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Rehabilitation of Military Training Areas Damaged by Tracked Vehicles at Fort Carson, CO

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by
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The U.S. Army installation at Fort Carson, Colorado, has a long history of tactical training activities by tracked and wheeled vehicles. These training maneuvers have caused extensive damage to the soils and vegetation of the semiarid pinyon-juniper woodland and shortgrass prairie ecosystems of the installation. The resulting erosion and loss of training realism are serious problems for the Army. The goal of this Facilities Engineering Applications Program (FEAP) project was to develop and demonstrate ecologically effective and economically feasible soil rehabilitation and revegetation techniques to increase soil stability and provide a more realistic training environment.

In areas where training traffic was excluded, vegetative cover increased and the percent bare ground decreased on both treated and untreated shortgrass prairie areas. The prairie areas receiving the revegetation treatment are recovering faster and have higher percentages of desirable native grasses (both volunteer and planted) than the untreated areas, which tend to recover more slowly and have less grass cover and more weedy species. The pinyon-juniper areas are recovering more slowly due to harsher site conditions.

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FOREWORD

This research was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC) in coordination with the Headquarters, U.S. Army Corps of Engineers (HQUSACE) Directorate of Research and Development (DRD), under part of the Facilities Engineering Applications Program (FEAP).

The work was accomplished by Argonne National Laboratory (ANL), Argonne, IL under contract and by the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (USACERL). Ray R. Hinchman and Ralph P. Carter are employed by ANL. Kenneth G. McMullen is employed by the U.S. Army, Fort Carson, CO. Dr. R.K. Jain is Chief of USACERL-EN. The technical editor was Gloria J. Wienke, Information Management Office.

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REHABILITATION OF MILITARY TRAINING AREAS DAMAGED BY TRACKED VEHICLES AT FORT CARSON, CO

1 INTRODUCTION

Background

Nearly 12 million acres* of land are managed by the U.S. Department of the Army, including significant semiarid and arid areas in the western United States. Fort Carson, Colorado comprises part of the semiarid land. The installation was established in 1942 and is currently the training site for the 4th Infantry Division (Mechanized) and several support units, with a total of about 20,000 troops. The installation also serves as a part-time training site for several National Guard units. Decades of training use have adversely affected the pinyon-juniper woodland and shortgrass prairie ecosystems on the installation.

Fort Carson consists of 137,391 acres; about 56,170 acres are usable for tactical maneuvers by tracked and wheeled vehicles. This is considerably less than the 85,000 acres deemed necessary to adequately train the three infantry brigades and five tank battalions assigned to the installation.[1] Not only are the foothills and plains of Fort Carson some of the most intensively used Army lands in the United States, but they also have a low tolerance to military disturbance.[2]

Tactical training units require extensive vehicular traffic in off-road areas to conduct deployment, positioning, camouflaging, and attack maneuvers. At Fort Carson, shortgrass prairie areas alternate and are interspersed with pinyon-juniper areas over the western half of the installation. The pinyon-juniper foothills are favored maneuver areas because they provide desirable concealment and observation and firing points. These maneuvers damage or destroy grasses, forbs, tree seedlings, and tree roots. Because many preferred training areas have moderate to steep slopes, soil disturbance and loss of vegetative cover in these intensively used areas make them extremely susceptible to soil erosion by wind and water. Mature trees and shrubs are destroyed when vehicles push them over or they are damaged when vehicles sideswipe them, breaking branches and ripping bark. Both pinyon pine and juniper are slow-growing species, requiring 100 to 150 years to attain the size of existing trees.[3] Although strict measures have been imposed to make company and platoon leaders responsible for minimizing tree destruction, pinyon-juniper degradation continues at a rate that may eventually render these areas useless for training.

Shortgrass prairie areas are affected primarily when vehicles create roadways and tank trails by repeatedly driving over the same courses and by cross-country maneuvers. The resulting roads are usually rutted, compacted, and without vegetation. At vehicle turning points, soil disruption is extensive. Deep ruts alternate with berms of loose soil thrown up by tank treads; a large amount of dust is raised with the

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* A metric conversion table is provided on page 44.

[1] Dames and Moore, *Land Use and Management Plan for Fort Carson, Colorado*, Report No. DACA 45-77-C-032 (1977).

[2] W.D. Goran, L.L. Radke, and W.D. Severinghaus, *An Overview of the Ecological Effects of Tracked Vehicles on Major U.S. Army Installations*, USACERL Technical Report N-142/ADA126694 (U.S. Army Construction Engineering Research Laboratory [USACERL], February 1983).

[3] P.T. Tueller and J.E. Clark, "Autecology of Pinyon-Juniper Species in the Great Basin and Colorado Plateau," paper presented at The Pinyon-Juniper Ecosystem: A Symposium (Utah State University, 1975).

passage of each vehicle. Concentrated maneuvers or bivouacs in the grassy areas create large expanses of severe disturbance (less than 10 percent vegetative cover). Several of these areas cannot be used during moderate to high winds because of blowing dust.

Training also causes soil compaction, loss of wildlife habitat, and the loss of training realism provided by diverse natural vegetation and topography. These effects are worsened in areas of low precipitation such as Fort Carson because of (1) the relatively low percentages of natural, stabilizing vegetative cover (ranging from 70 percent to less than 10 percent on undisturbed sites); (2) the long periods required to reestablish native, adapted plant communities; and (3) the susceptibility of Fort Carson soils to erosion.

To solve these problems, it is necessary to develop practical, effective rehabilitation methods. Solutions are not readily apparent because there is little information on the stabilization and rehabilitation of disturbed pinyon-juniper ecosystems. Most available information on pinyon-juniper deals with its eradication to improve land for grazing. Earlier studies concluded that pinyon-juniper woodlands at Fort Carson "have no practical means of being seeded successfully" and that "natural revegetation through plant succession is the only known means at the present time when considered realistically."[4]

Objectives

The overall broad objectives of this project are to demonstrate the revegetation and stabilization of a severely disturbed test site at Fort Carson that represents all aspects of military vehicle training damage. The demonstration consists of developing, implementing, monitoring, and evaluating an ecologically effective and economically feasible rehabilitation prescription designed specifically for the permanent, self-sustaining revegetation of pinyon-juniper woodland and shortgrass prairie ecosystems. The rehabilitation prescription will be such that it can be integrated into Army land management programs.

The project is specifically designed to compare treated (revegetated) areas that are excluded from vehicle traffic (termed "rest") with (1) untreated areas that are excluded from traffic (termed "natural revegetation areas") and (2) untreated areas that receive normal training traffic (termed "controls"). The treated areas have received a site-specific rehabilitation treatment that consisted of fertilization, tillage, seeding, and harrowing.

The data presented in this report address the following major questions posed by the Facilities Engineering Applications Program (FEAP) demonstration project:

1. Can severely damaged shortgrass prairie and pinyon-juniper ecosystems on the FEAP site be successfully revegetated at a reasonable cost by using the rehabilitation prescription and excluding training traffic?

[4] Dames and Moore.

2. Does excluding training traffic alone result in adequate natural revegetation of similar damaged areas within an acceptable time frame?

3. Are there biologically and statistically significant differences between the plant communities developing on comparable areas that either received the revegetation treatment or were only excluded from training traffic?

4. What is the vegetative composition, quality, and time of development for the revegetation community on treated- or rested-only areas?

Approach and Scope

Managing the natural resources at Fort Carson requires that two conflicting objectives be considered. One objective is the training mission; the second is the need to maintain the natural resources and to use the land in an environmentally conscientious manner. This second objective is stated Army policy and is also necessary to preserve these lands for continued training under realistic conditions, as well as for wildlife habitat, recreation, and grazing outleases.[5] To successfully reach these objectives requires careful planning, development of innovative rehabilitation strategies, communication between all parties involved (land managers, training personnel, and contractors), detailed monitoring of the rehabilitation progress and costs, and concerted management efforts during and after the initial (revegetation) phase of the project.

This project is designed to demonstrate ecologically effective and economically feasible vegetative and soil rehabilitation techniques at a highly disturbed tactical training site. The demonstration site is characterized by rough terrain and steep slopes in a vegetative zone that is transitional between shortgrass prairie and pinyon-juniper woodland. The rehabilitation aspect of this project at Fort Carson is being implemented through the following tasks:

1. Select and characterize a demonstration site that is representative of typical ecosystems and training damage at Fort Carson.

2. Develop a rehabilitation prescription for the site on the basis of site-specific characteristics, post-rehabilitation training needs, and land uses, and document the methods and technical specifications used.

3. Install the rehabilitation prescription at the site using a qualified, experienced contractor, and monitor the contractor operations and costs.

4. Quantify, evaluate, and document the progress of the rehabilitation efforts by monitoring changes over time in key vegetative parameters (e.g., vegetative cover, species composition, succession) and in precipitation using on-site measurements, observations, photographs, and records of costs.

5. Develop recommendations for treatment modifications and alternatives.

Much of the information and methodology used for disturbed land rehabilitation has been developed for strip-mine reclamation or rangeland rehabilitation. Military training damage differs in that it

[5] R.S. Baran, et al. *An Overview of Potential Methods for Maintaining Training Area Environments in Arid and Semiarid Climates*, USACERL Technical Report N-130/ADA130075 (USACERL, April 1983).

encompasses both soil disturbance and compaction and lies somewhere between strip-mining and rangeland use in severity.[6] Thus, many existing land rehabilitation techniques are applicable, with modifications, to lands damaged by military training. In this project, these modifications involved conducting tillage and seeding operations under difficult and essentially untried field conditions and developing procedures to formulate multipurpose seed mixtures for specific military training sites. As the evaluation of results from this project continues, additional new approaches are being developed for management of lands used for training.

Mode of Technology Transfer

It is recommended that the results and recommendations from the demonstration be incorporated into the Integrated Training Area Management (ITAM) program and be used in ongoing efforts to develop an environmental awareness educational program and in cost-benefit analyses of rehabilitation options.

It is also recommended that the demonstrated rehabilitation principles and technology be transferred to installations experiencing similar problems of training area degradation via briefings, workshops, manuals, narrated slide presentations, videotapes, and other formats of technology transfer.

[6] R.S. Baran, et al.

2 DESCRIPTION OF THE STUDY AREA

Environmental Setting of Fort Carson

Fort Carson is located in east-central Colorado, about 8 mi south of Colorado Springs (Figure 1). Portions of the site are in southwestern El Paso County, northern Pueblo County, and eastern Fremont County. Fort Carson is 25 mi long and varies from 2 to 12 mi wide between Highway 115 on the west and Interstate Highway 25 on the east. Elevations range from 5180 ft at the southwest corner to 6960 ft at the northwest boundary. Due to the high elevation, the climate of Fort Carson is characterized by cool summers and cold winters.

Yearly precipitation on Fort Carson varies from 11 in. in the south to 16 in. in the north and is both low and erratic compared to areas east of the Mississippi River. During any given year, rainfall may be one-half to double the average amount.[7] Eighty-one percent of the precipitation occurs during April through September, often as thundershowers and with occasional hailstorms; this compares favorably with the frost-free period (May 8 to October 4) during which most vegetative growth occurs. However, soils are often driest in the spring when plant growth begins. In 2 of every 10 years, 8 in. or less of precipitation will occur in April through September in the Fort Carson area.[8] Average annual snowfall on the installation is about 27 in., but snow moisture content is usually low. Prevailing winds are from the north and west. Average wind speed is 8 mph, with occasional gusts in excess of 50 mph. The highest winds occur in spring, especially in April.

Fort Carson is located in a transitional zone where the Great Plains merge with the foothills of the Rocky Mountains. The streams draining Fort Carson are mostly intermittent and flow generally from northwest to southeast into Fountain Creek. The vegetation is a mosaic of two major plant community types: (1) shortgrass prairie, primarily on the flat to gently sloping eastern areas, with relatively deep soils of silt and clay, and (2) pinyon-juniper woodland, occupying the steeper western foothills on sandy soils that are often shallow and rocky. A few areas of ponderosa pine forest are located at higher elevations.

Selection of the Demonstration Site

The demonstration site (hereafter called the FEAP site) used for the training area rehabilitation project was selected in early March 1984 based on the following criteria.

- Located in an area currently used for tank maneuvers.

- Identifiable by Range Control and accepted by other training personnel as an area that can be excluded from training traffic without adversely affecting the training mission.

[7] P. Packer, *Rehabilitation Potentials and Limitations of Surface-Mined Land in the Northern Great Plains*, Technical Report INT-14 (U.S. Forest Service, 1974).

[8] Soil Conservation Service, *Soil Survey of El Paso County Area, Colorado* (U.S. Department of Agriculture, 1981).

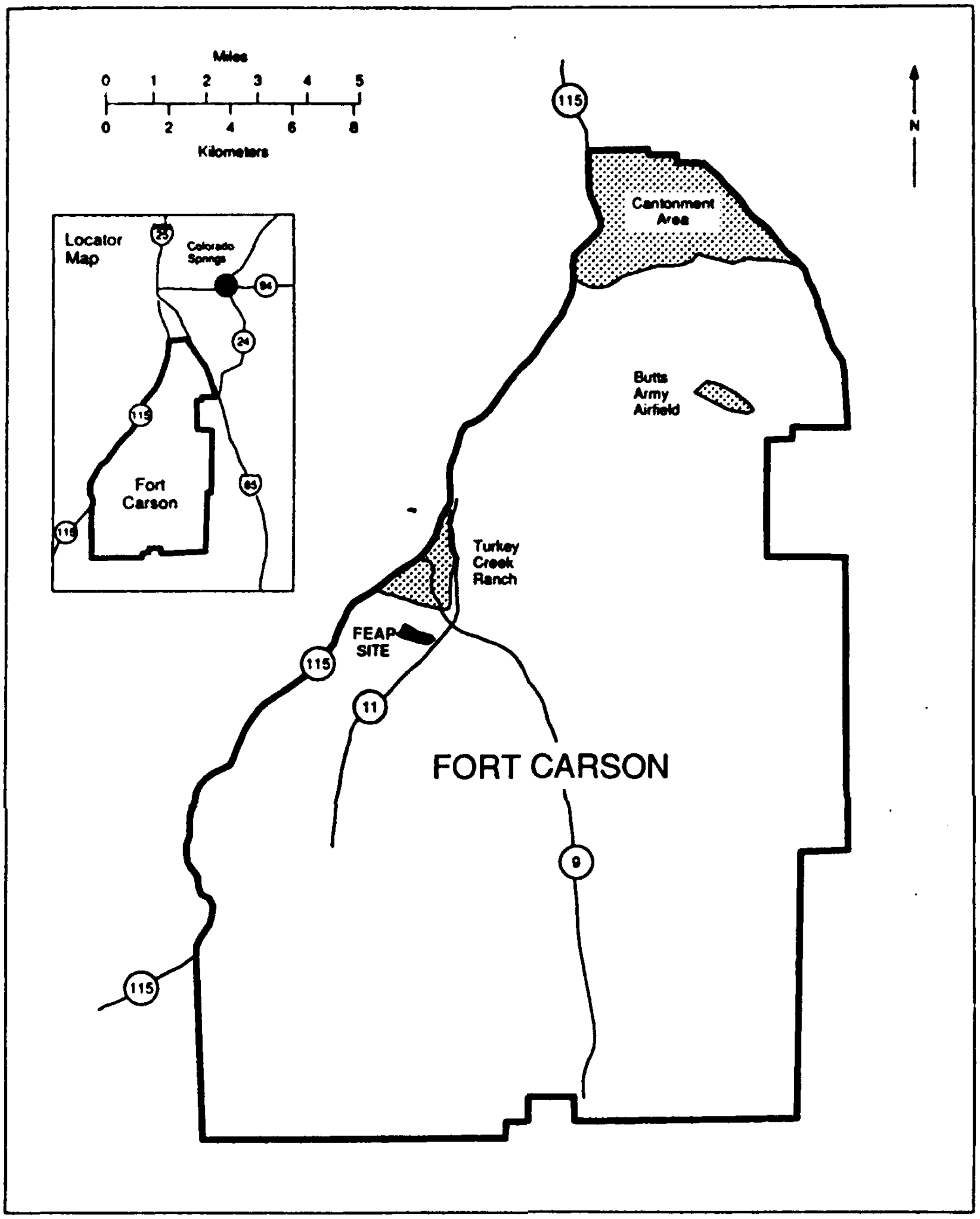

Figure 1. Location of the FEAP site.

• Representative of Fort Carson as a whole and, more specifically, of the "California strip" maneuver area (a long strip of land along Fort Carson Road 11 that is heavily used for tracked vehicle training and maneuvers). Therefore, the demonstration site should encompass a range of levels of disturbance, erosion problems, slopes, aspects, soil types and depths, plant communities, and vegetative cover percentages.

- Accessible to revegetation equipment necessary to implement the rehabilitation prescription.

- Large enough to provide an adequate field test/demonstration and within the limits of a typical rotational management scheduling unit.

Site selection at Fort Carson was conducted with the cooperation of personnel from the Environmental Division, Directorate of Engineering and Housing (DEH); Range Control; and the U.S. Department of Agriculture Soil Conservation Service (SCS). Three potential sites tentatively approved by Range Control were examined. One was rejected because of conflicts with training schedules that would have occurred during contractor revegetation operations. Another was rejected because it lacked topographic and vegetational diversity. The selected site is described in detail in the next section. An adjacent site with similar soil, vegetation, and disturbance characteristics, but receiving normal training use, is being used as a control site for this project.

Description and Development of the Demonstration Site

The FEAP site is located in Training Area 20 of Fort Carson, south of Turkey Creek Ranch within T17S, R67W, of El Paso County. The site is on the west side of Road 11, about 0.6 mi south of the junction with Road 9 (Figure 1) and is reached via the gate at Turkey Creek Ranch off Colorado Highway 115.

The site (Figure 2) varies considerably in topography, vegetation, and levels of disturbance. As such, it is representative of many areas and conditions found at Fort Carson. The east side consists of steep, rocky slopes with thin skeletal soils and widely spaced clumps or individual trees of pinyon and juniper. The west, south, and north sides consist of deep, sandy soils and steep to moderate slopes with dense areas of pinyon-juniper separated by open areas. Treeless, gently sloping or nearly flat shortgrass prairie areas occur around the perimeter. Levels of disturbance from training activities range from severe to none. The 85-acre site includes a 12-acre area with steep east-west ridges that produce areas inaccessible to tracked and wheeled vehicles. This area (crosshatched area in Figure 2) has been "excluded" from the demonstration site.

The site was divided into eight treatment areas representing all slope aspects. Tank trails, permanent landmarks, and compass headings were used to establish treatment area boundaries. Four treatment areas, totaling about 40 acres, received the rehabilitation treatment and four were left untreated (see Figure 2). The outer perimeter and treatment area boundaries were marked with 4-ft-tall rebar stakes with their tops painted ellow. Detailed descriptions of the soils and the treatment areas as they appeared before rehabilitation are given in the Appendix.

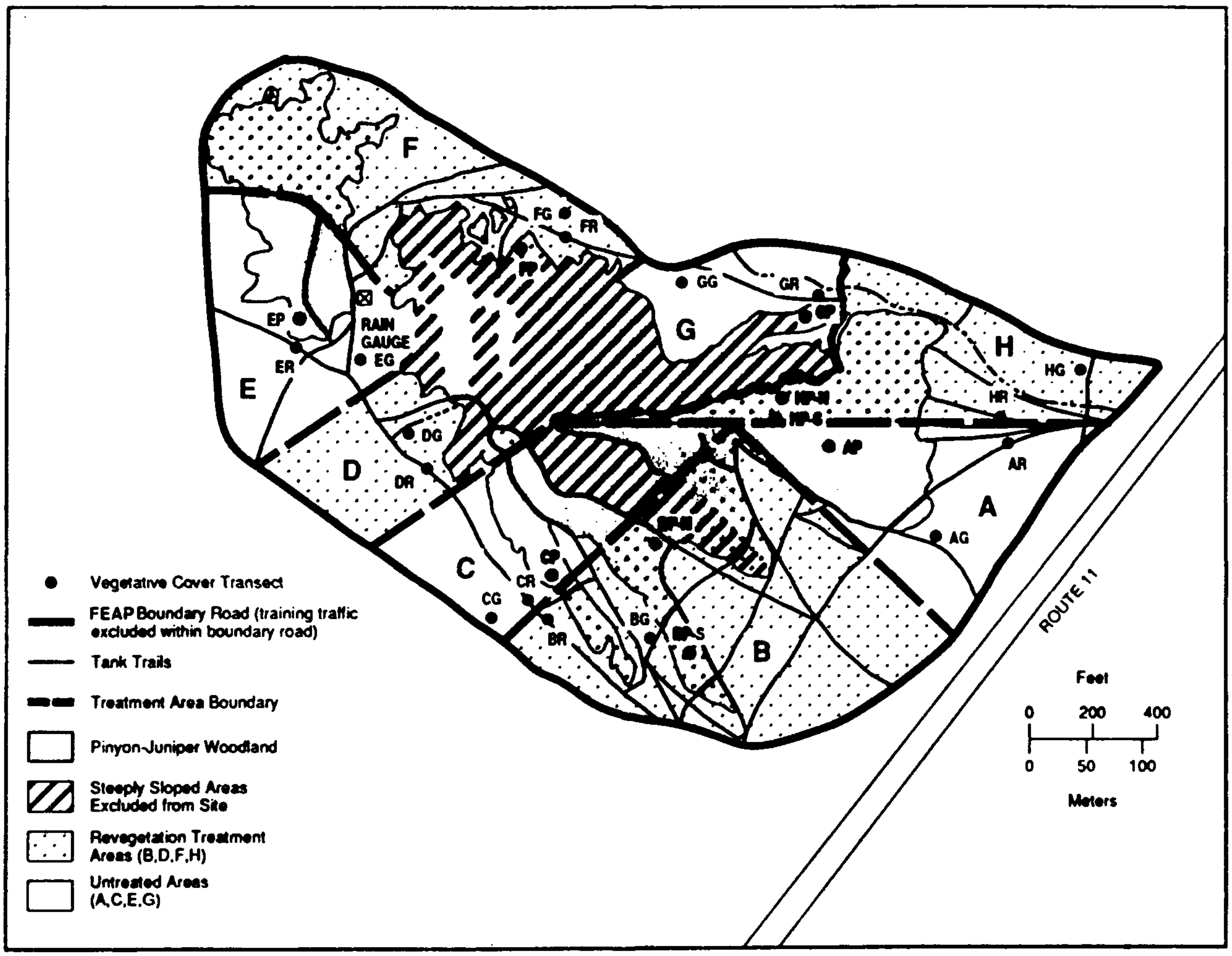

Figure 2. Characteristics of the FEAP site.

3 REHABILITATION TREATMENT

Development

Soil Sampling and Analysis

Seven composite soil samples (consisting of 6 to 16 individual subsamples per composite) were collected from areas of uniform soil and vegetation types (Figure 3). Major slope aspects were sampled separately. The soil cores in each composite sample were taken to a depth of 10 in. unless rock was encountered.

The soil samples were air-dried and processed using methods adapted from Sobek et al.[9] Chemical and physical characteristics included organic matter content (Walkley-Black method[10]); soluble salts concentration (conductivity of saturated extract[11]); soil pH, 1:1 in water;[12] cation-exchange capacity for arid-land soil;[13] available phosphorus (Olsen method[14]); and particle size distribution or texture (hydrometer method[15]). Total Kjeldahl nitrogen and total phosphorus were determined using industrial methods (Nos. 369-75A/B and 329-74W/B6[16]).

Species Selection

Species selection involved consideration of site-specific topography, climatic conditions, and chemical and physical soil characteristics. Other factors were the type of plant community desired, the planned post-revegetation land use, and other site limitations such as soil depth, rockiness, and slope. A relatively large number of candidate species met most of the criteria (Table 1). The final seed mixture selection was based on cost and availability of seed, dominant species in the existing vegetative cover, and recommendations from the local and State soil conservation services, the Colorado Department of Natural Resources, and Fort Carson personnel. The seed mixture, application rates, sources of seed, and other data are presented in Table 2.

Rehabilitation Specifications

Technical specifications for the rehabilitation treatment were also developed (Appendix). The specifications included plant nutrient requirements, fertilizer application rate, tillage methods to reduce soil compaction and prepare the seedbed, seeding methods, the perimeter boundary marking system, general conditions, and work descriptions.

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[9] A.A. Sobek, et al., *Field Laboratory Methods Applicable to Overburden and Mine Soils*, Technology Series EPA-600/2-78-054 (U.S. Environmental Protection Agency, 1978).

[10] D.W. Nelson and L.E. Sommers, "Total Carbon, Organic Carbon, and Organic Matter," *Methods of Soil Analysis, Part 2* (American Society of Agronomy, 1982).

[11] J.D. Rhoades, "Soluble Salts," *Methods of Soil Analysis, Part 2* (American Society of Agronomy, 1982), pp 167-180.

[12] "Determination of Soil Water pH," *Methods of Soil Testing*, G.A. Cahoon, Ed. (Council on Soil Testing and Plant Analysis, 1974).

[13] J.D. Rhoades, "Cation Exchange Capacity," *Methods of Soil Analysis, Part 2* (American Society of Agronomy, 1982), pp 149-158.

[14] "Determination of Phosphorus by Olsen's Sodium Bicarbonate Extraction," *Methods for Soil Testing*, G.A. Cahoon, Ed. (Council on Soil Testing and Plant Analysis, 1974).

[15] P.R. Day, "Particle Fractionation and Particle-Size Analysis," *Method of Soil Analysis, Part 1* (American Society of Agronomy, 1965), pp 545-567.

[16] *Technical Auto Analyzer II Industrial Methods* (Technicon Instruments Corp., 1977).

Implementation

Contractor Selection

Contractor selection was initiated by contacting 13 contractors suggested by personnel from Fort Carson, the SCS, and the Colorado Department of Natural Resources. Eight contractors (Appendix) requested copies of the technical specifications. Three contractors attended the site examination visit, which was mandatory before submitting a bid. Contractor selection was based on bid price and overall capability to accomplish the work (e.g., equipment availability, personnel expertise, and revegetation experience).

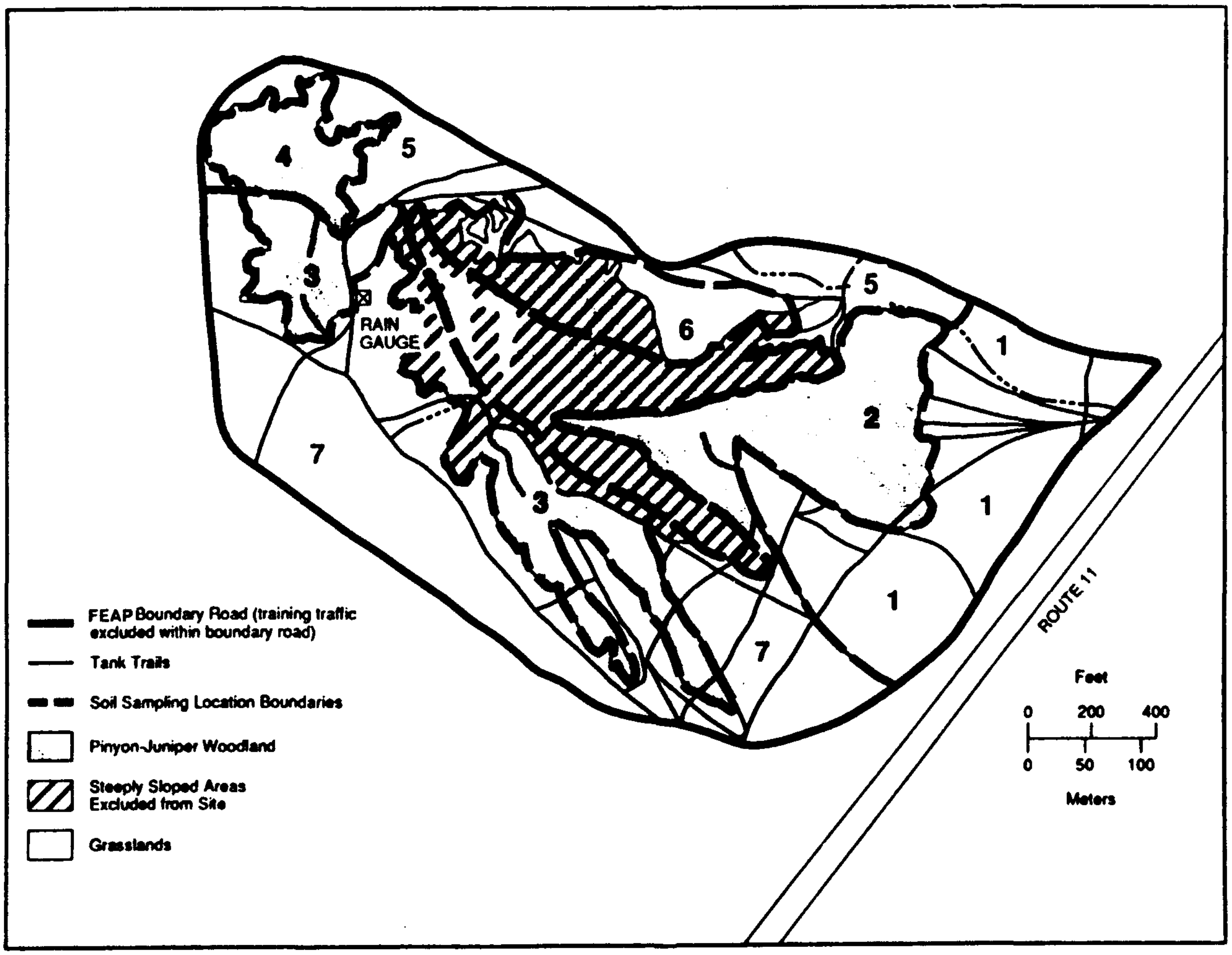

Figure 3. Soil sampling locations at the FEAP site.

Table 1

Selection Criteria for Plant Species at the FEAP Site

1. Can grow well/normally in 10 to 18 in. mean annual precipitation (MAP) zones and is native to, or adapted to, the Southern Rocky Mountain Foothills and/or the Upper Arkansas Valley Rolling Plains.

2. Capable of providing military training realism.

3. Tolerant of continued use of its habitat for military training (vehicle traffic, trampling, soil/air pollution, etc.) as characterized by:

   a. Vegetative reproduction by root sprouting, rhizomes, stolons, tillers, etc.;
   b. Tolerant of top breakage/abrasion;
   c. Tolerant of soil compaction, burial, etc; and
   d. Tolerant of soil/air pollutants associated with training activities.

4. Seed available commercially at reasonable cost.

5. Seeding and management methods applicable to site conditions and required equipment available.

6. Capable of high levels of survival in a variety of adverse natural conditions and useful (documented) in revegetation/rehabilitation. Tolerant of:

   a. Drought/below-normal precipitation,
   b. Low fertility, and
   c. Shallow root zone.

7. Has good soil stabilization characteristics, such as an extensive, fibrous root system; high root/shoot ratio; and low, spreading growth habit.

8. Produces large numbers of viable seeds, establishes well from seed, and has relatively high germination rates under field conditions.

9. Grows at a relatively rapid rate and/or has short life cycle, resulting in a minimal rest period (rotation).

10. Has desirable multiple-use characteristics for:

    a. Wildlife habitat (e.g., food, cover, nest sites),
    b. Grazing, and
    c. Recreation.

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* A.A. Thonburg, *Plant Materials for Use on Surface-Mined Lands in Arid and Semiarid Regions*, Report SCS-TP-157 (Soil Conservation Service, 1982).

Table 2

Characteristics of the Seed Mixture for the FEAP Site

Species	Pure Live Seed (lb/acre)[a]	Purity (%)	Germination (%)	Origin	Source
Western wheatgrass *Agropyron smithii* var. Arriba	3.4	92.59	89	Kansas	Arkansas Valley Seed
Streambank wheatgrass *Agropyron riparium* var. Sodar	1.1	96.61	90	Colorado	Southwest Seed Inc.
Crested wheatgrass *Agropyron cristatum* var. Fairway	1.0	93.87	80	South Dakota	Arkansas Valley Seed
Blue grama *Bouteloua gracilis* var. Hachita	1.7	49	76	New Mexico	Arkansas Valley Seed
Sideoats grama *Bouteloua curtipendula* var. Vaughn	2.1	80	76	Texas	Southwest Seed Inc.
Indian ricegrass *Oryzopsis hymenoides* var. Paloma	1.1	95	77	New Mexico	Southwest Seed Inc.
Mammoth wildrye *Elymus giganteus*	0.9	41.39	89	Washington	Northplan Seed Producers
Curlleaf mountain mahogany *Cercocarpus ledifolius*	0.6	98	90	Colorado	Arkansas Valley Seed
Northern sweetvetch *Hedysarum boreale*	1.1	96	87	Utah	Goble's Seed Co.
Galleta *Hilaria jamesii* var. Viva	1.1	63.57	83	Texas	Southwest Seed Inc.
Sand dropseed *Sporobolus cryptandrus*	0.9	97.76	90	Arizona	Arkansas Valley Seed
Total	15.0	--	--	--	--

[a]To convert lb/acre to kg/ha, multiply by 1.12

Installation of Rehabilitation Treatment

The rehabilitation treatment, accomplished by Phillips Seeding and Reclamation of Lafayette, Colorado between May 19 and 24, 1984, consisted of fertilization, tillage/seedbed preparation, seeding, harrowing, and boundary marking.

Fertilization. Each area receiving the treatment (Figure 2, areas B, D, F, and H) was fertilized at a rate of 30 lb/acre each of nitrogen (N) and potash (P_2O_5) using 150 lb/acre of 20-20-0 fertilizer. The fertilizer was applied with a broadcast spreader mounted on the back of a four-wheel-drive truck. The spreader covered an area about 40 ft wide, which was adequate to cover the area in and around the pinyon-juniper tree islands at a safe distance from branches and root systems.

Tillage/Seedbed Preparation. Severely disturbed areas with less than 20 percent vegetative cover were chisel plowed (light ripping) to produce a loose-textured seedbed. These areas included the relatively bare areas such as tank trails and areas that had been subjected to repeated maneuvering and turning. These areas, which comprised about 40 percent of the treated areas, were chisel plowed to a nominal depth of 6 to 8 in. with a Ford 117 spring-loaded chisel plow. Care was taken to stay several feet outside the lateral reach of the canopies of individual trees or tree islands to prevent damage to the roots.

Seeding. The entire ground surface of each treatment area receiving the rehabilitation treatment was seeded with the prescribed seed mixture (Table 2 and Schedule C in the Appendix) using a Tye 80-in. rangeland grass drill with three seed boxes. The seed mixture was modified slightly from that in the technical specifications based on the availability of seed. Because only a small amount of mammoth wildrye was available on the market in early May 1984, the amounts of the two grama grasses were increased and sand dropseed was added to the mixture. Species with small, smooth seeds (indian ricegrass, galleta, sand dropseed, and northern sweetvetch) were placed in a separate seed box on the drill to prevent settling. Wherever possible, drill seeding was done on the contour. Areas inaccessible to the drill (within and around pinyon-juniper tree islands and very steep areas) were seeded by a manually operated broadcast seeder at twice the drill-seeding rate.

Harrowing. The ground surface of each seeded area (except for the interiors of tree islands and the root areas of trees) was harrowed with a 12-ft-wide spike-tooth harrow. Harrowing was done to cover drilled seed left uncovered by surface irregularities.

Boundary Sign Marking. Training traffic is excluded from the site by highly visible "no trespassing" signs placed every 75 yd around the perimeter of the site. The site is also designated as an off-limits area on range maps provided by Fort Carson Range Control to training personnel and troops maneuvering in the California strip area.

Contractor Monitoring and Supervision. Contractor operations and performance were monitored and supervised during the treatment. Researchers from Argonne National Laboratory and the U.S. Army Construction Engineering Research Laboratory (USACERL) were present on the site at all times when the contractor was working.

Post-Implementation Monitoring of Vegetative Cover and Precipitation

Purpose. Composition and development of the plant community are monitored annually on permanent transects at the FEAP and control sites. The control site is similar in all respects to the FEAP site but receives normal training traffic. The percent live herbaceous plant cover (by species), tree and shrub canopy cover (by species), litter cover, and bare ground are determined. Generally, total vegetative cover (herbaceous plant cover plus litter) or its reciprocal (bare ground) correlate highly with erosion rates and soil stability.[17] However, all types of vegetative cover do not provide equal erosion protection and soil stabilization. Grasses are usually better for erosion control than most forbs because grasses have multiple stems, branching rhizomes, and a fibrous root system; forbs usually have a single stem and often have a shallow or tap root system that does not bind the soil as well as grass roots. Dead grasses (one type of litter) tend to remain intact and rooted in the soil for several years; the aboveground parts of dead forbs tend to break up into loose litter at the end of the growing season.

The monitoring data are used to assess the degree of ecosystem recovery and the development of successional trends on areas representing discrete combinations of vegetative type, treatment options, and level of initial damage. The time of revegetation progress on these areas can also be determined from the monitoring data. Because precipitation is important to plant growth and can vary considerably between relatively close sites in this area, installation of a rain gauge at the FEAP site was considered essential.

Methods. In each of the eight treatment areas at the FEAP site, and in two areas at the control site (north and south slope aspects), three permanent 99-ft transects were established. The transects were distributed among shortgrass prairie and pinyon-juniper ecotypes on disturbed areas of either severe or moderate-to-low damage. The starting point of each transect was selected randomly, and marked with a numbered metal tag attached to a steel rebar stake driven into the ground at each end of the transect. Each transect was then geographically defined by taking compass headings to two prominent landmarks and the compass heading of the transect line. A total of 25 transects were established on the FEAP site and 6 on the control site (Figure 2).

For data analysis, the transects were grouped by ecotype (shortgrass prairie or pinyon-juniper woodland) and damage level (severe or moderate-to-low). Areas of severe damage included tank trails in both the shortgrass prairie and pinyon-juniper ecotypes, and extensive denuded and compacted maneuver areas, primarily in the woodlands. The severely damaged areas also correspond to the areas that required chisel plowing as part of the rehabilitation treatment.

The areas of moderate-to-low damage were defined in both ecotypes as having sustained tank damage in the form of a few or multiple tracks but not to the point of denuding the soil surface of vegetation. These areas usually had 40 percent or more of the vegetative cover that would be expected on a similar undisturbed site, and they received only harrowing.

Before monitoring, several possible methods to measure plant cover, litter, and tree/shrub canopy cover were considered for use at the FEAP site. The point-intercept method,[18] using a point frame with 10 pins, was selected based on discussions with personnel from USACERL, Fort Carson, and the SCS, and on field trials of several alternative vegetative cover measurement methods. In this method, 10 pins are dropped at each meter along the transect, for a total of 300 pins (points) per transect. As each pin is

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[17] L. Hoffman, R.E. Ries, and J.E. Gilley, "Relationship of Runoff and Soil Loss to Ground Cover of Native and Reclaimed Grazing Land," *Agronomy Journal*, Vol 75, No. 4 (1983), pp 599-602; R.O. Meeuwig, "Infiltration and Soil Erosion as Influenced by Vegetation and Soil in Northern Utah," *Journal of Range Management*, Vol 25 (1970), pp 185-188.

[18] D. Mueller-Dombois and H. Ellenberg, *Aims and Methods of Vegetation Ecology* (John Wiley and Sons, 1974); C.D. Bonham, *A Survey of Techniques for Measurement of Herbaceous and Shrub Production, Cover and Diversity on Coal Lands in the West* (Office of Surface Mining [Region V] and Uniscale Corp., 1980); J.C. Chambers and R.W. Brown, *Methods for Vegetation Sampling and Analysis on Revegetated Mined Land*, Technical Report INT-151 (U.S. Department of Agriculture, Forest Service, 1983).

lowered through the vegetation, its first contact with a plant (identified to genus and species, if possible), litter, rock, or bare ground is recorded. The number of "hits" on each plant species or cover category, expressed as a percentage of the total number of pins dropped per transect, is the percent cover.

Canopy cover of trees and shrubs on the permanent transects is measured by a line-intercept method[19] in which the linear extent of the tree or shrub parts (by species) that extends over the transect tape is measured and expressed as a percentage of the total transect length. Measurement of vegetative cover by species permits grouping the data into various cover subsets that are important for evaluating cover quality and successional trends (e.g., grasses, forbs, and weeds). For example, the category named "weeds" (kochia and Russian thistle) was broken out from the forbs category (all other forbs) to better evaluate the effects of these aggressive invaders on plant community development. Cover measurements were made on all transects in July of 1984, 1985, and 1986.

During July 1984, a tipping-bucket rain gauge was installed at the FEAP site in an open, grassy location in treatment area E (Figure 2). The rain gauge is equipped with a battery-operated solid state electronic event recorder (Datapod) and a minimum/maximum thermometer. Precipitation data from the Butts Field Station (Fort Carson) have been used in addition to the site data.

Data Analysis. The means of the plant cover percentages recorded by species and the means of the percentages of several other cover categories from transects in each ecotype and damage category were analyzed for biologically and statistically significant differences. These differences were determined using analysis of variance and covariance techniques for unbalanced data (General Linear Models) developed by the Statistical Analysis Sytem (SAS) Institute for computerized data analysis.

The cover data presented in this report are the actual percentages; however, the statistical analyses were run on data that were transformed using the arc sine of the square root of the percentage expressed as a decimal fraction.[20] This transformation stabilizes the variance and also tends to normalize the data. The trends (a consistent or prevailing tendency that is not statistically significant) discussed in this report are based on direct field observations and are often documented by photographs.

[19] J.C. Chambers and R.W. Brown.

[20] Personal communication, B.A. Carnes, Biological and Medical Division, Argonne National Laboratory, 1985.

4 RESULTS AND DISCUSSION

Soil Analyses

The results of the physical and chemical analyses of soil samples from the FEAP site are presented in Table 3. These data confirm the predominance of erodible soils of loose consistency that have been mapped for the site.[21] These soil data were used to select the revegetation species and to determine the fertilizer requirements. Because the two soil types on the site (Rizozo-Neville complex and Neville-Rednun complex) are common throughout the California strip area of Fort Carson, this detailed soil analysis (not available previously) may be useful in developing revegetation prescriptions and management plans for other sites in this heavily used training area.

The FEAP site is considered a low-stability resource area because of steep slopes and shallow soil depths.[22] For comparison, a nearby flat area of shortgrass prairie, with similar soils and light-to-moderate damage due to restricted training use (Sullivan Park), is considered a high-stability resource area.

Precipitation at Fort Carson

Monthly precipitation at the FEAP site and 18-year monthly averages from the Butts Field Station 8.7 mi away are presented in Table 4. Precipitation was above normal at Fort Carson in both 1984 and 1985 and was below normal in the spring and early summer before the 1986 monitoring session. The appearance of the vegetation at the FEAP site in 1985 was dramatically different from that in 1986. In July 1985, most of the grasses and forbs were alive, vigorous, and green, and luxuriant stands of weeds (kochia and Russian thistle) occurred on some of the severely disturbed areas (both treated and untreated). In July 1986, some weeds were still present but were much smaller, most of the grasses were already dormant, and many of the forbs were dormant or dead.

Rehabilitation Strategies

Vegetative growth, production, and succession represent the integration of environmental parameters at a particular site. The end point of natural plant succession on disturbed areas is to reestablish a stable plant community that is similar to the natural undisturbed communities in the vicinity. The strategy of rehabilitation is basically the same as that of natural succession, namely increasing control of, or equilibrium with, the physical environment to achieve maximum protection from disturbances, either natural or those induced by man. Thus, rehabilitation is really managed interference of natural succession, which is usually unacceptably slow. The goal of the rehabilitation work at the FEAP site is to rapidly establish a plant community that will stabilize the disturbed areas against erosion. However, initially these revegetation communities are only functionally similar to the much more diverse undisturbed communities.

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[21] Soil Conservation Service, 1981.

[22] Dames and Moore.

Table 3

FEAP Site Soil Characteristics

Sample Location	Exchangeable Bases (meq/100 g)[a] Ca	Mg	Na	K	pH	Organic Carbon (%)	Electrical Conductivity (mmho/cm)	Phos-phorus (μg/g)	Total Kjeldahl Nitrogen (mg/g)	Particle Size (%) Sand	Silt	Clay
1	51.44	3.50	0.06	0.88	7.91	1.92	0.570	8.88	2.14	22	34	44
2	62.00	3.44	0.06	1.00	7.99	2.75	0.629	5.93	2.94	24	40	36
3	44.06	5.00	0.06	0.44	8.14	0.67	0.600	2.54	1.11	19	28	58
4	34.06	3.38	0.06	0.38	8.47	1.12	0.361	4.04	1.04	14	14	72
5	13.00	4.56	0.06	0.63	8.08	0.90	0.580	7.71	2.08	16	19	65
6	38.00	2.75	0.06	0.50	8.24	0.89	0.449	2.21	1.25	16	26	58
7	39.38	4.94	0.06	0.69	8.22	1.29	0.560	9.38	1.71	26	42	32

[a] meq/100 g = cmo/(i)kg^{-1}.

Table 4

Monthly Precipitation at Fort Carson*

Month	FEAP Site 1984	FEAP Site 1985	FEAP Site 1986	Butts Field Average 1969-1986
January	0.90**	0.47**	0.00	0.51
February	0.01**	0.20	0.16	0.29
March	1.39**	2.75	0.90	0.81
April	1.31**	1.98	0.47	1.22
May	0.71**	3.59	0.60	2.61
June	2.78**	0.62	2.67	2.05
July	6.13**	6.61	2.75	2.76
August	3.63	1.66	6.64	2.49
September	0.81	1.65**	0.98	1.00
October	5.89	0.49	1.17	0.57
November	0.08	0.42	0.70	0.61
December	0.35**	0.46**	0.26	1.04
TOTAL	23.99	20.90	17.30	15.96

*In inches.
**Data from Butts Field Station, before installation of the FEAP rain gauge or when FEAP data were unavailable.

The severely damaged areas have improved greatly where the treatment was used and training traffic was excluded. These areas include tank roads in both the grass and woodland ecotypes, and large expanses of rocky, barren maneuver ground, primarily in the pinyon-juniper areas.

A dense, vigorous vegetative cover composed predominantly of native grasses is the most effective and practical means of controlling erosion and stabilizing the loose soils of the FEAP site and similar areas in the California strip training area of Fort Carson. A complete list of the plant species encountered during 1984, 1985, and 1986 is presented in Table 5. The point-intercept method was used to develop the list. Field observations and monitoring data collected through 1986 at the site indicate that such plant communities are being reestablished on several severely disturbed areas that received the rehabilitation treatment. The data also indicate that revegetation by desirable grasses is occurring most rapidly on the treated areas. Areas that did not receive the rehabilitation treatment but were excluded from training traffic have also shown a considerable increase in plant cover, indicating that rest alone is beneficial. The results pertaining specifically to the shortgrass prairie and pinyon-juniper woodland ecotypes of the FEAP site are discussed in the following paragraphs. These results are then compared with the control site.

Table 5

Plant Species Encountered on the Cover Transects Using the Point-Intercept Method

Type	Scientific Name	Common Name(s)
Grasses	Agropyron smithii	Western wheatgrass
	Agropyron spp.	Wheatgrass
	Aristida spp.	Three-awn
	Aristida fendleriana	Fendler three-awn
	Aristida longiseta	Red three-awn
	Bouteloua curtipendula	Sideoats grama
	Bouteloua gracilis	Blue grama
	Bromus japonicus	Japanese brome
	Elymus spp.	Wildrye
	Hilaria jamesii	Galleta
	Munroa squarrosa	False buffalograss
	Oryzopsis micrantha	Littleseed ricegrass
	Panicum capillare	Ticklegrass, witchgrass
	Schedonnardus paniculatas	Tumblegrass
	Sitanion hystrix	Bottlebrush squirreltail
	Sporobolus cryptandrus	Sand dropseed
	Stipa robusta	Sleepygrass
	Tridens pilosus	Hairy tridens
	Unidentified grasses	
Forbs	Amaranthus spp.	Amaranth, pigweed
	Artemisia frigida	Fringed sagewort
	Cardaria draba	Whiteweed
	Chenopodium album	Lambsquarter
	Chaenactis douglasii	Dusty maiden, bride's bouquet
	Cirsium spp.	Thistle
	Dyssodia papposa	Fetid marigold
	Eriogonum spp.	Wild buckwheat
	Euphorbia spp.	Spurge
	Gaura coccinea	Gaura
	Grindelia squarrosa	Curlycup gumweed
	Haplopappus spinulosus	Spiny goldenrod
	Helianthus annus	Common sunflower
	Heterotheca villosa	Hairy goldaster
	Hymenoxis odorata	Bitterweed
	Kochia iranica	Kochia
	Lactuca spp.	Prickly lettuce
	Lappula spp.	Lappula
	Linum lewisii	Blue flax

Table 5 (Cont'd)

Type	Scientific Name	Common Name(s)
Forbs (cont'd)	Lygodesmia spp.	Skeletonweed
	Melilotus alba	White sweetclover
	Opuntia polycantha	Plains prickly pear cactus
	Physalis hederaefolia	Ivy-leaved groundcherry
	Physalis lobata	Purple-flowered ground cherry
	Psoralea tenuiflora	Slimflower scurfpea
	Ratibida columnifera	Upright prairie coneflower
	Salsola kali	Russian thistle
	Spaeralcea coccinea	Copper mallow, scarlet globe mallow
	Thelesperma filifolium	Greenthread
	Townsendia grandiflora	Townsendia, Easter daisy
	Tragopogon spp.	Goatsbeard, salsify
	Verbena bracteata	Bracted verbena
	Verbesina encelioides	Crownbeard
	Xanthocephalum sarothrae	Broom snakeweed
	Yucca glauca	Yucca
	Unidentified forbs	
Trees/Shrubs	Cercocarpus montanus	True mountain mahogany
	Juniperus monosperma	One-seed juniper
	Pinus edulis	Pinyon pine
	Rhus trilobata	Skunkbrush sumac

Shortgrass Prairie Ecotype

Areas of Severe Damage

Statistically Significant Results. The shortgrass prairie ecotype comprises the most accessible areas of Fort Carson and, as such, is often a patchwork of grassy areas of moderate-to-low damage separated by tank trails, vehicle tracks, and large, severely disturbed areas. Cover data for treated and untreated shortgrass prairie transects on the FEAP site that initially had severe damage are summarized in Table 6. In 1986, the severely damaged areas that had been treated had significantly more ($P = 0.02$) grass cover than similar untreated areas undergoing natural revegetation (traffic exclusion only). This greater grass cover is biologically significant because it indicates an increase in vegetative cover quality and implies that these treated areas are less susceptible to erosion and more similar to the natural plant communities in the vicinity than the untreated areas. The much smaller increase in grass cover on the severely damaged untreated areas between 1985 and 1986 is not significant.

An equally important finding is a significantly greater (P = 0.06) rate of grass cover development on the treated areas (severe damage) compared to the untreated areas over the 3-year period monitored. A realistic analysis of these rates suggests that grass cover development on even the most rapidly recovering untreated areas (e.g., area A in Figure 2) could take an additional 2 to 3 years to attain the grass cover levels on the treated areas in 1986. These estimates are tentative because the FEAP plant communities are still undergoing successional change. The analysis of the increased rates of grass cover assumed a further increase in the rate on untreated areas in succeeding years (as occurred between 1985 and 1986 on the treated areas) and a leveling of the rate of increase on treated areas at about 40 percent grass cover.

Other significant differences within cover categories were also found, usually within treatments and between years. As such, they are of interest in terms of revegetation rates, time courses, and succession within a particular plant community, but they do not directly address the more important comparisons between treated and untreated areas. For example, the cover categories of total herbaceous plants, grasses, forbs, and weeds increased significantly between 1984 and 1985 for both treated and untreated areas (Table 6). Some of these categories were also significantly different between 1985 and 1986. Because most severely damaged areas were essentially bare of vegetation at the start of the project (either from revegetation operations or their existing disturbed condition), the large increases in cover are not unexpected. The differences between 1984 and 1985 were most likely due to the exclusion of training traffic at the beginning of the project and the above-average precipitation in the spring of 1985 (Table 4).

The values for most other cover categories were not significantly different during 1986, even though most of the paired values (treated vs untreated) were quite dissimilar (Table 6). Large differences in the rate and degree of revegetation progress on identical transects (i.e., within the same treatment, ecotype, and damage category) resulted in relatively high data variability within cover categories and thus limited the number of significant differences. These differences in revegetation rates are readily observable in the field and are probably due to differences in site characteristics such as aspect, slope, soil type and thickness, and, in some cases, vehicle trespass damage.

Another factor contributing to the lack of significant differences between cover categories other than grass on treated and untreated areas in 1986 was the large amount of plant biomass produced in 1985 due to above-normal precipitation. The biomass was predominantly weeds on the untreated areas, whereas it was mostly grass on the treated areas. Much of this biomass carried over to 1986 as litter and, because litter was not sorted by species for this analysis, both weed and grass litter were recorded as the same component in 1986. Thus, the data from treated and untreated areas appear to be more similar than they actually are because grass litter contributes considerably more to high cover quality than does weed litter.

Trends, Field Observations, and Photographic Documentation. The 1986 data (Table 6) confirm the consistent trend toward higher grass cover on treated areas that was observed in the field in 1984 and 1985 but was not statistically significant in 1985. The 1986 increases in grass and litter on the untreated areas (Table 6) suggest that rest alone may be beneficial, but the quality of cover developing on the untreated areas (mostly weedy forbs and loose litter) is lower than that on the treated areas (more grasses and rooted litter). These trends and field observations are documented in Figures 4 through 8, which represent a time series of views of the east slope of the FEAP site from just before rehabilitation work in April 1984 (Figure 4) to July 1986 (Figure 8). The photos show four central roads (tank trails) with a severely damaged pinyon-juniper woodland in the background (see Figure 2 for a map of this area). In Figure 4,

Table 6

Means of Cover Categories and Bare Ground for Shortgrass Prairie Transects on Areas of Severe Damage

Category	Percent Cover on Treated Areas*			Percent Cover on Untreated Areas*		
	1984	1985	1986	1984	1985	1986
Total vegetative cover	7.4	59.6	71.6	6.2	64.3	68.8
Total herbaceous plant cover	3.7	46.8	43.6	4.0	39.2	26.4
Grass cover	3.1	8.0	26.6**	2.6	3.6	4.6**
Forb cover	0.2	1.8	0.5	0.3	2.3	0.3
Weed cover	0.5	37.1	16.5	1.1	33.2	21.5
Litter	3.7	12.8	28.0	2.2	25.1	42.4
Bare ground	92.6	40.4	28.5	93.8	35.7	31.2

*Treated areas received the rehabilitation prescription and were excluded from training traffic; untreated areas were excluded from training traffic only and are undergoing natural revegetation.

**These values are significantly different ($P \leq 0.05$). Only the differences between means from treated and untreated transects within the same cover category and year are indicated.

the stake in the foreground and another at the left edge of the third road from the left mark the boundary between area A to the left, which will be untreated, and area H to the right, which will receive the rehabilitation prescription. Figure 5 shows the two roads in area H after they have been chisel plowed and the two untreated roads in area A.

Figures 6 through 8 are monitoring photographs taken in July of 1984, 1985, and 1986, respectively. The July 1984 photo (Figure 6) shows conspicuous growth of grasses and some weedy forbs on the treated areas (two roads on the right and right foreground) and predominantly weedy growth (mostly dark green kochia plants) on the untreated areas (two roads on the left and left foreground). In July 1985 (Figure 7), the site vegetation is alive and vigorously growing due to above-normal precipitation in the spring and early summer of 1985. Extensive growth of large weeds is responsible for the darker color of the two untreated roads on the left. An erosion gully that has deepened considerably since 1984 is just in front of the monitoring crew member at the edge of the untreated road. The locations of the two treated roads on the right side are difficult to discern, but they have somewhat more weedy growth than the adjacent

Figure 4. View of the east slope of the FEAP site before rehabilitation work in April 1984.

Figure 5. View of east slope of the FEAP site immediately after chisel plowing the treated areas in April 1984.

Figure 6. View of the east slope of the FEAP site in July 1984.

Figure 7. View of the east slope of the FEAP site in July 1985.

Figure 8. View of the east slope of the FEAP site in July 1986.

grassy areas of low disturbance. In July 1986 (Figure 8), the two treated roads are very difficult to discern, but the entire area looks more uniform because grasses have begun to invade the untreated roads. Because the period before the July 1986 monitoring session received below normal precipitation, very few large weeds were encountered in 1986, unlike 1985. Many of the forbs and grasses were dormant or dead in 1986. The progress of revegetation on treated area H and the natural revegetation exhibited by untreated area A in Figures 4 through 8 is typical of many areas of the site. However, there are some portions of each treatment area where revegetation is progressing more slowly, probably because of adverse microsite conditions.

Dispersal of Existing Grass Propagules by Revegetation Operations. During the July 1984 monitoring session, it was observed that western wheatgrass plants growing in the treated (chisel plowed) tank trails traversing grassy areas of the east slope (area H) were either tiny solitary seedlings or almost mature clumps ranging from a few stems up to 6 to 8 in. across. The clumps were much too large to have originated from the May planting. Apparently, during revegetation operations, existing clumps of western wheatgrass were broken up and dispersed throughout the treated areas by the plowing and spiketooth harrowing action. These clumps had resprouted and become well established in the 1.5 months since treatment, as evidenced by the growth of new rhizomes and shoots. This mechanical dispersal of grass vegetative propagules by revegetation equipment operations has been observed on several treated tank trails where good grass and forb cover is present on either side of the trail and the soil is moderately deep. It does not occur in pinyon-juniper areas where the soil is thin or where vegetation adjacent to the trail is sparse.

These observations suggest that chisel plowing and harrowing only (no seeding) of disturbed areas surrounded by grassy areas may be an effective, less expensive, rehabilitation alternative. This option could be evaluated by first chisel plowing a section of compacted tank trail and then harrowing back and forth into the grassy area and across the chisel plowed trail to drag in the propagules. The distance that propagules may be effectively dispersed by this method is limited, and determining this distance should be part of any studies that are initiated. The large increases in grass cover on some treated areas in the shortgrass prairie ecotype of the FEAP site (Table 6) are apparently due to a combination of the revegetation seeding and the effect of this mechanical propagule redistribution.

Effects of Weedy Invaders. In the absence of traffic and with the adequate moisture available in 1985, annual weedy species, primarily kochia and Russian thistle, quickly formed dense stands on areas disturbed by previous training and project activities at the FEAP site. Both of these opportunistic, fast-growing species appear to be well adapted to several dissimilar soil disturbance conditions, including the disturbed soil resulting from chisel plowing and harrowing of the treated areas and the bare, compacted soil on the severely disturbed untreated areas. Following either type of soil disturbance, high levels of soil moisture (especially from early spring precipitation) are most effective in producing large weed populations. At the FEAP site, without traffic to destroy some of the young plants, the weeds flourished even more than normal and were the major component of the plant community on some transects in the severely disturbed areas in 1985 (Figure 7). Weedy growth on such areas is not unexpected or totally undesirable, because weeds can act as a "nurse crop" for the slower-growing perennials as long as competition for moisture does not become severe.

The untreated areas within the shortgrass prairie ecotype will probably continue to produce a larger weed component than will the treated areas for several years because higher than normal seed reserves were produced in 1985 and the seeds of these weedy annuals germinate earlier in the spring than the seeds of the more desirable native perennials (which, in untreated areas, must depend on natural dispersal mechanisms). Thus, the weedy plants compete more effectively for available moisture and nutrients, and the disturbed site undergoes a slow, natural revegetation process. However, once established, the perennials can start growth sooner in the spring from existing crowns than the annuals can germinate from seed. In this way, the perennials gradually outcompete and replace the annuals. With time, the successional process will eventually result in a plant community on the untreated areas that is similar to the community on the treated areas. The minimum time frame of 2 to 3 additional years predicted for this process is probably too long to consider rest alone as a viable rehabilitation alternative because a particular land parcel can be removed from training use for only a short time.

Extensive growth of large weeds can also affect the actual measured values of other cover components. Based on field observations made in 1985, it is likely that the percentages of grasses, forbs, and litter in plant communities developing on the severely disturbed areas in the shortgrass prairie ecotype (both treated and untreated) were actually somewhat higher than the values calculated in this study. This may have resulted from a shading effect of the large numbers of tall, live weeds on these areas and on an unavoidable sampling effect inherent in the point intercept method (as the point frame pins are dropped, tall plants with large, horizontally placed leaves--such as kochia--tend to be hit more often than either short plants, especially those with narrow vertical leaves--such as young grass plants, or the litter that is under or near the tall weeds). In 1985, the planted grasses (in their first full season of growth) were usually single shoots less than 8 in. tall that had not yet formed tillers, whereas many of the weeds were as tall as 3 ft and were extensively branched.

Areas of Moderate-to-Low Damage

Statistically Significant Results. In the shortgrass prairie areas with moderate-to-low initial damage, changes in plant communities were much less obvious and discernible, either over time or in response to the revegetation treatment (Table 7). Only limited significant differences were detected between treated and untreated (rest only) areas. However, smaller and slower changes were expected because both seeded plants and volunteers had to emerge into an existing stand that, in some cases, was little modified from the natural, stable grassland community.

On the areas that were initially moderately damaged, a significantly greater amount of weed and forb cover was measured on the treated areas than on the untreated areas in 1985, probably due to soil disturbance associated with revegetation operations. However, the amount of weed cover on these treated transects was less than one-third that on the severely disturbed transects, and the forbs were primarily annual early colonizers that drop out of the community after 1 or 2 years. The moderately disturbed treated areas were harrowed but not chisel plowed, whereas the severely disturbed areas were chisel plowed and harrowed. These observations suggest a direct relationship between the degree of soil disruption and the amount of weed cover that develops during the following season. Because 1985 was a year of above-normal precipitation, this soil disruption effect may have been intensified. In addition, some significant differences occurred within treatment categories between years on these moderately disturbed areas.

Trends and Field Observations. On the treated areas of moderate-to-low damage, there was a consistent trend of increasing rates of grass cover and litter development that was not matched on the untreated areas (Table 7), which suggests a positive effect of the revegetation treatment. Grass cover on the untreated areas also increased to some degree in 1985, suggesting that part of the increase on the treated areas was probably due to a combination of exclusion of training traffic and above-normal moisture. However, in 1986, with lower-than-normal precipitation in the spring, grass cover declined slightly on the untreated areas but increased more than 40 percent over 1985 levels on the treated areas.

Pinyon-Juniper Woodland Ecotype

Statistically Significant Results

No highly significant differences in cover categories were detected, either between treated and untreated areas or between years within a treatment category.

Trends and Field Observations

Due to rocky, shallow soils in the pinyon-juniper woodland areas of Fort Carson, these areas sustain considerably more long-term damage from tank traffic than do most grassland areas. Such damage is also more serious than grassland damage because of the long time required to replace the trees.

Table 7

Means of Cover Categories and Bare Ground for Shortgrass Prairie Transects on Areas of Moderate-to-Low Damage

	Percent Cover on Treated Areas*			Percent Cover on Untreated Areas*		
Category	1984	1985	1986	1984	1985	1986
Total vegetative cover**	35.3[x]	62.1	73.2	67.2[x]	70.4	81.0
Total herbaceous plant cover	17.8	36.3	39.4	22.1	34.7	31.9
Grass cover	11.9	21.5	36.3	17.1	32.1	30.6
Forb cover**	4.3	4.2[y]	2.2	3.2	2.3[y]	1.2
Weed cover**	1.7	10.7[z]	0.9	1.8	0.4[z]	0.1
Litter	17.5	25.8	33.7	45.2	35.7	49.2
Bare ground	64.7	37.9	26.9	32.8	29.6	19.0

* Areas receiving the rehabilitation treatment were excluded from training traffic; untreated areas were excluded from training traffic only and are undergoing natural revegetation.

** Values in a given row followed by the same letter (i.e., x, y, or z) are significantly different ($P \leq 0.05$). Only the differences between means from treated and untreated transects within the same cover category and year are indicated.

The cover data for severely and moderately damaged pinyon-juniper transects on the FEAP site are summarized in Tables 8 and 9, respectively. The plant community is naturally more sparse within this ecotype and revegetation is progressing more slowly on both the treated and untreated areas than in the grassland areas. However, the areas that received the rehabilitation treatment are beginning to show improvement. A consistent trend toward higher percentages of grass cover over the past two seasons on the treated areas of both severe and moderate damage is apparent in the data and was also observed in the field. In the severely damaged pinyon-juniper areas, grass cover on the treated areas more than doubled from 4.0 percent in 1985 to 9.5 percent in 1986. In 1986 it accounted for 75 percent of the total herbaceous plant cover. During this period, grass cover on the untreated areas remained at less than 2 percent.

Table 8

Means of Cover Categories and Bare Ground for Pinyon-Juniper Transects on Areas of Severe Damage

Category	Percent Cover on Treated Areas*			Percent Cover on Untreated Areas*		
	1984	1985	1986	1984	1985	1986
Total vegetative cover	22.1	32.0	33.8	14.0	56.7	38.7
Total herbaceous plant cover	2.8	8.6	12.6	8.6	45.8	5.7
Grass cover	0.6	4.0	9.5	0.2	1.2	1.8
Forb cover	1.8	0.5	1.8	2.6	1.8	3.5
Weed cover	0.4	4.1	1.3	5.9	42.9	0.4
Litter	19.2	23.3	21.2	5.4	10.9	33.0
Bare ground	77.9	68.0	66.2	86.1	43.4	61.4
Tree/shrub canopy cover	6.2	5.3	0.4	5.4	5.9	6.5

*Treated areas received the rehabilitation treatment and were excluded from training traffic; untreated areas were excluded from training traffic only and are undergoing natural revegetation.

The higher weed cover in 1985 on treated areas of moderate damage no doubt reflects the increased weed growth caused by soil disturbance associated with the revegetation treatment in 1984 and the favorable soil moisture conditions in 1985. Also in 1985, several large areas within the severely damaged treatment area H were observed to be covered with relatively dense stands of a small annual Lepedium species. These aggressive, colonizing plants were probably responding to the soil disturbance associated with chisel plowing and harrowing because they were not observed in the untreated area A. Although Lepedium is not a noxious weed, it is considered an invader with low value for erosion control. Its presence in the thin, stony soils of the pinyon-juniper ecotype is probably ecologically comparable to the presence of kochia and Russian thistle in the deeper disturbed soils of the grassy areas. Lepedium was not observed in 1986; however, extensive areas of small planted grasses were developing on many portions of the severely damaged treated area where it had grown the year before. This conclusion was inferred based on the occurrence of the grass plants in drill rows; these grasses were mostly less than 3 in. tall and were not identifiable to genus.

Table 9

Means of Cover Categories and Bare Ground for Pinyon-Juniper Transects on Areas of Moderate-to-Low Damage

Category	Percent Cover on Treated Areas*			Percent Cover on Untreated Areas*		
	1984	1985	1986	1984	1985	1986
Total vegetative cover	38.4	54.6	68.5	43.7	56.6	53.7
Total herbaceous plant cover	5.6	14.3	15.1	6.9	10.2	7.0
Grass cover	2.1	4.5	12.5	4.5	6.0	5.5
Forb cover	2.8	3.0	2.0	2.2	3.4	1.4
Weed cover	0.7	6.8*	0.7	0.1	0.9*	0.1
Litter	32.9	40.4	53.5	36.9	46.3	46.7
Bare ground	61.6	45.4	31.5	56.3	43.4	46.3
Tree/shrub canopy cover	28.5	23.0	31.6	25.7	30.6	28.8

* Treated areas received the rehabilitation prescription and were excluded from training traffic; untreated areas were excluded from training traffic only and are undergoing natural revegetation.

** Values are significantly different ($P \leq 0.05$). Only the differences between means from treated and untreated transects within the same cover category and year are indicated.

The untreated areas of both severe and moderate damage decreased in total herbaceous plant cover and total vegetative cover in 1986. This decrease probably resulted from the low precipitation in the period before the July 1986 monitoring session.

Tree and shrub canopy cover measurements are not included in the total vegetative cover values. Although the woody species provide some erosion protection in the form of raindrop interception, they have essentially no effect on either sheet or rill erosion, which are so prevalent and damaging to the thin, disturbed soils in the often steeply sloped terrain where the pinyons, junipers, and shrubs occur. Also, normal growth in these species occurs too slowly for them to be included in the type of rehabilitation program being demonstrated at the FEAP site.

The tree/shrub canopy cover data are included in the data summaries to provide information on year-to-year changes in this cover category. These variations should not be large on the FEAP site if the exclusion of military traffic is effective. In the normal traffic (control) area, these data provide evidence of damage to trees by tanks and other vehicles, and field observations have confirmed the destruction of entire trees and extensive tree damage since the project was initiated. In several cases, such tree damage reduced the tree/shrub cover measured on an adjacent transect. Thus, differences in tree/shrub canopy cover from year to year within particular treatment and damage categories are due to a combination of normal growth and death of tree parts, sampling error, and, in the case of the normal traffic control area and at least one FEAP woodland transect, vehicle damage or destruction of trees.

Comparison of Untreated Areas on the FEAP Site With the Control Site

Statistically Significant Results

The cover data for severely and moderately damaged transects on all untreated areas (which were rested by barring training traffic) on the FEAP site and on the control site (which received normal training traffic) are summarized in Tables 10 and 11. These data indicate significantly higher amounts of total cover in 1986 ($P = 0.04$) and weeds in 1985 ($P = 0.004$) on the severely damaged untreated areas of the FEAP site than on the severely damaged areas of the control site. This is a further indication that rest alone is beneficial in providing more vegetative cover on severely damaged areas susceptible to erosion.

Trends and Field Observations

Examination of the data shows that the 1986 increase in cover on the FEAP site transects is due almost entirely to an increase in litter. Most of this increase in litter probably resulted from the high percentage of weed cover that occurred in 1985 and carried over to 1986 as litter. Although weed litter provides some erosion protection, grass cover and grass litter provide the best erosion protection. Levels of grass cover were low for all 3 years on the untreated areas of the FEAP site. No type of vegetative cover ever exceeded 20 percent on the severely damaged areas of the control site for any of the 3 years. Heavy training traffic on the areas prevents even the weeds from growing on these sites. No significant differences were detected when the areas of moderate-to-low damage of the FEAP site and control site were compared.

Field observations have confirmed that during the monitoring period, the large decreases in tree/shrub canopy cover on the control site (both severely and moderately damaged areas) are due to tree damage and destruction by tracked vehicles.

Rehabilitation Costs

The cost of installing the Fort Carson FEAP site rehabilitation treatment, as an essentially experimental procedure, was about $402/acre. A breakdown of this cost by materials, labor and equipment, and mobilization (based on application to the 40-acre FEAP site) is given in Table 12. Based on experience with research sites on mined land, the cost of installing experimental reclamation procedures by contractors is usually 25 to 70 percent above normal costs for similar work because of small plots (which require time-consuming maneuvering and turning with equipment and attention to boundary lines), special conditions, and often untried procedures. For example, soil ripping was a difficult but important task on the steep slopes of the FEAP site because of shallow soils, rocks, and the extreme compaction on some of the tank trails and large maneuver areas.

Table 10

Means of Cover Categories and Bare Ground for Untreated Transects and Control Transects on Areas of Severe Damage

Category	Percent Cover on Untreated Areas of FEAP Site*			Percent Cover on Control Site*		
	1984	1985	1986	1984	1985	1986
Total vegetative cover**	9.3	61.2	56.7[x]	19.1	18.3	19.6[x]
Total herbaceous plant cover	5.8	41.8	18.1	7.9	6.8	6.5
Grass cover	1.6	2.6	3.5	2.5	2.7	2.1
Forb cover	1.2	2.1	1.6	3.0	2.1	0.9
Weed cover**	3.0	37.1[y]	13.0	2.3	2.0[y]	3.6
Litter	3.5	19.4	38.7	11.2	11.5	13.1
Bare ground	5.4	5.9	6.5	14.2	18.6	9.8
Tree/shrub canopy cover	5.4	5.9	6.5	14.2	18.6	9.8

* The untreated areas of the FEAP site received no rehabilitation prescription but were excluded from training traffic; the control site included areas where no action was taken, i.e., no treatment and normal traffic, and where all the vegetation is natural.

** Values in a given row followed by the same letter (i.e., x or y) are significantly different ($P \leq 0.05$). Only the differences between means from treated and untreated transects within the same cover category and year are indicated.

Based on these considerations and on recent consultations with the contractor, estimates were generated for hypothetical cases at Fort Carson, including a larger (200-acre) management scheduling unit (MSU) in each ecotype (pinyon-juniper and shortgrass prairie) and five similar MSUs in each ecotype to which the rehabilitation treatment would be applied (Table 13). Because seed is the most expensive item in the treatment, a lower-cost option using a less diverse seed mixture recommended by the SCS was included in the estimates presented in Table 13. It should be noted that the cost per acre decreases as the size of the rehabilitated area increases. Thus, the complete treatment could be applied to 1000 acres (or five 200-acre MSUs) of disturbed pinyon-juniper training land at Fort Carson for less than ($265/acre).

Table 11

Means of Cover Categories and Bare Ground for Untreated Transects and Control Transects on Areas of Moderate-to-Low Damage

Category	Percent Cover on Untreated Areas of FEAP Site*			Percent Cover on Control Site*		
	1984	1985	1986	1984	1985	1986
Total vegetative cover	57.2	64.5	69.3	72.0	74.9	57.6
Total herbaceous plant cover	15.4	24.2	21.2	24.9	27.7	20.7
Grass cover	11.7	20.9	19.8	19.7	21.8	12.0
Forb cover	2.8	2.7	1.3	5.3	5.8	8.2
Weed cover	1.0	0.6	0.1	0.0	0.1	0.5
Litter	41.6	40.3	48.1	47.1	47.1	36.9
Bare ground	42.8	35.5	30.7	28.0	25.1	42.4
Tree/shrub canopy cover	25.7	30.6	28.8	53.3	28.0	25.3

* The untreated areas of the FEAP site received no rehabilitation prescription but were excluded from training traffic; the control site included areas where no action was taken, i.e., no treatment and normal traffic, and where all the vegetation is natural.

No procedures used at Fort Carson provide a reasonable comparison for the rehabilitation treatment in terms of cost and revegetation success. The most commonly used range restoration methods are pitting, and pitting and seeding. The costs of these procedures by local farmers/contractors are considerably lower (about $40/acre) than the costs of the rehabilitation procedure (even over extended areas), but the effectiveness of the pitting procedures on increased vegetation cover and soil stability is uncertain. A study conducted at Fort Carson in 1977 compared more than 30 pitted, and pitted and seeded areas with adjacent untreated areas. For almost every plant parameter compared (e.g., cover, density, frequency), treated areas had lower average values than untreated areas.[23] In addition, pitting methods probably should not be used in the steeply sloped pinyon-juniper areas, the areas most in need of rehabilitation.

[23] A.M.B. Rekas and W.L. Kirk, *Environmental Baseline Description for Use in the Management of Fort Carson Natural Resources, Report 3, Inventory and Assessment of Current Methods for Rangeland Conservation and Restoration*, Technical Report M-77-4/ADA053975 (U.S. Army Waterways Experiment Station, 1978).

Table 12

Contractor Operations and Materials Costs for the Rehabilitation Treatment*

Item	Cost Per Acre ($)
Materials	
Seed	182
Fertilizer	30
Labor and equipment	
Broadcast fertilizer	10
Chisel plowing	55
Drill seeding	60
Harrowing	20
Mobilization**	45
Total	402

*Based on application to 40 acres. To convert acres to hectares, multiply by 0.405; to convert cost per acre to cost per hectare, multiply by 2.47.

**Cost to the contractor of moving workers and equipment to and from the site.

Military Training Considerations

Through rehabilitation, tank trails and other severely disturbed areas in the shortgrass prairie areas of the FEAP site have already developed a considerable increase in training realism. For example, a driver approaching the revegetated east slope in area H of the site will now have to choose where to drive up the slope rather than following an existing road as before. The environmental advantage of probable soil stabilization associated with the increase in grass cover is also important. The morphology and growth characteristics of grasses make them more tolerant of tracked vehicle damage than are weedy or native forbs. Thus, the higher level of grass cover developing on the treated areas should provide a training landscape that is more stable and resistant to erosion than the untreated areas when the site is reopened to vehicle traffic.

Several trespasses by military vehicles have occurred on the site during the course of the project. Although these excursions have not caused any significant damage to revegetation communities, several transects were affected and one tank trail was severely redisturbed during 1986. Even though the no-trespassing boundary signs are highly visible, some troops have ignored them. These trespasses are of some concern because they indicate a breakdown in communication between training and management personnel and are potentially harmful to the success of this rehabilitation project.

Table 13

Estimated Rehabilitation Costs* of the FEAP Site and Other Management Scheduling Units (MSUs) and Options

Site and Seed Mixture	Operations**	Seed	Mobilization	Total
FEAP site (40 acres)				
FEAP mix***	175	182	45	402
Pinyon-juniper woodland sites				
200-acre MSU				
FEAP mix***	140	145	9	294
SCS mix 1⁺	140	50	9	199
Five 200-Acre MSUs				
FEAP mix**	130	132	1.8	264
SCS mix 1***	130	45	1.8	177
Shortgrass prairie sites				
200-acre MSU				
Reclamation mix⁺⁺	125	60	9	194
SCS mix 2⁺⁺⁺	125	25	9	159
Five 200-acre MSUs				
Reclamation mix⁺⁺	115	50	1.8	167
SCS mix 2⁺⁺⁺	115	20	1.8	137

*In 1986 dollars per acre.
**Operations include fertilization, tillage, seeding, and harrowing.
***Seed mixture used on the FEAP site (see Table 2).
⁺Seed mixture recommended by the SCS for shallow foothills range sites. Cost based on double application rate for critical areas (Soil Conservation Service 1978).
⁺⁺Cost estimate based on a reclamation seed mixture (more diverse than SCS Mix 2) and application rate for severely disturbed areas.
⁺⁺⁺Seed mixture recommended by the SCS for loamy foothills range sites.

5 SUMMARY AND CONCLUSIONS

Evaluation of the long-term success of the rehabilitation project after only three growing seasons is risky at best, considering the variability of the site, the previous training uses, and the semiarid climate of Fort Carson. The site exhibits a mosaic pattern of vegetative succession, in which revegetation is progressing at different rates in discrete areas. Revegetation progress depends on microenvironment, ecotype, and treatment category. Stable patterns will begin to emerge only after several more seasons of monitoring. These conclusions are based not only on the monitoring data but also on a special familiarity with the site, the revegetation operations, and the visual evidence of improvement (or lack of it) that is not always reflected in the data.

The most encouraging results to date have been in the shortgrass prairie areas of the site that were severely damaged at the start of the project. For these areas, the 1986 monitoring data indicate a significantly larger amount of grass cover on the treated areas than on the areas of rest only. Over the period of the demonstration, grass cover increased at a significantly greater rate on the treated areas than on the untreated areas. Based on these rates, it is estimated that the untreated areas will require a minimum of 2 to 3 additional years of rest to attain the amount of grass cover present on the treated areas in 1986. These findings are important because the grass component of total vegetative cover contributes most to increased cover quality. In the case of disturbed land rehabilitation, high cover quality corresponds to enhanced ability to provide erosion protection and soil stabilization.

The increased grass cover percentages evident in the 1986 monitoring data have been confirmed by field observations made in 1985 and 1986. In the field, several of the severely damaged shortgrass prairie areas that received the revegetation treatment were nearly indistinguishable visually (and in photographs) from the surrounding grassy areas (which had only minor damage). Adjacent untreated areas were still visually distinguishable in 1986 due to the presence of larger amounts of weedy vegetation. These increases in visual similarity should result in increased training realism on the treated areas because they now more closely resemble the adjacent low-damage areas, which essentially comprise the natural grassland community in the vicinity.

In the shortgrass prairie ecotype, significant differences between treated and untreated areas have not been detected for cover categories other than grass on the severely damaged areas or for any cover categories on the areas initially having moderate-to-low damage. However, the treated portions of the moderately damaged areas have shown a consistent trend in grass cover increase that is not matched by the untreated areas.

Field observations in some severely damaged shortgrass prairie areas also indicate that viable grass propagules (e.g., root and rhizome fragments, crowns) were probably dispersed from adjacent stands into recently chisel-plowed roads by the mechanical action of harrowing during revegetation operations. These grass propagules apparently became established and grew, possibly contributing to the higher levels of grass cover measured on transects in these areas for all monitoring sessions. Based on this observation, a test of a potential revegetation option using chisel plowing and harrowing only (no seeding) is proposed. If successful, the cost savings could be considerable because the cost of seed is a major fraction of the total revegetation cost. The major objectives of the initial tests should be to determine if adequate plant cover results from this tillage-only approach and to define the limits on the size of the damaged area that can be revegetated by this method.

These field observations and monitoring data also indicate that discrete areas of damaged shortgrass prairie having certain favorable site characteristics (relatively flat, with deep soils and good grass cover on adjacent areas) could be revegetated and returned to training use within 3 years. To achieve this, the selected sites would be treated using the treatment discussed in this report, or a modification of it (such as described above), and would be excluded from training traffic during the revegetation period (two growing seasons). Lower-than-normal precipitation during the revegetation period could extend the time necessary to attain adequate cover.

In both 1985 and 1986, the severely damaged shortgrass prairie areas of the site that did not receive the revegetation treatment (rest only) had substantial and significant increases in percent total vegetative cover and decreases in percent bare ground when compared to similar areas receiving normal training traffic (control areas). This indicates that rest alone is beneficial in terms of increased erosion protection, although the cover quality is lower than that developing on treated areas.

In the severely disturbed pinyon-juniper areas, revegetation is progressing more slowly. However, the monitoring data and field observations indicate encouraging positive trends, including consistent increases in herbaceous plant cover and grass cover on the treated areas during the monitoring period (grass cover more than doubled between 1985 and 1986, and grasses accounted for 75 percent of the total cover in 1986). In 1986, herbaceous plant cover decreased on the untreated areas (probably due to low precipitation) and consisted primarily of colonizing forbs. Additional monitoring will be required to verify these trends and to determine if they will be maintained. Field observations and measured decreases in tree/shrub canopy cover on the control site provide evidence of continuing damage to trees by military vehicles since the project was initiated.

Although the treatment was expensive when compared to current range restoration methods used at Fort Carson, considerable cost reductions can be realized if larger areas are rehabilitated. In addition, the effectiveness of the currently used pitting and seeding methods is uncertain.

Some heavily used areas of Fort Carson that are likely to be subjected to repeated training use and damage (e.g., in the California strip) should be considered for an interim reclamation approach. In this approach, soil stability, rotation period, and training realism of the land parcel are given the highest priority in the species selection criteria. Fast-growing perennials and annuals, many of which may be introduced species, are planted to attain adequate plant cover in the shortest possible time so the land parcel can be rotated back to training use. Of secondary importance on interim reclamation sites would be the quality of the plant community for wildlife habitat, forage for grazing, or similarity to preexisting vegetation. This approach would be acceptable because the parcel would probably not have a chance to attain any of these secondary uses or conditions before it was damaged again to the extent that rehabilitation would have to be repeated.

When the site is reopened to military training traffic, an important task will be to determine the fate of the new plant communities that developed on the treated and untreated areas during the no-traffic period. This effort should include (1) monitoring of vegetation, erosion, and environmental parameters, and (2) determining training intensity, vehicle type, and special conditions at the site (e.g., soil moisture). Data from such a monitoring program will be necessary to establish rotational cycles of maintenance and repair. If feasible, control of training use and intensity should be established to prevent the degradation of sites to the level exhibited by the FEAP site before the project began.

METRIC CONVERSION TABLE

1 acre	=	0.405 hectare
1 ft	=	0.305 m
1 in.	=	25.4 mm
1 mi	=	1.6 km
1 yd	=	0.914 m

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APPENDIX:

BIDDERS LIST, NOTICE TO BIDDERS, AND TECHNICAL SPECIFICATIONS FOR THE REHABILITATION PROGRAM

FORT CARSON TRAINING AREA REHABILITATION PROGRAM

BIDDERS LIST

Bill Gregory
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Swink, CO 81077
303/384-4181

Geisman Service
Hank Geisman
15813 Weld, County Route 5
Longmont, CO 80501
303/535-4963

Randall & Blake, Inc.
Stuart Cameron
4901 S. Windermere
Littleton, CO" 80120
303/795-2582

Spec International Inc.
John Miller
4742 N. Oracle Road
Suite 212
Tucson, AZ 85705
602/742-4121

Paul Reed Landscape Co.
2555 Villa Loma Drive
Colorado Springs, CO 80917
303/591-9590

Henry Schuler
Box 398 Simla, CO 80835
303/541-2396

Turf Constructors Inc.
Dennis Riley
710 Kipling, Suite 107
Lakewood, CO 80215
303/541-2396

Phillips Seeding & Reclamation
Mark Phillips
11843 Billings
Lafayette, CO 80026
303/665-2618

FORT CARSON TRAINING AREA REHABILITATION PROGRAM

REVEGETATION WORK

NOTICE TO BIDDERS

Potential contractors should submit a bid price for the entire job that includes all items and requirements described in the Technical Specifications and all activities and work necessary to provide the complete and finished revegetation project.

During the prebid site visit, bidders should take into account the approximate nature of the stated sizes and the condition (Annex 1) of the areas to be treated. Actual sizes as laid out on the site may be slightly larger or smaller than those listed due to the use of natural features and contours or existing tank trails as boundaries between treatment areas. Other values and amounts, which cannot be estimated at this time, include the total number of acres to be drill seeded as opposed to the acres broadcast seeded. These amounts depend, to a large extent, on the type of equipment available to a particular bidder and the skill of the operators in using it. These amounts (acres drilled vs broadcast) could, in turn, affect the amount of seed required.

For these reasons, bidders will be required to examine the project site carefully during the site examination day that will be conducted by Argonne before submitting a bid. The site (see Figures [A]1 and [A]2) will be available for examination on April 12 between 8:00 a.m. and noon.

All bids, in addition to the bid price for the entire job, shall contain a list of the major equipment and implements that will be used on the Fort Carson revegetation work and a list of other similar revegetation or range improvement jobs (locations, size, nature of the work, and a person to contact) that have been completed recently. Bids are to be mailed to:

and must be received by Argonne not later than April 27, 1984

4/2/84

ARGONNE NATIONAL LABORATORY

TECHNICAL SPECIFICATIONS FOR FORT CARSON TRAINING AREA REHABILITATION PROGRAM

I. GENERAL CONDITIONS

A. Scope of Work

The principal features of the work described in these specifications are the fertilization, soil tillage and seedbed preparation, seeding, and installation of boundary markers on an approximately 85 acre site extensively disturbed by tracked vehicle training activities on Fort Carson, Colorado (Figure [A]1).

These specifications have been prepared to provide adequate documentation to contract the revegetation work required to rehabilitate the site (see also Annex 1, Detailed Site Characterization). Of the entire site, a total of about 40 acres, distributed among 4 treatment areas (B, D, F, and H in Figure [A]2) will be revegetated according to these specifications while 4 remaining treatment areas (A, C, E, and G in Figure [A]2 will be untreated and used as control areas. Since specific acreages and quantities are not known at this time, the specifications have been formulated on a unit basis (acres, pounds of PLS seed, etc.). The quantities represented in Schedule C or other parts of these specifications are approximate only, being given for the basis for the comparison of bids. Rocky soils and steep slopes are to be anticipated. "Accessible areas", as used in these specifications, are those areas of 20% slope or less. All work will be done in accordance with these Technical Specifications and shall be further directed by the Project Manager or the Site Coordinator who will also provide final approval of all equipment, materials, methods, operations, and any necessary changes and/or substitutions. All contractor work is to be completed in accordance with the schedule in Section IV.

The existing vegetation on the site consists primarily of pinyonjuniper woodlands on steep to gentle slopes interspersed with, and surrounded by, open grassland areas on mostly gentle slopes. The disturbance on these areas ranges from very slight to severe. "Tank trails" and some gently sloped to flat areas between hills are compacted and denuded of vegetation while other areas show evidence of only a few passes by tracked vehicles.

The goal of the revegetation effort will be to establish a vigorous, predominantly native, self-perpetuating, grass-dominated, vegetative cover on the disturbed areas that: 1) is capable of stabilizing the surface soils against erosion by wind and water, 2) has the potential for providing palatable range forage for livestock, and 3) will eventually permit return of the area to realistic training use. These specifications for the revegetation operations have been formulated based on actual site conditions and to provide the greatest opportunity for rehabilitation success for a one-time effort at a reasonable cost.

The demonstration site treatment areas shown in Figure [A]2 are briefly described below. More detailed information on the soils and vegetation on the site is included in Annex 1.

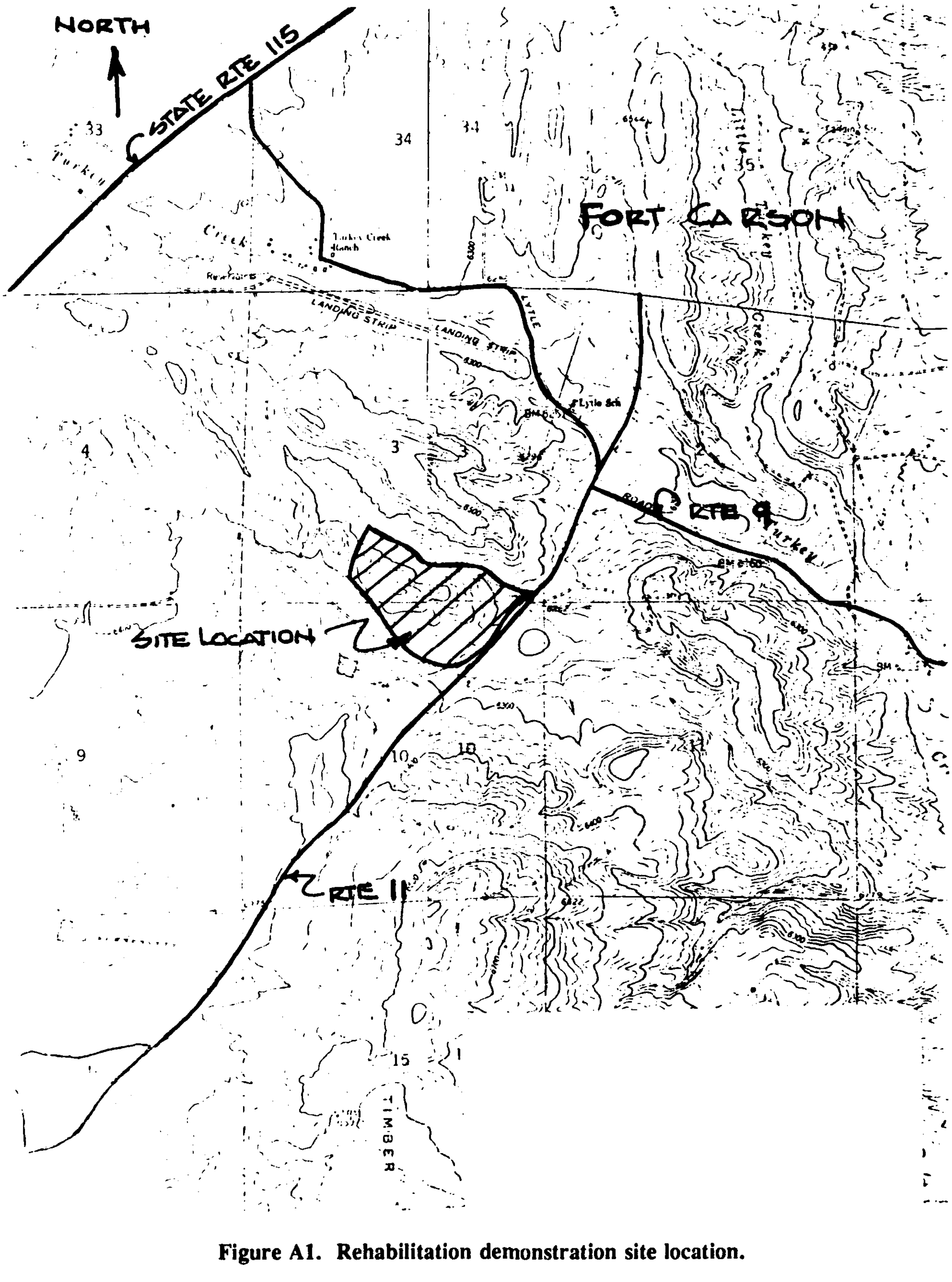


Figure A1. Rehabilitation demonstration site location.

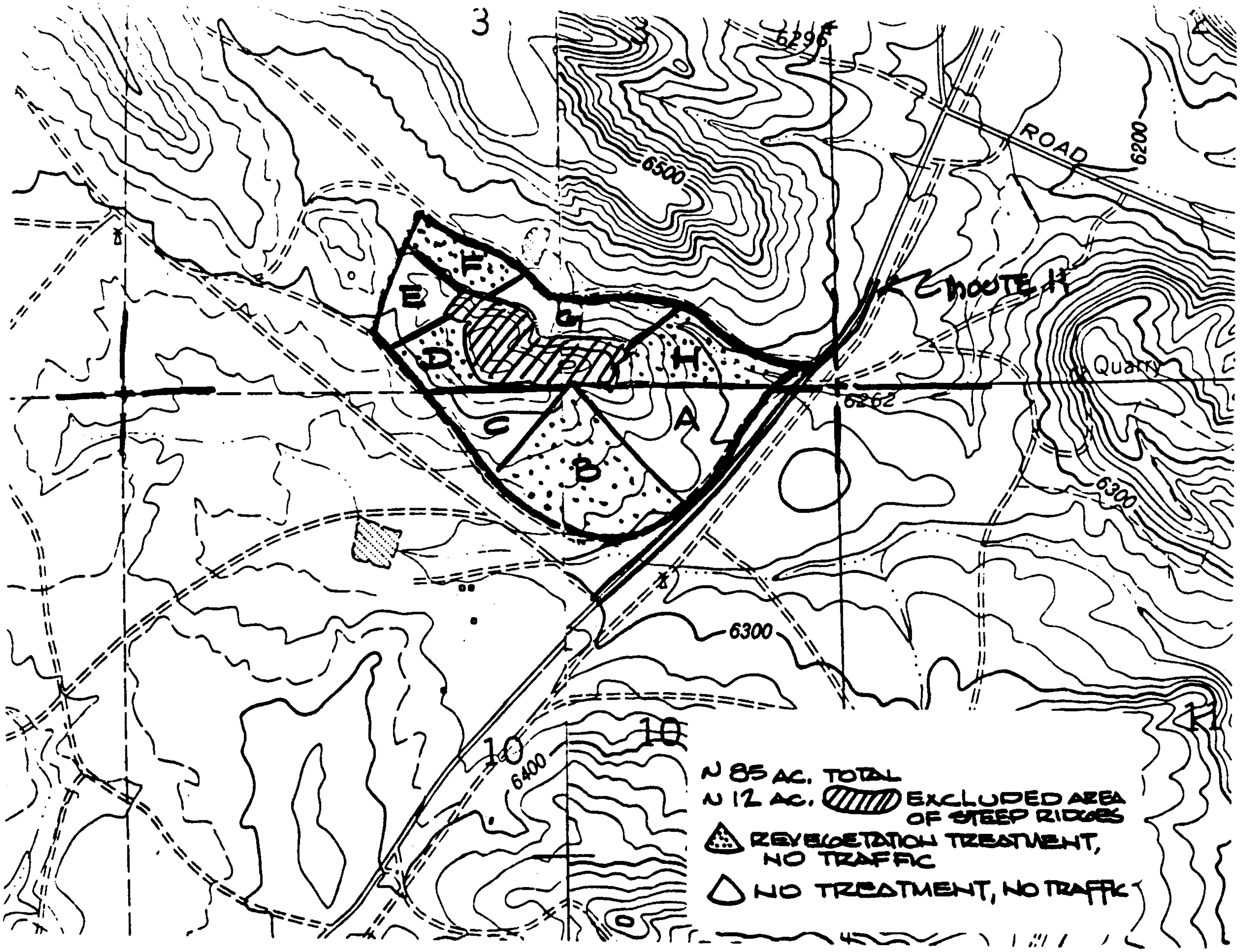


Figure A2. Site plan.

Treatment Area A - no treatment, no traffic; about 15 acres in size, E/SE aspect (90-135°). Upper part: long rocky slopes (8-30%) with shallow gravelly soils (Rizozo-Neville complex, map unit 76 on the El Paso County soil survey) over sandy limestone bedrock. Widely spaced, damaged pinyon and juniper trees with highly disturbed, practically denuded, compacted areas between. Lower part: moderately deep soils (Neville-Rednun complex, map unit 58 on the El Paso County soil survey) on gentle slopes (5-15%), mostly an open, treeless area with grass/forb vegetation that is moderately to lightly damaged by vehicle traffic.

Treatment Area B - treatment, no traffic; about 18 acres in size, SE/S aspect (135-25°). Upper part: rocky, variable slopes (5-60%) with shallow to moderately deep soils (76) supporting relatively dense stands and islands of pinyon-juniper. Soil disturbance and tree breakage moderate, with compacted tank trails. Lower part: moderately deep soils (58) on gentle slopes (5-15%). Mostly an open treeless area with grass/forb vegetation that is moderately to lightly damaged by vehicle traffic. Grassland and fingers of pinyon-juniper alternate on this area.

Treatment Area C - no treatment, no traffic, about 7.75 acres in size; S aspect (215-255°). Upper part: rocky, variable slopes (5-40%) with shallow to moderately deep soils (76) supporting islands of pinyon-juniper separated by broad, grassy to bare, disturbed swales. Soil disturbance and tree breakage moderate to severe with compacted tank trails. Lower part: moderately deep soils (58) on gentle slopes (0-15%). An open, treeless grassland area that is moderately to lightly damaged by vehicle traffic.

Treatment Area D - treatment, no traffic; about 5 acres in size; S/SW aspect (255-270°). This treatment area, both upper and lower parts, is very similar to Treatment Area C.

Treatment Area E - no treatment, no traffic; about 6 acres in size; W aspect (270-310°). Entire area with variable slopes (5-40%) with shallow to deep soils (76) supporting relatively dense stands of pinyon-juniper interspersed with broad, grassy to bare, disturbed swales. Soil and tree disturbance moderate in most areas and severe in the more flat areas as well as compacted tank trails.

Treatment Area F - treatment, no traffic; about 4.75 acres in size; NW/N aspect (310-0°). Upper part: undulating topography with variable slopes (8-40%) and moderate to deep soils (76) supporting relatively dense stands of pinyon-juniper interspersed with many compacted tank trails. Soil and tree disturbance light to moderate. Lower part: open areas of deep soils (58) on gentle slopes with grass/forb vegetation with light to moderate disturbance.

Treatment Area G - no treatment, no traffic; about 6.5 acres in size; N/NE aspect (0-40°). Upper part: variable slopes (10-50%) with shallow to moderately deep, moist soils (76) supporting closely spaced pinyon-juniper. Many very steep areas on the flanks of the excluded ridges. Soil and tree disturbance slight to moderate with compacted tank trails and highly disturbed swales. Lower part: open areas of moderately deep soils (58) on variable slopes (5-20%) with grass/forb vegetation with light to moderate disturbance.

Treatment Area H - treatment, no traffic; about 10 acres in size; NE/E aspect (40-90°). Upper part: long, rocky slopes (8-30°) with shallow, gravelly soils (76) over sandy limestone bedrock. Widely spaced, damaged pinyon and juniper trees with highly disturbed, practically denuded areas between. Very steep areas on the flanks of the excluded ridges. Lower part: moderately deep to deep soils (76 and 58) on gentle slopes (5-15%). An open, treeless area with grass/forb vegetation that is moderately to lightly damaged by vehicle traffic and which contains several deep erosion gullies.

B. Project Location

The project site (also known as Fort Carson/CERL Site #3) is located in Fort Carson Area 4C south of Turkey Creek Ranch. The exact location is shown on the maps in Figures [A]1 and [A]2. The site is on base road 11, 2/3 mile south of the junction with base road 9 (the road that goes through Turkey Creek Ranch to Colorado 115). The site is bounded by dirt roads or tank trails on all sides and is currently marked with blue flagging tape on laths placed about every 100 yards. The corner markers have blue and orange flagging tape.

C. Project Access

Access to the project site is via Colorado 115 south from Colorado Springs to the gate into Fort Carson at Turkey Creek Ranch. Clearance from the Fort Carson Range Control Officer must be obtained each day before entering the project site and must be in accordance with the rules listed in Annex 2.

D. Security

Security of all equipment, materials, supplies, and tools shall be solely the responsibility of the contractor. Loss by any theft, vandalism, pilferage, fire, flood, or waste in no way reduces the obligation of the contractor to complete all work described herein. No payment shall be made for lost or damaged materials or equipment.

E. Storage and Parking

The project manager will designate storage and parking areas. Use of other areas will not be permitted. Maintenance and housekeeping of these areas will be the responsibility of the contractor.

F. Protection of Vegetation

Contractor shall avoid unnecessary destruction of existing vegetation at the site unless authorized by the project manager for accomplishment of work.

G. Construction and Potable Water

Construction water will be available near the project site at a location to be designated by the project manager. Potable water shall be provided by the contractor.

H. Handling and Storage of Materials

All materials shall be handled and stored in such a manner as to preserve their quality and fitness for the work.

I. Cleanup

The contractor shall, at all times, maintain the project site in an orderly manner and keep the site free from accumulations of debris, waste material, or rubbish. At the completion of work, the contractor shall remove from the area all materials, tools, equipment, and rubbish, as determined by the Project Manager.

II. DESCRIPTION OF WORK

A. Fertilization

1. Description: This portion of the work shall consist of providing all mechanical equipment, trained operators, materials, and supplies to apply dry fertilizer to treatment areas B, D, F, and H immediately prior to tillage. At the contractor's option, fertilization and tillage may be a simultaneous operation.

2. Materials: The fertilizer shall be a dry, free-flowing product, uniform in composition, supplying 30 pounds of nitrogen and 30 pounds of P_2O_5 per acre at the rate applied. The fertilizer shall be delivered to the project site in the original unopened containers or by bulk delivery, each bearing the manufacturer's guaranteed analysis with affixed label, tag, or certified bill of lading.

3. Requirements: Fertilizer shall be uniformly mechanically broadcast immediately prior to tillage operations, during which it will be incorporated into the soil. Fertilizer will be applied to all accessible portions of the treatment areas including those that will be either drill or broadcast seeded.

B. Tillage/Seedbed Preparation

1. Description: This portion of the work shall consist of providing all mechanical equipment, tillage implements, trained operators, materials and supplies to till, loosen and/or scarify the soils, prepare a seedbed for drilled and broadcast seed, and incorporate previously spread fertilizer into the soils of treatment areas B, D, F, and H. This operation will also level major soil surface irregularities, such as the berms thrown up by turning tracked vehicles. Rocky soils and steep slopes are to be anticipated. All areas to be revegetated shall have a seedbed prepared by mechanical tillage (harrowing, light discing, etc.) sufficient to incorporate fertilizer, provide adequate soil-seed contact for germination, enhance plant root penetration and development, and improve water infiltration and availability within the root zone.

2. Requirements: Tillage operations shall be completed immediately prior to seeding to minimize erosion. A minimum of the upper 2 inches of the existing soil shall be loosened, scarified, and mixed during the tillage operation. The previously applied fertilizer shall be thoroughly incorporated into the soil as part of this operation. In partially vegetated areas, this operation will be accomplished with a harrow or other implement that satisfies the above requirements, but does not completely disrupt the existing vegetation. Areas denuded of vegetation that may also be compacted (tank trails, bare open or flat areas, etc.) will be lightly disced (2 inches deep) followed by dragging or harrowing to smooth the surface and produce a favorable seedbed. All surface manipulation operations will be accomplished when the soils are sufficiently dry to avoid clodding or compaction and will be conducted on the contour whenever possible to minimize erosion.

C. Seeding

1. Description: This portion of the work consists of providing all necessary mechanical equipment, seeding implements, trained operators, materials, and supplies to drill or broadcast range plant seeds and cover them adequately with soil to ensure good germination in treatment areas B, D, F, and H. As much surface as possible in each treated area will be drill seeded with the remainder (steep slopes, rocky, inaccessible areas, etc.) to be broadcast seeded (as designated by site coordinator and contractor).

2. Materials: All seed shall be furnished in bags or containers clearly labeled to show the name and address of the supplier, the seed name and variety, weight, and analysis (germination, % PLS, %

weeds, etc.). All seed amounts and rates are expressed on a pure live seed (PLS) basis. The seed mixtures, application rates, and related information is shown on Schedule C. Broadcast seeding rates will be double the rates shown for drill seeding.

3. Requirements: The seed mixture and amounts shown in Schedule C shall be drill seeded at an appropriate depth on as much area of the treatment areas as possible using a heavy-duty range drill with at least two seed boxes so that the smooth and/or small seeds in the mixture (Indian ricegrass, sweetvetch, and galleta) can be delivered separately to the seed tubes to avoid the problem of "settling out" in the mixture. Drill seeding will be carried out as close to the existing trees and shrubs as possible without causing breakage of branches or damage to roots by the equipment.

All areas inaccessible to the drill equipment as well as areas under and around the trees and shrubs, will be broadcast seeded by a vehicle-mounted or hand operated broadcast seeder at twice the drill seeding rate.

The seeding equipment must be able to accommodate the various kinds of seeds in the mixture, plant them at the desired rates and depths, and cover them sufficiently with soil. If a chain drag or other implement to cover the seed is not incorporated in the seeding equipment, covering the seed by dragging or light harrowing (or equivalent) will be carried out as a separate operation.

D. Installation of Boundary Markers

1. Description: This portion of the work shall consist of providing all mechanical equipment, trained operators, materials, and supplies required to install highly visible boundary markers (Figure [A]3) around the perimeter of the site. The markers are designed to exclude tracked vehicle and other training traffic from all of the treatment areas (A-H). Each boundary marker will consist of 2 steel fenceposts with a fluorescent orange traffic cone around each base of the post and the "no trespassing" sign mounted at the top.

2. Materials: The sign posts shall be standard steel 6'-6" fenceposts. The signs, as shown in Figure [A]3, and 18" high PVC fluorescent orange cones will be provided by Argonne National Laboratory, to be installed by the contractor.

3. Requirements: The boundary markers will be installed every 75 yards around the perimeter of the site, requiring about 45 markers or 90 posts. The operation will consist of firmly driving the steel fenceposts and securely attaching the traffic cone to the base and the "no trespassing" sign to the top as shown in Figure [A]3.

III. Applicable Documents

Figure [A]1 - General Project Site Map
Figure [A]2 - Detailed Project Site Map
Figure [A]3 - Boundary Marker Diagram
Annex 1 - Detailed Site Characterization (#3)
Annex 2 - Rules for access to CERL/ANL demonstration site.
Schedule C - Seed Mixture/Species Characteristics

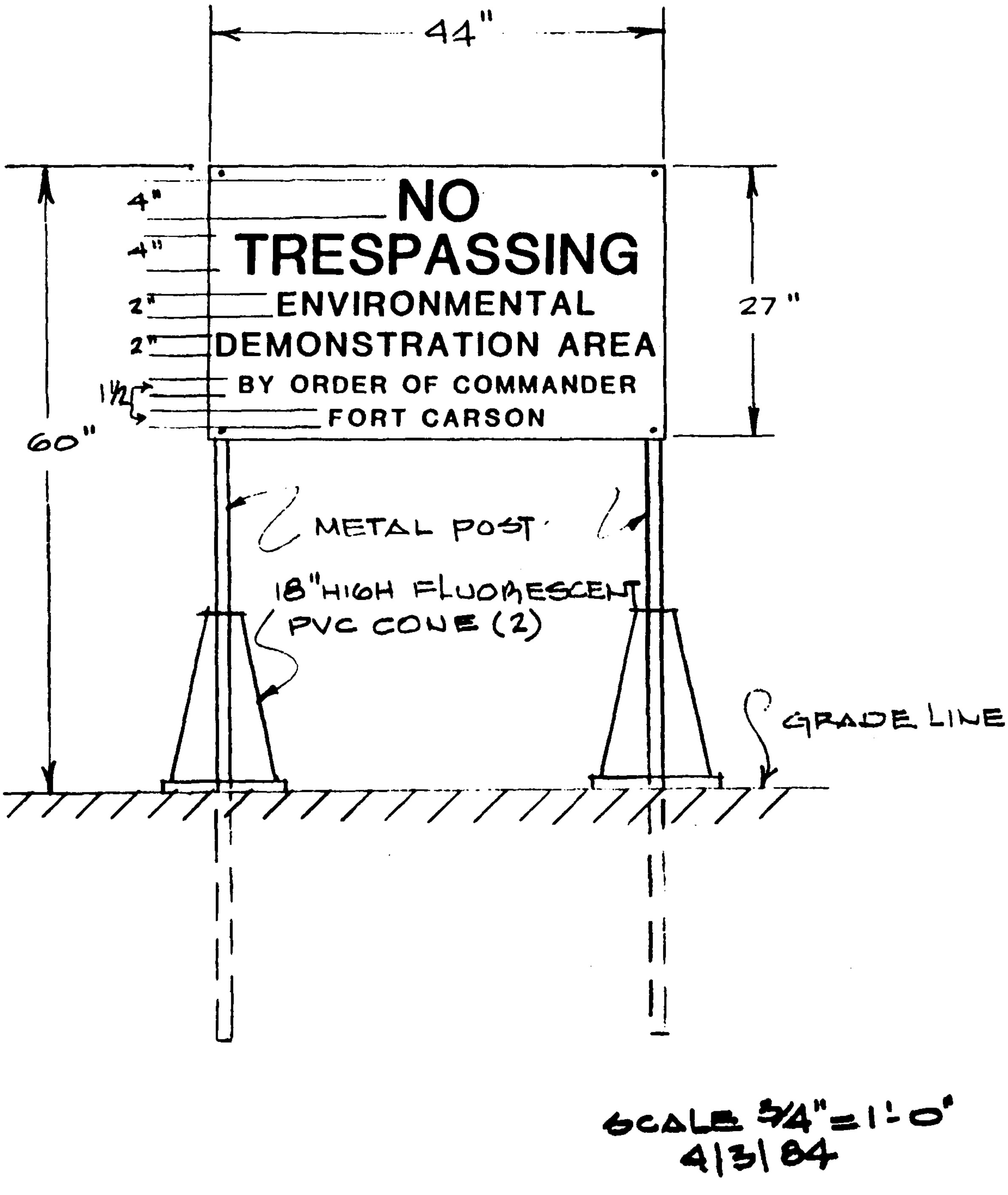
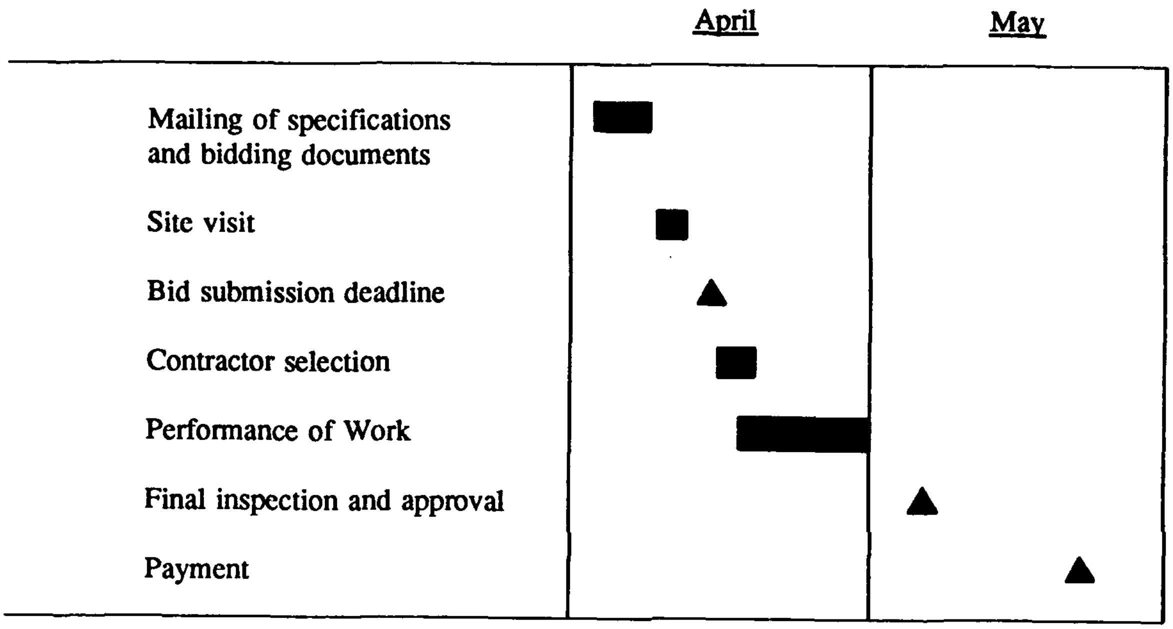


Figure A3. Boundary marker.

IV. Schedule

Schedule for Fort Carson Training Area Rehabilitation Program

Revegetation Work



V. Payment

Application for payment of the bid price accepted for the entire job shall be made upon completion of all work and shall be subject to the approval of the project manager or the site coordinator.

ANNEX 1

FORT CARSON TRAINING AREA REHABILITATION PROGRAM DETAILED SITE CHARACTERIZATION (SITE #3)

The primary Fort Carson rehabilitation demonstration site is located in Area 4C south of Turkey Creek ranch within T17S, R67W of El Paso County. The site is on the west side of base road 11, 2/3 mile south of the junction with base road 9 (the road that goes through Turkey Creek ranch to Colorado 115). The demonstration site represents areas of various degrees of military training use and ecosystem degradation, vegetation types (pinyon-juniper and grassland), and other factors (soil types and depths, erosion potentials, slopes, aspects, etc.) that are typical of large areas of the Fort Carson reservation.

The site encompasses about 85 acres within its boundaries, but a series of steep ridges running generally east-west produces slopes in the center of the site that are inaccessible to both tracked and wheeled vehicles. Therefore, this area comprising about 12 acres has been "excluded" from the site (crosshatched area, Figure [A]2). The remainder of the site has been divided into treatment areas (stippled areas, treated; clear areas, no treatment) representing major aspects and vegetation types.

Two soil types are represented on the site, the Neville-Rednun complex and the Rizozo-Neville complex. The Neville soil in both complexes is deep and well drained. It formed in calcareous loamy alluvium derived from red-bed sandstone and shale. Typically, the surface layer is reddish gray fine sandy loam about 4 inches thick. The substratum is reddish brown heavy fine sandy loam about 6 inches thick over light reddish brown loam that may extend to a depth of 60 inches or more.

Permeability of the Neville soil is moderate. Effective rooting depth is 60 inches or more. Available water capacity is high. Surface runoff is medium, and the hazards of erosion and soil blowing are moderate. Some gullies have formed along drainageways and trails. The main limitations of the Neville soil for urban use are its limited ability to support a load, moderate shrink-swell potential, and frost action potential.

The Neville-Rednun complex corresponds to map unit 58 on the El Paso county soil survey and occurs on 3 to 9 percent slopes. These gently to moderately sloping soils are on uplands. Elevation ranges from 5900 to 6500 feet. The average annual precipitation is about 14 inches, the average annual air temperature is about 47 degrees F, and the average frost-free period is about 140 days.

The Neville soil makes up about 60 percent of this complex, the Rednun soil about 30 percent, and included areas about 10 percent.

Included with these soils are areas of Satanta loam, 3 to 5 percent slopes, and a few outcrops of red sandstone. The Rednun soil is on the less sloping parts of the landscape. The Rednun soil is deep and well drained. It formed in calcareous alluvial fan sediment derived from red-bed sandstone and shale. Typically, the surface layer is brown loam about 6 inches thick. The subsoil, about 35 inches thick, is reddish brown heavy clay loam in the upper part and sandy clay loam in the lower part. The substratum is reddish brown sandy clay loam to a depth of 60 inches or more.

Permeability of the Rednun soil is slow. Effective rooting depth is 60 inches or more. Available water capacity is high. Surface runoff is medium, and the hazard of erosion is slight to moderate. These soils are used as rangeland, for wildlife habitat, and for military maneuvers.

The native vegetation on the complex is mainly western wheatgrass, needlegrasses, big bluestem, side-oats grama, blue grama, and native bluegrasses. If the range has deteriorated, blue grama, junegrass, and native bluegrasses increase. Sleepygrass and annuals replace these grasses if the range has seriously deteriorated.

The main limitations of the Rednun soil are slow permeability, shrinkswell potential, and frost action potential. Special designs for buildings and roads are needed to overcome these limitations.

The Rizozo-Neville complex corresponds to map unit 76 on the El Paso county soil survey and occurs on 3 to 30 percent slopes. These gently sloping to moderately steep soils are on uplands, terraces, and fans. Elevation ranges from 6000 to 6500 feet. The average annual precipitation is about 14 inches, the average annual air temperature is about 47 degrees F, and the average frost-free period is about 140 days.

The Rizozo soil makes up about 35 percent of the complex, the Neville soil about 25 percent, and other soils about 40 percent.

Included with these soils are areas of Fortwingate-Rock outcrop complex, 15 to 60 percent slopes, Nederland cobbly sandyloam, 9 to 25 percent slopes; Neville-Rednun complex, 3 to 9 percent slopes; and Rock outcrop.

The Rizozo soil is shallow and well drained. It formed in medium textured residuum weathered from red sandstone. Typically, the surface layer is reddish brown loam about 3 inches thick. The underlying material is reddish brown loam about 7 inches thick. Hard, red, fractured sandstone is at a depth of about 10 inches.

Permeability of the Rizozo soil is moderatel_ apid. Effective rooting depth is 4 to 20 inches. Available water capacity is low. Surface runoff is medium to rapid, and the hazard of erosion is moderate to high. Soil slippage is common on the steeper slopes. The soils in this complex are used as rangeland and for wildlife habitat, recreation, and military maneuvers.

Native vegetation on the Rizozo soil consists of an overstory of pinyon and juniper and an understory of blue grama, side-oats grama, western wheatgrass, Scribner needlegrass, and needle-and-thread. The dominant shrubs are mountain mahogany and skunkbrush sumac.

The native vegetation on the Neville soil is mainly cool- and warmseason grasses such as western wheatgrass, side-oats grama, and needle-and-thread. Smaller amounts of other grasses, such as little bluestem, junegrass, mountain muhly, and blue grama, are scattered throughout the stand. The main limitations of the Rizozo soil for construction are shallow depth to bedrock, a stony surface, and steep slopes.

The site also encompasses two range sites, Loamy Foothills and Shallow Foothills that correspond, for the most part, to the Neville-Rednun soil complex and the Rizozo-Neville complex, respectively.

ANNEX 2:

RULES FOR ACCESS TO CERL/ANL DEMONSTRATION SITE AT FORT CARSON, COLORADO

1. A list of ANL personnel and ANL contractors that require access to Fort Carson environmental demonstration sites will be furnished to Bill Severinghaus, Tom Warren, and Charles Markle.

2. Each day before proceeding to the site, all ANL personnel and ANL contractors will report to the range officer's office for clearance.

3. All personnel will refrain from handling exploded or unexploded ammunition or other potentially hazardous training devices. Unexploded devices should be reported to the range officer who will arrange for disposal.

4. Activities at Fort Carson should be limited to those necessary to the completion of the demonstration program. Areas of access and travel are limited to site #3 and Vic Diersing's site, including the road through Turkey Creek Ranch and Route 11 south to the sites.

SCHEDULE C

Seeder Box*	Pure Live Seed lb/a (drill)	Percent in mix	Species Com. & Scien. Name Cultivar/Variety	Seeds per lb	Seeds sq ft at 1 lb/a	Season of growth**	Orgin***	Growth form † ave. size	Precip. Range	Comp. Suit. Index	Drought toler.	Approx. cost/lb (PLS)	Comments
P	3	20	Western wheatgrass <u>Agropyron smithii</u> var. Arriba	115,000	2.6	C P	N	S 1-3 ft	10+	50	1	$4.70	Erosion control, critical area stabilization drought tolerant
P	1	10	Streambank wheatgrass <u>Agropyron riparium</u> var. Sodar	160,000	3.7	C P	N	S 1-3 ft	8-19	48	1	4.50	Stabilization of steep, erodable areas
P	.9	10	Crested wheatgrass <u>Agropyron christatum</u> var. Fairway	200,000	4.6	C P	I	B 1-3 ft	8-19	54	1	1.60	Sod-forming habit for stabilization good for p/j and brushland
P	.5	20	Blue gamma <u>Bouteloua gracilis</u> var. Hachita	725,000	16.7	W P	N	S 6-24 in	8+		1	4.25	Drought tolerant, renews growth quickly self-seeding
P	.9	10	Sideoats grama <u>Bouteloua curtipendula</u> var. Vaughn or Niner	191,000	4.4	W P	N	B 1-3 ft	8+		1-2	5.70	Semi-shade tolerant for growth under p/j. Drought tolerant erosion control
S	1	10	Indian ricegrass <u>Oryzopsis hymenoides</u> var. Palmoa	160,000	3.7	C P	N	B 1-25 ft	6+	45	1	10.40	Adapted to shallow, sandy soils. Drought tolerant
S	3	10	Mammoth wildrye <u>Elymus giganteus</u>	55,000	1.3	C P	I	S 1-3 ft	8-18	45	1	?(10.00)	Adapted to sandy soils
P	.75	-	Curlleaf mountain mahogany <u>Cercocarpus ledifolius</u>	51,865	1.2	Ever-green P	N	Shrub 3-20 ft	8+	33	1	?(32.00)	Root-sprouter, adapted to shallow, rocky soils, drought-tolerant, soil stabilization
S	1	-	Northern sweetvetch <u>Nedysarum boreale</u>	60,000	1.4	C P	N	Forb 1-2 ft	10+	46		30.00	Requires inoculation, drought tolerant
S	1	10	Galleta <u>Hilaria jamesii</u> var. Viva	170,000	4.0	W P	N	S 1-2 ft	9-20		1	26.00	Drought tolerant, adapted to rocky shallow soils and p/j cover
	13.1 Total--approx. 40 seeds/sq ft												

* P = primary mixture, S = seed in separate seeder box
** C = cool, W = warm, P = perennial.
*** N = native, I = introduced.
† S = sod, B = bunch.

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Depot System Command 17201
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TSARCOM 63120
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Army Depots
Seneca 14541
ATTN: SDSSE-ADE
New Cumberland 17070
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Letterkenny 17201
ATTN: Fac Engr/Envr Ofc
Tobyhanna 18466
ATTN: SDSTO-AF-E
Scranton 18505
ATTN: Fac Engr/Envr Ofc
Anniston 36201
ATTN: SDSAN-DAS-FE
Memphis 38114
ATTN: DDMT-WI
Lexington-Blue Grass 40111
ATTN: SDSLB-ASF-C
Red River 75501
ATTN: SDSRR-S
Pueblo Army Depot 81001
ATTN: Fac Engr/Envr Ofc
Tooele 84074
ATTN: SDSTE-FW
ATTN: SDSPU-A
ATTN: SDSTE-UM
ATTN: SDSTE-ASF-E
Ogden 84402
ATTN: Fac Engr/Envr Ofc
Navajo 86015
ATTN: AZXA-AS-F
Sharpe 95331
ATTN: SDSSH-AFE-E
ATTN: SDSSH-ASF
Sierra 96113
ATTN: SDSSI-FE

Arsenals
Pine Bluff 71602
ATTN: SARPB-ETD
Picatinny 07801
ATTN: SMCAR-ISE-N

Aberdeen Proving Ground, MD 21010
ATTN: STEAP-FE-M
ATTN: STEAP-FE-E
ATTN: NGB-ARI-E
ATTN: DRDAR-CLT-E

Dugway Proving Ground 84022
ATTN: STEDP-PO
ATTN: STEDP-MT-L-E (2)

Electronic Proving Ground 85613
ATTN: LD (FAC MAO)

Jefferson Proving Ground 47250
ATTN: STEJP-DEH

Yuma Proving Ground 85365
ATTN: STEYP-PL
ATTN: STEYP-FE-P

Army Ammunition Plants
Holston 37660
ATTN: SMCHO-EN
Milan 38358
ATTN: SARMI-EN
Mississippi 39529
Indiana 47111
ATTN: SMCIN-EN
Crane 47522
ATTN: Fac Engr/Envr Ofc
Iowa 52638
ATTN: SMCIO-EN
Kansas City 67357
ATTN: SMCK-CE
McAlester 74501
ATTN: Fac Engr/Envr Ofc
Riverbank 95367
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Medical Bioengr Res & Dev Lab 21701
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Director, USAWES 39180
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ATTN: DRSTA-Q
ATTN: DRSTA-SP

Armament R&D Command 07801
ATTN: DRDAR-LCM-S

Belvoir R&D Command 22060
ATTN: STRBE-U
ATTN: ATZA-DEH-EN

Electronics R&D Command 20783
ATTN: DELHD-FA

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WASH DC 20332

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Transportation Research Board (3) 20418

Institute for Water Resources 22060

Defense Personnel Support Ctr 19145

Defense General Supply Ctr 23297

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