severely disturbed sites were established in differing soil types across Fort Irwin (Figure 5-5). The results of the ANOVA for seed germination in 2000 showed that there were significant differences in two main treatments, soil type ($p = 0.003$) and irrigation ($p = 0.000$). Soil amendments and stabilization techniques did not have significant differences ($p = 0.111$ and $p = 0.222$ respectively). Results in 2001 showed significant differences in the same two main factors ($p=0.000$ for soils and $p=0.005$ for irrigation) although the relationships were completely opposite for irrigation. The Central Corridor site had higher establishment with additional germination occurring at all sites in 2001. All of the sites had poor germination averaging less than 1 seedling/meter2. This would not provide an adequate number of plants to successfully revegetate an area. The irrigation treatment caused almost a three-fold increase in the number of seedlings over all sites during 2000 but showed a decline by 2001 with the non irrigated plots showing a large increase in new seedlings in 2001.

Even though irrigation was shown to be an important aid in restoration during the first year, this was not true the following year that had additional germination caused by several good precipitation events during the spring of 2001. Although seedling numbers are up in 2001, they still averaged under 1 seedling/meter$^2$ which is not sufficient to provide an adequate number of seedlings that would be needed to restore these severely disturbed sites.

These results indicate that when sites move along the threshold into severely disturbed conditions, Phase V as described previously in the threshold model, even intense restoration techniques are not adequate to bring these areas back to a sustainable condition even with no further impacts.

### 5.5.2.2 Heavily Disturbed Sites

The experimental design for the heavily disturbed sites included three main factors: soils, fertilizer, and irrigation. Five heavily disturbed sites were established in differing soil types across Fort Irwin (Figure 5-5). Several techniques, ripping/harrowing and mulching, were applied to all plots because they would be considered necessary in any restoration scenario. Relatively low levels of fertilizers were applied particularly the nitrogen component. Heavy nitrogen application in arid environments has been shown to stimulate weed growth at the expense of the desired perennial species. Following fertilizer application, the plots were ripped and harrowed where needed to incorporate the fertilizer into the soil and to relieve compaction. The plots were then seeded in the same manner as the severely disturbed sites. Next the plots were mulched and crimped at the same levels as the severely disturbed plots.

Irrigation was applied at three separate times during the late winter and early spring time period. The amounts and type of application was the same as on the severely disturbed sites. In addition to the standard irrigation, selected plots received a single summer irrigation in an attempt to stimulate warm season species germination particularly creosote bush, desert thorn, and white bursage. Plots at the Drinkwater and Langford sites received the summer germination irrigation.

The results of the data analysis using 2000 data for seed germination showed that there were significant differences in two main treatments, soil type ($p = 0.003$) and irrigation ($p = 0.000$). In 2001 the data analysis, ANOVA, showed that soil type was still significant ($p=0.000$) but the relationship with irrigation was not as strong ($p=0.082$). Unlike the severe sites, irrigation still had a positive effect on seedling density. Fertilizer did not have significant differences in either year ($p = 0.719$ in 2000 and $p=0.703$ in 2001).

The Drinkwater site still had many more seedlings compared to the other sites. Soil conditions at the Drinkwater site are more favorable to seed germination and establishment. The soils contain a higher percentage of silts and clays, which means that they have a far greater capacity to hold and maintain moisture for seed germination.

Irrigation also had an influence although it was significant at the 0.10 level. The irrigated plots averaged almost twice and many seedlings as the non-irrigated plots ($2.1/m^2$, $1.1/m^2$ respectively). The fertilizer treatment showed no significant differences. The means were almost the same with the control (no fertilizer) averaging 1.75 seedlings/$m^2$ and the fertilizer plots averaging 1.70 seedlings/$m^2$.

Except for the Drinkwater site, all of the sites had such poor germination that they would not provide a sufficient number of seedlings to establish an adequate vegetative cover. These sites had received intensive mitigation treatments including irrigation and still were not able to recover sufficiently. Other revegetation treatments would be needed to restore these heavily disturbed sites. The Drinkwater site provided some insight into what may be hindering revegetation at the other sites. This led us to initiating a new suite of experiments and reclamation trials focusing on seed pretreatments along with irrigation during germination.

#### 5.5.2.3 Moderately Disturbed Sites

The experimental design for the moderately disturbed sites included three main factors: soils, fertilizer, and irrigation. Five moderately disturbed sites were established in various soil types (refer to Figure 5-5). Only four were sampled in 2001 because of time constraints. The objectives of these treatments were very different than the other disturbance levels. Because vegetation (particularly resistant species) was still present on the moderate sites, the objective was to determine how we could enhance and stimulate growth of the existing vegetation rather than establish new plants on site. The techniques and variables to be assessed were very different than in the other disturbance levels. Fertilizers consisting of both macro and micronutrients were applied at normal levels. These were then raked into the soil because we could not get reclamation equipment onto these sites without destroying the plants that were already established on the plots.

Irrigation of the plots was focused on getting water deeper into the soil profile so the amount of supplemental irrigation was higher in the January and February irrigations when evaporation would be less. In January a total of 4 cm (1.58 inches) was applied and in February/March a total of 3 cm (1.18 inches) was applied. No irrigation was applied in the March period.

### 5.5.2.3.1 Growth

The variable that was important at the moderately disturbed sites was growth. This was assessed by measuring leader length of the two dominant shrubs, creosote bush and white bursage in 2000. Results of the ANOVA for leader length of white bursage showed that there were significant differences in two main treatments, soil type ($p = 0.000$) and irrigation ($p = 0.000$). The third main treatment, fertilizer, was not significant but was close with a p-value of 0.084.

In 2001, only white bursage was sampled to assess growth. ANOVA results for this species showed that in 2001 there were significant differences in only one main treatment, soil type ($p=0.000$). Irrigation was not significant which shows that there is no residual effect of increased growth and irrigation from a previous year.

As is 2000, the Central Corridor site had the greatest leader lengths for white bursage averaging 216.7 mm which was significantly higher than all other sites. The John Wayne, Langford and Drinkwater sites averaged close to the same values in 2001 (159.4, 155.8, and 147.8 mm respectively). In 2000 the John Wayne sites had significantly less growth than the two other sites.

There was a positive trend with fertilizer application and growth of white bursage. We anticipate that fertilizer may take longer to show results since much of the fertilizer may not be in the root zone and available for plant uptake following surface application.

### 5.5.2.3.2 Reproduction

In 2000, the relationship of inflorescence length and seed per inflorescence was analyzed for white bursage at the Langford site. Twenty inflorescences from different plants were measured and then all the seeds were counted for each inflorescence. The length of each inflorescence was then correlated with the number of seeds to determine if we could use inflorescence length to predict seed production and hence reproduction potential. Given this strong correlation, we measured inflorescence lengths from 20 plants on several different treatments at the Langford site in 2000. The ANOVA from this data showed that there was a significant difference between the irrigated and non-irrigated plots ($p=0.000$). There was no difference between the fertilizer levels ($p=0.388$) nor was there any interaction between the irrigation and fertilizer treatments. The inflorescence lengths in the irrigation treatment averaged over two times the inflorescence lengths of the non irrigated treatment and approximately seven times as many seeds.

In 2001, we measured inflorescence lengths on 20 individuals of white bursage on each plot at the four moderate treatment sites. Results from the ANOVA for this data showed that two main effects, soils and fertilizer, showed significant differences among treatments (p=0.000 and p=0.034 respectively). In 2000 there was an irrigation effect but no fertilizer effect. We can conclude that an initial irrigation treatment has an impact the first year but no residual effect. However, fertilizer is not immediately available for reproduction by white bursage the first year but does increase reproduction (as measured by inflorescence length) the second year.

## 5.6 Laboratory Seed Germination Tests

Because of poor germination at many of the reclamation trial sites in 2000, we tested the seed and found it to be viable. We then proceeded to isolate the reason why we did not get germination at these severely disturbed sites. We observed from our heavily disturbed sites, particularly the Drinkwater site, that some species did have reasonable germination. But there was minimal seed germination of the two dominant species at Fort Irwin, creosote bush and white bursage. These two species had made up the bulk of the seed mix, which caused our observed number of seedlings to be very low. If reclamation by seeding is going to be successful, good germination from these two species is essential particularly since they are two of the more resistant species to training activities.

To focus on solving this problem, we searched the available literature and talked with others who have had success germinating seed for nurseries (Graves et al, 1975). We then set up what turned out to be a series experiment to determine pre-treatments that would hasten and improve germination so we could fully utilize the limited water that is available in these disturbed arid conditions. The literature and personal communications all led to the conclusion that both creosote and white bursage had chemical inhibitors that delayed germination. These inhibitors could be removed from the seed coat by rinsing of the seed with water or through the use of activated charcoal.

### 5.6.1 Experiment 1

Our first experiment tested four major treatments, running water, soaking in standing water, soaking in thiourea, and soaking in a product called "Smoke" (water soluble chemicals collected by condensing smoke) which was shown to be effect for some Australian species. One hundred seeds of white bursage and creosote were treated and placed in petri dishes to assess germination. Each treatment was replicated three times. Since running water had been shown to be effective in commercial venues, we set up several treatments to test the length of time needed to enhance germination. We also tested the effect of drying the seeds after the chemical inhibitors had been removed so that they could be used in commercial seeding equipment. The treatments showing the best germination for creosote bush was the running water for 140 hours followed by drying for 24 hours or no drying. A problem with this treatment that would make it unsuitable for use in the field is that after 140 hours many of the seeds had the root radicles emerging which would be subject to damage during the seeding process. Thus a shorter period of time would be more appropriate for actual field implementation.

The results for white bursage were different than creosote with the highest germination occurring in the running water after 36-48 hours. Drying of the seeds after a 48 hours rinse greatly decreased germination of white bursage; however, drying after a 36 hour rinse improved germination. The soak, urea, and smoke treatments were not effective.

### 5.6.2 Experiment 2

We conducted a second experiment to validate the results of the first experiment and to evaluate the effect of other parameters on germination. We tested the effects of darkness, seed source, drying, and cooling of seeds on germination. For creosote bush, those seeds that were rinsed and placed in darkness germinated better than those that were in a 12 hour light- 12 hour dark alternating environment. The seeds in the 30 hour rinse showed a slight increase in germination under continuous darkness increasing from 42.7% to 47.7% while the seeds from the 40 hour rinse showed an even larger increase under continuous darkness (46% to 62%).

The pattern for white bursage was slightly different. The 40 hour rinse was similar to creosote with an increase under 24 hour darkness. The difference was in the 30 hour rinse where the 24 hour darkness treatment was less than the alternating light and dark treatment (43.3%, 51.7% respectively).

Results of the analysis for seed source also showed differences in germination. For white bursage, there was a 10% difference in germination between the two seed lots tested. Despite this initial difference, the rinsing treatments still increased germination over the control.

The 30 hour rinse increased germination to 51.7% up from an initial 33.0%. The 40 hour rinse was not as effective but germination still increased to 47%. The differences were not as dramatic for creosote bush with the control seed lots being very similar (33.3% and 35.3%). Again the rinse treatments improved germination over the controls. The 30 hour rinse for seed lot 1 increased germination to 43.3% while the same treatment increased germination in seed lot 2 to 41.3%. The 40 hour rinse for seed lot 1 increased seed germination even more with an average germination of 46.0%. There was no 40 hour rinse for seed lot 2 for comparison.

The influence of drying of seeds that had been rinsed showed consistent results. Regardless of the rinse treatment, the seed source, or the species tested, drying of the seed for 12 hours following treatment tended to reduce germination. Results from the initial test showed mixed effects of drying but these tests all show consistent declines with drying.

The final parameter tested was the effect of cooling the seeds following treatment. If one could hold seed in a refrigeration unit following treatment, then one could remove the seeds when conditions were right and seed the area of interest without having to wait for the seeds to be treated. Likewise if more seed was treated than was actually needed the residual seed could be held until a latter date. To test this, seed was treated and placed in a refrigerator for 7 days and then removed and placed in petri dishes for germination. The results of this treatment for white bursage showed that for both the 30 hour rinse and the 40 hour rinse with 12 hour dry there was a large decline in germination were the seeds had been refrigerated prior to placement in petri dishes. This same pattern held for creosote bush.

### 5.6.3 Experiment 3

The third experiment tested seed treatments in a soil matrix at varying temperatures and soil moisture contents. Data from this would help determine the best time of the year to seed and how often irrigation would be needed. The four seed treatments consisted of a control (untreated seed), seed that was rinsed for 48 hours, seed that was rinsed for 48 hours followed by 12 hours of drying, and seed that was soaked for 48 hours. After the seed was treated it was sown into pots containing a sand matrix similar to that of Fort Irwin soils. Three temperature regimes were tested. One set of pots was kept inside with daytime temperatures around 22° C cooling to 18° C at night. A second set of pots was placed in an unheated garage where daytime temperatures averaged 13° C and night temperatures averaged 9° C. The third set was placed outside with no protection where daytime temperatures averaged 8° C and night temperatures averaged 4° C. The pots were instrumented with soil moisture/temperature probes and data were recorded regularly. Water was applied to the particular set of pots when the soil moisture reached a particular moisture condition i.e. when soil moisture declined to 80%, the pots in that treatment were irrigated to bring the moisture level back to 100%. This treatment was not watered again until the moisture level declined again to 80%.

For white bursage, no germination occurred at the 8° C treatment. Germination was very much delayed, generally by 10-14 days, at the 13° C treatment and total germination was also greatly reduced. However, even with these changes, the basic pattern of improved germination with rinsing of seeds was evident. Unlike the previous tests in petri dishes, drying of the seed did not decrease germination but actually increased it slightly although not significantly. ANOVA for the data from the 22° C white bursage tests showed that there was a significant difference among the seed treatments ($p=0.008$).

For creosote bush only the 22° C temperature treatment had any germination after 30 days when the experiment was concluded. ANOVA results of the data for creosote bush again validated the increase in germination with rinsing of the seed. Soaking of the seed for 96 hours also showed improved germination. This 96 hour soak treatment was not applied to the white bursage seed. The main effect, seed treatment, was significant with a p-value of 0.018.

The second factor tested in this experiment was soil moisture. Results from creosote bush showed no difference among the four levels of moisture tested with a p-value of 0.806. Likewise, because of the variability among the treatments there was no significant differences among the moisture treatments for white bursage (p=0.387).

### 5.6.3 Experiment 4

The final laboratory experiment focused on increasing the effectiveness of water applied by placing gravel mulch on the pots. Seeds were again rinsed and sown into a sand matrix. Various amounts of gravel were then applied to create varying degrees of gravel cover on the surface ranging from 0% to 100% at 25% increments. Results of ANOVA analyses show that for creosote bush there is a significant difference among treatments (p=0.031). There is not a significant difference among the treatments for white bursage due to the greater variability (p=0.089). The pattern for germination is similar to creosote bush with the 48 hour rinsed seed with 0% gravel being the best treatment for both species and the untreated seed, control, being generally the lowest.

One of the greatest assets of treating the seed is the reduction of time until seedling emergence. When this is combined with greater germination, it is a tremendous benefit to revegetation of disturbed arid areas.

## 5.7 Spring 2001 Field Trials

The results from the laboratory experiments helped to refine our next set of field trials that focused on getting the dominant species at Fort Irwin, white bursage and creosote, established from seed. Trials were focused on only two soil types and were much smaller in total area and number of treatments than the earlier trials. The primary variables tested were (1) seed pretreatment, rinsing of seeds for ~36 hours with a drying for 2 hours and a control with non-treated seed and (2) mulching. The two spring trials, March and April, differed on the mulching treatment because some of the initial non-replicated plots in the March trials performed so well. March trials included fully replicated gravel, straw, and no mulch plots with a non-replicated plot with plastic mulch and a non-replicated plot with soil stabilizer. The April trials include fully replicated plots for all of the mulch treatments including the plastic and soil stabilizer treatments.

### 5.7.1 March Trials

This experimental design was applied to a site at the Langford heavy location and at the John Wayne severe location because access to these sites was more favorable. The Langford plot was seeded February 27th and the John Wayne plot was established on March 3rd. Site preparation included tilling

of the sites to reduce compaction. Plots were raked slightly and then hand seeded with a mix of five species common in the area at rates shown in Table 5-1.

Following seeding the plots were lightly raked to bury the seed and rolled to ensure good seed topsoil contact. Mulch treatments (straw, gravel, plastic and stabilizer) were then applied to those plots receiving mulch. Irrigation was applied to the Langford site for 10 days following seeding with a total of 4.65 cm of water being applied during that period. The John Wayne site received

**Figure 5-6. Picture of gravel and straw treatments at Langford site, March 2001.**

irrigation for six days following seeding with a total of 2.95 cm being applied. Both sites received an additional 0.74 cm of water on March 15th. Soil temperatures on these sites averaged near 15° C with the straw mulch plots being 2-3 degrees lower and the plastic mulch plots being 8-10 degrees warmer.

**Table 5-1. Seeded species used during field trials.**

| Common Name | Scientific Name | % of Mix | Pure Live Seed/m2 |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Creosote bush | *Larrea tridentata* | 48.6 | 491 |
| White bursage | *Ambrosia dumosa* | 20.7 | 209 |
| Big galleta | *Pleuraphis rigida* | 12.8 | 129 |
| Goldenhills | *Encelia farinosa* | 8.5 | 86 |
| Anderson’s wolfberry | *Lycium andersonii* | 9.4 | 96 |
| TOTAL | | 100.0 | 1011 |

#### 5.7.1.1 Langford Site

The success of the pretreatment of seed continued to be evident in field trials for white bursage where the treated seed averaged 165.6 seedlings/m$^2$ (~79% germination) while the control plots averaged only 77.2 seedlings/m$^2$ (~37% germination). Germination of creosote bush was poor overall with the treated seed averaging 23.5 seedlings/m$^2$ (~5% germination) and the control seed treatments averaging 18.1seedlings/m$^2$ (~ 4% germination). Creosote bush germination improved in the plastic mulch treatment at Langford which averaged 57.5 seedlings/m$^2$ (~12% germination) where soil temperatures were 10 degrees warmer. Germination of white bursage also increased under the warmer conditions facilitated by the plastic mulch. Germination on all surface treatments was excellent with the plastic mulch yielding the greatest germination followed by the stabilizer, gravel, bare ground and straw treatments. All of the treatments performed extremely well compared to the 2000 trials

Of the three other species seeded at this site, Anderson's wolfberry had no germination in this or any of the subsequent trials. Goldenhills had excellent germination at the Langford site with three surface treatments (plastic, stabilizer, and gravel) averaging over 30 seedlings/m$^2$ (~35% germination). Big galleta showed poor germination except with the plastic mulch treatment where it averaged 16.5 seedlings/m$^2$ (~13% germination).

#### 5.7.1.2 John Wayne Site

The success of the pretreatment of seed was evident at this site for white bursage where the treated seed averaged 92.9 seedlings/m$^2$ (~44% germination) while the control plots averaged only 54.8 seedlings/m$^2$ (~26% germination) both of which are lower than comparable treatments at the Langford site. Germination of creosote bush was poor overall with the treated seed averaging 11.3 seedlings/m$^2$ (~2% germination) and the control seed treatments averaging 8.5seedlings/m$^2$ (<2% germination). Creosote bush germination improved in the plastic mulch treatment at John Wayne which averaged 34.0 seedlings/m$^2$ (~7% germination) where soil temperatures were 10 degrees warmer. The other surface treatments were very similar with the exception of straw treatment, which was lower than the rest.

Goldenhills germination was about half of that at the Langford site. The highest germination occurred in the bare-no gel treatment which averaged 17 seedlings/$m^2$ (~20% germination) while the straw treatment was the least averaging 7 seedlings/$m^2$. Big galleta overall had poor germination and similar to the Langford site only the plastic mulch had reasonable germination averaging 8 seedlings/$m^2$ (~6% germination). The straw and bare-no gel treatments had no germination.

### 5.7.2 April Trials

Based on the success of the plastic and stabilizer, the experimental design was modified for the April trials to include full replications of these surface treatments at both the Langford and John Wayne locations. Both sites were seeded April 16th. Site preparation and seeding rates and species mix were the same as the March trials. Irrigation was applied to the both sites for four days following seeding with a total of 5.9 cm of water being applied during that period. Both sites received an additional 2.3 cm of water during April 23rd-26th for a total of 8.2 cm. Soil temperatures on these sites averaged 22° C with the straw mulch plots being 2-3 degrees lower and the plastic mulch plots being 8-10 degrees warmer.

#### 5.7.2.1 Langford Site

Treated seed of both white bursage and creosote bush outperformed control seed. Treated seed of white bursage averaged 106.5 seedlings/$m^2$ (~51% germination) while the control plots averaged 58.4 seedlings/$m^2$ (~28% germination). Germination of creosote bush was much better during the April trials that the March trials and averaged 65.7 seedlings/$m^2$ (~13% germination) for the treated plots and 28.5 seedlings/$m^2$ (~6% germination) for the control plots.

Creosote bush had excellent germination on the plastic mulch treatment particularly with treated seed averaging 214 seedlings/$m^2$ (~44% germination) while the control seed averaged 104.7 seedlings/$m^2$ (~21% germination). Even with this later seeding date, creosote bush germination improved with the higher soil temperatures generated under the plastic mulch. This was also true for white bursage were germination in the treated seed plastic mulch plots averaged 206 seedlings/$m^2$ (~99% germination) while the control seed in the plastic mulch plots averaged 152 seedlings/$m^2$ (~73% germination). Germination was also excellent in the stabilizer and gravel mulch treatments with treated seed.

Goldenhill did have good germination at the Langford site with the treated seed in the surface treatments (stabilizer and gravel) averaging over 16.7 seedlings/$m^2$ (~19% germination). Germination rates were about half of those that occurred on this site during the March seeding. Goldenhill appears to prefer the cooler temperatures of the previous seeding. Conversely big galleta showed poor germination except with the hotter plastic mulch treatment where it averaged 22.3 seedlings/$m^2$ (~17% germination) on the treated seed plots. Like creosote bush, big galleta germinates better under warmer conditions and performed better during the April trials.

#### 5.7.2.2 John Wayne Site

Like the Langford site, treated seed of both white bursage and creosote bush outperformed control seed. Treated seed of white bursage averaged 88.9 seedlings/$m^2$ (~43% germination) while the control plots averaged 55.7 seedlings/$m^2$ (~27% germination). Germination of creosote bush was much better during the April trials than the March trials and averaged 91.9 seedlings/$m^2$ (~19% germination) for the treated plots and 29.2 seedlings/$m^2$ (~6% germination) for the control plots.

Creosote bush had excellent germination on the plastic mulch treatment particularly with treated seed averaging 216 seedlings/$m^2$ (~45% germination) while the control seed averaged 112.7 seedlings/$m^2$ (~23% germination). Even with this later seeding date, creosote bush germination improved with the greater soil temperatures generated under the plastic mulch. This was not true for white bursage where germination in the treated seed plastic mulch plots was greatly reduced averaging 51.3 seedlings/$m^2$ (~25% germination) while the control seed in the plastic mulch plots averaged 40.7 seedlings/$m^2$ (~20% germination). Germination was best in the stabilizer treatment with treated seed averaging 144 seedlings/$m^2$ (69%). Germination of white bursage was much lower during the April seeding than the March seeding at this site unlike creosote which performed much better during the April trials.

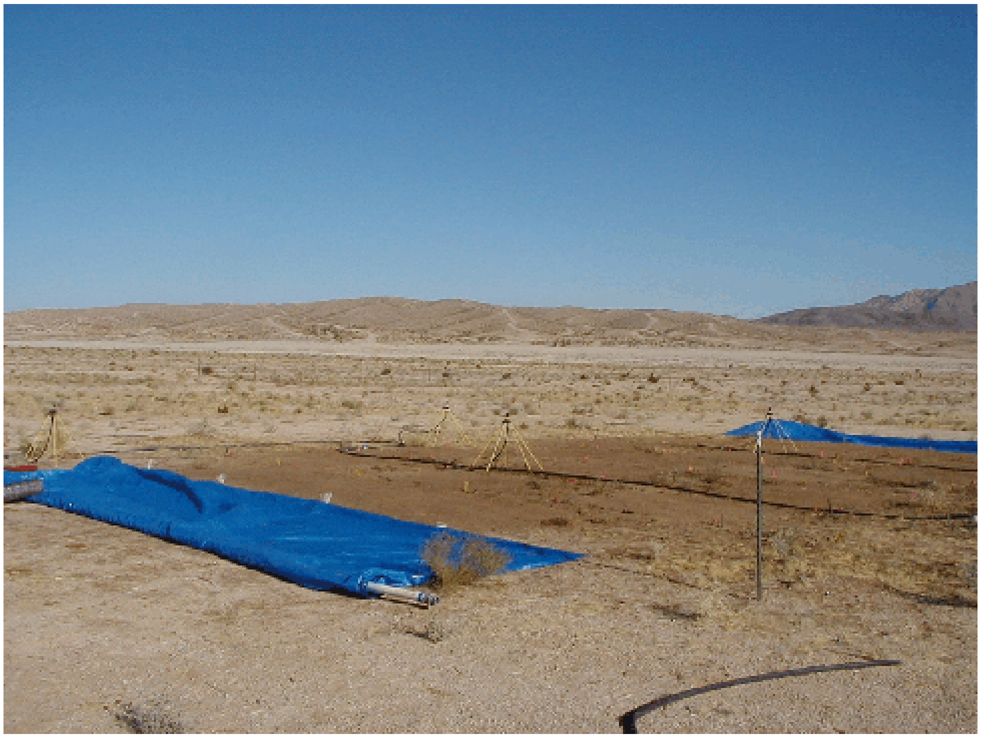
Goldenhill did have good germination at the John Wayne site with the treated seed in all of the surface treatments. The straw treatment performed best averaging 18.7 seedlings/$m^2$ (~22% germination). Germination rates were similar to those that occurred on this site during the March seeding except for the plastic treatments which was much lower in April. Goldenhill appears to prefer the cooler temperatures. Conversely big galleta showed poor germination except with the hotter plastic mulch treatment where it averaged 16.7 seedlings/$m^2$ (~13% germination). Like creosote bush, big galleta germinates better under warmer conditions and performed better during the April trials.

## 5.8 Fall 2001 Field Trials

The success of the spring trials led us to consider a series of fall trials. If temperature was the key to germination of creosote bush seed once seedcoat inhibitors had been removed than it should be possible to seed in the fall after the soil temperatures had cooled to the range for creosote bush germination. This would have a great advantage in that the young seedlings would be entering the relative cool and wet winter period where they would not be as stressed for moisture. Timing would be critical since our mid summer trials had shown no germination due to high soil temperatures. We conducted two trials, a small set in September when we anticipated that soil temperatures may still be too high for germination and a larger set in October with similar mulch treatments to the spring trials.

### 5.8.1 September Trials

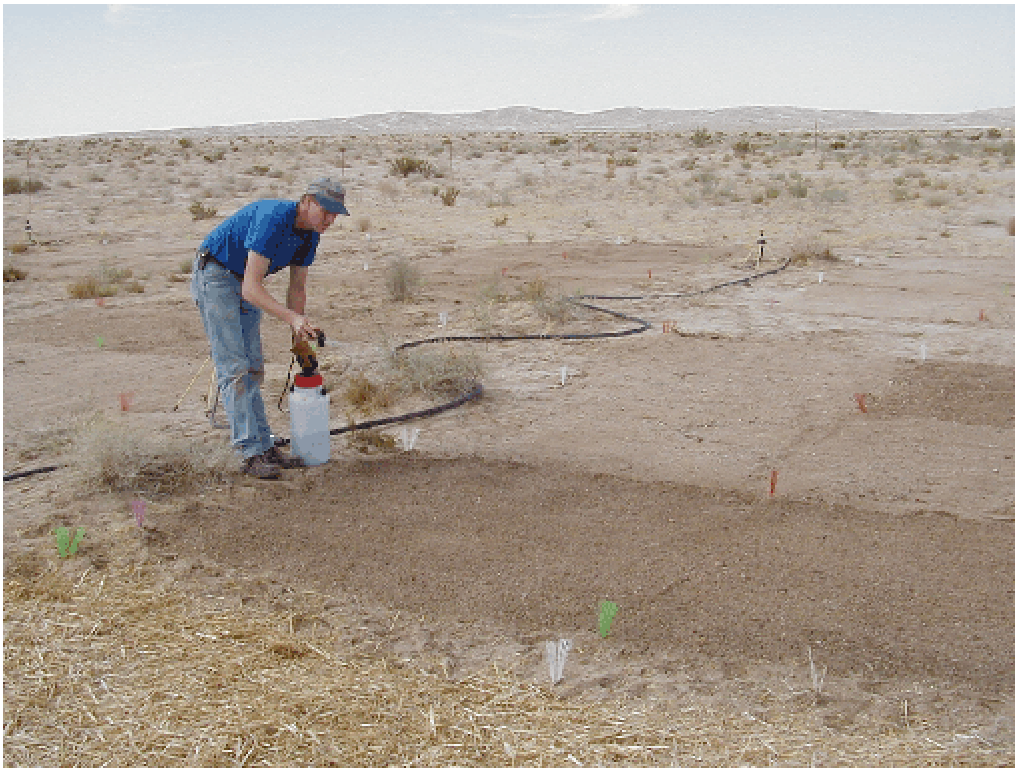
In early September, a set of trials was initiated. This was a small effort focused at assessing whether



temperatures had cooled enough to get germination. We had tested a July seeding in 2000 and had no germination due to the high soil temperatures. The design also looked at minimum water needs for germination with plots receiving from 1.5 cm to 6.1 cm of water total over 3-6 day period of time. These trials occurred only at the Langford site (Figure 5-7). These

**Figure 5-7. Photograph of plot layout for September trials at Langford site.**

plots were sampled for germination on two dates, September 13th and October 11th. Germination was very poor for these trials but still showed the effect of increasing irrigation on emergence. Not only is the total amount of irrigation important in enhancing seed germination but the timing of that irrigation is important. A smaller amount of water spread over more days was not as effective than the same amount spread over half as many days. This is due in large part to the hot temperatures in September and the greater evaporation that occurs with moisture on the surface of the soil. The percent germination of the four species tested was always less than 3% and generally less than 1%. These values are very low compared to the March or April trials. We conclude from these trials that soils were still too warm for optimal germination or that more irrigation would be necessary to improve germination.



### 5.8.2 October Trials

A second set of fall trials was established in October at the Langford site only (Figure 5-7). Surface and seed treatments were again tested as well as variable amounts of irrigation. These trials were sampled in late October but germination had not occurred on any of the plots. Soil temperatures averaged around 21° C but the day length was short. Reasons for this poor germination appeared to be marginal soil temperatures and herbivory (See Appendix B.2).

**Figure 5-8. Photograph of plot layout for October trials at Langford site.**

## 5.9 2002 Demonstration Area

In April, we implemented the reclamation techniques that were very successful last spring i.e. pre-treated seed and targeted irrigation, on a large 7 acre demonstration site at Fort Irwin. (Figure 5-9). The area consisted of 3 sites with 2 different soil types. Mulch techniques and irrigation amounts varied on these sites to further improve our techniques and reduce costs. The demonstration area was seeded on April

9th and irrigated for the next 9 days. Winds were very high during this period and irrigation was not as effective as the previous spring. At the end of April, the site was revisited and evaluated. Germination and establishment of seedlings was low. Density of seedlings ranged from 0 to 1/$m^2$. The reasons for the poor success appeared to be 2-fold: (1) the whole desert Southwest region is experiencing a severe drought having not experienced any rainfall since last September and only .86 inches in the past 12 months, so despite our limited irrigation, there was not adequate moisture for establishment, and (2) many seedlings that had germinated were eaten by birds since no other food source was available due to the drought (germination under the plastic mulch was good but most were eaten after the plastic

**Figure 5-9. Demonstration plot mulch treatments at Fort Irwin, April, 2002**

was removed). The lack of precipitation, high winds, and hot temperatures, are most likely the worst conditions that one would expect on this site. Under these conditions seeding success or any revegetation success will be poor. Although germination was poor, those seedlings that did get established performed very well and had substantial growth by October, 2002.

# 6.0 TECHNOLOGY TRANSFER

Technology transfer was accomplished through a variety of ways, including:

- Meetings with scientist using and developing erosion and military land condition models.
- Meetings with natural resource managers are DoD and DOE installations such as the Nevada Test Site, Tonopah Test Range, Yuma Proving Grounds, Dugway Proving Grounds, Twentynine Palms, Jornada Experiment Range, and Camp Williams. Sample imagery was obtained when available.
- Presentations and posters at scientific meetings, conferences, and workshops
- Direct contact by U.S. Postal Service mail and email
- Through indirect contact through the Technical Advisory Team
- Interactions with other related SERDP Projects
- Placement of manuals in key libraries in the Western United States
- Posting of Adobe Acrobat files (portable document files) on selected websites

## 6.1 Pertinent DoD Models

During the first year of the study, Dr. Warren contacted modelers working with applicable models such as ATTACC, Revised Universal Soil Loss Equation, and models in LCTA and TMSES programs. Vegetation parameters that are used as inputs to these models were identified. Plant cover was identified as the single most important component of vegetation for modeling efforts. Additionally, Dr. Warren gathered regional cost estimates from reclamation scientists in federal and state agencies, and other knowledgeable individuals for reclamation practices on arid and semiarid lands. During 2001 training was received at Fort Irwin from Dr. Alan Anderson regarding plant parameters needed for ATTACC.

## 6.2 Meetings With Installation Resource Managers

Many meetings were held over the course of four years with resource managers at selected DoD and DOE sites in the western United States. The object was to invite as many managers as possible in a given location from various state and federal government agencies, resource management organizations (e.g., The Nature Conservancy), and consultants. A presentation was made introducing our goals and objectives and previewing various techniques. Sample imagery was requested at each meeting to evaluate the types of imagery available from installations and to apply techniques which permitted us to further test our methods and applicability to a variety of site conditions.

Installations visited included: Fort Irwin in California), Nellis Air Force Base in Nevada, Fort Bliss in Texas, Hollaman Air Force Base in New Mexico, White Sands Missile Range in New Mexico, Camp W.G. Williams, Utah Army National Guard in Utah, Hill Air Force/Ogden Air Logistics Center in Utah, Dugway Proving Grounds in Utah, Edwards Air Force Base in California, Fort Hunter Liggett in California, Marine Corps at 29 Palms in California, Yakima Proving Grounds in Washington, Fort Huachuca and Yuma Proving Grounds in Arizona.

DOE facilities that were visited included: Hanford in Washington, Nevada Test Site in Nevada, Idaho National Environmental Laboratory in Idaho. Meetings were also held with other non-military organizations which included: Desert Research Institute in Reno, Nevada, The Nature Conservancy, Provo, Utah, The Nature Conservancy, Las Cruces, New Mexico, University of Nevada Reno, Nevada, Brigham Young University (Dept. of Botany and Range Science) in Provo, Utah, Utah State University (Dept. of Forest Resources) in Logan, Utah, New Mexico State University in New Mexico, Unitec and Walcoff Technologies in New Mexico, U.S. Forest Service, Battelle Pacific Northwest Laboratories in Washington, National Remote Sensing Applications Center in Salt Lake City, Utah, U.S. Environmental Protection Agency in Nevada, U.S. Geological Survey, Biological Services, in Nevada and Arizona, USDA Agricultural Research Service in Las Cruces, New Mexico (Jornada Experiment Range), USDA Agricultural Research Service in Salt Lake City, Utah, and USDA Agricultural Research Service in Cheyenne, Wyoming.

## 6.3 Integrated Training Area Management (ITAM) Meetings

Dr. Ostler has attended ITAM meetings the last four years. He and Dr. Hansen made presentations at the tenth and eleventh annual ITAM workshop in Nashville, Tennessee in August, 2001 and Savannah, Georgia in August, 2002. Discussions at these meetings were held with key scientists working at many installations. Contact was made with several ITAM scientists from the various facilities in the Southwest who would be potential users of techniques developed during this project. Copies of our Microsoft Power Point® presentation were made by the ITAM GIS Steering Committee and distributed to interested parties at the workshop.

## 6.4 Other Scientific Meetings, Conferences, and Workshops

Dr. Ostler presented a poster at the Tri-Service Environmental Technology Symposium in San Diego, California in June. Dr. Ostler and Dr. Hansen presented a paper at the 18th Biennial Color Photography and Videography Workshop held in May 2001 at Amherst, Massachusetts. Contact was made with other research scientists doing remote sensing and image processing in the United States and foreign continents such as Europe and Africa. Dr. Ostler presented a poster at the Ecological Society of America (ESA) Meetings in Snowbird, Utah in 2000. He also presented a paper on the seed pretreatment research and a poster on assessing vegetation change at the joint ESA and Society for Ecological Restoration meetings in Tucson in August, 2002. Dr Ostler presented two posters at the 4$^{th}$ Conference on Research & Resource Management in the Southwest Deserts in May, 2002. We presented posters at the SERDP Symposia in Washington D.C. each year from 1999-2003

More than 90 people attended the workshop in Las Vegas, Nevada on August 2 and 3, 1999 (Scoping Workshop) and October 22 and 23, 2002 (Final Workshop). Copies of the Microsoft Power Point® Presentations for the final workshop are included in the CD rom attached to this report. Agendas, meeting summary notes, abstracts, and summary evaluation forms are included in Appendix C. The final workshop included an evaluation form to assess whether the information provided was useful and what form of technology transfer was preferred. The data showed that most of the attendees preferred workshops over web site tutorials (>2:1) or PDF files (>4:1). Most thought that the workshops should be 2 days for vegetation change analysis while the attendees were about equally split between 1 and 2 days for reclamation techniques.

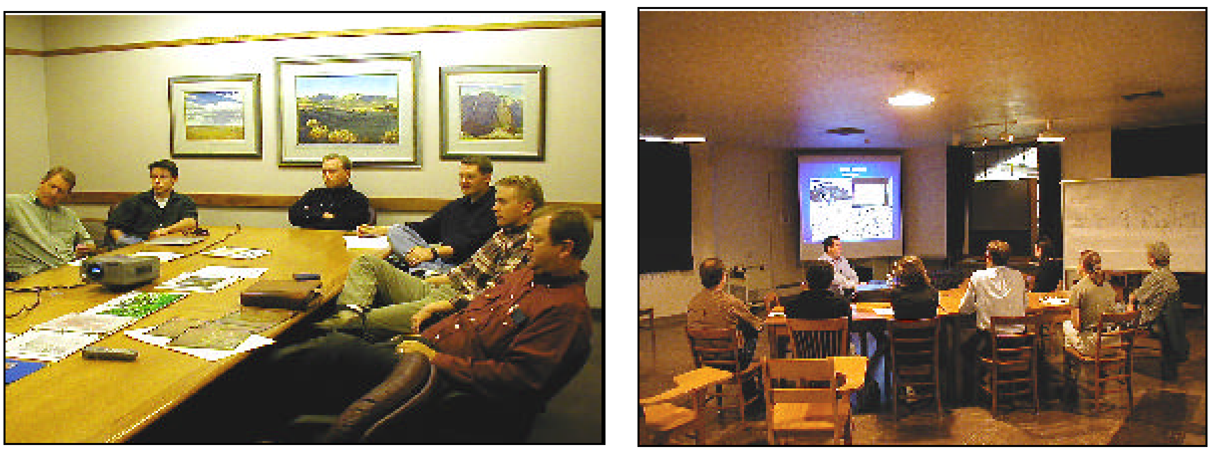
## 6.5 Direct Mail and Technical Advisory Team Contacts

The Technical Advisory Team was contacted to provide mailing and contact lists for U.S. Postal and e-mail to scientists and natural resource managers that might be interested in attending the workshop or receiving additional information about new developed techniques. One U.S. Postal mailing and three e-mails were sent to inform individuals with either manuals, CDs or software being sent to those requesting copies who did not attend the workshops. All workshop attendees received a copies of the manuals and other software and files. .

## 6.6 Interactions with Other SERDP Projects

To date, more than a dozen meetings and phone conversations have been held with principal investigators from SERDP projects CS-1098 and CS-1055 to discuss ways of collaborating research and sharing data. Principal investigators from both projects visited us during the fiscal year to share research ideas. Images were received from Dr. Paul Tueller (CS-1098) and analyzed to determine usefulness for their project. Several high resolution (1-m [3-ft]) panchromatic IKONOS images were provided of Mojave Desert vegetation sites at Twentynine Palms. Mr. Mark W. Brennan (Corporate Director for Remote Sensing Solutions) of Pacific Meridian Resources (A Space Imaging Company - provider of IKONOS imagery) provided us with a listing of existing IKONOS images for military bases and DOE facilities in the western United States. Desert Research Institute scientists have also met periodically to discuss collaboration of research efforts. Dr. Eric McDonald is currently doing soil moisture modeling under various reclamation strategies at Fort Irwin. Dr. Ostler and Dr. Anderson are preparing a manuscript for a scientific journal edited by Dr. McDonald. Coordination meetings were also held with Dr. Doug Ramsey (Utah State University, in Logan, Utah) and Dr. Scott Tweddell (U.S. Army Corps of Engineers, ERDC-CERL, Champaign, IL) regarding technology transfer of remote sensing techniques to the DoD. Images were provided by Dr. Tweddell for selected areas at Twentynine Palms Marine Corps Air Ground Command Center, California. These images were processed using our techniques and results returned to Dr. Tweddell.

## 6.7 Training Meetings with Installation Personnel



During the fall of 2001 and spring of 2002 several technology transfer meetings were held with **Figure 6-1. Examples of small discussion groups in Utah (left) and New Mexico (right) for transferring new image analysis technologies to military installations.**

more than four dozen natural resource, geographic information system, and remote sensing scientists. These meetings provided a forum for presenting new techniques and encouraging dialogue between scientists (Figure 6-1 and 6-2). Followup from the meetings provided exchange of images and information about software and upcoming scientific meetings and conferences. Microsoft Power Point® presentation were developed to introduce new technologies in image processing and revegetation to scientists at military installations. Copies of these presentations are found in the accompanying CD which also contains the electronic PDF versions of the manuals, software, workshop presentations, and other files.

## 6.8 Deposition of Manuals in Selected Libraries


Copies of the User's Manuals were deposited at the U.S. Department of Energy Public Information Library at Las Vegas, Nevada, the Lied Library at the University of Nevada Las Vegas in Las Vegas, Nevada, The Brigham Young University Library at Provo, Utah, and the U.S. **Figure 6-2. Examples of vegetation types encountered at military installation in New Mexico and Texas during technology transfer meetings.**

Forest Service Remote Sensing Application Center in Salt Lake City, Utah.

## 6.9 Website Access to User's Manuals

Both user's manuals are accessible through selected websites on the World Wide Web Internet. These PDF files available at:

- U.S. Department of Energy's Office of Scientific and Technical Information (OSTI):

DOE/NV/11718—729, *Vegetation Change Analysis User's Manual*

Full text web viewable (black and white) PDF (22137K)
http://www.osti.gov/gpo/servlets/purl/801915-X5dWul/webviewable/

Full native text format (color) PDF (65014K)
http://www.osti.gov/gpo/servlets/purl/801915-YSI3xi/native/

DOE/NV/11718—731, *New Technologies to Reclaim Arid Lands User's Manual*

Full text web viewable (black and white) PDF (23930K)
http://www.osti.gov/gpo/servlets/purl/804924-KSqIyz/webviewable/

Full native text format (color) PDF (16423K)
http://www.osti.gov/gpo/servlets/purl/804924-EWB40y/native/

- Desert Managers Group at http://www.dmg.gov/documents.html

# 7.0 RECOMMENDATIONS

We concluded from our efforts that the most effective way to make people aware of new technologies and transfer the information to them was in a workshop format where we presented the information but also provided them a user's manual of the technologies. We provided evaluation forms at our final workshop that asked attendees which format of technology transfer they thought was most effective. The results of the survey the first day showed greater than 2:1 of the attendees favored a workshop over a website online tutorial and greater than 4:1 over a PDF file or site-specific instructions. Results of the survey the second day also showed very similar preferences for a workshop over the other forms of technology transfer. While our final workshop was a total of two days in length it covered two topics. Feedback from the workshop evaluation forms stated that more time was needed so participants could have a little more hands-on experience with the diagnostic software and more discussion and perhaps a field trip for the reclamation area. When asked in the evaluation, "What did you like best about the workshop?", the answer was most often "the user's manuals" followed closely by "discussions or demonstrations of the software".

For our technologies, we also felt that site visits to individual installations were very effective particularly when we had arranged to obtain imagery of their site prior to that visit. Having done some initial analysis of their data, we could then show them how diagnostic analysis could be used on their own site. It also allowed us to meet with 4-10 people at each site for half a day where they could ask specific questions regarding their needs. This type of interaction is not possible on a website and only minimally effective at a workshop because of limited time for discussions.

Recommendations regarding details of the diagnostics and reclamation techniques are provided in section 5.0 in the two user's manuals provided as Appendix A.2 and A.3 with this final report.

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