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NEW TECHNOLOGIES TO RECLAIM ARID LANDS USER'S MANUAL

OCTOBER 2002

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New Technologies to Reclaim Arid Lands Users Manual

October 1, 2002

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS v

LIST OF ACRONYMS xv

ABSTRACT xvii

1.0 INTRODUCTION 1

- 1.1 Background 1
- 1.2 Goals and Objectives 1
- 1.3 SERDP Users Manuals 2
- 1.4 Relationship to Other Users Manuals and Technologies 2
- 1.5 Conceptual Model for Disturbance of Arid Land 3
- 1.6 Sustainable Ranges 4
- 1.7 Applicability 6

2.0 RECLAMATION PLANNING 9

- 2.1 Reclamation Plan and Technique Selection Table 9
- 2.2 Objectives 9
- 2.3 Constraints and Limitations 10
- 2.4 Subcontracting 11
- 2.5 Scheduling Considerations 11
- 2.6 Field Site Assessment 12
- 2.7 Site Preparation 12
- 2.8 Species Selection 12
- 2.9 Technique Selection 14
- 2.10 Monitoring 15
- 2.11 Remediation 15

3.0 RECLAMATION TECHNIQUES 17

- 3.1 Erosion Control 17
  - 3.1.1 Objectives 17
  - 3.1.2 Principles 18

TABLE OF CONTENTS (cont)

3.1.3 Techniques 23
3.1.3.1 Physical Techniques 24
3.1.3.2 Chemical Techniques 28
3.1.3.3 Cultural Techniques 33
3.1.3.4 Biological Techniques 33
3.1.4 Special Considerations 33

3.2 Site Preparation 34
3.2.1 Objectives 34
3.2.2 Principles 34
3.2.3 Techniques 36
3.2.4 Special Considerations 39

3.3 Soil Amendments 42
3.3.1 Objectives 42
3.3.2 Principles 42
3.3.3 Techniques 44
3.3.3.1 Synthetic Polymer Soil Conditioners 44
3.3.3.2 Organic Materials 46
3.3.3.3 Fertilization 47
3.3.4 Special Considerations 50

3.4 Seeding 51
3.4.1 Objectives 51
3.4.2 Principles 51
3.4.3 Techniques 52
3.4.3.1 Species Selection 52
3.4.3.2 Seeding Method 56
3.4.3.3 Seed Acquisition 57
3.4.3.4 Custom Seed Collection 60
3.4.3.5 Handling Seed 61
3.4.3.6 Timing of Seeding 61
3.4.3.7 Seed Pretreatment 62
3.4.3.8 Seeding Calibration 62
3.4.3.9 Minimize Predation 65
3.4.4 Special Considerations 65

3.5 Planting 65
3.5.1 Objectives 66
3.5.2 Principles 66

TABLE OF CONTENTS (cont)

3.5.3 Techniques 67
3.5.3.1 Species Selection 68
3.5.3.2 Holding Facility 69
3.5.3.3 Timing of Planting 69
3.5.3.4 Implementation 69
3.5.3.5 Plant Protection 71
3.5.4 Special Considerations 72

3.6 Grazing and Weed Control 73
3.6.1 Objectives 73
3.6.2 Principles 73
3.6.3 Techniques 75
3.6.3.1 Grazing Control 75
3.6.3.2 Weed Control 77
3.6.4 Special Considerations 78

3.7 Mulching 79
3.7.1 Objectives 79
3.7.2 Principles 79
3.7.3 Techniques 81
3.7.3.1 Criteria for Mulch Selection 81
3.7.3.2 Mulch Application 82
3.7.4 Special Considerations 84

3.8 Irrigation 86
3.8.1 Objectives 86
3.8.2 Principles 86
3.8.3 Techniques 87
3.8.3.1 System Design 87
3.8.3.2 Amount of Irrigation 90
3.8.3.3 Timing of Irrigation 90
3.8.4 Special Considerations 91

3.9 Site Protection 91
3.9.1 Objectives 92
3.9.2 Principles 93
3.9.2.1 Understanding Special Regulations 93
3.9.2.2 Understanding the Site Mission and Training Activities 93
3.9.2.3 Educating and Training Site Personnel 93
3.9.2.4 Understanding Physical and Cultural Tools 94
3.9.2.5 Monitoring and Providing Adaptive Management 94

TABLE OF CONTENTS (cont)

3.9.3 Techniques 95
3.9.3.1 Working with Range Control 95
3.9.3.2 Providing the Location of Protected Areas on Maps 95
3.9.3.3 Posting Signs at the Site Perimeter 95
3.9.3.4 Controlling Access Using Berms and Barriers 96
3.9.4 Special Considerations 96

4.0 MONITORING AND REMEDIATION 99

4.1 Monitoring 99
4.1.1 Purposes of Monitoring 99
4.1.2 Key Elements of a Monitoring Plan 99
4.1.3 Techniques 99
4.1.3.1 Qualitative Monitoring 100
4.1.3.2 Quantitative Monitoring 100
4.1.4 Frequency of Monitoring 102
4.1.5 Success Criteria 103
4.1.6 Reference Areas 103
4.1.7 Summarize and Report Monitoring Results 104

4.2 Remediation 104

5.0 COSTS 107

5.1 Erosion Control 107
5.2 Site Preparation 108
5.3 Soil Amendments 110
5.4 Seeding 111
5.5 Planting 113
5.6 Grazing and Weed Control 114
5.7 Mulching 114
5.8 Irrigation 115
5.9 Site Protection 116
5.10 Cost Effectiveness 116

6.0 DECISION TOOLS FOR SELECTION OF RECLAMATION TECHNIQUES 119

6.1 Objectives 119
6.2 Principles 119
6.3 Flow Diagram 120

TABLE OF CONTENTS (cont)

6.4 Table of Techniques to be Considered 120
6.4.1 Priority 121
6.4.2 Slope Steepness 122
6.4.3 Techniques to be Considered 124

6.5 Limitations and Special Considerations 124

7.0 RECOMMENDATIONS 125

7.1 Reclamation Planning 125
7.2 Erosion Control 125
7.3 Site Preparation 126
7.4 Soil Amendments 126
7.5 Seeding 126
7.6 Planting 127
7.7 Grazing and Weed Control 128
7.8 Mulching 128
7.9 Irrigation 128
7.10 Site Protection 129
7.11 Monitoring and Remediation 129
7.12 Costs 130

8.0 Literature Cited 131

9.0 APPENDICES 147

9.1 Sample Seed Mix Matrix. Seeding Rate is 20 PLS lbs/acre
9.2 Pre-Treating Seed to Enhance Germination of Desert Shrubs
9.3 Regional Cost Estimates for Reclamation Practices on Arid and Semiarid Lands
9.4 Post-Closure Monitoring Checklist
9.5 Internet Web Sites for Habitat Restoration

DISTRIBUTION LIST

LIST OF FIGURES

Figure 1-1. A conceptual model of thresholds in a Mojave Desert ecosystem. 4

Figure 1-2. Costs, risks, and time required for recovery following disruption increase more rapidly in dry environments than in moist environments. 5

Figure 1-3. Projected recovery for disturbed vegetation may require hundreds of years to achieve predisturbance levels of vegetation cover in arid lands. 5

Figure 1-4. Map of the Mojave, Sonoran, and Great Basin Deserts in the southwestern United States. 7

Figure 3-1. Wind erosion on denuded areas in the Mojave Desert. 18

Figure 3-2. Wind erosion strips soil resources from the surface and deposits them around vegetation, burying small plants at the National Training Center in Fort Irwin, California. 19

Figure 3-3. Water erosion in the Mojave Desert resulting from severe thunderstorms. 21

Figure 3-4. Dozer basin used to catch runoff from roadway and upslope in Fort Irwin, California. 26

Figure 3-5. Example of gravel armoring (1.5 cm in diameter) used to control erosion. 27

Figure 3-6. Applying chemical soil stabilizer with a hydromulcher. 29

Figure 3-7. Seedlings on newly revegetated area 35

Figure 3-8. Road grader ripping a site during site preparation. 37

Figure 3-9. Chisel-tooth plow followed by a drag harrow used to reduce compaction and roughen the upper 10-15 cm (4-6 in) of the soil. 38

Figure 3-10. Offset disk being pulled by tractor to break up clods. 38

Figure 3-11. Unexploded ordnance may create unseen hazards that should be removed before earth-disturbing activities. 40

Figure 3-12. Water-insoluble polymer after absorbing water and expanding. 45

Figure 3-13. Fertilized (dark green plots in the background) versus unfertilized (light green) plots. 48

Figure 3-14. Fertilization of shrubs may promote greater seed set of fertilized shrubs (bottom) compared to unfertilized shrubs (top). 49

Figure 3-15. Fluffy seeds (A -left) and heavy seeds (B –right) have different properties that require their separation into different mixtures while seeding. 63

Figure 3-16. Drill seeder dispersing seed on the ground with chains dragging on the soil surface to cover the seed 64

Figure 3-17. Transplants provide a head start for plants and many will flower and provide seed within the first or second year 66

LIST OF FIGURES (cont)

Figure 3-18. Example of a typical schedule for obtaining site-adapted plants and monitoring their survival....67

Figure 3-19. Digging holes with a power auger (left) allows the operator to provide sufficient holes and keep ahead of the planting crew (right)....70

Figure 3-20. Transplant is carefully lowered into the hole (left) to minimize root disturbance....71

Figure 3-21. Plants are watered soon after planting to settle the soil around the plant and to ensure that roots are not damaged by the adjacent dry soil....71

Figure 3-22. Construction of fenced plots at Fort Irwin, California, which resulted in greater plant density and cover than in unfenced plots....74

Figure 3-23. Fenceline contrast illustrating the effect of controlling herbivory by rabbits in central Nevada after one year....75

Figure 3-24. Transplant protector tubes at Fort Irwin, California....76

Figure 3-25. Conversion of sagebrush into annual grasslands dominated by red brome following fires on the Nevada Test Site....78

Figure 3-26. Blowing sand captured by a crimped straw mulch and gravel mulch....80

Figure 3-27. Applying straw with a blower requires three people....83

Figure 3-28. The crimper presses straw into the soil orienting the stems vertically....83

Figure 3-29. Applying tackifier with a hydroseeder....84

Figure 3-30. Equipment to apply plastic mulch developed for agricultural use could be adapted for use in arid land revegetation....85

Figure 3-31. Setting up irrigation system hardware....88

Figure 3-32. Portable irrigation system designed to provide supplemental water for plant establishment....89

Figure 3-33. Example of wobbler heads attached to flexible, portable polypipe....92

Figure 3-34. Siebert signs with night vision reflective tape....96

Figure 3-35. Berms combined with transplants to direct traffic down established roads at Fort Irwin, California....97

Figure 4-1. Double Tracks clean-up site (Nellis Air Force Range, Nevada) before (A) and after (B) seeding....101

Figure 5-1. Soil crust developed from chemical soil stabilizer that was applied to severely disturbed and highly erodible soils at Fort Irwin, California....109

LIST OF FIGURES (cont)

Figure 6-1. Flow diagram of decision making for erosion control and revegetation techniques. 121

Figure 6-2. Site recovery in 1993 at the National Training Center from a heavily disturbed area (1990) after three years of good precipitation. 122

LIST OF TABLES

Table 2.1. Example of a field visit planning sheet. 13

Table 3-1. Soil material suitability for salvage and reclamation use. 43

Table 3-2. Suggested list of species adapted to arid environments of Southwestern U.S. 56

Table 3-3. Sample seed mix matrix. Seeding rate goal is 22.5 PLS kg/hectare. 55

Table 3-4. Comparison of seeding techniques. 56

Table 4-1. Example of a soil-erosion rating and classification form for assessing erosion status in the field. 102

Table 5-1. Regional average cost for supplemental erosion control practices. 108

Table 5-2. Regional average cost ($/hectare) for site preparation activities. 109

Table 5-3. Regional average cost ($/hectare) for broadcast fertilization. 111

Table 5-4. Regional average cost ($/hectare) for seeding practices. 112

Table 5-5. Regional average cost ($/plant) for live plants. 113

Table 5-6. Regional average cost ($/hectare) for mulching with straw or hay. 115

Table 6-1. Table of techniques showing recommended considerations by priority and slope steepness. 123

LIST OF ACRONYMS

ATTACC	Army Training and Testing Area Carrying Capacity
BLM	Bureau of Land Management
BN	Bechtel Nevada
C:N	carbon to nitrogen
$CaCl_2$	calcium chloride
cm	centimeter
CRWMS	Civilian Radioactive Waste Management System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
EG&G/EM	EG&G/Energy Measurements
ERT	Environmental Research Technology, Inc.
ft	foot
GIS	Geographic Information System
h	horizontal
IECA	International Erosion Control Association
in	inch
ITAM	Integrated Training Area Management
kg	kilogram
kg/ha	kilogram per hectare
km^2	square kilometer
lb	pound
lb/acre	pound per acre
LCTA	Land Condition Trend Analysis
µm	micrometer
m	meter
m^2	square meter
mi	mile
M&O	Management and Operating
$MgCl_2$	magnesium chloride
mm	millimeter
mph	mile per hour

LIST OF ACRONYMS (cont)

NPI	Native Plants, Inc.
NRCS	National Resources Conservation Service
NTC	National Training Center
NTS	Nevada Test Site
PLS	pure live seed
RUSLE	Revised Universal Soil Loss Equation
SERDP	Strategic Environmental Research and Development Program
TMSES	Terrain Modeling and Soil Erosion Simulation
TZ	tetrazolium
USACERL	U.S. Army Construction Engineers Research Laboratory
USDA	U.S. Department of Agriculture
USDI	U.S. Department of Interior
UXO	Unexploded ordnance
v	veritcal
WEPS	Wind Erosion Prediction System
WEQ	Wind Erosion Equation

ABSTRACT

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

New reclamation and restoration techniques are needed in desert ranges to help mitigate the adverse effects of military training and other activities to arid-land environments. In 1999, a cooperative effort between the U.S. Department of Energy (DOE), the U.S. Department of Defense (DoD), and selected university scientists was undertaken to focus on mitigating military impacts in arid lands.

As arid lands are impacted due to DoD and DOE activities, biological and soil resources are gradually lost and the habitat is altered. A conceptual model of that change in habitat quality is described for varying levels of disturbance in the Mojave Desert. As the habitat quality degrades and more biological and physical resources are lost from training areas, greater costs are required to return the land to sustainable levels. The purpose of this manual is to assist land managers in recognizing thresholds associated with habitat degradation and provide reclamation planning and techniques that can reduce the costs of mitigation for these impacted lands to ensure sustainable use of these lands.

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

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

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

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

This users manual focuses on the development of new reclamation techniques that have been implemented at the National Training Center at Fort Irwin, California, and are applicable to most arid land reclamation efforts. New diagnostic techniques for rapidly assessing changes in vegetation are described in a separate companion report: *Vegetation Change Analysis, Users Manual* (Hansen and Ostler, 2002).

1.0 INTRODUCTION

1.1 BACKGROUND

Approximately 70 percent of all U.S. military training lands are located in arid and semi-arid areas. Training activities may adversely affect vegetation, damaging plants and reducing the resilience of vegetation to recover once disturbed. The cumulative impacts may result in loss of the seed pool and soil resources such as organic matter and soil microorganisms needed to recycle soil nutrients. Fugitive dust resulting from a loss of vegetation creates additional problems for human health, increases accidents due to decreased visibility, and increases maintenance costs for roads, vehicles, and equipment.

Under conventional technologies to mitigate these impacts, it is estimated that up to 35 percent of revegetation projects in arid areas will fail due to unpredictable natural environmental conditions and because of reclamation techniques that were inadequate to restore vegetative cover in a timely and cost-effective manner. In 1999, a cooperative effort between the U.S. Department of Energy (DOE), the U.S. Department of Defense (DoD), and selected university scientists was undertaken to focus on mitigating military impacts in arid lands.

Bechtel Nevada assembled a team of scientists to address these problems in arid lands. The research team included researchers and advisors from government, universities, and private industry. Collaborators include DOE National Nuclear Security Administration Nevada Operations Office, Bechtel Nevada (BN), DoD – Fort Irwin, Center for Ecological Management of Military Lands at Colorado State University, U.S. Army Construction Engineers Research Laboratory, California State University – Dominguez Hills, and Weber State University – Applied Ecological Services, Inc. Fort Irwin, the U.S. Army's National Training Center (NTC) located near Barstow, California, in the Mojave Desert, was selected as the primary test site for development of new technologies. The approach focuses on specific problems of the NTC, but is suitable for other DoD and DOE facilities in arid and semiarid areas.

In the fall of 1999, a workshop was conducted in Las Vegas, Nevada, to review the program's goals and objectives. Key features of the program's proposed research were presented and invited scientists knowledgeable in remote sensing and revegetation provided feedback to shape the technologies as provided here

1.2 GOALS AND OBJECTIVES

This manual is designed to assist users in understanding basic principles of land reclamation and selecting new and cost-effective techniques for rehabilitation and restoration of disturbed habitats at their facilities. The reclamation and diagnostic tools presented will enable management to maximize utilization of limited training environs and thus increase operational readiness. It will help reduce the amount of downtime and off-limit areas imposed by rehabilitation/mitigation activities by identifying critical stages of habitat degradation and focusing resources to extend resiliency of training areas for longer periods of time. It will also

be useful in developing and evaluating the cost effectiveness of new rehabilitation and restoration techniques for short-term and long-term range sustainability.

Innovative technologies developed and discussed in this manual will provide valuable tools to ensure continuation of military testing and training currently threatened by deteriorating site conditions. Techniques developed in this project will decrease the risk of violating particulate standards of the Clean Air Act that could potentially restrict or reduce testing and training exercises. New rehabilitation and restoration techniques will find immediate application for Integrated Training Area Management (ITAM) personnel located at military facilities in the western United States where ecosystem sustainability for training and testing is at risk. Applying techniques identified in this manual will increase the success of restoration and possibly save as much as $5 million annually within the DoD. Strategies proposed here will improve the efficiency and effectiveness of revegetation efforts, reduce the risk of failures in restoration efforts, and maximize the use of areas for training or other mission-related activities.

1.3 SERDP USERS MANUALS

The technologies evaluated and tested are divided into two principal areas: (1) diagnostics and (2) restoration techniques. Technologies are described in two separate user's manuals:

- ***Vegetation Change Analysis User's Manual.*** Hansen, Dennis J., and W. Kent Ostler. 2002. DOE/NV/11718--729, Bechtel Nevada, Ecological Services, Las Vegas, NV 89193. Prepared for the U.S. Department of Energy, National Nuclear Security Administration Nevada Operations Office, Environment, Safety, and Health Division, NV 89193-8518

- ***New Technologies to Reclaim Arid Lands User's Manual.*** Ostler, W. Kent, David C. Anderson, Derek B. Hall, and Dennis J. Hansen. 2002. DOE/NV/11718--731, Bechtel Nevada, Ecological Services, Las Vegas, NV 89193. Prepared for the U.S. Department of Energy, National Nuclear Security Administration Nevada Operations Office, Environment, Safety, and Health Division, NV 89193-8518

These manuals were distributed in a workshop held in Las Vegas, Nevada, during the fall of 2002. The purpose of the workshop was to facilitate technology transfer by presenting the new technologies and assisting scientists working at selected military installations to understand how these technologies could assist them in managing biological resources at their sites.

1.4 RELATIONSHIP TO OTHER USER'S MANUALS AND TECHNOLOGIES

There are several books and publications on arid-land restoration that have been developed for specific areas and purposes and that outline general factors that should be considered for these harsh areas (Allen, 1988; Crosswhite and Crosswhite, 1982; Goudie, 1990; Wallace, *et al.*, 1980). Many of these contain helpful information and should be read to understand the unique problems associated with revegetation of arid lands. There are only a few publications that would be considered users manuals for revegetation of the southwestern deserts of the United States (Bainbridge et al., 1998; Bainbridge et al., 1993; Cox et al., 1982; Institute for Land Rehabilitation, 1979). While these provide valuable information, they are not inclusive of many

aspects of reclamation. Also, DoD facilities often have unique or different goals and objectives that make reclamation of DoD sites more difficult. The DoD in cooperation with other government agencies, has developed several references to aid Land Rehabilitation and Maintenance coordinators throughout the United States in developing reclamation plans and implementing those plans at their sites.

One such tool is the VegSpec (http://ironwood.itc.nrcs.usda.gov/Netdynamics/Vegspec/pages/HomeVegspec.htm), which is a training area plant species design software tool that aids the installation land managers with selecting plant species that are suitable for rehabilitating disturbances or for landscaping around facilities. VegSpec utilizes soil, plant, and climatic data to select plant species that are suitable and adapted to specific sites and objectives. The VegSpec identifies plant species that meet users defined land-use criteria. The system helps calculate a seeding rate and evaluates the mixture for potential compatibility problems. It also helps design the planting dates, seed placement, planting method, propagule treatment, seedbed and site preparation, temporary cover, and soil amendments. This program was developed for all locations in the United States and does not work well for arid lands particularly if the user is trying to reestablish a native vegetation cover on a disturbed site.

1.5 CONCEPTUAL MODEL FOR DISTURBANCE OF ARID LAND

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

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

The lack of water in arid and semiarid military ranges is perhaps the most limiting factor in the growth and resiliency of vegetation to withstand training impacts (Wallace et al., 1980; Verma and Thames, 1978). In desert areas, the cost of recovery, risk of failure, and time needed for recovery increase dramatically and curvilinearly with the severity of impact (Figure 1-2). In

moist environments, costs and associated restoration requirements increase only slightly with the increase in level of disruption because there are fewer limiting factors in moist environments and recovery is more dependent on the vegetative growth rate. In arid ranges, the impacts to vegetation become increasingly severe as training impacts increase in frequency and duration at rates that are disproportionate to early stages of disturbance. Even under natural conditions, severely disturbed sites in the Mojave Desert are projected to take up to 200 years to restore

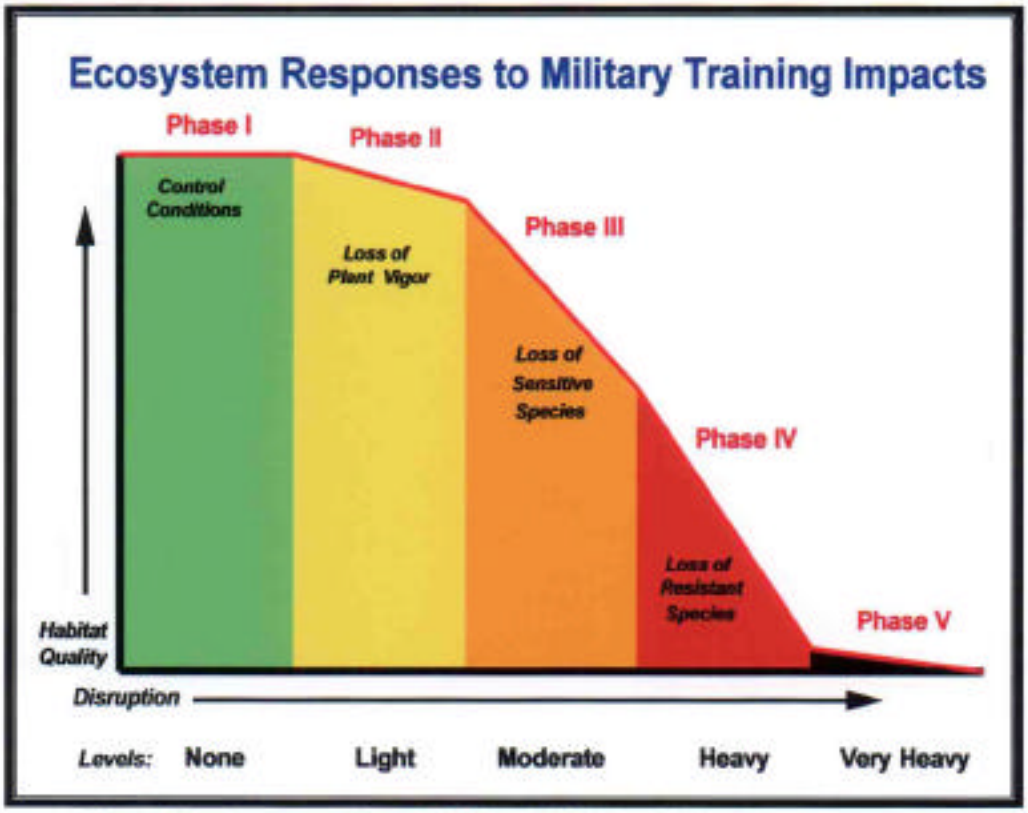

Figure 1-1. A conceptual model of thresholds in a Mojave Desert ecosystem.

vegetation comparable to pre-disturbance conditions (Figure 1-3) (Angerer et al., 1994; Vasek, 1980; Webb and Wilshire, 1980). Lands that have been drastically disturbed in deserts create serious challenges for revegetation. Frequent and continued impacts require new restoration techniques to increase cost efficiency of mitigation efforts and to enhance natural plant establishment in synchrony with natural, often unpredictable climatic patterns.

1.6 SUSTAINABLE RANGES

The DoD has undertaken a new approach to managing DoD-controlled lands. This approach recognizes that the ranges have to be managed on a sustainable basis and they need to ensure that vital live training infrastructures will be available indefinitely to support training readiness. The objective of sustainable ranges is to maximize the capability, availability, and accessibility of

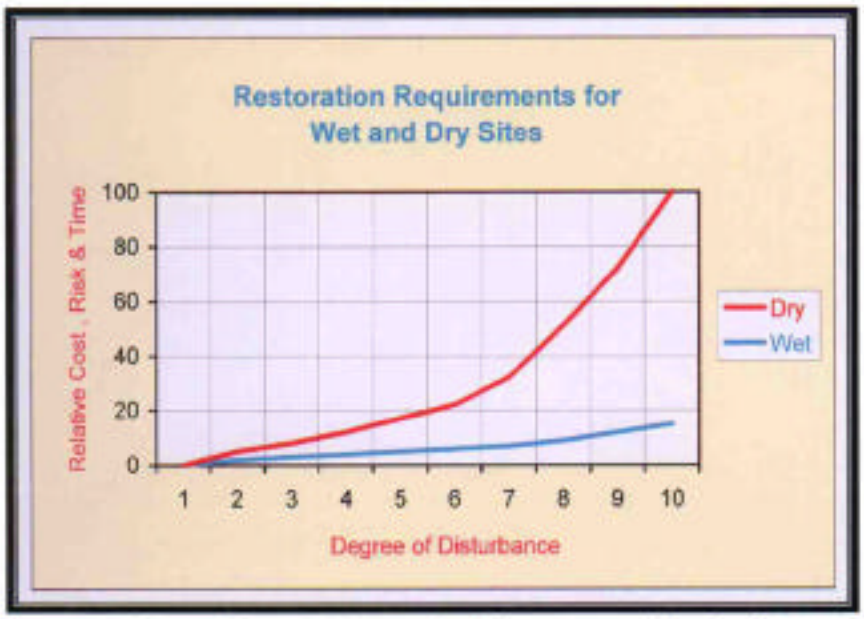

Figure 1-2. Costs, risks, and time required for recovery following disruption increase more rapidly in dry environments than in moist environments.

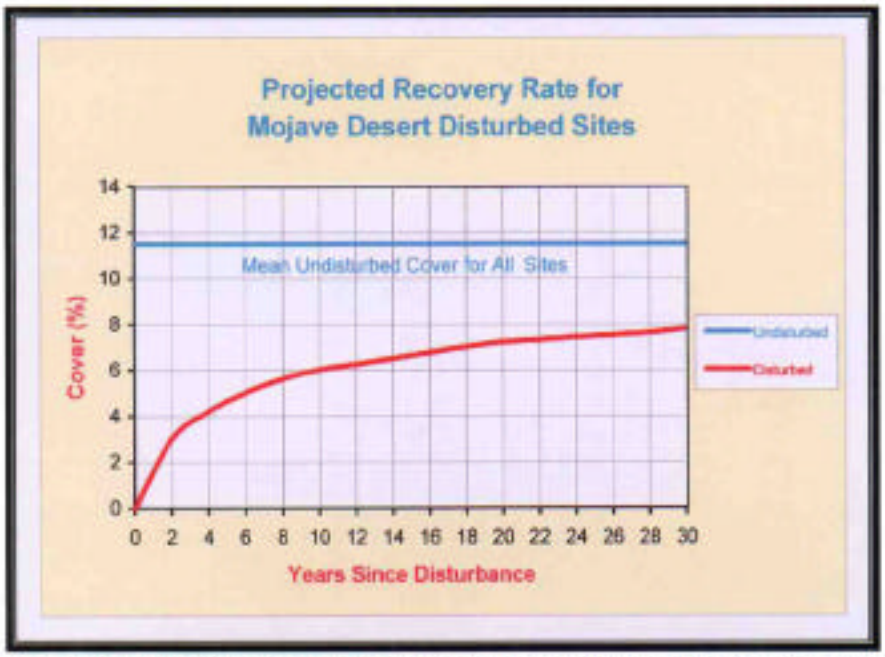

Figure 1-3. Projected recovery for disturbed vegetation may require hundreds of years to achieve predisturbance levels of vegetation cover in arid lands.

ranges and training land. Ensuring the availability of ranges is accomplished in part through maintenance of the ranges. Assessments are conducted to evaluate the condition of the ranges in terms of environmental compliance and stewardship as well as environmental impacts on live training execution, particularly safety. For the U.S. Army, this assessment is accomplished through the LCTA program. New techniques to assist with LCTA assessments are discussed in the companion to this user's manual, Vegetation Change Analysis User's Manual (Hansen and Ostler, 2002). When conditions at training area have seriously degraded, then active mitigation needs to occur to protect the area from further loss of resources. This can be accomplished by numerous techniques including simply restricting activities on the site. As discussed above, recognizing and mitigating a downward trend early in arid areas is critically important and can save valuable resources, time, and money. Techniques to assist with this mitigation are presented in this user's manual.

1.7 APPLICABILITY

This user's manual is written specifically for the arid regions of the southwestern United States, specifically the Great Basin, Mojave, and northern Sonoran Deserts (Figure 1-4). While principles can be used in other arid areas, the species lists, timing of revegetation, costs, and other techniques are focused on these areas. These desert areas are differentiated primarily by temperature. The Great Basin Desert generally has freezing conditions during the winter months and plants often go dormant to avoid these cold temperatures. The Mojave and Sonoran Deserts rarely experience temperatures below freezing and, if so, generally only for a few days. Summer temperatures are also much higher in the Mojave and Sonoran Deserts. Precipitation patterns also differ among these deserts. The Great Basin Desert has a bimodal distribution with spring (March-April) and fall (October-November) periods of higher precipitation. The northern portion of the Sonoran Desert has higher summer precipitation (July-September) while the Mojave Desert receives slightly higher winter precipitation (December-February). The amount, distribution, and consistency, or lack thereof, are important factors in determining when and how to revegetate these desert areas.

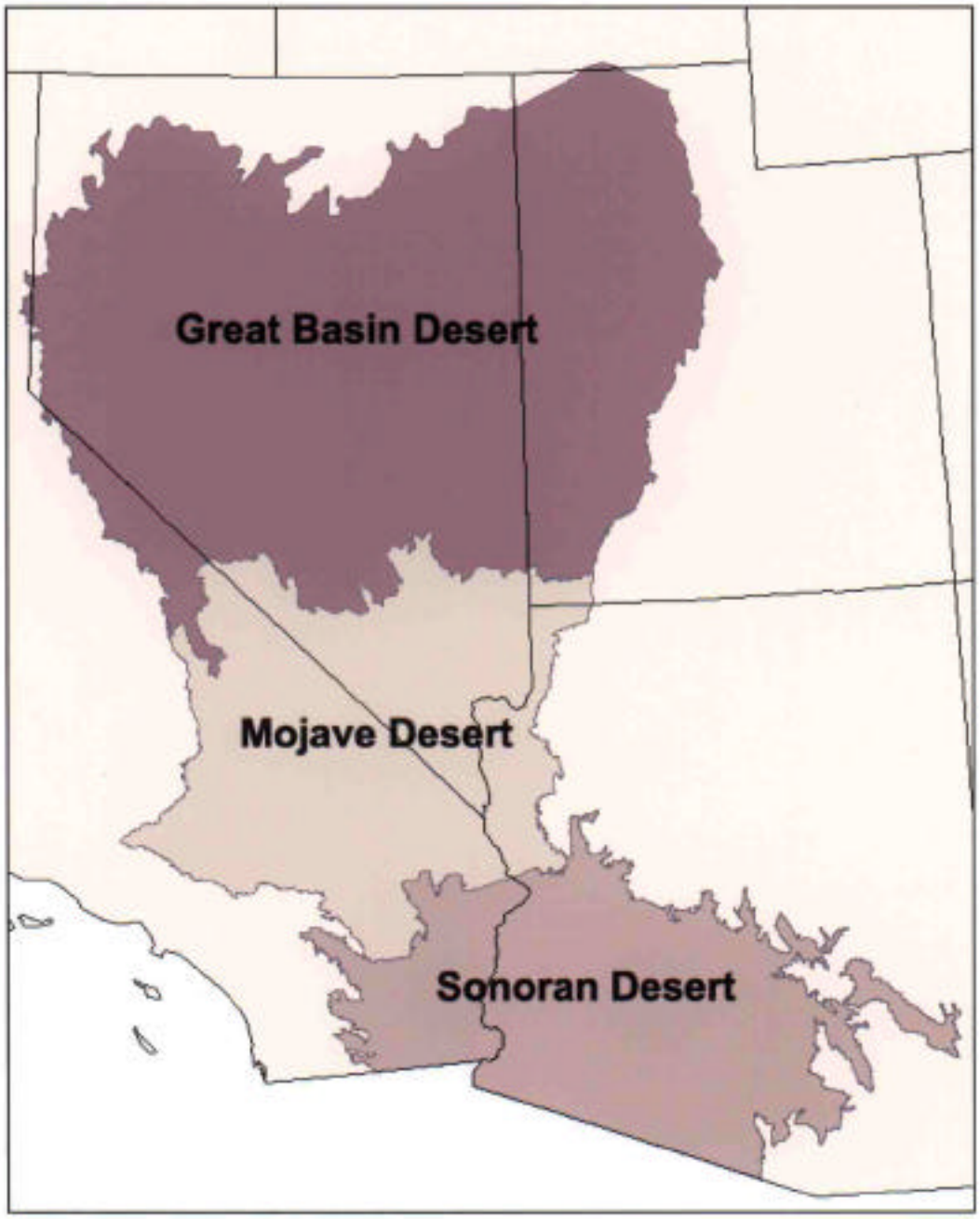

Figure 1-4. Map of the Mojave, Sonoran, and Great Basin Deserts in the southwestern United States.

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2.0 RECLAMATION PLANNING

The accomplishment of a successful revegetation program is dependent upon the development and execution of an orderly documented plan. Proper planning is often the most critical factor to ensure successful reclamation efforts. Conversely, improper planning is the major reason for failure in reclamation projects, particularly in arid lands. The planning process should be started early, preferably at the inception of the project development activities. The schedule for revegetation should be closely coordinated with other entities so that the site will be ready for revegetation at the proper time. Early in this process is when stakeholders or land managers identify concerns and priorities and misconceptions or misunderstandings are resolved.

2.1 RECLAMATION PLAN AND TECHNIQUE SELECTION TABLE

A reclamation plan first and foremost identifies the land-use objectives. This is critical because it will determine which techniques and species will be used in reclaiming the site. In addition to this, the plan should describe constraints, scheduling, contracting, site assessment, site preparation, species selection, technique selection, monitoring, and remediation. Each section in this user's manual presents and describes general principles, techniques, and variables that should be considered for their proper use.

To assist users of this manual in how to make selections of species, techniques, etc., we have included a flow diagram and a table in Section 6.0, "Decision Tools for Selection of Reclamation Techniques." This manual is designed to first present and discuss the various techniques and the rational for their use. The decision table that can be used to determine site-specific techniques based on information that the user would provide then follows these discussions. This should provide a background and basis from which to make decisions within the table.

2.2 OBJECTIVES

Objectives or goals may focus on erosion control, restoring or creating wildlife habitat, or enhancing aesthetics. Regulatory requirements and future use of the site may also define reclamation objectives. Some agencies and states have standards that must be met for revegetation of land, which are often tied to a performance bond. While neither DOE nor DoD has such standards, they do have internal regulations and executive orders that serve as drivers for revegetation of disturbances. The U.S. Fish and Wildlife Service may also mandate certain requirements to compensate for threatened or endangered species habitat losses due to various activities (e.g., reclamation of disturbances in desert tortoise habitat).

Sometimes the most difficult task is to determine reasonable objectives for the reclamation site. This is particularly difficult if the source of the disturbance is still occurring (i.e., training is still occurring). Land managers may have very different opinions on how the land should be used beyond the overriding and long-term goal to ensure that the range is available for realistic training. Land-use objectives may include erosion control, native plant community restoration, trafficability, slope stability, landscaping around facilities, livestock grazing, or wildlife habitat.

Multiple objectives may be necessary if the site is large and topographically and hydrologically diverse. An area with steeper slopes may need to focus on slope stability while this would not be necessary for a flatter area where wildlife habitat may be more important.

The objectives need to be realistic and based on the extent of disturbance of the site and the resources available. From the conceptual model discussed above, extensive disturbances where seed and soil resources have been lost from a site and where active erosion is occurring will require significant resources to reclaim. Perhaps just controlling erosion from such a site would be all that would be practical. Limited resources could be used on other larger areas to ensure they did not degrade to Phase V of the conceptual model.

Project objectives and goals are usually measured in terms of vegetative cover, density (number of plants established per unit area), species diversity, or all of the above. These characteristics of the vegetation are used to measure success and determine costs and, therefore, must be realistic; otherwise, success may be unattainable. Interim goals and standards are often desirable to ensure that the process is on track and will eventually reach the long-term goal.

Selecting an undisturbed area adjacent to the disturbance to use as a reference area or as the objective of the reclamation efforts is often a good strategy. One could also use LCTA data if sampling transects are nearby and representative of the site conditions. Even with the best reclamation practices, it may take several to many years for some sites to recover to levels comparable to the reference area. While recovery in deserts is slow, it is important to ensure that the basic elements are in place to reach the desired goal. For example, cover and size of plants may not be equivalent to the reference area one to three years after reclamation but plant density and diversity should be. Cover and size will generally increase with time but density and diversity often decrease. This will be discussed further in Section 4.0, "Monitoring and Remediation."

2.3 CONSTRAINTS AND LIMITATIONS

There are often many limitations that exist on active training ranges that do not exist at other locations. One of the most important limitations is access to the range at the proper time for reclamation activities. For example, at Fort Irwin, range access is generally restricted for three of every four weeks due to active training and live-fire activities. It is often very difficult to accomplish all that is needed in that very limited timeframe. When this is combined with narrow timeframes for a technique such as seeding, which may only be suitable for a 60-day period each year, one may only have an opportunity to seed two weeks during a year. Thus coordination and proper staffing for those periods becomes extremely important.

On most DoD sites, there are areas where unexploded ordnance (UXO) become a serious constraint particularly when soil disturbance is anticipated. Areas have to be cleared prior to any reclamation activities and this has to be coordinated well in advance.

Similarly there are archeological and environmental interests that must be considered that can constrain when activities occur. Often, archeological or biological surveys have to be done prior to any surface disturbance to identify and avoid any sensitive areas or threatened or endangered species.

2.4 SUBCONTRACTING

Many DoD facilities do not have the equipment, staff, or expertise to implement a reclamation plan. Contracting the actual reclamation work with an experienced reclamation company provides a good alternative to accomplish the work. It is very important to select a reliable company that has demonstrated experience in the reclamation of arid lands. There are many reliable companies that do this type of work particularly for state transportation departments or mining operations. The reclamation plan becomes extremely critical if the work is going to be subcontracted because it can be used to form the basis of the contract. It is important that the subcontractor understands all of the constraints and limitations of working on your site so that they can provide the proper staffing and equipment to accomplish the work in a limited period of time.

2.5 SCHEDULING CONSIDERATIONS

A reclamation project can be very complex and could actually begin years before the actual seeding or planting of the site is conducted. Because of this, it is extremely important that a schedule be developed to ensure that activities be conducted at the appropriate time. This is particularly critical for seeding when there may be a very narrow period where conditions are right for success (this is further discussed in Section 3.4, "Seeding"). Providing proper plant materials to a site may require two years advanced planning to obtain plants that are the right species, ecotype, and size, and are hardened properly for your area. Seed of many native species are not available every year because they are collected from wild stands rather than field-grown as are agricultural crops or landscape plants. Thus, in dry years there may be no seed produced or harvested, so scheduling to acquire seeds early is very important.

In addition to issues of obtaining plant or seed materials, it is important to schedule the reclamation activities with other ongoing activities on the site. Most sites will be actively training and reclamation work will have to be scheduled during the breaks in that training or when activities are compatible. Some aspects of the reclamation project could be accomplished early, such as site preparation, leaving as much time as possible to accomplish those tasks that have to be done in a very narrow time frame.

Timing is critical for both transplanting and seeding. Transplanting should take place when soil moisture is high and plant metabolism is low. For the Great Basin Desert, that may be in the fall before the winter snows or in the spring after the snows have melted and plants are still somewhat dormant. For the Mojave Desert, it could be from late fall to early spring. Seeding must precede the period of reliable moisture so that there will be adequate water available for germination and early plant growth. Seeding also must coincide with a period of suitable growing temperatures. Summer precipitation may be adequate for growth, but temperatures are high and soils dry out quickly making seedling germination and establishment improbable. In the Great Basin and Mojave Deserts, the best period for seeding native plant species is in the late winter or early spring (December – March). In the Sonoran Desert where late summer rains are more consistent, late summer and early fall are suitable times for seeding. The schedules for revegetation should be closely coordinated with other entities so that biological timelines are not compromised in favor of fiscal timelines.

2.6 FIELD SITE ASSESSMENT

One of the most important tasks that is needed to develop a suitable reclamation plan is a field visit to the site to conduct an assessment of the environmental parameters and conditions of the site, and select a suitable reference area to assist in determining the reclamation objectives. Table 2-1 shows a typical assessment sheet and examples of data that should be collected. Three areas of information need to be collected: (a) physical conditions such as total area, slope, aspect, precipitation, soil types, soil depths; (b) biological conditions such as plant species composition including gathering data from a reference area; and (c) other aspects that could create problems during reclamation efforts such as erosion potential, weeds or invasive species, and grazing by cattle, rabbits, or rodents.

An assessment of adjacent undisturbed areas can provide valuable information (i.e., site potential, vegetation associations, drainage patterns, plant spacing) to be used to define goals or standards for revegetation success, and to develop a specific reclamation strategy. Photographs of the disturbed site and the reference site are also valuable for later comparisons and documentation. A video camera that records visual and auditory field notes may also be used for documenting site conditions.

2.7 SITE PREPARATION

The effort expended and the equipment required for site preparation varies depending on the nature of the project, remoteness of the site, slope steepness, and soil texture. Site preparation may occur during any land disturbance, as a project is completed, or when the site is abandoned or decommissioned and the land is to be returned to its original use. Prior to a disturbance, site preparation may consist of vegetation salvaging or removal and topsoil salvaging and storage. Salvage of topsoil takes advantage of the existing seed bank and microbiota of the recovered soil and has been used effectively to jump start revegetation (Winkel et al., 1999). Site preparation may include reestablishing natural drainage patterns, alleviating soil compaction, replacing salvaged topsoil, preparing the seedbed, and constructing erosion control structures (see Schaller and Sutton, 1978, and Brown et al., 1986 for comprehensive reviews of site preparation practices).

A characteristic of sites on active training ranges is that the soils are often highly compacted. Compacted soils may not allow water to infiltrate but runs off causing soil erosion. Relieving compaction through ripping or other soil-loosening techniques is often required to allow water infiltration. Some porous soils (e.g., sand) may allow water to move too quickly through the soil profile and soil amendments (e.g., organic matter) may be needed to increase water-holding capacity.

2.8 SPECIES SELECTION

One of the most important aspects of the revegetation effort is the selection of plant species. Native species are often required because they are either adapted to the site conditions, or they are adapted to disturbances and perform well during the first few years (Wallace et al., 1980; Bainbridge et al., 1998). Past performance of particular plant species in similar conditions and

Table 2.1. Example of a field visit planning sheet.

Date: _____ Site: _____ GPS: Northing _____
Observer: _____ Location: _____ Easting: _____

Site Clearing & Preparation	*Samples*				
	1	2	3	4	5
Soils					
Location					
Depth					
Salvageable					
PH					
Fertility N/P/K					
Salinity					
Texture					
Plant Material Salvage					

Vegetation	*Native Vegetation Type:*		
Dominant Species	Relative Abundance		
	Abundant >25%	Common 5-25%	Uncommon <5%
2			
3			
4			
5			
Invading Species or Weeds:			
1			
2			
3			
4			
5			
Potential Problems:			
Grazing/Rodents			
Steep Slopes			
Wind Erosion Potential			
Water Erosion Potential			
Remarks:			

availability of seed or plant material should be primary considerations when developing a species list for the reclamation plan. The source of the seed or plant materials should be as close as possible geographically to the area being revegetated or, as a minimum, originate from similar environmental conditions (e.g., soils, elevation, slope, and climate). National and local databases with characteristics of species performance (i.e., transplant mortality, ease of germination, and availability of seed) can be valuable resources to identify species adapted to a particular site (U.S. Department of Agriculture [USDA] 2002; http//plants.usda.gov). Information from these databases and from the site assessment helps determine the species to use and quantity of seed or transplants of each species.

2.9 TECHNIQUE SELECTION

Many factors determine which reclamation techniques will be the most cost-effective (i.e., lowest cost for each established plant). Two broad approaches to revegetation in arid environments are seeding and transplanting. Seeding has a much lower initial expense and, where it can provide reliable results such as in the Intermountain Desert, is the preferred approach. Seeding is less reliable when climatic conditions, particularly rainfall, are variable such as are experienced in the Mojave Desert. An alternative to seeding is the use of transplants. Transplanting avoids the initial seed germination and seedling survival periods, which often prove to be fatal; however, upfront (i.e., growing and planting) costs are higher. Transplants may require supplemental irrigation particularly in areas with less than 200 millimeters (mm) (7.9 inches [in]) of rainfall and high temperatures. Irrigation techniques (i.e., catchments, pitting, berms, deep watering) that direct water to individual plants greatly decrease the amount of supplemental water needed to establish transplants. Whether to seed or use transplants is determined by the amount of natural precipitation, its reliability, the harshness of the site, the need to establish a quick cover, the need to establish woody species, the steepness of the side slopes, its priority, and the visibility of the site.

The selection of appropriate conservation and water management treatments is also an important part of the reclamation plan. Factors that are usually considered include irrigation, mulching, fertilization, soil amendments, and fencing. If it is imperative that a vegetative cover be established on the site as quickly as possible, supplemental irrigation may be appropriate. Irrigating to supplement natural precipitation should be limited both in time and volume to (a) avoid major diebacks when the irrigation is stopped, (b) minimize the potential for increased salts at soil surface, and (c) keep costs low. Fertilization also may be necessary if soils are impoverished and plant responses to fertilizer are favorable. Care must be taken because fertilization, particularly fertilizers high in nitrogen, tends to encourage weedy invasive species that compete with desirable species. In the arid southwest, protection from wind and water erosion to protect fragile soils and young seedlings is often a necessity. It is commonly accomplished with organic mulches (e.g., straw) that add organic matter to the soil, lower surface temperatures, retain moisture, and shield young seedlings from the effects of wind and water erosion. Some sites may need protection from herbivores. This need will be determined during the site assessment by evaluating the impact of herbivores on the existing vegetation.

2.10 MONITORING

The two major components of monitoring are onsite inspections and the evaluation of the revegetation success. Onsite inspections are particularly critical where erosion is a problem. Onsite visits after the first major rainstorms need to be specified in the plan. This helps determine if erosion control treatments (e.g., water bars and contour trenches) function as designed. The objectives are to evaluate the success of these techniques early on and identify problem areas in order to avoid major problems later. Adverse conditions at these problem areas would then be corrected as specified in the remediation section (see Section 2.11, "Remediation").

Species performance during the first six months and periodically over the next five years will indicate whether remedial measures are needed to achieve the goals established for the site. Once plants mature and become established, plant cover and density should be compared with adjacent undisturbed areas or standards previously established. If the objectives for the site are met, monitoring may be suspended or scheduled at longer intervals. Monitoring of restoration projects identifies those treatments or techniques that contribute to the long-term success of the revegetation effort. Once identified, these treatments and techniques can be refined and incorporated into future revegetation plans, leading to greater success and lower costs.

2.11 REMEDIATION

If plant densities are low after the first six months reseeding or planting may be appropriate. If plant densities decline or plant cover is low after three to five years, other remedial actions (i.e., supplemental water, fertilization, etc.) may be employed to increase plant growth, plant vigor, or seed set. Usually, within five years, natural drainage patterns are evident and some recontouring or other remediation work may be necessary. This is probably the most overlooked aspect of the reclamation plan, but it is very important for the long-term stability of sites and to ensure that long-term objectives are met. Sufficient resources for adequate remediation should be included in the reclamation plan to ensure success.

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3.0 RECLAMATION TECHNIQUES

3.1 EROSION CONTROL

Natural erosion is a process that has always acted on the landscape. Accelerated erosion is caused by man-made disturbances to the landscape that disrupt the equilibrium resulting from the interactions among climate, slope geomorphology, substrate properties, and vegetation (Munshower, 1994). The two main types of erosion are wind and water.

3.1.1 Objectives

One of the primary considerations in land reclamation is erosion control. The objectives of erosion control are to: (a) minimize the loss of soil resources due to water and wind; (b) be compliant with existing regulations (e.g., Clean Water Act, Clean Air Act); (c) create a safer, healthier environment; and (d) reduce costs of damage caused by erosion (e.g., road maintenance, vehicle repairs).

It is important to recognize that the top layers of soil are the first to be eroded. Loss of these surface layers can be critical because they contain most of the organic matter, nutrients, seed bank, and micro- and macroorganisms. They also usually have more favorable physical (e.g., soil structure, infiltration rate) and chemical (e.g., pH, mineral concentrations) properties for plant growth (Munshower, 1994). Once these layers are lost, it is difficult and costly to replace them and in many cases impossible to do so.

Staying in compliance with regulations can be critical to keeping a project in operation. Excessive fines may be assessed and the project completely shut down for noncompliance. In addition, the stakeholders and general public's perception of the project and the reputation of the installation or land manager should be considered.

Good erosion control practices make for a safer, healthier environment. Minimizing the amount of dust in the air maintains good visibility, which can reduce the number of accidents, injuries, and fatalities that can be caused by poor visibility conditions. Many people also suffer from respiratory diseases that become exacerbated when air quality is poor.

Good erosion control practices can also reduce operating costs. Some examples of damage caused by poor erosion control practices include damage to vehicles caused by rough roads resulting from improperly built roads that allowed water to run down or across the road instead of off or away from the road, windshield pitting and paint damage caused by severe dust storms (e.g., brown-out conditions), engine damage caused by clogged air filters, and the costs associated with accidents (e.g., lost work productivity, insurance claims, legal fees, etc.). Furthermore, poor erosion control practices can lead to increased road maintenance and greater wear on vehicles (e.g., suspension parts, friction on bearings), which increases operating costs.

3.1.2 Principles

Wind erosion can be a serious problem in arid regions (Figure 3-1). Wind can potentially remove more sediment than rainfall (International Erosion Control Association [IECA], 1992). Lack of vegetative cover, low soil moisture, high wind velocities, and exposed soil material on the surface all add to the wind erosion hazard (Verma and Thames, 1978).

Figure 3-1. Wind erosion on denuded areas in the Mojave Desert.

The basic mechanisms for soil movement due to wind are airborne suspension, saltation, and surface creep. Particles with diameters smaller than 100 micrometers (μm) can be suspended in air when they become dislodged from the surface. Particles of this size have downward velocities less than the velocities of the wind, thus they can be carried for great distances. Saltation involves soil particles with diameters ranging from 100 to 1,000 μm. When a soil particle impacts the soil surface, it may bounce into the air or dislodge other particles into the air. As the particles rise, they are moved downwind. Since the particles are too large to remain suspended, they fall back to the surface where they impact the surface soil particles again. If enough particles become suspended, it can result in a severe dust storm that can reduce visibility, damage vehicles, and create unsafe driving and working conditions.

Blowing sand particles can also cause mechanical damage to both young and mature established plants. The saltation process continues as long as the wind speed is sufficiently high. This process generally represents the greatest movement of soil by wind. Particles with diameters greater than 1,000 μm are too heavy to become airborne; however, they move along the surface through a process known as surface creep. Particles moving by saltation may have sufficient energy to move much heavier particles sometimes hundreds of times heavier. The net result of

the continual bombardment of the surface by saltating particles is a slow forward creep of heavier particles along the ground (Foth and Turk, 1972). Sand particles may then accumulate in small dunes around vegetation (Figure 3-2), burying young plants and damaging the stems of mature plants.

Figure 3-2. Wind erosion strips soil resources from the surface and deposits them around vegetation, burying small plants. (National Training Center in Fort Irwin, California.)

There have been numerous studies conducted to model erosion and describe factors impacting erosion and, thus, predict soil erosion from wind. Smith et al. (1982) present a summary of 15 wind erosion models. These models vary in their complexity and ability to predict erosion under various conditions. One of the most commonly used wind erosion models was developed by researchers with the USDA Soil Conservation Service, presently the National Resources Conservation Service (NRCS) (Woodruff et al., 1972). The Wind Erosion Equation (WEQ), is expressed as $E = f(I,K,C,L,V)$ where:

E = the average annual soil loss in tons/acre/year
I = soil erodibility index in tons/acre/year
K = surface roughness
C = climatic factor (wind velocity and surface soil moisture)
L = unsheltered field length measured along the direction of the prevailing wind
V = vegetative cover

This equation identifies the five major factors influencing wind erosion. Soil erodibility by wind is a function of the amount of erodible fines (i.e., silt, clay) in the soil. The largest soil aggregate size that is normally considered to be erodible is approximately 0.84 mm (0.03 in) diameter. Thus, the soil erodibility factor, can be determined experimentally by standard dry-sieving techniques, although the reliability of such estimates may not be accurate under all conditions (Black and Chanasyk, 1989). Numerical values can also be found in data tables from the United States Department of Agriculture (USDA) Natural Resource and Conservation Service (NRCS).

Surface roughness refers to the micro-topography of the surface. A rough irregular surface is less prone to wind erosion than a smooth, compacted surface.

The climatic factors of wind velocity and surface soil moisture affect wind erosion. The higher the wind velocity the higher the erosion potential. Certain regions are prone to high winds which increase the potential for wind erosion (Figure 3-2). Wind direction should also be taken into account because, although soil can blow in all directions, the majority of sedimentation occurs in the direction of the prevailing wind. Moist soils have a lower erosion potential than dry soils because the moisture acts to bind soil particles together and makes them heavier. Furthermore, when soils with fines (i.e., silt, clay) in the surface layers get wet and then dry, a crust forms sometimes called a raindrop crust. This crust can also help reduce wind erosion. Unsheltered field length refers to the length of unprotected bare soil that is exposed to the wind. The longer the field length the higher the potential for wind erosion.

Vegetative cover is very important because there is an inverse relationship between percent vegetative cover and wind erosion potential. Vegetation acts as a barrier to trap wind-blown soil particles and dissipate the wind's energy, thus disrupting the saltation process. A new technique for measuring perennial plant cover using aerial photographs has been developed by Hansen and Ostler (2002).

The U.S. Army uses a modified WEQ to predict wind erosion losses on lands it manages. The five factors are the same, but they are measured differently with specific application to U.S. Army training activities. Data from the modified WEQ are used in the ATTACC system to establish current and predict future land condition thresholds (Cochran and Anderson, 2000). ATTACC is a methodology and integrated decision support system for estimating the operations and support costs of using land at Army installations for training purposes. The ATTACC methodology includes specific processes and algorithms to predict land rehabilitation and maintenance requirements based on training load and environmental conditions (U.S. Army Environmental Center, 1999a).

A new computer-based system, the Wind Erosion Prediction System (WEPS), is being developed to replace WEQ as a prediction tool to assess soil loss by wind from agricultural fields and to provide new capabilities such as assessing plant damage, calculating suspension loss, and estimating PM-10 emissions from the field (Wagner, 1996). Unlike WEQ, which is an empirical equation, WEPS is a process-based, daily time-step, computer model that predicts soil erosion via simulation of the fundamental processes controlling wind erosion.

Many studies have also been conducted to model erosion losses by water, particularly on croplands (Wischmeier and Smith, 1978; Williams, 1975, 1981; Johnson, 1983; Hawkins, 1985). Perhaps the most widely accepted model (although it has been widely criticized) for predicting soil loss by water is the Universal Soil Loss Equation (Wischmeier and Smith, 1978). A Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) has also been developed, but is intended to predict soil losses from rangelands rather than agricultural lands. RUSLE is expressed as A = RKLSCP where:

A = average annual soil loss
R = erosivity of the climate at a particular location
K = soil erodibility factor
L = slope length factor
S = slope steepness factor
C = cover-management factor
P = supporting practices factor

Climate is a primary component of the erosion process. It is important to know not only the total annual amount of precipitation a site receives but also the distribution and form of that precipitation throughout the year. For instance, many otherwise very arid areas are prone to severe thunderstorms at certain times of the year. These storms can drop a significant amount of rainfall in a short period of time causing extensive erosion (Figure 3-3).

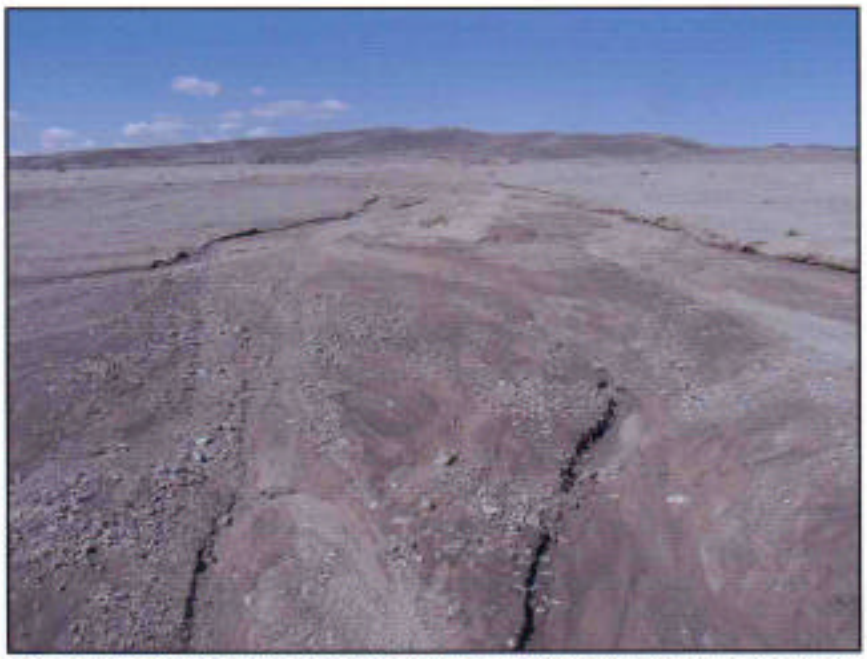

Figure 3-3. Water erosion in the Mojave Desert resulting from severe thunderstorms.

Some areas, particularly at more northerly latitudes and higher elevations, may receive precipitation in the form of snow that persists for a period of time. As the snow melts, some of the water infiltrates into the soil and the rest runs off in stream channels. These streams may be ephemeral or perennial and can carry large amounts of sediment.

Different soil types have different erodibility characteristics. Erodibility is a measure of the soil's susceptibility to detachment and transport by water or wind (Lal and Elliot, 1994). It is a function of soil texture, organic matter content, soil structure, and permeability (IECA, 1992). Sandy soils have higher infiltration rates and, therefore, lower runoff rates and are more easily detached, but less easily transported (due to large particle size) than silt soils. Clay soils are not easily detached because of strong cohesion among particles, but infiltration rates are low which may lead to a greater runoff and increased erosion. Silt soils tend to have the greatest erodibility because particles are easily detached (lack of cohesion) and transported (Lal and Elliot, 1994).

Topography of a site and surrounding areas is another primary component of the erosion process. Topography includes the length, slope (ratio of horizontal distance to vertical rise; expressed as a ratio, percentage or degree), and shape of the landform. Topography determines the path water will travel and how much energy it will carry. Water running off of steeper slopes will have a lot more energy than water running off gentle slopes of the same length. The shape is important because convex slopes magnify slope base erosion while concave slopes reduce base erosion (IECA, 1992). Water follows the path of least resistance. Therefore, one can predict with some degree of certainty the path of travel for water flowing off or through a site. Particular attention should be paid to the location of natural drainage ways on both the project site and the surrounding area. These drainage ways should be left intact where possible to allow runoff to follow its natural course or modified so that water is diverted onto the site in a non-erosive way. It is also important to know the position of a site with respect to the watershed it is located within (i.e., how much area sheds water onto the site).

Cover management (i.e., manipulation of plant cover, mulching, tilling, and rock armoring) is the single factor most easily changed, represents the effect of land use on erosion, and describes the effects of differences between vegetation communities, tillage systems, and the addition of mulches (Renard et al., 1997). The rate of erosion is directly proportional to the amount of permanent or temporary cover. The function of cover is to reduce the rainfall impact, reduce surface water velocities, increase infiltration, trap sediment, retain soil particles, and promote permanent vegetation establishment (IECA, 1992). Numerical determinations for cover can be found in USDA-NRCS publications. Also, a new technique for measuring perennial plant cover using aerial photographs has been developed by Hansen and Ostler (2002). Supporting or conservation practices typically affect erosion by redirecting runoff around the slope so that it has less erosivity or slowing down the runoff to cause sedimentation (Renard et al., 1997). Conservation practices and their cost-effectiveness are tracked closely in the ATTACC system.

The U.S. Army uses a modified RUSLE to predict water erosion losses on lands it manages. The six factors are the same, but they are measured differently with specific application to U.S. Army training activities. As with wind erosion, data from the modified RUSLE is used in the ATTACC system to establish current and predict future land condition thresholds.

The main principles of erosion control are: (a) understand the erosion process and the factors contributing to erosion, (b) dissipate the energy of wind and flowing water, (c) control where the water flows, (d) reduce saltation, (e) control sediment transport and deposition, (f) protect soil resources (e.g., organic matter, nutrients, seed bank, fine soil particles, etc.) to promote vegetation establishment and growth, and (g) protect plants from mechanical damage (e.g., sandblasting stems).

Understanding the factors that influence erosion, the principles of erosion control, knowing how soil particles move, and the particular site conditions will influence the selection of control techniques that should be implemented at a site. For example, because wind erosion of sand is proportional to the cube of the wind velocity, cutting the wind speed in half will reduce the sand movement to one-eighth the original amount.

Two excellent references on erosion control principles and techniques that include data tables for erosion equation factors and applicability and photographs of numerous erosion control techniques can be found in Israelsen et al. (1980) and Israelsen et al. (1984). Also, a publication by the U.S. Army Environmental Center (1999b) provides valuable information and a dichotomous key for deciding which dust control measures to use. This key was designed primarily for a military application but may have broader applicability to other areas as well.

3.1.3 Techniques

Many techniques are effective at controlling both wind and water erosion. Selection of the most appropriate and cost-effective technique is based on integrating site-specific conditions with knowledge of the primary factors contributing to erosion. In the arid regions, erosion control measures should be aimed at (a) slope and soil surface stability and (b) conservation of soil moisture to facilitate effective vegetative establishment. Techniques vary considerably in cost, effectiveness, and longevity. No single technique is suitable for all situations, and techniques need to be tailored to site-specific conditions.

The first thing that should be considered in selecting a suitable technique is to determine the length of time that erosion protection is needed. Temporary measures are appropriate for areas that are still active and are generally less expensive than permanent alternatives. These temporary techniques will not be discussed as a separate group but will be discussed within the general types of control techniques.

Erosion control techniques can be grouped into four main types: physical, chemical, cultural, and biological. Within each group are techniques that have varying effectiveness, longevity, and cost. These techniques will be described within each group and general comparisons will be made concerning their relative effectiveness. Selecting an appropriate erosion control technique is based on: (a) the goal of the erosion control efforts (i.e., short-term stabilization or long-term stabilization), (b) the effectiveness of the technique for particular site conditions, (c) the availability and cost of materials, and (d) the cost of transportation and application of the material.

3.1.3.1 Physical Techniques

Physical techniques create a physical change to the surface that reduces erosion by dissipating or absorbing the energy of wind and flowing water, controlling where the water flows, and controlling sediment transport and deposition. Four different techniques will be discussed that fall within the physical group: (a) windbreaks, (b) structures and surface manipulations, (c) substrate armoring, and (d) mulching.

3.1.3.1.1 Windbreaks

Vegetation (e.g., shelterbelts, hedgerows, trees), windscreens, and fences have been used effectively as windbreaks for many years. The majority of the research done on these physical barriers has been in association with snow management and agricultural production using biological windbreaks. The physics associated with wind reduction, deposition patterns, and effective distances of barriers are very similar regardless of whether soil or snow is being trapped. The barriers function to reduce the wind speed thus decreasing the energy available to transport soil or snow particles. As the energy decreases, sediment is deposited near the base of the fence. In large, very heavily disturbed areas prone to high winds, several centimeters (cm) of fine blow sand can accumulate around establishing plants (refer back to Figure 3-2) or stubble mulch, essentially burying them, and blowing sand can also mechanically damage stems and kill plants. When attempting to establish a vegetative cover in areas prone to high winds, it is recommended that windbreaks be used to protect the establishing plants.

Shelterbelts and hedgerows have limited application in arid areas but have been used around contonement areas to shelter permanent dining and residential areas. Elmore and Hartley (1985a) tested several types of windscreens and fences and provide results of durability and costs of various types of screens and fences. They found that the DuPont Canada L-300 windscreen with 5 centimeters (2 in) mesh to be the most durable of the eight types tested. The cheapest was Canadian-style wood-slat snow fences. Windscreens generally have an effective protective distance equal to 30 times the height of the barrier for snow (Raine and Stevenson, 1977; Native Plants, Inc. [NPI] Reclamation Services, 1985a) and less for soil particles. There are many factors that influence the effectiveness of windscreens including porosity, type of material used for construction, placement, etc. These factors must be understood and considered in designing an effective system of controlling erosion. Windbreaks should be placed so that they are perpendicular to the prevailing wind direction.

Establishing vegetative windbreaks is challenging in arid areas and may take a while to establish. Supplemental watering is usually required as well. The primary disadvantage of the windscreens is the initial cost (Elmore and Hartley, 1985a). They do not supply a long-term solution to stabilization since moderate upkeep would be required to maintain the windscreens. They can be used effectively in combination with vegetative treatments and provide the short-term stabilization necessary for establishing vegetation.

3.1.3.1.2 Structures and Surface Manipulations

There are numerous types of structures and surface manipulations that can be used for erosion control. Contour trenching is a common practice of erosion protection of disturbed lands from

high-intensity precipitation. Trenches are constructed with the blade of a bulldozer, usually with two to four passes, along the contour at periodic intervals on a slope. The interval is determined by the slope and substrate and should be short enough so that the volume and energy of runoff between trenches up-slope do not wash out the trenches below. Long slopes may require interceptor ditches to divert water off the exposed slope and energy-dissipating drop structures to ensure that water does not build up within the trenches; then breach the trench washing out down-slope structures.

Baffles or dams may be constructed regularly along the length of the trench to prevent too much water from pooling up and rupturing the trench. The trenches are usually seeded after construction to help stabilize the trenches and provide cover. The trenches act as catchments for moisture and prevent the water from running down the slope, which in turn reduces the formation or enlargement of existing gullies. Contour trenching is usually done only on moderate-to-steep slopes where the potential for excessive erosion occurs. This technique is costly and substantially modifies the landscape. The use of contour trenches in the United States has been reviewed comprehensively by Upadhyay (1977).

Contour furrowing is similar to trenching but the furrows are substantially smaller than trenches, closer together, and only control moderate amounts of runoff. Typically, they are constructed on more gentle slopes than trenches. Heavy equipment, usually a bulldozer or specially designed furrower, is used to construct furrows. For further information on contour trenching and furrowing, see Vallentine (1989).

In addition to contour trenching and furrowing, other techniques such as pitting, imprinting, gouging, or dozer basins have been used to control both wind and water erosion and encourage vegetation establishment (Figure 3-4). These techniques result in small basins, pits, or other indentations that act to roughen the surface and collect water in the bottom of the indentations, which aids in vegetation establishment. Special equipment (e.g., modified disk plow, rotary drum pitter, subsoiler, and imprinter) pulled by tractors or bulldozers are used to create the pits. Large basins, several meters wide and 15 to 61 cm (6 to 24 in) deep, can be pressed into soft soil with a blister press, created with a bulldozer blade, or scalped out with a rear-mounted basin blade (Vallentine, 1989). Dollhopf et al. (1985) have shown that large dozer basins (approximately 8 meters [m] by 6 m by 1 m deep) (26 feet [ft] by 20 ft by 3 ft) were more effective at controlling erosion than smaller gouges (40 cm by 60 cm by 15 cm deep) (1.3 ft by 1.97 ft by 0.49 ft). The larger basins reduced runoff by 75 percent and erosion by 92 percent while the smaller gouges reduced runoff by 18 percent and erosion by 50 percent.

Clary (1989) reported that soil losses from high winds on an area receiving land imprinting were one half that of a similar area that was drill-seeded. The majority of the soil loss occurred in the first year prior to vegetation establishment. Other researchers have demonstrated similar improvements in moisture retention, erosion control, and improved vegetation establishment from land imprinting. These techniques are usually only used on flat-to-gently sloping terrain.

The disadvantages to these techniques are they can be expensive to implement and the smaller basins may fill in after a few years.

Figure 3-4. Dozer basin used to catch runoff from roadway and upslope in Fort Irwin, California.

Diversion structures and barriers (e.g., check dams, dikes, water bars, and straw bales) can be used for runoff spreading and retention. Their purpose is to intercept surface runoff and divert it in a controlled direction at a non-erosive velocity (Verma and Thames, 1978). Part of this process includes channeling the water in the proper direction. This can be done with ditches, culverts, and pipes. It is important to remember that flowing water has a lot of energy, especially on moderate-to-steep slopes or even on long gently sloping slopes. Allowing the water to flow in meanders, as opposed to straight channels, can dissipate much of this energy. Water diversion bars are typically made in roads to divert the water from the road into adjacent areas. Sediment basins can also be constructed to slow down the runoff and allow the sediment to be deposited in the basin. Tractors or other heavy equipment are generally required to construct and maintain diversion structures.

Wattles, cylindrical straw bales encased in plastic netting, can be placed in small washes to slow down the runoff and catch the sediment, and are usually anchored with rebar or long staples. Straw bales, sandbags, and other materials can be placed in small channels to divert runoff. Proper anchoring techniques should be used to attach these materials to the substrate. Old tires wired together have been used to create effective "gully plugs" that trap sediment and reduce the energy of flowing water. Design and field layout of diversion structures for erosion control should be properly engineered and incorporated into the reclamation plan. These structures can be costly to build and require some maintenance to keep them in proper working order.

3.1.3.1.3 Substrate armoring

Substrate armoring involves the application of a rock or gravel material over the soil substrate (Figure 3-5). The gravel or rock absorb the energy of the wind or water and prevent the soil particles from becoming dislodged or displaced, thus controlling erosion. The gravel also acts as mulch to retain soil moisture. It also moderates soil temperatures.

Figure 3-5. Example of gravel armoring (1.5 cm in diameter) used to control erosion.

Gravel is typically used on flat-to-gently sloping terrain, and controls both wind and water erosion. This technique simulates the naturally occurring "desert pavement" found in many arid lands. A study conducted by EG&G/Energy Measurements (EG&G/EM) determined that a 2.5-cm (1-in) layer of gravel significantly reduced the sediment yield from wind erosion when compared to a control (EG&G/EM, unpublished data). Another study by EG&G/EM showed that plant emergence was greater under a 2.5-cm (1-in) layer of gravel compared to a 5-cm (2-in) layer of gravel (EG&G/EM, unpublished data). The U.S. Bureau of Mines conducted a small-scale study on the effectiveness of a thin covering of gravel to simulate desert pavement (Dean et al., 1986). Three sizes of gravel (1.3-1.9 cm, 1.9-2.5 cm, and 2.5-3.8 cm) (0.51-0.75 in, 0.75-1.00 in, and 1.00-1.50 in) were applied to 1 m by 1 m (3.3 ft by 3.3 ft) plots along with control plots receiving no gravel cover. The gravel was applied such that 60 percent of the soil surface was covered. They report that "…sand blown from the outdoor test plots over a

1-1/2 year period was recovered and weighed. All three sizes of aggregate reduced blowing sand to a small fraction of that from the comparable uncovered plots." They also recommend that more work needs to be done to assess the effects of the degree of cover and size range of aggregate at different wind speeds. Good emergence from several species was also obtained under a 2.5-cm (1-in) layer of gravel (1-cm [0.5-in] diameter) with 60-70 percent cover (BN, unpublished data). Heavy equipment is most often used to apply and spread the gravel. This technique is very effective but is costly to implement.

Washbanks and other waterways subject to excessive erosion should be protected. The most common way to do this is to line the substrate with rocks or other material. Loose rock is called riprap. Gabions are frequently used to armor washbanks and consist of rocks placed in wire mesh cages that are emplaced in the washbank. Drop structures are used below falling water to dissipate the energy of the falling water. They are usually made of rocks, similar to riprap, cement, or asphalt. These techniques are labor-intensive and usually require the use of heavy equipment to distribute the loose rock or maneuver the gabions.

3.1.3.1.4 Mulching

Mulches can be either organic or inorganic. Organic mulches are usually an agricultural crop residue or industrial by-product (Kay, 1978). The most common organic mulches used in the western United States include straw, hay, and wood residues. Some common inorganic mulches include rock, soil and shredded plastic. Mulches protect the soil against raindrop impacts, intercept surface runoff, protect the seed, reduce temperature fluctuations, and reduce evaporation (Verma and Thames, 1978). For more detailed information about mulches, see Section 3.7, "Mulching."

Erosion control blankets or mats are a type of surface mulch that are used primarily to control erosion on steep slopes (Martin, 1986) and rocky soils. Mats are constructed of straw, or other organic material, woven together or held in place by some woven material (e.g., plastic netting). Seeds can be placed under the mat or impregnated into the organic material. The weave is loose enough to allow seedlings to root into the ground and grow through the woven material. Mats must be anchored to the substrate, usually with large staples or rocks, and the edges buried to prevent wind from lifting the mat off the surface. Mats are expensive but effective, and, in some areas with steep, erodible slopes, the only realistic alternative (Munshower, 1994).

3.1.3.2 Chemical Techniques

Chemical control involves the application of a reagent with the soil to form a wind and water resistant crust on the soil surface. Most commonly, they are mixed with water and applied with a hydromulcher or sprayer (Figure 3-6). Chemicals are commonly used as treatments for dust control on mine roads and tailings to control surface erosion (Parks and Rosene, 1971; Yardley et al., 1980; Havens and Dean, 1969; Veel and Carr, 1980). They have also been used rather commonly to control wind and water erosion on sites unsuitable for plant growth because of harsh climatic or toxic soil conditions (Dean et al., 1986). Bolander and Yamada (1999)

Figure 3-6. Applying chemical soil stabilizer with a hydromulcher.

wrote a good reference document on dust control selection and application for unpaved roads. Stabilizers are very effective at disrupting the saltation process. We have seen "Dust devils" travel through an unstabilized area and essentially stop when they reached a stabilized area.

There are many different types of chemicals that can be used to effectively stabilize soil. The choice of a particular chemical is dependent on: (a) the characteristics of the soil (e.g., texture, pH), (b) current use of the area to be stabilized, (c) the end use of the area to be stabilized, (d) compatibility of the chemical with other erosion control and reclamation techniques (e.g., vegetation establishment), and (e) local climatic factors (Williamson et al., 1982). There are numerous products available that have been shown to be effective under various conditions. In making the selection that is most suitable for a particular area, one needs to evaluate costs, availability, application methods, duration of effective control, and the intended use of the area following stabilization.

One of the shortcomings of chemical stabilizers that form crusts is that they are vulnerable to physical disruptions such as vehicle travel or even animals walking on the surface. Once the crust is broken, it can be rapidly undercut leading to the loss of surface stability. Water-soluble chemicals that penetrate further into the soil may be more suitable for areas that will receive more surface disturbance.

Chemical stabilizers generally fall into seven categories: (a) hygroscopic salts, (b) lignosulfonates, (c) asphalt emulsions, (d) petroleum resins, (e) elastomeric polymers, (f) organic tackifiers, and (g) water-soluble synthetic polymer soil conditioners. Rates mentioned are only suggested rates from the literature and vary by product. Therefore, it is

recommended that product labels or vendors be consulted for specific rates. Other product types and formulations are available and may be equally cost-effective; however, they are not as commonly used and not thoroughly tested and will not be discussed here.

3.1.3.2.1 Hygroscopic Salt Solutions

Hygroscopic salt solutions absorb moisture from the air and, thus, increase moisture content of the soil. The most commonly used hygroscopic salts are magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$). These salts are commonly used in the mining industry for dust control purposes on roads. They are usually applied in a liquid concentrate form with approximately 30 percent solids (Bohn and Johnson, 1983). Careful consideration of how these salts will affect the soil in providing a suitable media for plant emergence and establishment must be given before using these salts.

3.1.3.2.2 Lignosulfonates

Lignosulfonates are by-products of the sulfite pulping process. They have been extensively used throughout the mining industry for dust control on roads. Lignosulfonates are a solution of lignin and sugars, which are water-soluble. They are usually diluted with water to 4:1 to 12:1 for application generally with a sprayer. They are inexpensive and form a wind-resistant crust; however, because they are water soluble they tend to leach down and away from the surface in wetter climates. The U.S. Bureau of Mines tested three specific types of lignosulfonates, calcium, sodium and ammonium lignosulfonates, and found that they were effective stabilizers at rates of 2,690 kilograms per hectare (kg/ha) (2,400 pounds [lb]/acre). They also tested 20 different types of chemical stabilizers and found that a calcium lignosulfonate, Norlig A, was the only chemical that was effective on both acid and carbonate tailings (Havens and Dean, 1969).

3.1.3.2.3 Asphalt Emulsions

Asphalt emulsions are commonly used in the mining industry and provide a good wind-resistant layer for erosion control. Experimentation with asphalt-based products has occurred since the 1950s. These substances consist almost entirely of carbon and hydrogen with very little oxygen, nitrogen, or sulfur. Like lignosulfonates, asphalt emulsions can be diluted with water so they can be shipped as a concentrate and diluted prior to application. When diluted with solvents, they are commonly referred to as cutback asphalt.

3.1.3.2.4 Petroleum Resins

Petroleum resins are generally prepared from waste products of refinery operations. These are usually emulsions, which are 40-60 percent solids and shipped as concentrates. They are diluted with water at rates ranging from 4:1 to 15:1 for application. Petroleum by-products have been widely used for dust control and have been shown to be effective stabilizers and often very compatible with biological stabilization techniques (Dean et al., 1969, 1974). The U.S. Bureau of Mines tested a resinous adhesive, Coherex®, for its effectiveness for wind and water erosion protection. They found that it created a good wind-resistant surface at minimal cost; however, good resistance to water erosion was not achieved until application rates and costs were significantly increased (Dean et al., 1974). EG&G/EM also tested Coherex® and found it to be

effective at controlling wind erosion, persisted a long time, was compatible with seedling emergence, and withstood some trafficking but it was expensive, not aesthetically pleasing, and difficult to clean application equipment (EG&G/EM, unpublished data).

3.1.3.2.5 Elastomeric Polymers

Elastomeric polymers are an emulsion of rubber or plastic-type materials which bind the surface soil materials together to form a crust or protective coating of the soil surface. Latex usually binds together the surface particles, while plastic polymers form a film over the soil surface. These products represent the largest number of commercially available chemical stabilizers. The products are generally shipped as concentrates and diluted with water at rates of 6:1 to 99:1. Usually, a curing period is needed to form the film or crust. The U.S. Bureau of Mines tested three types of elastomeric polymers and found that they were exceptionally effective at controlling wind and water erosion on sandy tailings and produced satisfactory results on both acidic and alkaline tailings (Dean et al., 1974). EG&G/EM tested four copolymers including Agri-Lock®, Chem-Loc®, Poly-Tac®, and Soil Master® (EG&G/EM, unpublished data). All were effective at controlling wind erosion, compatible with seedling emergence, and relatively inexpensive, but only had moderate longevity. Poly-Tac® and Soil Master® had the poorest longevity rating.

3.1.3.2.6 Organic Tackifiers

Organic tackifiers are made from plant extracts and bind soil particles together to form a crust or film on the soil surface. Some examples include: Terrabind®, M-Binder®, Hydro-Stik®, Sentinel®, J-Tac®, Guar®, and Alpha Plantago®. Organic tackifiers can also be used in combination with different types of mulch to adhere the mulch to the soil surface. These tackifiers usually come in dry powder or liquid form, are usually diluted with water in varying ratios, and applied with a hydromulcher. Some products can be applied in dry powder form as well as diluted with water. These products are relatively inexpensive and environmentally safe.

3.1.3.2.7 Water-Soluble Synthetic Polymer Soil Conditioners

Water-soluble synthetic polymer soil conditioners are complex chemical compounds that are used as soil conditioners to stop erosion and water runoff, increase water infiltration into soils containing clay, and prevent soil crusting (Weeks and Colter, 1952; Wallace and Wallace, 1986, 1989). They interact with the soil to stabilize the structure of the surface and form water-stable aggregates. The polymers can be applied to damp or dry soil in the dry state with a broadcast, drill, or aerial seeder. In one study, rates of 5.6-16.8 kg/ha (5.0-15.0 lb/acre) reduced erosion 90 to 100 percent. They can also be applied in solution with a hydromulcher or through an irrigation system at a rate of 1 to 500 milligrams/liter (1-500 parts per million) (Wallace and Wallace, 1989). These products are relatively inexpensive and environmentally safe.

The U.S. Bureau of Mines has provided some of the most extensive research on chemical stabilizers. The U.S. Bureau of Mines tested several samples of acidic, neutral, and basic mill tailings of varying salt content, which were segregated into sand, slime, and combined fractions to evaluate the effectiveness of various chemical stabilizers (Dean et al., 1974). Seventy

chemicals were tested and the best conditions and effective rates of application were determined for the most promising materials. The materials were evaluated under laboratory conditions. The coherency of the tailings surfaces after treatment was determined by both air and water systems. A water jet was used to simulate water erosion while a wind tunnel was used to simulate wind erosion. The ten most cost-effective chemicals were (a) Coherex® (a resinous adhesive); (b) Lignosulfonates; (c) Compound SP-400®, Soil Gard®, and DCA-70® (elastomeric polymers); (d) cement and milk of lime; (e) Paracol TC 1842® (a resin emulsion); (f) Pamak WTP® (a wax, tar, and pitch product); (g) Petroset SB-1 (an elastomeric polymer); (h) Potassium silicate; (i) PB-4601® (a polymeric stabilizing agent); and (j) Rezosol® (an elastomeric polymer). Armbrust and Dickerson (1971) determined Coherex®, DCA-70®, Petroset SB®, Polyco 2460®, Polyco 2605®, and SBR Latex S-2105® to be the best of 34 commercially available products tested for temporary wind erosion control. Plass (1973) also reported the effectiveness of soil stabilizers for erosion control.

Many chemical stabilizers are effective at controlling erosion for a period of three to six months. There are several that have exhibited adequate surface protection up to one year and one chemical stabilizer, Soil Seal (a latex acrylic copolymer), was shown to be effective at controlling dust from a dried evaporation lagoon at the Rocky Mountain Arsenal after 18 months. In a field test of 17 chemical stabilizers applied along bench areas of a uranium mill tailings in Wyoming, several chemicals, Wallpol 40-133® (vinyl acetate/acrylic), SP-400® (a latex emulsion), and CPB-12® (an acrylic emulsion), were fairly effective for one year (Elmore and Hartley, 1985a).

Climatic conditions play an important part in the longevity of chemical stabilizers. Field tests conducted on taconite tailings in Minnesota showed an effective longevity of only four months, which was much less than that reported for the same chemicals in the Wyoming tailings study (Bohn and Johnson, 1983). The Minnesota site received over 9 cm (3.5 in) of precipitation per month, which was considerably more than the Wyoming site (<2.5 cm [1 in]). Other researchers have noted similar loss of effectiveness caused by rain and water erosion (Elmore and Hartley, 1985b).

In general, degradation can be expected to accelerate if broken by traffic. Also, chemical stabilization of sands is more effective and has a longer duration than stabilization of fines. This is probably indicative of the better penetration of the chemicals into sandy soils, causing a thicker crust to develop.

Climatic conditions and soil composition are very different among sites. There are also many other factors, such as improper storage or application, that could influence the effectiveness of the materials tested and provide contradictory results. Certain chemicals during storage break down or solidify under freezing temperatures. Also, unused product may be considered a hazardous waste so disposal requirements may be an issue. One must be careful in using results and data from other sites, without gaining an understanding of the parameters under which the material was tested. Site-specific testing is also encouraged when possible.

3.1.3.3 Cultural Techniques

Cultural treatments refer to proper land management practices such as conservation cropping systems, contour tillage (e.g., plowing perpendicular to the slope), contour cultivation, and proper grazing systems. Additionally, strict control and management of off-road driving can substantially reduce the potential for erosion. These practices are generally used in conjunction with the other three erosion control techniques (Verma and Thames, 1978). Proper grazing management should focus on maintaining the integrity of the existing vegetation or enhancing the establishment of new vegetation. Depending on the site, one to several years of protection from grazing by livestock and wildlife may be necessary to ensure the establishment of new vegetation.

3.1.3.4 Biological Techniques

While physical, chemical, and cultural erosion control techniques are important, by far the most effective erosion control technique is biological. Establishing a permanent, vegetative cover on a site will control erosion better and longer than any other technique. Vegetation protects the soil from erosion mainly by intercepting raindrops and absorbing their kinetic energy before they can fall to the ground and dislodge soil particles. Stocking (1994) lists several other interactive processes between a plant and soil that affect erosion including the following:

- The physical binding of soil by plant stems and roots
- Electrochemical and nutrient bonding between roots and soil
- Detention of runoff by plant stems and organic litter
- Improved infiltration along root channels
- Greater incorporation of organic matter into the soil, resulting in better structural and water-holding qualities
- Increased faunal and biological activity, leading to better soil structure

Vegetation also minimizes wind erosion by decreasing wind velocity at the surface, thereby disrupting the saltation process.

Establishing a permanent, vegetative cover on a site can be done by seeding, transplanting, stimulating existing vegetation, or any combination of these techniques. These techniques are described in detail in later sections (see Sections 3.3, "Soil Amendments"; 3.4, "Seeding"; and 3.5, "Planting"). It can be difficult and expensive to establish a permanent vegetative cover, especially in arid areas. However, the alternative of leaving a site barren and exposed to erosion forces makes the effort and cost of revegetation worth it.

3.1.4 Special Considerations

In some instances, there may be disturbed areas, that for whatever reason (e.g., routinely disturbed or not cost-effective to mitigate), do not warrant the use of erosion control practices. These areas are known as sacrifice areas and should be fully utilized. For example, rather than selecting new areas for encampment sites (2.6 square kilometers [km^2] [1.0 square mile] in size)

each time, two to three areas could be selected for most encampments so that new areas are not constantly being disturbed. Road corridors can have side berms bladed or rough areas graded or graveled to discourage the widening of the corridor by drivers desiring a smoother or less dusty ride. Entry onto side roads that are selected for closure can be blocked to discourage use. Sacrifice areas should be selected and managed carefully to minimize the potential for erosion.

3.2 SITE PREPARATION

3.2.1 Objectives

The objectives of site preparation are to: (a) minimize erosion, (b) prepare a seedbed suitable for seed germination, and (c) provide a suitable soil medium for plant establishment and growth.

3.2.2 Principles

The principles of site preparation include: (a) understanding proper erosion control principles and technique implementation; (b) providing safe sites for seed; (c) reducing competition; and (d) providing proper soil aeration, good water infiltration, and proper soil structure.

One of the primary objectives of site preparation is to minimize erosion. Therefore, a good understanding of erosion control principles and techniques is important. One of the first considerations in site preparation should be what erosion control techniques are needed to minimize wind and water erosion on the disturbed site. Consideration should also be given to areas off of the disturbed site and the location of a site in relationship to the surrounding landscape. For example, check dams may need to be constructed upstream on washes that cross the site to protect key features (e.g., roads and culverts) from being washed out. Failure to consider and implement proper erosion control techniques can result in severe erosion problems and even revegetation failure on sites where a lot of money has been invested in the revegetation process. If possible, erosion control structures should be constructed before revegetation occurs so the revegetated site does not have to be disturbed and revegetated again. In addition, site disturbance during construction should be minimized as much as possible.

Seeds need a suitable environment or safe site in order to successfully germinate (Figure 3-7). Examples of safe sites include properly buried seed, seed in depressions that collect additional moisture from runoff, and under or at the base of rocks or dirt clods where seeds are protected from blowing sand and shaded from excessive solar radiation. Safe sites provide protection from seed predators, mediate the thermal environment, and enhance soil moisture. A rough seedbed with ridges and depressions is much better than a smooth level seedbed because a rough seedbed provides many more "safe sites," which results in increased seed germination and establishment. A rough seedbed is preferred for broadcast seeding small-seeded species, whereas a smooth seedbed is better for drill seeding large-seeded species (Munshower, 1994). In most rangeland seedings in arid areas, a rough seedbed is best. Vogel (1987) noted that on some mined areas seeded vegetation is established in depressions left by tractor tires but few plants are found between depressions.

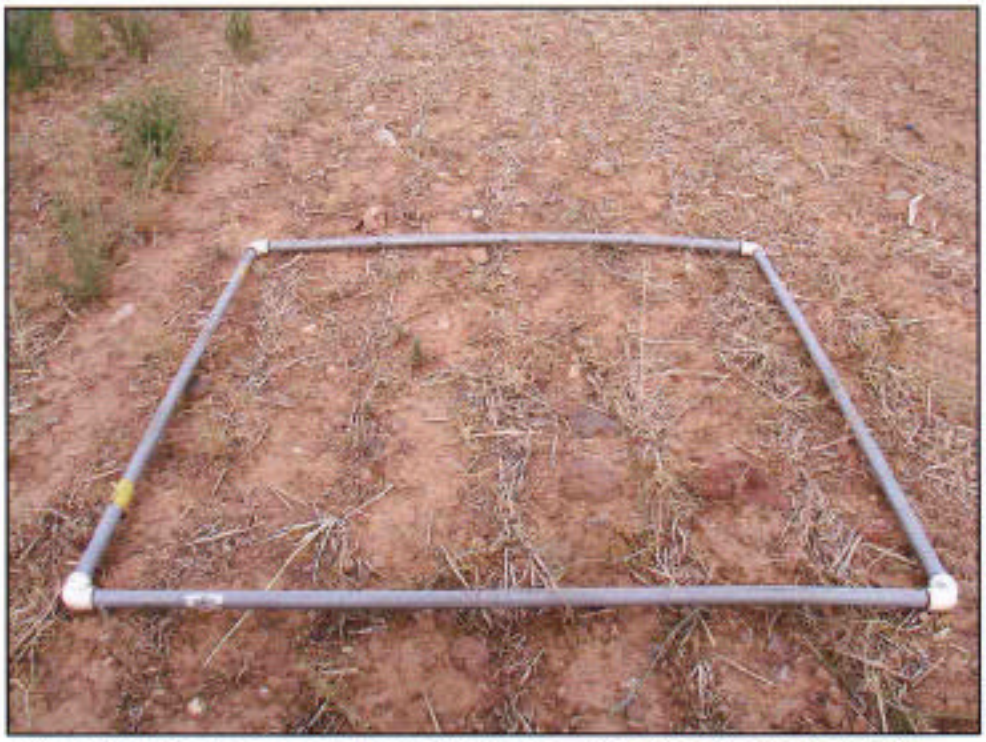

Figure 3-7. Seedlings on newly revegetated area. (Note the safe sites in mulched furrows and uneven micro-topography.)

Existing vegetation and future vegetation from the existing seed bank on a site may compete with establishing seedlings for critical resources such as sunlight, moisture, and nutrients. Vallentine (1989) reported that a major purpose of seedbed preparation is to reduce or eliminate enough of the undesirable existing vegetation and reduce the seed supply of these competitive species in order to enhance the establishment of desirable plant species. This can be accomplished through mechanical or chemical (i.e., herbicides) control (see Section 3.6, "Grazing and Weed Control," for more details on herbicide use). Care should be taken to minimize disturbance to any existing desirable plants on the site as these plants will provide future seed sources.

Root growth in arid environments is very important. Desert plants invest heavily in root system development. The investment in resources can constitute over half of their total net primary production (Caldwell, 1976; Caldwell and Richards, 1986), and the primary productivity directed to roots substantially exceeds that devoted to shoots (above-ground parts) (Caldwell, 1987). This results in a large root:shoot ratio, which is intuitive because desert plant roots need more space to extract the limited moisture and nutrients from arid land soils. Roots need oxygen in order to function properly. While roots of different species have different oxygen requirements, proper aeration of the soil is necessary to maintain healthy root systems. Techniques such as ripping, disking, and mulching help to aerate the soil and provide a suitable environment for root growth.

Plants need water to survive. According to Brown (1995), "Water is the primary solvent within which all physiological processes occur, and in which gases, minerals, and solutes enter into the plant and are translocated...Water is essential for the maintenance of turgidity in plants, which controls stomatal opening, gas exchange, cell enlargement, and growth." A plant gets most of its water from the soil through its root system. The soil on a site needs to have good water infiltration properties to allow a vegetative cover to establish and persist on the site. Infiltration reduces soil erosion and provides water that the roots can absorb as needed. Infiltration also decreases evaporation of water from the soil surface leaving more water for plants to use.

Heavily compacted sites are not conducive to good plant establishment. Brown et al. (1986) state that compaction must be alleviated because it reduces infiltration, inhibits the percolation of water, prevents root penetration, and contributes to concentrations of salts above the compaction zone. Several studies have shown that both tracked and wheeled vehicles cause increased soil compaction (Braunack, 1986; Barnes et al., 1971; Chancellor, 1976, Soane et al., 1981a,b, 1982; Radcliffe et al., 1989; Gassman et al., 1989). It is important to relieve compaction not only at the surface (10-15 cm [4-6 in]) but also below the surface (30-91 cm [1-3 ft]) as well to encourage deep root penetration, particularly in arid environments. Soil structure is also important for seed germination and establishment. If the surface is too powdery, it will be susceptible to wind erosion. Also, seeds can be buried too deep, and fine-textured soils can develop a crust when wetted that may prevent seedling emergence. Fine-textured soils generally have more structure than coarse-textured soils. Soils should not be worked (i.e., disked, harrowed, etc.) when they are wet because this tends to increase compaction and destroy soil structure.

3.2.3 Techniques

Techniques for erosion control have already been discussed in Section 3.1, "Erosion Control." Some of these (i.e., pitting, imprinting, and gouging) also enhance the seedbed by acting as water catchments and creating safe sites for seeds. The following discussion will focus on seedbed preparation techniques. These techniques include ripping, chiseling, disking, harrowing, and slope chaining. Ripping, chiseling, disking, and harrowing should always be done on the contour to minimize erosion.

Ripping is the practice of pulling a steel tooth or shank through the soil, subsoil, or overburden (Munshower, 1994), and is used primarily to relieve compaction. "It may also be used on a slope to roughen the surface and destroy any slippage plains that might develop between overburden and subsoil or between subsoil and surficial soil layers." (Munshower, 1994). The depth and degree of compaction and the soil type determine the ripping depth and the type of equipment to use. The distance between ripper teeth should be approximately equal to the length of the ripper teeth (USDA Forest Service, 1979a). Soils with relatively high amounts of clay and silt particles are especially susceptible to compaction (Vogel, 1987). Compaction can also occur in sandy soils, but is usually less severe in these types of soils.

For heavy compaction, deep rippers pulled by large bulldozers or road graders are very effective (Figure 3-8), and can rip to a depth of about 0.9 m (3 ft). Deep ripping is not advised where it will bring highly acid or alkaline materials or buried waste to the surface. Avoid deep ripping on slopes where rapid infiltration of water can create an unstable mass prone to slippage and

Figure 3-8. Road grader ripping a site during site preparation.

landslides. Subsoilers are another type of equipment that may be useful on some sites that are relatively rock free. They differ from rippers in that they have less of a tendency to bring materials to the surface or mix soil horizons.

The largest subsoilers can rip to a depth of 2.7 m (9 ft) but shallow ripping (30 to 45 cm [12 to 18 in]) is more common. Subsoiling should be avoided where it will penetrate into sandy or other pervious layers in which water tables will drop rapidly during drought (Vogel, 1987).

For sites with light to moderate compaction in the surface layers (top 30 cm [12 in]), a chisel-tooth plow (Figure 3-9) can be used. Chisel-tooth plows have several arms with chisel points and are usually pulled behind a farm tractor. The arms operate against a heavy spring allowing them to ride over large surface and subsurface rocks. Chisel points should be inspected regularly for wear and replaced as necessary. Heavy wear occurs in rocky soils, particularly in sandstone. Chisel-tooth plows leave a seedbed smooth enough to accommodate drill seeders pulled by farm tractors, and rough enough to catch broadcast seed and trap moisture and runoff water. They will break compacted layers that are impenetrable to disks but are not effective in heavily compacted soils (Vogel, 1987). They can also be used to incorporate fertilizer into the soil and kill shallow-rooted weeds that may have become established (Munshower, 1994).

Disking is used to break up surface crusting, break up dirt clods, smooth the surface, incorporate lime into the soil, and mix organic matter or an established vegetative cover into the soil. Farm tractors are generally used to pull a disk (Figure 3-10). Tandem disks and offset disks mix the soil as opposed to just inverting it. Disking produces a good seedbed. However, a disked seedbed may be more susceptible to erosion than a seedbed prepared with a chisel-tooth plow.

Figure 3-9. Chisel-tooth plow followed by a drag harrow used to reduce compaction and roughen the upper 10-15 cm (4-6 in) of the soil.

Figure 3-10. Offset disk being pulled by tractor to break up clods.

Also, rocky sites are not very conducive to disking because large rocks tend to raise the disk or portions of it out of the soil, rendering the disk ineffective (Vogel, 1987). Disking is usually limited to 40 cm (16 in) of penetration, and does not break compaction in subsurface materials (Brown et al., 1986).

Harrowing is the final process of seedbed preparation. The purpose of harrowing is to break up clods, smooth the surface, and close air pockets. Several types of harrows are available including the pipe harrow, spring-tooth harrow, spike-tooth harrow, and drag harrow (Figure 3-9). The pipe harrow is adapted to rocky and steep sites and scarifies soil sufficient for covering broadcasted seeds on burns, abandoned roads, or excavation scars but does not kill large shrubs or sprouting plants. It brings many rocks to the surface.

The other three harrows are adapted for secondary tillage, weed control, and smoothing the soil surface, but are not adapted to rough, rocky, or brushy sites (Vallentine, 1989). Harrows are usually equipped to attach to disks or other pieces of equipment such as disks and chisel-tooth plows. This allows one to rip or disk and harrow both at the same time. This practice reduces project time and cost and minimizes the amount of trafficking over the site.

For steep slopes (greater than 3horizontal [h]:1vertical [v]) where equipment cannot be used safely or effectively but access above the slope is possible, a technique called slope chaining can be used to prepare the seedbed. The slope chain consists of a length of lead chain pulled by a truck or tractor connected to various lengths of scarifying chains depending on the length of slope, and a slope wheel connected by swivels. Pairs of 15-cm (6-in) steel picks or other scarifying devices are welded to the scarifying chain at right angles. The slope wheel has a heavy 227-kilograms (kg) (500-pound [lb]) weight attached. The lead chain is attached to a truck or tractor operating on a road or bench above the slope. The chain is dragged across the slope. Several passes are usually necessary. Slope chaining is not very effective on rocky or compacted sites (Hansen and McKell, 1991).

3.2.4 Special Considerations

In many areas of the arid western United States, caliche layers have developed in the subsurface soil layers. Caliche is formed by calcium carbonate precipitating in the lower soil horizons which cements soil and rock particles together, thus forming a hardpan layer (Schlesinger, 1985). The caliche layer may be found at varying depths below the surface within a site. Depending on the thickness of the caliche layer, one may or may not be able to break through this layer with standard site preparation techniques. Rocky soils present similar challenges for site preparation. Adding topsoil to critical revegetation areas may be effective in creating a soil medium for plant establishment and growth; however, in most cases, this is probably not cost-effective or practical. Other techniques, such as the use of chemical soil stabilizers could be used to control erosion on these sites.

UXO is a big concern in certain areas, especially on DoD and some DOE lands. Proper UXO surveys should be completed prior to any site preparation work and personnel involved in site preparation should be trained in UXO. Workers should be aware of the potential for UXO even in areas that are not considered UXO areas (Figure 3-11).

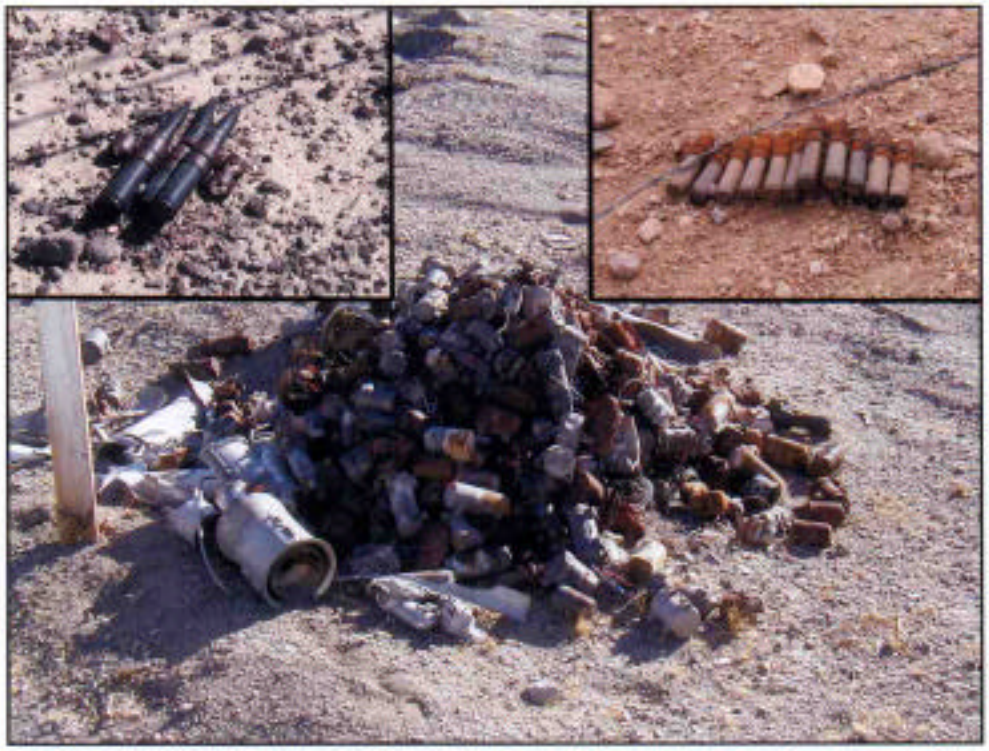

Figure 3-11. Unexploded ordnance may create unseen hazards that should be removed before earth-disturbing activities.

In addition to surveys for UXO, it is often necessary to survey areas for any cultural or archeological artifacts. Some areas may also require surveys for biological resources such as endangered or sensitive species prior to any surface disturbance.

In some cases, it may be necessary to salvage topsoil from a site, store the topsoil, and then redistribute the topsoil back over the site at a later date. Topsoil is a general term and applies either (a) to the soil surface, usually to the plow depth or the minimum depth that a scraper operator can successfully lift from the soil; or (b) to the depth of material that expresses good plant growth-supporting characteristics. Most of the organic matter and nutrients, seed bank, and micro- and macroorganisms are found in the top layers of soil. These layers also usually have more favorable physical (e.g., soil structure, infiltration rate) and chemical (e.g., pH, mineral concentrations) properties for plant growth (Munshower, 1994). The purpose of salvaging topsoil is to keep this valuable resource for use at a later date. Once these layers are gone, it is difficult and costly to replace them and in many cases impossible to do so.

Salvaging topsoil is sometimes considered a necessary reclamation practice to preserve topsoil properties. However, during the salvaging process, soil structure, soil microflora, plant nutrients, and the seed bank may be damaged. Some of this damage can be minimized through proper topsoil handling (Civilian Radioactive Waste Management System [CRWMS] Management and Operating [M&O] Contractor, 2001). Topsoil handling techniques, stockpile depth, erosion protection, and timing of stockpiling are important parameters in maintaining a viable topsoil

(Chambers, 1989; Colorado Natural Areas Program, 1998). The fewer times the topsoil is handled the better, both in terms of cost and maintaining topsoil integrity. Hansen and McKell (1991) recommend that topsoil be salvaged and stockpiled when relatively dry to minimize compaction; however, some moisture may be desirable to help maintain soil structure (Chambers, 1989). CRWMS M&O (2001) recommend that heavy equipment not be operated on top of the stockpile while it is being built, but that the topsoil be dumped and pushed into place to the desired depth in order to minimize compaction. Topsoil can be stockpiled to a depth of 2.0 m (6.6 ft) with little effect on soil viability (CRWMS M&O, 1999).

It is important to store the topsoil properly to maintain the viability of the topsoil, especially the soil microbes. Maintenance of microbial populations (including mycorrhizal fungi) in stockpiled soil is influenced by the amount of organic material in the soil (Elkins et al., 1984; Visser, 1985), the amount of water in the soil (Miller et al., 1985) and the length of time the soil is stockpiled (Miller et al., 1985; Viceroy Gold Corporation, 1995). Vegetation that form mycorrhizal relationships with beneficial fungi can be planted on the stockpiled soil to maintain microbial populations and organic matter U.S. Department of Interior (USDI Bureau of Land Management [BLM], 1992; Brown and Hallman, 1984; USDA Forest Service, 1979b). The vegetation also helps to minimize erosion. Topsoil erosion control may also include spraying chemical soil stabilizers on the stockpiles and checking them periodically (e.g., semiannually) for erosion. Topsoil stockpile location is also important for erosion control. Stockpiles should be located on level ground, if possible; not in a drainage or wash; and up-slope of disturbances. For many sites, the most feasible way to stockpile topsoil is to use heavy equipment (e.g., road grader, bulldozer, or front-end loader) to scrape the topsoil into a berm off to the side of the area to be disturbed. The berm can then be stabilized for erosion control. This way, there is no cost or labor in transporting topsoil to a stockpile area and back to the disturbed site during site preparation.

After the disturbance is complete and the site is ready for site preparation, the spoils (i.e., subsurface soils not conducive to good plant establishment) and topsoil should be distributed back over the disturbance. This process is called recontouring. The topsoil should be spread over the top of the subsoil, or if needed, any additional fill material, to a uniform depth. Recontoured slopes should be no steeper than 2h:1v, because revegetation efforts are rarely satisfactory on slopes steeper than this (USDA Forest Service, 1979b). Slopes should be 3h:1v or less if equipment will access the site (USDI BLM, 1992); however, slopes of 4h:1v or less are more conducive for vegetation establishment (CRWMS M&O, 2001).

Slope length and slope shape should also be considered during recontouring. Slope lengths that exceed 15.25 m to 30.5 m (50 ft to 100 ft) at 4h:1v or steeper may result in concentrated water flow, depending on soil texture and vegetative cover. In comparison, slopes of 5h:1v become problematic at lengths of 46 m (150 ft) or greater (Ferris et al., no date). Water diversion channels can be constructed above slopes and at intervals to direct water off the slope and control erosion on long slopes.

Another consideration during site preparation is vegetation removal and plant salvaging. Before topsoil is salvaged, it may be appropriate to brush rake existing vegetation into piles. Brush rakes consist of several curved teeth attached vertically to a heavy-duty frame and they often have replaceable tips to protect the rake teeth. Brush rakes usually replace the standard dozer

blade, but some can be attached directly to the standard dozer blades. A brush rake is superior to a standard dozer blade or road grader because soil is filtered through the rake and not scraped into the brush piles. Brush piles can be chopped and spread over the site and incorporated into the soil during site preparation activities. This provides valuable organic matter, microbial spores, and possibly seed to the soil (Hansen and McKell, 1991).

Some plant species (e.g., cacti, yuccas, and Joshua trees) that grow slowly but transplant well may be selected to collect or salvage before disturbance occurs. In fact, some areas require salvaging of certain species by law. The state nursery or extension office are good sources of information on how to properly salvage, store, and transplant different species (see Section 3.5, "Planting"). Transplanting during the proper time of year and into suitable moist substrates is a key consideration.

3.3 SOIL AMENDMENTS

3.3.1 Objectives

The objective of using soil amendments is to incorporate supplemental materials into the existing soil matrix to provide a suitable growth medium for plant germination, emergence, growth, and reproduction.

3.3.2 Principles

Soil provides a medium where seeds can germinate. In fact, good seed-soil contact is a major germination requirement for most species. Once germinated, plants need soil in which to establish their root systems. Soil provides the rooting medium from which roots extract water, nutrients, and oxygen to sustain and perpetuate life. Plants have specific requirements for water, nutrients, and oxygen. Amendments cause the following changes in the rooting medium: (a) improved hydrologic properties (e.g., water holding capacity, infiltration), (b) macro- or micronutrient additions, (c) organic matter increases, (d) improved aeration, (e) pH changes, (f) reduced erosion, and (g) temperature modification (Munshower, 1994).

When the soil profile is modified or even destroyed by disturbance, the natural physical and chemical properties of the soil are modified or lost to the point where the soil may not be suitable for plant growth. In order to replace these lost properties or make the soil suitable for plant growth, soil amendments are sometimes needed. Soil amendments are defined as natural or man-made materials that are applied and incorporated into the soil profile to improve the soil-water or soil-air relationships by altering soil physical and chemical properties (USDI BLM, 1992). Amendments should not be confused with mulches, which are used to alter surface characteristics and environment (Vogel, 1987).

In order to determine which amendments are necessary, field and laboratory soil chemical and physical tests should be conducted (Vogel, 1987). Table 3-1 lists some soil chemical and physical parameters to measure, and provides a suitability rating based on the test results. This

table should be used as a general guide to determine if soil at a particular site is suitable for plant growth. Soil fertility tests may also be performed to better define which amendments may be

Table 3-1. Soil material suitability for salvage and reclamation use (USDA Forest Service, 1979b).

Definition: suitability, as defined, is the qualities and properties of natural soils or soil material that chemically and physically provide the necessary water and nutrient supply for the top growth and root development of plants.

Criteria: the following groups of ratings are indicators of potential quality of natural soil profiles, certain soil horizons, or the underlying parent material, disregarding nutrient levels.

	Levels of Suitability[1]			
Major parameters	**Good**	**Fair**	**Poor**	**Unsuitable**
USDA soil texture	Fine sandy loam, very fine sandy loam, loam, silt loam, sandy loam	Clay loam, sandy clay loam, silty clay loam	Sandy, loamy sand, sandy clay, silty clay, clay	Clay textured soils with more than 60% clay
Salinity (mmho/cm)	Less than 3	3-6	6-9	More than 9
Alkalinity (exchangeable sodium percentage, ESP)	Less than 4	4-8	8-12	More than 12
Concentration of toxic or undesirable elements, i.e., boron, selenium, arsenic, % lime, etc.	Very low	Low	Moderate	High
Soil pH	6.1-7.8	5.1-6.1 7.9-8.4	4.5-5.0 8.5-9.0	Less than 4.5 More than 9.1
Additional parameters to be evaluated				
Moist consistency	Very friable, friable	Loose, firm	Very firm, extremely firm	
Coarse fragments, % by volume	0-10	10-20	20-35	More than 35
Available water-retention capacity (in/in)	More than 0.16	0.08-0.16	Less than 0.08	
Permeability (in/hr)	0.6-6.0	0.2-0.6	Less than 0.2 or greater than 6.0	
Organic matter (%)	More than 1.5	0.5-1.5	Less than 0.5	
Soil structure	Granular, crumb	Platy, blocky, prismatic	Massive, single grain	

[1]*Ratings may be raised one class if soil amendments or management practices can be applied to overcome the limitations.*

needed. Analyses of nitrogen; phosphorus; potassium; certain trace elements (e.g., iron, zinc, manganese, selenium, boron, and copper [DTPA extractable]); presence of calcium, magnesium, and sodium; and cation exchange capacity are commonly conducted to determine nutrient levels. Tests for salinity-sodicity (pH; soluble salts; water soluble calcium, magnesium, sodium, and potassium; sodium adsorption ratio; exchangeable sodium percentage; water soluble anions CO_3, HCO_3, SO_4, Cl, and NO_3; and gypsum) and acidity (pH, sulfide [qualitative], acid-base equilibrium, and lime requirement) may also be conducted. The initial test for alkaline or acidic soils is pH. If the pH is greater than 7, run tests for salinity-sodicity. If the pH is less than 7, run tests for acidity (USDA Forest Service, 1979b). Soils in the arid areas of the western United States are generally alkaline. Acidic soils are rarely a problem. However, sodic and saline soils can be problematic in these areas (see Section 3.3.4, "Special Considerations").

It is critical to know which plant species will be used during revegetation and what are their specific requirements for growth. Some adapted species may thrive in poor quality soils but die in good quality soils. Obviously, the seeded plant community should match the potential of the site to maintain that community with the minimum input of amendments.

3.3.3 Techniques

Three primary techniques are used to ameliorate soils that are marginally suitable for plant growth. These include: (a) the use of synthetic polymer soil conditioners, (b) adding organic matter, and (c) fertilization.

3.3.3.1 Synthetic Polymer Soil Conditioners

Bear (1952) first introduced synthetic polymer soil conditioners to the scientific community. Azzam (1980) reviewed the subject including over 500 references. These polymers can be either water-insoluble or water-soluble (Wallace and Wallace, 1989; Wallace and Wallace, 1990). For a detailed description of the mechanisms involved in soil conditioning by these polymers (Wallace et al., 1986).

Water-insoluble polymers are usually cross-linked and swell in the presence of water from 50 to 400 times their weight (Figure 3-12) (Azzam, 1985; Henderson and Hensley, 1986). Depending on the degree of cross-linking and the base material in the polymers, 40 to 95 percent of the water in the gels can be available to plant roots. Cross-linked polymers do not combine with clay in soil like the water-soluble ones do (Wallace and Wallace, 1990). The main purpose for using water-insoluble polymers is to increase the water-holding capacity of the soil. Azzam (1985) lists three ways a specific water-insoluble polymer, RAPG-3700, preserves water and include: (a) bound water absorbed by the polymeric matrix via swelling, (b) free water incubated in aggregate's structure, and (c) condensed water restored as a result of mulching the soil surface with the polymer. He also described additional benefits of using this polymer which include increased aggregate stability, lack of cracking and crusting, decreased evaporation and transpiration, increased fertilizer use efficiency, and increased plant productivity. Water-insoluble polymers can be applied to soil in the dry state with a broadcast, drill, or aerial seeder, or applied emulsified in water to wet soils with a hydromulcher. For best results, the polymer

Figure 3-12. Water-insoluble polymer after absorbing water and expanding.

should be worked into the top 8-15 cm (3-6 in) of soil with a disk or harrow. Applying 22.4 kg/ha (20.0 lb/acre) of a water-insoluble polymer increased emergence and initial establishment of seedlings at two sites near Yucca Mountain, Nevada, but did not appear to increase long-term survival over control plots (Winkel et al., 1999). SoilMoist™ is one example of a commercially available water-insoluble polymer.

Water-soluble polymers are not cross-linked and, therefore, have much reduced absorbent properties compared to water-insoluble polymers. Their primary purpose is for erosion control but may also increase pore space in soils containing clay, increase water infiltration into soils containing clay, and make friable soil that is easy to cultivate (Wallace and Wallace, 1989). Water-soluble polymers can be applied to wet or dry soil in the dry state with a broadcast, drill, or aerial seeder, or applied in solution with a hydromulcher or irrigation system. For best results, the polymer should be worked into the top 8-15 cm (3-6 in) of soil with a disk or harrow. Additionally, Wallace (1988) determined that using a solution of water-soluble polymer improved transplant survival and growth. He states, "The reason for inclusion of solution of the polymer is to preserve the stability of the soil aggregates, which results in better aeration around the roots of the transplants." The concentration in solution for transplants is usually 200-500 milligrams/liter (200-500 parts per million) (Wallace and Wallace, 1990).

The polymers themselves are relatively inexpensive, but to apply them and disk them into the soil requires an additional one or two passes over the site. Also, some evidence suggests that long-term plant survival does not increase with the use of the polymers.

3.3.3.2 Organic Materials

The addition of organic materials to the soil can decrease bulk density, increase water infiltration, and increase water-holding capacity of the soil. Chemically, organic materials can reduce acidity, increase cation exchange capacity, add plant nutrients, help hold nitrates, and reduce leaching losses. Some organic materials also provide an energy source for beneficial soil microorganisms and soil fauna (Vogel, 1987). Munshower (1994) reported that organic amendments improve hydrologic properties, reduce erosion, and modify temperature extremes. Morgan et al., (1986) reported that the landscape industry used large amounts of organic amendments in the soil with transplants to improve soil aeration.

Many different types of organic amendments have been tested and are mostly agricultural, industrial, municipal, residential, and forestry-related wastes or residues. These include barnyard and poultry manure, composted garbage, leaves, sewage sludge and effluent, and combinations of these materials, such as garbage or leaves mixed with sewage sludge. Crop residues, such as straw, and residues such as bark and wood chips from sawmills and wood-conversion operations have been used both as soil amendments and as mulches (Vogel, 1987).

Vogel (1987) discussed factors influencing rates of application of different organic materials. These factors include the purpose for which they are applied, physical and chemical properties of the soil, depth of incorporation, and cost of obtaining and applying the materials. He further suggests some application rates of different materials: barnyard manure and composted garbage, 34 to 67 metric tons/ha (15-30 tons/acre) and sewage sludge and effluent, volumes equivalent to 45-112 metric tons/ha (20-50 tons/acre) of dry matter. Munshower (1994) suggests applying wood residues (e.g., wood chips, sawdust) at a rate of 1,700 kg/ha (1,500 lb/acre) or more. Straw as an organic amendment can be applied at a rate of 1.1 to 4.5 metric ton/ha (0.5-2 ton/acre) (Mannering and Meyer, 1963; Meyer et al., 1970; Thornburg, 1982).

Livestock waste is one of the most complete organic additives that can be applied to a disturbed soil (Meek et al., 1982). The most common means of distribution is with a manure spreader. After spreading, the manure should be incorporated into the soil with a disk, plow, or rototiller. Manure is especially useful in acid wastes but may be problematic in saline soils. Manure additions should be carefully assessed before using on saline soils because animal wastes have a high salt load and exacerbate the salt problem (Vogel, 1987). They may also contain seeds of undesirable plants, such as invasive species. Another problem with using manure is its availability. If a manure source is close to the reclamation site, it can be a relatively inexpensive organic amendment. Otherwise, transport costs may be too high to use this amendment.

Compost is derived from the biological decomposition of any solid waste. Research in the Northwest clearly reveals the benefits of compost additions to arid rangelands (Brandt and Hendrickson, 1991). They suggest that the greatest benefit is its ability to augment the water-holding capacity of the soil. Manure spreaders can be used to distribute compost over the disturbed site after which the compost can be incorporated into the soil with a disk, plow, or rototiller. Large quantities of compost are generally available near urban areas at a relatively inexpensive price. In other areas, transport costs may preclude the use of composts.

Sewage sludge is the material (organic and inorganic) removed from wastewater at sewage treatment plants. The sludge contains a number of nutrients and organic residues that make it a valuable amendment for degraded sites (Hill and Montague, 1976). Sewage sludge may be applied to a site with a manure spreader and incorporated into the soil with a disk, plow, or rototiller. Like compost, large quantities of sewage sludge are generally available in urban areas at a relatively inexpensive price. In other areas, transport costs may prevent the use of sewage sludge. The presence of phytotoxic metals in sewage sludge can also be problematic, and may limit the use of it as a soil amendment. Federal guidelines regulate acceptable levels of the metals and should be followed if sewage sludge is used.

Wood residues are by-products of wood processing or conversion operations and include wood chips or fibers, sawdust, and bark fragments. They are an inexpensive organic material that can be distributed over a site with a dry blower, hydromulcher, or manure spreader and then incorporated into the soil with a disk, plow, or rototiller. If applied with a dry blower or hydromulcher, wood particles must be ground to the proper size so as not to ruin the equipment. Sawdust tends to be rapidly digested by microbes and has an undesirable carbon:nitrogen ratio while chips and bark fragments last much longer and are the more common form of wood residue used as an organic amendment (Munshower, 1994). Nitrogen fertilization is strongly recommended if wood residues are used (Munshower, 1994; Vogel, 1987).

Straw is primarily composed of the stems of cereal grains such as wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), or oats (*Avena sativa*). As a soil amendment, it is typically spread over a site using a dry blower and then disked or plowed into the soil. Like manure, having a straw source relatively close to the reclamation site makes straw a relatively inexpensive organic amendment. Otherwise, transport costs may preclude the use of this amendment. In addition, straw may contain large amounts of seed that may germinate and create competition for native plant species.

The incorporation of some organic materials, such as animal manure and composted sewage sludge, adds plant nutrients to the soil. However, incorporating materials that are not composted and are high in cellulose (e.g., wood residues, straw), may cause a nitrogen deficiency to plants as the material decays, so additional nitrogen fertilizer should be applied for the benefit of the vegetation. For herbaceous vegetation establishment, an extra 7-11 kg (15-25 lb) of nitrogen for each 0.9 metric tons (1.0 ton) of high cellulosic or non-composted organic material incorporated into the soil is recommended (Vogel, 1987). Munshower (1994) also advocates the use of nitrogen fertilizer when organic amendments such as straw or wood residues are used and gives as a general rule that nitrate additions should maintain a carbon:nitrogen ratio between 12:1 and 20:1. In contrast, wheat straw crimped into the soil has been used as an organic mulch (4.5 metric ton/ha [2 tons/acre]) at numerous reclamation sites in south-central and central Nevada with great success without the use of fertilizers (Hall and Anderson, 1999; CRWMS M&O, 2001).

3.3.3.3 Fertilization

Fertilization is the process of adding nutrients to the soil to compensate for low levels of nutrients that have been lost or just naturally occur in low amounts. The purpose of fertilization

is to increase the productivity of the soil so that the plants growing in the soil will have the necessary resources to establish, grow, and reproduce, thereby creating a permanent, self-perpetuating plant community. Fertilizer can be added prior to or at the time of seeding, after seeding, or during transplanting. Bauer et al. (1978) states that, "Nutrient deficiencies, especially of [nitrogen] N and [phosphorous] P, are widespread in soils of the semiarid and arid regions and are expected to be the major nutritional problem in spoilbank reclamation from the standpoint of areal extent and distribution. Known deficiencies of other nutrients exist in soils of the region, but the areal distribution is low in comparison to N and P."

In arid areas of the western United States, fertilization is generally not recommended as a revegetation technique when seeding with native, adapted species (CRWMS M&O, 2001; Munshower, 1994; Vallentine, 1989) for several reasons. These include: (a) although soils in these areas have a low nutrient status, native plant species evolved under these conditions and are adapted to the low nutrient levels (Munshower, 1994); (b) fertilization has not been shown to increase germination and establishment of seeded species; (c) fertilization is usually not cost-effective; and (d) fertilization stimulates the growth of undesirable annuals (Figure 3-13) (Patterson and Youngman, 1960; Sneva, 1963; Wilson et al., 1966; Kay, 1966) that may decrease perennial productivity or out-compete the seeded perennial seedlings for critical resources such as water and nutrients (Patterson and Youngman, 1960; Wilson et al., 1966; Hall, et al., 1999; Hormay, 1943a,b; Holmgren, 1956).

Figure 3-13. Fertilized (dark green plots in the background) versus unfertilized (light green) plots. Fertilization promotes the introduced annual grass, *Schismus arabicus*.

It may be effective to use fertilizer after seedlings have become established or after established plants have been damaged from disturbance (e.g., encampments, trafficking) to increase the productivity of these plants (Figure 3-14).

Figure 3-14. Fertilization of shrubs may promote greater seed set of fertilized shrubs (bottom) compared to unfertilized shrubs (top).

Increased productivity may come from higher seed production, increased cover and biomass, and overall improved plant vigor. A study conducted at Fort Irwin, California showed that fertilizer broadcast on the surface (27 kg N/ha, 22 kg P/ha, and 22 kg K/ha [24 lb N/acre, 20 lb P/acre, and 20 lb/K/acre]; N = Nitrogen, P = Phosphorus, and K = Potassium) increased the leader and inflorescence length of white bursage (*Ambrosia dumosa*). This, in turn, yielded more seeds per plant on fertilized plots than unfertilized plots. The greatest increase did not occur until the second growing season after fertilization occurred. Observations on a few plots showed that doubling the fertilizer rate actually caused a decrease in leader and inflorescence length, while using only 5 kg N/ha (4 lb N/acre) did not affect leader and inflorescence length (BN, unpublished report). Site-specific trials may be needed to determine if fertilizer is a cost-effective technique to use. Also, sufficient moisture is required to make the fertilizer effective. Seeding adapted legume species is recommended when possible because legumes fix nitrogen that benefits not only themselves but surrounding plants as well (Hansen and McKell, 1991). Fertilizer can be applied dry with cyclone or broadcast-type spreaders, pull-type flow spreaders, regular lime-spreading trucks, and with aircraft or even by hand on small areas (Vogel, 1987). It can also be applied in solution with a hydromulcher or through an irrigation system.

Fertilizers may also be used during transplanting. Hansen (1989) recommends that fertilizers for shrub transplants be used in sterile substrates such as mine tailings and deep subsoils that are deficient in nutrients, and that fertilization is not required when using fertile topsoil. When

fertilizer is used, Hansen suggests the use of a slow-release fertilizer such as a 20-gram (0.7-ounce) tablet of 20 percent N, 10 percent P, and 5 percent K that should be placed in the bottom of the transplant hole and covered with a light layer of soil before inserting the transplant.

3.3.4 Special Considerations

Sodic soils, soils high in sodium, can be problematic in some areas because they have poor water infiltration and percolation. Vogel (1987) discusses a few potential solutions to problems with sodic soils. These include using sodium-tolerant plant species, leaching the sodium from the soil with irrigation water, adding topsoil and organic matter to improve soil aggregation, and disking and subsoiling to improve structure and drainage (deep tillage should be avoided in areas with a high water table to prevent water from rising to the surface carrying sodium into the rooting zone).

Several amendments have also been used to ameliorate sodicity and include calcium chloride, gypsum, ammonium nitrate, and ammonium sulfate (Munshower, 1994; Vogel, 1987). Calcium chloride and gypsum supply calcium ions to the amended soil and lower sodium adsorption ratios. The ammonium radical (NH_4^+) also displaces sodium. This, in turn, flocculates the soil, increases infiltration, permits leaching of salts deeper into the profile, and reduces surface soil crusting. Calcium chloride is more expensive than gypsum but is more soluble than gypsum (Munshower, 1994). "A combination of gypsum (80 percent), ammonium sulfate (10 percent), and calcium chloride (10 percent) has been found to be twice as effective as gypsum alone in preventing sodium from migrating up into topsoils spread over sodic minesoils" (Vogel, 1987). If these amendments are used and the sodium ions are displaced, these ions must then be leached out of the rooting zone. In arid areas, this requires the use of a lot of supplemental irrigation.

Saline soils, soils with basic salts other than sodium, may also be problematic. Using adapted, saline-tolerant plant species is the best solution. However, in some cases saline soils may be treated with acid-forming chemicals (e.g., sulfur, sulfuric acid, iron sulfate, aluminum sulfate, and lime sulfate) and leaching to promote plant growth (Vogel, 1987).

Results from the soil analysis should determine if sodicity or salinity is a problem. Application rates for the amendments should be based on the extent of the problem as determined by the soil analysis.

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3.4 SEEDING

Direct seeding is a common practice used in the reclamation process. Usually sites that are being reclaimed have been disturbed to a degree that leaves a soil void of viable native seeds. On relatively small sites, seed from adjacent undisturbed areas might eventually find its way onto the site. This is especially true on narrow disturbances (e.g., pipelines and roads). However, in most instances areas being revegetated are large sites, or have been severely disturbed, and the native seed pool has been exhausted. The determination to actively revegetate a disturbed area or merely protect the site from future disturbance is a decision to be made during the planning phase (Section 2.0, "Reclamation Planning").

3.4.1 Objectives

The objective of seeding is to return to the disturbed site a sufficient number of viable seeds of plant species native to the site so that a sustainable vegetative cover might be established. Seeding relies heavily on the natural revegetation process. The goal is to get enough viable seed back into the soil so that when conditions are favorable, the seed germinates and becomes established on the site.

3.4.2 Principles

Direct seeding is an effective method of increasing the number of viable seeds in the soil. It is relatively inexpensive and if proper techniques are used and soil moisture is high enough, direct seeding can be successful.

There is a risk associated with direct seeding because it relies heavily on natural processes, which may be unpredictable and unreliable. Natural conditions that favor seed germination and growth of native species occur infrequently in the arid regions of the Southwest (Wallace et al., 1980; Bainbridge et al., 1995), which results in a low percentage of germination of seeds in the soil. Usually large amounts of viable seed are placed in the soil, assuming only a small percentage will actually experience conditions that will allow germination.

The key to success with direct seeding is to enhance those factors that encourage seed germination. First, providing high-quality seed adapted to the site. There must be good seed-to-soil contact. There must be sufficient water in the soil for the seed to meet germination requirements and become established. The soil should be firmly compacted around the seed to ensure that the seed does not dry out. Once the young seedling is established, it must be protected either from severe environmental conditions, unnatural competition for resources, or herbivory. Enhancing any or all of these factors increases the potential for successful revegetation.

3.4.3 Techniques

3.4.3.1 Species Selection

The selection of appropriate plants for the site may be the most critical part of reseeding a disturbed site (Wiesner, 1997). Plant species should be native to the site or are known to occur in the vicinity as determined either from pre-disturbance plant surveys or sampling of reference areas. Much of this information would have been collected during site assessments (Section 2.0, "Reclamation Planning"). If a species list is not available, a list of species for the particular region may be used (Table 3-2). There are other references as well which provide lists of species that may be adapted to particular site conditions (Ostler and Allred, 1987; Thornburg, 1982; Winkel et al., 1999; Wallace et al., 1980). SERDP has a project (see: www.crrel.usace.army.mil/gcd/curr-research.htm) that is developing wear-resistant cultivars of species that will be useful on military training lands in the Great Basin and other semiarid lands.

Prior to the first contact with seed companies, species should be selected and the quantities of each estimated. The species to be used in the reseeding of a site will be determined by the goals established during the planning process (Section 2.0, "Reclamation Planning"). If the goal is to return the site to pre-disturbance conditions, then the mix of species should reflect the composition of the native plant community. This does not mean to include all species found on the site in the seed mix, but species should be prioritized based on abundance and cover of the species found in the native plant community. Different goals may demand different species and the species mix should reflect those goals.

Once the species to be used are identified, the quantity of each species needs to be determined. This determination is best completed using a combination of quantitative and qualitative methods. A common method used to quantitatively estimate the amount of seed needed is to prepare a simple matrix showing the species, the number of seeds per kg, the number of seeds per square meter (m^2) at 1 pure live seed (PLS) kg/ha, the cost per PLS kg, and other criteria, such as percent germination or seed purity (Table 3-3). If the goal is to seed 22.4 PLS kg/ha (20 PLS lb/acre) of seed, and a particular species accounts for 20 percent of the density on the undisturbed community, then 20 percent of 22.4 PLS kg or 4.5 PLS kg (4 PLS lb) of seed of that particular species should be included in the mix (Table 3-3). This should be repeated for each of the species. By determining the PLS kg required for each species while using the matrix, you can calculate the number of seeds per m^2.

The qualitative evaluation of the seed mix considers the size of the seed, experience with the performance of the species on other projects, importance of the species in the plant community or in meeting revegetation goals, and the anticipated cost for the seed. The goal of the number of seeds/m^2 should take all of these factors into consideration. If seeds are larger and germination is relatively high, less seeds/m^2 may be suggested, unless maybe the species accounts for the majority of the cover, so the number of seeds may be increased. Naturally if seeds are smaller and germination is low, more seeds/m^2 would be appropriate.

Table 3-2. Suggested list of species adapted to arid environments of Southwestern U.S.

Nomenclature		Region			Seed Mix Information								Transplants	
Scientific Name	Common Name	Great Basin	Mojave	No. Sonoran	Origin	No. Seeds/kg	Acceptable Range of Viability	Common Range of Purity	Seed mix category	Seed Availability	Ease of Establishment	Optimum Germination Temperature	Transplant Availability	Ease of Establishment
SHRUBS														
Ambrosia dumosa	White bursage		X	X	Native	187,391	10-25	60-85	Fluffy	Good	Fair	15-25	Fair	Good
Artemisia nova	Black sagebrush	X	X		Native	2,000,013	85-90	10	Fluffy	Fair	Good	3	Custom	Good
Artemisia tridentata	Basin big sagebrush	X	X		Native	5,555,592	55-94	10-50	Fluffy	Good	Good	17-21	Good	Good
Atriplex canescens	Fourwing saltbush	X	X	X	Native	122,058	17-94	90-95	Hard	Good	Good	2-40	Good	Good
Atriplex confertifolia	Shadscale saltbush	X	X		Native	143,079	0-53	80-90	Hard	Good	Good	0-29	Fair	Fair
Atriplex lentiformis	Big saltbush		X	X	Native	1,102,300	40-50	90	Hard	Good	Good	[10-15]	Good	Good
Atriplex polycarpa	Cattle saltbush		X	X	Native	1,763,680	23-70	38-40	Hard	Good	Good	9-15	Fair	Good
Atriplex spinifera	Spinescale saltbush		X		Native	88,184	10-64	90-99	Hard	Good	Fair	[10-25]	Custom	Fair
Baccharis sarothroides	Desertbroom		X	X	Native	11,023,000	40	5	Fluffy	Good	Fair	[10-25]	Good	Fair
Chilopsis linearis	Desert willow		X	X	Native	77,161	75	95	Hard	Good	Poor	[10-25]	Good	Good
Chrysothamnus viscidiflorus	Yellow rabbitbrush	X	X		Native	1,723,997	23-98	10	Fluffy	Fair	Fair	1-30	Fair	Good
Cleome isomeris	Bladderpod spiderflower		X		Native	8,818	65	90	Hard	Good	Good	5-15	Good	Poor
Coleogyne ramosissima	Blackbrush	X	X		Native	48,501	10-90	90	Hard	Custom	Poor	4	Custom	Poor
Encelia farinosa	Goldenhills		X	X	Native	771,610	60	40	Fluffy	Good	Good	40	Good	Fair
Encelia virginensis	Virgin River brittlebush		X		Native	478,398	77	86	Fluffy	Fair	Fair	10-20	Custom	Fair
Ephedra californica	California jointfir		X		Native	43,816	65-99	90-99	Hard	Good	Good	[10-25]	Fair	Fair
Ephedra nevadensis	Nevada jointfir	X	X		Native	43,816	65-99	90-99	Hard	Good	Good	5-25	Fair	Fair
Ericameria nauseosa	Rubber rabbitbrush	X	X	X	Native	1,528,229	36-99	10-70	Fluffy	Good	Good	3-20	Good	Good
Eriogonum fasciculatum	E. Mojave buckwheat	X	X	X	Native	992,070	20-65	10-80	Fluffy	Good	Good	5-20	Good	Fair
Grayia spinosa	Spiny hopsage	X	X		Native	367,650	51-100	90	Fluffy	Fair	Fair	10-30	Custom	Fair
Hymenoclea salsola	Burrobrush		X	X	Native	242,506	43-85	54	Fluffy	Good	Fair	20	Custom	Good
Kochia prostrata	Prostrate summercypress	X			Intro	898,815	50-80	50-70	Fluffy	Good	Good	[5-20]	Custom	Good
Krascheninnikovia lanata	Winterfat	X	X		Native	247,521	18-100	38-50	Fluffy	Good	Good	2-27	Fair	Fair
Larrea tridentata	Creosote bush		X	X	Native	180,777	6-90	56	Fluffy	Good	Poor	15-37	Good	Good

Nomenclature		Region			Seed Mix Information								Transplants	
Scientific Name	Common Name	Great Basin	Mojave	No. Sonoran	Origin	No. Seeds/kg	Acceptable Range of Viability	Common Range of Purity	Seed mix category	Seed Availability	Ease of Establishment	Optimum Germination Temperature	Transplant Availability	Ease of Establishment
SHRUBS (cont.)														
Lepidium fremontii	Desert pepperweed	X	X	X	Native	500,444	14-80	77-88	Hard	Fair	Fair	20	Custom	Fair
Lepidospartum squamatum	California broomsage		X	X	Native	859,794	30	20	Fluffy	Fair	Fair	[10-20]	Custom	Fair
Lycium andersonii	Anderson's wolfberry	X	X	X	Native	427,692	8-94	53	Hard	Good	Poor	20	Custom	Good
Picrothamnus desertorum	Bud sagebrush	X			Native	8,818,400	88-94	10-17	Hard	Custom	Fair	[5-15]	Custom	Fair
Sarcobatus vermiculatus	Greasewood	X			Native	629,634	16-94	50-90	Hard	Good	Good	4-30	Fair	Good
Senna armata	Desertsenna		X		Native	38,801	75	94	Hard	Good	Fair	15-20	Custom	Fair
GRASSES														
Achnatherum hymenoides	Indian ricegrass	X	X	X	Native	356,969	11-95	90-95	Hard	Good	Fair	5-25	Fair	Fair
Achnatherum speciosum	Desert needlegrass	X	X	X	Native	379,191	18-84	50	Hard	Fair	Fair	[15-25]	Fair	Poor
Aristida purpurea	Purple threeawn	X	X	X	Native	551,150	45	60	Other	Fair	Fair	20-40	Fair	Good
Elymus elymoides	Squirreltail	X	X	X	Native	422,302	66-100	90	Hard	Good	Good	12-32	Fair	Good
Hesperostipa comata	Needle and thread	X			Native	253,529	13	70-90	Hard	Good	Fair	[10-20]	Fair	Fair
Pleuraphis jamesii	James' galleta	X	X		Native	350,531	14-98	20-40	Fluffy	Good	Fair	24-35	Fair	Fair
Pleuraphis rigida	Big galleta		X	X	Native	577,605	88	9	Fluffy	Fair	Fair	[25-35]	Fair	Fair
Psathyrostachys juncea	Russian wildrye	X			Intro	385,805	83-90	85-95	Hard	Good	Good	20-30	Custom	Good
Sporobolus airoides	Alkali sacaton	X	X	X	Native	2,645,520	80	85	Hard	Good	Fair	27-32	Custom	Fair
Sporobolus cryptandrus	Sand dropseed	X	X	X	Native	11,684,380	80	80-95	Hard	Good	Good	5-35	Custom	Good
FORBS														
Abronia villosa	Sand verbena		X	X	Native	149,913	40	60	Hard	Good	Fair	[10-20]	Custom	Good
Bailey multiradiata	Desert marigold		X	X	Native	2,336,876	60	80	Hard	Good	Good	[10-20]	Fair	Good
Erodium cicutarium	Redstem stork's bill	X	X	X	Intro	491,185	58-80	80	Hard	Good	Good	20-30	Custom	Good
Eschscholzia californica	California poppy		X	X	Native	645,948	49-75	98	Hard	Good	Good	15	Good	Good
Eschscholzia mexicana	Mexican gold poppy		X	X	Native	1,873,910	60	90	Hard	Good	Good	15	Fair	Good
Penstemon palmeri	Palmer's penstemon	X	X		Native	1,344,806	58	90-95	Hard	Good	Fair	10-20	Custom	Good
Plantago insularis	Indian wheat		X	X	Native	716,495	75	98	Hard	Good	Fair	[10-20]	Custom	Good
Salvia columbariae	Chia		X	X	Native	1,918,002	60	90	Hard	Fair	Fair	[10-20]	Custom	Good
Senna covesii	Senna		X	X	Native	242,506	65	98	Hard	Fair	Fair	[10-20]	Custom	Good
Sphaeralcea ambigua	Desert globemallow	X	X	X	Native	1,102,300	25-95	90	Hard	Good	Good	5-40	Fair	Good

Table 3-3. Sample seed mix matrix. Seeding rate goal is 22.5 PLS kg/hectare. Table in English units of measurements shown in Appendix 9-1.

Scientific Name	No. Pure Live Seed /kg [A]	Recom-mended Rate (PLS kg/ha) [B]	Factors to consider in determining the recommended seeding rate				Cost B*No. Hectares*C
			Density (plants/m^2) in Reference Area	Ease of Establish-ment	Cost/PLS kg [C]	No. PLS/m^2 A*B/10000	
SHRUBS							
Atriplex confertifolia	142,780	5.4	1.0	Good	$ 33	76.8	$ 177
Ephedra nevadensis	43,725	3.0	0.3	Good	$ 33	13.2	$ 100
Ericameria nauseosa	1,525,040	0.2	0.2	Good	$ 22	34.2	$ 5
Eriogonum fasciculatum	990,000	0.3	0.2	Good	$ 88	33.3	$ 30
Grayia spinosa	366,883	0.7	0.1	Fair	$ 66	24.7	$ 44
Hymenoclea salsola	242,000	2.7	0.4	Fair	$ 99	65.0	$ 266
Krascheninnikovia lanata	247,005	5.3	1.2	Good	$ 70	130.0	$ 371
Lycium andersonii	426,800	0.2	0.1	Poor	$ 121	9.6	$ 27
Picrothamnus desertorum	8,800,000	0.1	1.0	Fair	$ 880	98.6	$ 99
GRASSES							
Achnatherum hymenoides	356,224	2.9	1.0	Fair	$ 33	103.7	$ 96
Achnatherum speciosum	378,400	0.0	0.2	Fair	$ -	0.4	$ -
Elymus elymoides	421,421	1.3	0.3	Good	$ 55	56.6	$ 74
FORBS							
Sphaeralcea ambigua	1,100,000	0.2	0.2	Good	$ 101	24.6	$ 23
TOTALS		**22.4**	**6.2**			**670.7**	

Cost/Hectare: $ 1,311

[1] = Seed not available

[2] = Species not in reference area but adapted to site

Table 3-4. Comparison of seeding techniques (USDA Forest Service, 1979a)

Method	Where appropriate	Considerations	Costs	Equipment
Broadcast/ Hydroseeding	Steep terrain Inaccessible areas Rocky terrain	Increased amount of seed required (double or more) Seed unprotected on surface Cannot be used on compacted soils Uneven seed distribution Success dependent on immediate and adequate precipitation	Equipment costs are higher Seed costs at least double Labor costs for application is higher, (i.e., hydromulcher operators (2-3), pilot)	Custom equipment Airplane Hydroseeder
Drill seeding	Relatively flat terrain Accessible to tractor If rocky, small rocks that will not obstruct drill seeder	Requires good site preparation Even seed distribution Immediate precipitation not critical	Equipment costs are moderate Seed costs lower than broadcast seeding Labor will require 1 operator for drill seeder If site is mulched, 3-4 personnel needed	Tractor Drill seeder Mulcher Crimper

Seeding rates vary but usually range from 16.8-22.4 PLS kg/ha (15-20 PLS lb/acre) when drill seeding. Several researchers suggest that rates for broadcast seeding are 50 to 100 percent higher but this has not been needed if broadcasted seed is adequately covered with soil (Vallentine, 1989, Winkel et al., 1999). If irrigation is being used, the rates may be lower. Harsh conditions such as a very disturbed site with the potential of few, if any, native seeds in the soil, may warrant higher rates, 33.6-44.8 PLS kg/ha (30-40 PLS lb/acre). The increases may not be the same for all species, because other factors such as cost or species importance will vary.

3.4.3.2 Seeding Method

At this point in the seeding process, the method of seeding needs to be decided. There are typically two methods of seeding, drill or broadcast (includes hydroseeding). Drill seeding is a process of placing seeds directly in the ground at a specified depth. Depending on the condition of the soil surface and the nature of the seed drill, some form of seedbed preparation may be necessary. Seed distribution and germination is generally improved by drilling. Many seed drills can be adapted to place seeds at variable depths depending on their germination requirements. Seed drills are often equipped with press wheels or drag chains to help cover the seeds with soil and improve seed-soil contact. Where rough or steep terrain limits the access of drilling implements, broadcast seeding or hydroseeding may be required. Broadcast seeding is a

process of spreading seed onto the soil surface. Prior seedbed preparation is not always required or even desirable. Broadcasting is often the least expensive seeding alternative in terms of labor costs. This is due primarily to the fact that more ground surface can be seeded with a single pass of the seeding equipment (particularly with aerial seeding) than with drill seeding. However, because the seed is left on the soil surface, seed-soil contact may not be adequate for good germination success. Hence, it is necessary to seed at a higher rate or to drag an implement over the site following seeding to help cover the seed with a thin layer of soil. Seeding at a higher rate (some studies suggest 50-100 percent) will increase the cost of broadcast seeding. Hydroseeding is a process of spraying seed onto the soil via liquid slurry. It is much more expensive than drill seeding or broadcasting due to the cost of equipment and the cost of transporting large quantities of water used in this process.

There are appropriate times to use each method and there are advantages and disadvantages to each method (Table 3-4) (USDA Forest Service, 1979a). In some regions of the Great Basin and in the Mojave Desert, drill seeding may be the preferred method. However, there may be instances where broadcast seeding may be necessary. Broadcast seeding requires higher seeding rates, and usually results in poorer seed-to-soil contact and exposure of seeds to predation. When a site is hydroseeded, additional moisture either from natural precipitation or irrigation is necessary within a short time or the pre-soaked seed will fail to germinate or if the seed does germinate it will not survive.

Equipment needs are important for either broadcast seeding or drill seeding. Broadcast seeding requires a means of distributing the seed, which can vary from an airplane, a hand-held whirlybird, or a hydroseeder. Drill seeding is best done with a rangeland-type drill, preferably equipped with multiple seed bins and some mechanism to cover the seed and compact soil around it. If the revegetation plan specifies both drill seeding and broadcast seeding, the area for each method should be determined so that the total amount of seed can be calculated.

3.4.3.3 Seed Acquisition

There are hundreds of seed companies located throughout the United States (USDA NRCS, 2001) although the number of seed companies selling seeds of species adapted to arid lands is limited and it may be difficult to select just one that carries all of the seed that you need for your project (Currans et al., 1997; Sowards and Balzer, 1978). The first and usually most reliable way is to contact colleagues for their recommendations. The list may also be shortened by simply selecting those companies in a particular ecological region. Seed companies in Wyoming may not carry or be interested in species appropriate for the Mojave Desert and vice versa. It is preferable to select several companies so you have a range of the prices and availability. Contact seed companies as early as possible, several months in advance, if not earlier. Early contact assures acquisition of the seed needed, and equally important, it allows the seed company sufficient time to acquire the seed if it is currently unavailable. It is often advantageous to contact the seed companies prior to the harvest of the current year's seed crop. They will know the projected harvest for the year, whether a good year or bad year is anticipated, which may affect availability and cost.

There is certain information to ask each company: (a) use PLS as a standard unit of measure, not bulk (PLS = bulk weight x percent purity x percent germination) (Bishop and Bunter 1999); (b) confirm the species by scientific name; (c) obtain cost per PLS basis; (d) confirm the availability of the seed—is it in the warehouse now or are you betting on this year's collection; (e) confirm that amounts are available from the same lot; and (f) confirm the location of the collection and try and get as much detail as possible. It is ideal to have the collection in the vicinity of your site, but this is rare. The best you may get is in the same ecoregion. There are other items to consider such as shipping costs and other logistical issues, which may not seem as important but need to be addressed. The final selection probably will not be based entirely on costs, so information on availability and location of the collection may be the determining factors.

Most seed companies mix the seed at their warehouse, and custom mixes are common usually at no extra cost. If broadcast seeding is the method selected, seed can be mixed and delivered as one seed mix. If a multi-bin drill seeder is being used, a mix of the heavier seeds and a separate mix of lighter or fluffier seeds (with wings or appendages) will be advantageous. Specify, in writing, which species are to be included in which seed mix. The seed company can assist in making these categorizations if necessary.

Once the seed company is selected, the seed mix finalized and custom mixes identified, the seed can be ordered. A set of specifications for a seed purchase is commonly used to ensure that you received what you ordered (Hoag et al., 2001). Federal and state seed laws require the majority of the information on the seed tag (*Item 4*). Common seed specifications may include the following:

ITEM 1. Weights will be by PLS.

ITEM 2. All seed purchased will have been tested for purity and viability by a certified seed laboratory within 12 months of the date that the order is placed. Proof of certification (i.e., name of seed lab, test date, and test results) will be provided on the seed tag or sent to you at the time of shipping.

ITEM 3. All seed should be collected preferably from near your location. Seed from regions other than your region may or may not be accepted. If the vendor has no seed available from your region for certain species, they must consult with you before the seed is shipped or the seed may be returned to the vendor at the vendor's cost. Even after consultation, acceptance of seed originating from other regions will be at your discretion.

ITEM 4. A tag listing the following information will be provided for each species:

- Scientific name (variety if applicable) and common name
- Lot number
- Seed origin, including county, state, and elevation, when possible. Must identify the state at a minimum.
- Net weight (bulk and PLS)
- Pure seed (%)

- Inert matter (%)
- Other crop (%)
- Weed seed (%)
- Noxious weed seed (%)
- Germination (%) TZ-tetrazolium or fill/cut test
- Hard seed (%)
- Date tested
- Name and address of seed company

ITEM 5. Seed shall not contain prohibited noxious weed seed. Wet, moldy, otherwise damaged seed, or seed without verification of test by a certified seed laboratory shall not be accepted.

ITEM 6. Seed will be mixed and packaged in durable bags. Bags will be of woven plastic or a material that will allow air movement through the bag. Individual bags will not exceed 22.7 kg (50 lb) in weight.

ITEM 7. Seed will be provided for the following species in the amounts specified.

- Seed will be separated into two different mixes: one labeled heavy seed and one labeled light seed. For example:

HEAVY/HARD SEED

Scientific Name	*Common Name*	*PLS kg*
Atriplex confertifolia	Shadscale saltbush	14.5
Ephedra nevadensis	Nevada jointfir	9.80
Lycium andersonii	Anderson's wolfberry	0.70
Picrothamnus desertorum	Bud sagebrush	0.40
Achnatherum hymenoides	Indian ricegrass	11.2
Elymus elymoides	Squirreltail	3.40
Sphaeralcea ambigua	Desert globemallow	2.20

LIGHT/FLUFFY SEED

Ericameria nauseosa	Rubber rabbitbrush	5.10
Eriogonum fasciculatum	E. Mojave buckwheat	1.10
Grayia spinosa	Spiny hopsage	1.80
Hymenoclea salsola	Burrobrush	7.20
Krascheninnikovia lanata	Winterfat	16.3

ITEM 8. Seed will be delivered to the following address between dates that you set. Exact shipping dates should be confirmed and coordinated with Jane Doe (888) 123-4567 or John Doe (888) 012-3456. The shipping address is:

Jane Doe / John Doe
Company Name
Drop Point Bldg 23-790-1
Receiving Warehouse 160
Someplace, U.S. 12345

3.4.3.4 Custom Seed Collection

There may be situations when seed of a particular species cannot be procured commercially. If the species is a critical component to the success of your revegetation project, there are a couple approaches that may be taken. First, you can collect the seed. This may seem the appropriate thing to do if dense populations of the species are known, there is good access, and the work force is available. There are other considerations such as when to collect the seed (Chatterton and McKell, 1969), how to collect the seed, how to clean the seed, and where to store the seed. Timing of seed harvesting and evaluation of the current year's seed production is critical. Although the month or period when seeds mature is known for most species, the exact day may vary by week and from year to year. For some species it is critical that harvesting be completed within days of seed set, for other species within weeks or months is okay. In conjunction with seed harvesting it is important to know the status of the seed crop. If drought conditions or irregular precipitation patterns describe the current water year, it is unlikely that plants will produce an abundant crop of seeds and those seeds that are produced will most likely have lower germination or viability. The quantity of the current seed crop can be assessed with field visits. Quality, however, is best assessed by a certified seed-testing laboratory. Testing of seed early may determine whether seed harvesting is "worthwhile."

Seed collection techniques vary with almost each species. Some seed may be collected with beaters and hoppers, others can be vacuumed, others with makeshift combines, or even some with drop cloths and shaking (Plummer et al., 1968). Seed collection equipment may be relatively simple but, for the most part, equipment has to be custom-made. Seed cleaning requires specialized and potentially expensive equipment. Frequently, seed cleaning is a multi-machine process (Plummer et al., 1968) requiring trained machine operators. Some seed companies will clean seed that you have custom collected for a fee.

If there is some hesitancy in getting into the seed collection business, the other option is to contract with a seed collection company to collect and clean the seed. Some of the seed companies are willing to perform custom collections. A contract with a seed company can be written in a couple different ways. One way is to contract for the services of a seed company on a 'level of effort' basis (i.e., a specific number of hours, days, or weeks). This method would be appropriate if locations of dense populations of the species are known and a sufficient quantity of seed can be collected. However, if seed location and density are unknown, another option would be to contract for the collection of a given amount of seed (PLS kg). Most likely, the cost will be very high, because the seed company is taking a risk. However, if the species is a critical part of

the plant community, the increased cost of the seed may be justified. In future years, if the demand is high enough and the seed can be collected from native populations, seed may be available "off the shelf" and probably at lower prices (Dunne, 1997).

3.4.3.5 Handling Seed

Seed moisture and storage temperatures are probably the most important factors affecting the long-term viability of seed (Young et al., 1978). For each 1 percent reduction in seed moisture, the life of the seed is doubled and for each 5°C reduction in seed temperature, the life of the seed is doubled (Young et al., 1978; Kay et al., 1988; Lippitt et al., 1994). Although there are qualifications to these two statements, seed storage should be around 0-5°C with less than 14 percent seed moisture.

Airtight metal or glass containers may be advantageous over plastic porous bags if temperature and humidity are controlled. Other precautions should be made to protect seeds from insect damage that can destroy up to 25 percent of the seed per year, depending on the species. Treatments may include the use of fumigants in areas where seed is commonly stored for long periods of time. Rodents and other granivores can pose problems and precautions must be taken to store seed in containers or buildings that are free of rodents and seed-eating insects (USDA Forest Service, 1979a).

The time that seed is stored before it is used should be held to a minimum (i.e., short-term [weeks/months] storage is preferred over long-term [years] storage). Seed for a particular revegetation project is best delivered weeks before the seeding date. During this short period of storage, the key factors to consider are protection from rodents and moisture. If seed is to be stored from one season to the next, more stringent storage conditions need to be followed. This may include airtight containers and temperature-controlled rooms.

Storage conditions, for both long- and short-term storage, vary with each species (Stevens et al., 1981; Welch, 1996; Welch et al., 1996). Consult seed companies and universities (University of Arizona, San Diego State University, Colorado State University, and University of Nevada Reno) for recommendations on suggested storage conditions for each species. Though the goal of the National Seed Storage Laboratory in Fort Collins, Colorado, is to preserve seed rather than store it (http://www.ars-grin.gov/ars/NoPlains/FtCollins/nsslmain.html), they may have useful information on the storage requirements for a particular species.

Another important practice is to label seed containers, whether bags, boxes, cans, etc. The label should contain sufficient information to indicate which species are in the container, the date the seed was delivered, a copy of the seed tag sent by the vendor, and other pertinent information. It is advantageous to maintain a file of seed mixes. The information can be useful for future seed procurements and may be important in evaluating seed performance.

3.4.3.6 Timing of Seeding

Seeding should be completed at a time during the year that will maximize the effect of natural precipitation patterns and during a period when soil temperatures are favorable for seed

germination and seedling establishment. This is known as a seeding "window." These seeding windows naturally vary from site to site (Environmental Research Technology, Inc., 1981). For the arid southwestern deserts, two seeding windows might be considered. One would be in the late fall or early winter prior to winter and early spring precipitation and the second could be in the late summer or, even early fall, prior to or following summer monsoons. The first window would favor species that germinate at lower soil temperatures (cool season plants) and the latter would favor species requiring higher temperatures for germination (warm season plants). In the desert regions of the Great Basin, the seeding window is in the fall prior to winter precipitation. In the northern Sonoran Desert, the seeding window may be in late summer during or following the summer monsoon period. These seeding windows are determined by average precipitation and temperature patterns for the site. Optimal conditions are not going to occur every year, in fact, they may occur in only two out of six years in the Mojave Desert (Wallace et al., 1980).

Selecting a seeding window can also be used to promote the successful germination and establishment of certain species (Williams et al., 1974; Young et al., 1984). For example, the optimum soil temperature for the germination of creosote bush seed is 26°C (Barbour, 1968; Ackerman, 1979). Thus, selecting a seeding window when soil temperatures were around 26°C would favor the germination and eventual establishment of creosote bush over other species such as white bursage, which germinates at lower temperatures (Kay et al., 1977).

3.4.3.7 Seed Pretreatment

Pretreatment of seed may include washing, chemical treatments to break seed dormancy, or mechanical treatments to remove seed appendages or weaken the seed coat. Dormancy of seeds is a major concern for a revegetation project. Dormancy has evolved over time as a means of ensuring that the plant will only germinate under conditions that favor long-term survival. It is difficult to meet those conditions in normal reseeding procedures. Dormancy may be due to the formation of specialized seed coats that aid in dispersal, chemical inhibitors that must be removed from the seed or altered, and internal chemical pathways that must be stimulated before germination can occur. Some inhibitors may be removed from the seed by sufficient leaching by water (Ostler et al., 2002; see Appendix 9-2) or through biochemical degradation of chemical inhibitors by soil microbes, animals, or the seed itself. These processes may require weeks if not months in order for germination to occur (Hansen, 1989).

Many native seeds have specialized appendages that aid in natural seed dispersal, but become a hindrance to mechanical seed distribution. For example, winged seeds of many of the saltbushes (*Atriplex* spp.), burrobrush, greasewood (*Sarcobatus* spp.) hopsage (*Grayia* spp.), and others quickly plug seed-bin apertures unless they are dewinged during the seed cleaning process. Even the micro-appendages on white bursage seed can be "sanded" down so they move more freely through drill seeders.

3.4.3.8 Seeding Calibration

Any seeding method selected should optimize the potential for good seed germination and plant establishment. These goals are accomplished with a uniform distribution of the seed over the

site, good seed-to-soil contact and proper seed coverage with soil. Seed distribution must take into consideration seed sizes and shapes, especially if broadcast or drill seeding is the method of distribution. Lighter seed will have different distribution patterns than heavier seed when applied by hand, airplane, or a drill seeder (Figure 3-15).

Lighter, fluffier seed may even drift from the intended location and heavier seed may be concentrated around the source (e.g., hand or spreader). For areas with low relief and a relatively even surface, the use of a drill seeder with multiple seed bins offers several advantages. Seeds can be ordered and mixed by weight class (e.g., heavy seed and light or fluffy seed). Bins on a drill seeder usually are equipped to accommodate typical agricultural seed such as alfalfa, wheat, corn, etc., and are best adapted for the heavier native seed (e.g., Indian ricegrass, dewinged atriplexes, ephedra, senna, and forbs such as globemallow). One bin on the typical rangeland drill seeder accommodates the lighter or bulkier seeds, such as winterfat, rabbitbrushes, and some of the grass seed such as galleta. The bins have wider openings and usually have picker wheels that pull the seed into tubes funneling the seed to within inches of the soil surface; thus, little is lost to wind. Apertures on seed bins can be adjusted so seeding rates for the two bins are equivalent thus providing an even distribution of both heavy and light seed.

Seeding rates for the heavier seed is usually going to be different than the seeding rate for the lighter seed. Seeding calibration is a must before seeding begins. For broadcast seeding, whether by hand or with a mechanical seed distributor, it is difficult to calibrate other than

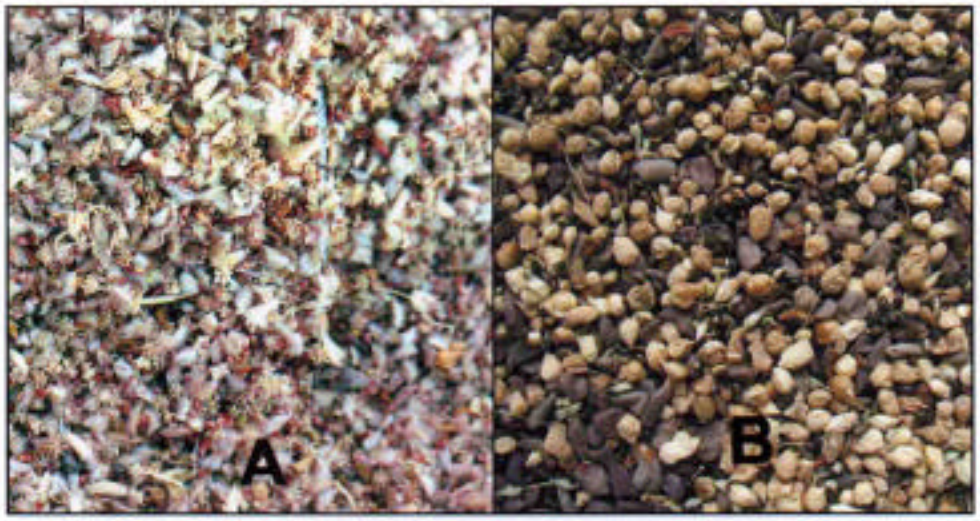

Figure 3-15. Fluffy seeds (A -left) and heavy seeds (B –right) have different properties that require their separation into different mixtures while seeding.

maybe determining the bulk seed to be used for a given section of the site and then weighing the seed and seeding the site section by section. With drill seeders the calibration process is much more precise (Pratt and Rasmussen, 2001). The number of bulk and PLS kg of seed being distributed by the drill seeder can be determined as well as the rate by seed bin. A couple of common techniques are used for seed drill calibration. A tarp of known length can be spread on the ground and the drill seeder driven over the tarp. The seed is then collected and weighed.

The area seeded is determined by multiplying the length of the tarp by the width of the drill seeder, thus obtaining a weight of seed distributed for a given area, which can then be used to calculate kg of seed/ha (the effects of the seeder vibrating as it bounces over the soil surface is usually ignored, even though these effects can be significant). If the goal was 22.4 PLS kg of seed/ha (20 PLS lbs. of seed/acre), bulk kg of seed must be converted to PLS kg (the information to make the conversion is normally on the seed tag).

Drill seeders with several bins with feeder tubes off of each bin can be calibrated with greater precision. Collection bottles are attached to each feeder tube or a representative number of the tubes (50 percent, at least). The drill seeder is operated for a given distance (e.g., 100 m), the seed collected in the bottles is weighed and a per hectare rate determined. Seed bin apertures or pulley wheels can be adjusted to attain the correct seed rate for each bin.

The placement of the seed in the soil is equally critical. A rule of thumb is to place the seed at a depth approximately three times its diameter. For small seed, such as sagebrush (*Artemisia*) and bluegrass (*Poa*) species, this may be 0.63 cm (0.25 in), for larger seed maximum depths are about 1.25 cm (0.5 in) (Plummer et al., 1968). Seed depth can be adjusted with a rangeland drill seeder. Other methods include drag chains (Figure 3-16), harrows, etc., that cover the seed in a more random method, and assumes that some, but not all, of the seeds will be covered to the proper depth.

Figure 3-16. Drill seeder dispersing seed on the ground with chains dragging on the soil surface to cover the seed.

Once seeds are evenly distributed over the site and at the proper depth, it is important to firm the soil around the seed. Packer wheels can be attached behind the seeding tubes of the drill seeder. The wheels press and pack the soil around the seeds. If irrigation is to be used, the first applications of water may be sufficient to compact the loose soil particles around the seeds.

3.4.3.9 Minimize Predation

Seed and young seedlings are both easily lost if not afforded protection. Seed has been observed being harvested by birds, ants, and nocturnal rodents. There are a few precautions that can be taken to minimize the impact from harvesting animals, but their effectiveness has not been demonstrated. The first measure is to ensure that seeds are covered during the seeding process. This may keep some animals, particularly ants, from accessing the seeds. At one time treating seed with chemical deterrents was a common practice (Plummer et al., 1968; Bainbridge et al., 1998), but such practices now are not recommended unless deterrents are environmentally safe.

If seeding windows at a site are flexible, the timing of seeding could be adjusted to correspond with times of the year when harvesting animal numbers are low (i.e., species are dormant or migratory). Ants may be diverted from newly seeded areas by using caches of cracked (not whole) wheat (Bainbridge et al., 1998) and mulches can be used to physically hide the seed from harvesters or make it difficult for them to get to the seed (Bainbridge et al., 1998).

After germination, young seedlings are very vulnerable to grazing animals. Rabbits, burros, horses, etc., can quickly render a successful revegetation site a failure. Fencing is essential in almost all situations (Section 3.6, "Grazing and Weed Control"). It may seem unnecessary and expensive during the planning phase but, without it, failure is almost a certainty for most sites.

3.4.4 Special Considerations

Special considerations may be required during custom collections or collection of rare plant species. Prior to custom seed collections, whether being made by a seed company or yourself, consideration must be given to land ownership. Permits may be required to harvest native seed from public lands (e.g., state or federal lands). If areas of seed collection are on public lands, appropriate approval should be obtained from the respective federal land management agency, (e.g., Forest Service, BLM, or state agencies). Although it is unlikely that private landowners have a written policy on seed collecting, they should be given the same courtesy as public landowners.

One other area of special consideration would be harvesting seed from plant species that may be considered rare, threatened, or endangered by federal or state agencies. There are special requirements and permitting for the collection of plants that are federally listed as threatened, or endangered. Many state agencies maintain a list of rare or sensitive plants and these same agencies may require permits to harvest seed from species on their lists. In addition, local offices of federal agencies may also have special requirements to harvest seed of rare plants.

3.5 PLANTING

Transplanting container-grown stock during revegetation projects is a common practice and offers several advantages. Although considered more costly than seeding, transplanting does provide an immediate and usually sustainable plant cover. Transplanting minimizes the risks associated with seed germination and early plant establishment, both of which are usually accomplished in a greenhouse under optimum conditions. Although there is a risk of plant

mortality during transplanting, the potential for plant establishment on a site is greatly increased when they are used as opposed to seeding.

3.5.1 Objectives

The objective of planting is to establish a quick vegetative cover by transplanting plants that are already equivalent in size and biomass to one-to-three-year-old plants grown under natural conditions. Planting bypasses the critical stage of seedling establishment, which is very difficult in arid environments. These transplants also can provide a ready seed source because they are sufficiently mature to produce viable seed (Figure 3-17).

3.5.2 Principles

There are several principles that must be followed for successful transplanting. The first is that plant materials, just like seeds, should be adapted to the environmental conditions specific to the site to be revegetated. Selection of adapted species is very important for the long-term survival at a site. For some projects where genetic integrity is important, this may mean selecting plant material grown from seed collected in the immediate vicinity of the revegetation site. This requires advanced planning, but will greatly improve the possibility of successful plant

Figure 3-17. Transplants provide a head start for plants and many will flower and provide seed within the first or second year.

establishment and long-term survival. If commercial sources of adapted plants are not available, the total process to obtain site-adapted plants may take two or more years and requires careful planning and coordination (Figure 3-18).

Hardening of plant materials is as essential as species selection to achieve success in plant establishment. The hardening process prepares plant materials for the harsh conditions of its new environment. Few, if any plants, can make the adjustment from greenhouse conditions to site conditions without proper hardening.

Proper planting techniques, although not complicated, are critical for transplant survival. In arid regions, the most critical factor is proper soil moisture. It is important that new transplants have adequate moisture for root development and eventual plant establishment. Once transplanted onto the project site, it is important to protect the investment from the elements such as wind and water, or from herbivory, a major cause of transplant mortality. New plant growth seems to be very palatable since it is usually devoid of natural repellants such as spines and toxins and, thus, vulnerable to local herbivores. This is even more critical when growth of the plants in the surrounding area is minimal and the new transplants are the only forage available.

3.5.3 Techniques

The techniques required for successfully planting and establishing transplants may be divided

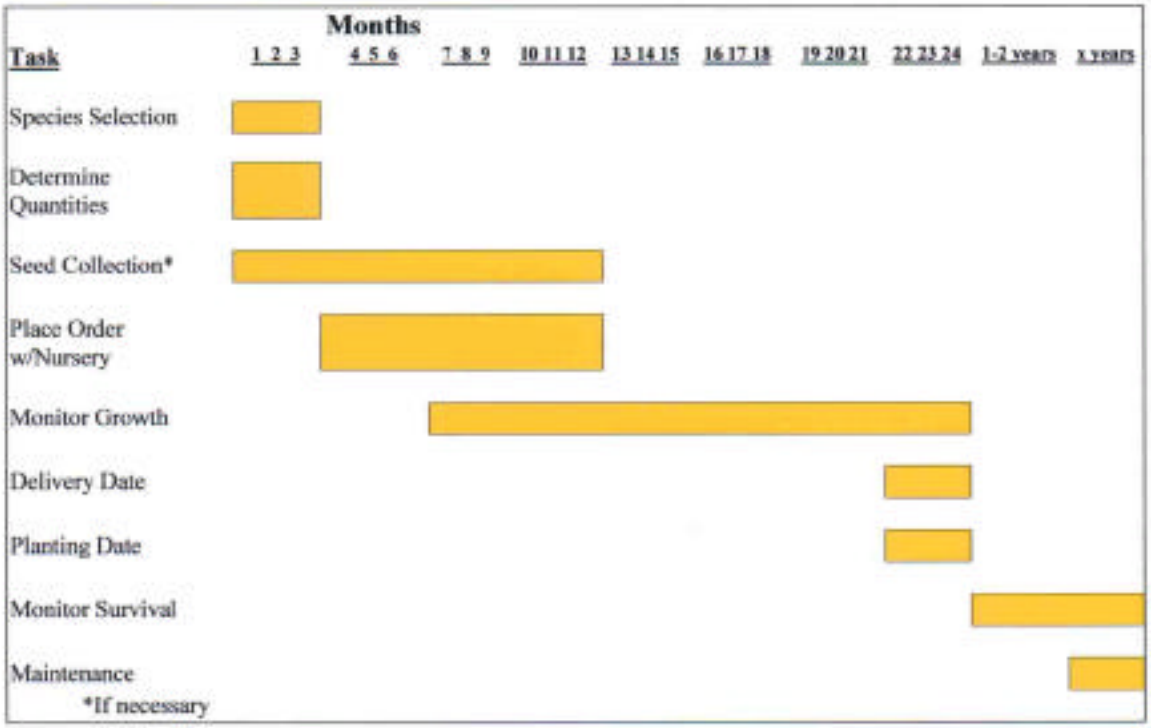

Figure 3-18. Example of a typical schedule for obtaining site-adapted plants and monitoring their survival.

into three equally important phases: (a) acquisition of quality plant material, (b) proper implementation or planting, and (c) protection and maintenance after planting. As mentioned, all are equally important. If proper planting techniques are not followed, even the best-adapted plants to the site may not survive. Or if young transplants are not protected from herbivores, the investment in quality-adapted plants and well-trained planting crews will be lost.

3.5.3.1 Species Selection

As discussed in 3.4.3.1 Species selection for seeding, the selection of appropriate plants for the site may be the most critical part to ensure the success of planting at your disturbed site. Plant species selected should be adapted to the environmental conditions of the site. Selecting species that are native to the site or are known to occur in the vicinity as determined either from pre-disturbance plant surveys or sampling of reference areas insures that the species are adapted to those environmental conditions. Table 3-2 provides a list of commonly available species that can be found at commercial nurseries. Sizes and availability are often quite variable so contact nurseries early to obtain what is best for your site. If you want to use species that occur on your site but that are not available commercially, then you may need to arrange to have them grown. Figure 3-18 provides some guidance on how long this process may take. At best, it will take one year to provide tubeling-sized plants that are hardened and ready for outplanting, so planning is needed early in the process. Larger sizes will require two-three years.

If seeding is going to be used as well as transplants, the number of transplants can be lowered. If only one species is to be used, the number of transplants may need to be increased. Consider also the survival of the transplants. In nearly all projects, a certain percentage will die during transplanting and never establish (Romney et al., 1987). So a higher number of each species will be needed to compensate for these losses. Common survival rates range from 50-90% depending on species, irrigation, and herbivory. If data are available on the transplant survival, adjustments (increases in the number to be planted) may be possible for each species to achieve the desired final density.

Once species and the number of each species have been determined, it is time to contact vendors. Sources vary from state to state, but there does not seem to be a large number of commercial nurseries growing a variety of native plant species. Some state agencies are good sources, primarily state forestry departments. Many grow plants for rehabilitation of state lands and have a variety of native species. With species and numbers in hand, the vendors should be queried as to the cost per plant, availability of plants, age of plant and size of container at time of delivery, source of seed used for plant materials, hardening period and procedures, and delivery charges to the site. If you are unfamiliar with the nursery, it would be appropriate to ask for references or examples of planting projects they have participated in. Once information has been gathered from nurseries, references and others, select the final species to be used, determine the number of each species, select a vendor, and place the order. Once the order is placed, it would be appropriate and prudent to visit the nursery on occasion. Inspect the plants to ensure there is good root development and size and vigor are good.

It is important that a physiological hardening of the plant materials occur prior to shipment to the site. Hardening is a process that requires about two to three months to prepare the plant material

for the climatic conditions typical of the site. The process is initiated by reducing the supply of moisture, altering nutrient balance, reducing (or increasing if planting in summer) temperatures, and increasing exposure to sunlight. If conditions at the site are significantly different from those at the nursery, it would be advantageous to site-harden the plants. This process may take weeks or months and is not accomplished by just withholding water prior to planting.

3.5.3.2 Holding Facility

An appropriate holding facility should be prepared well in advance of the arrival of plant materials. The purpose of the facility is to avoid or reduce moisture stress, avoid excessive heat or cold, protect the plants from mechanical damage, and provide a convenient staging area for transport to the site. The holding facility should consider the typical dry and windy conditions in the arid regions of the southwest. If plants are to be planted within a couple of days, the holding facility may be a frame with shade cloth for protection from direct sunlight and some type of wind barrier to minimize the effects of desiccating winds. In almost all cases, it will be necessary to ensure that the facility is protected (i.e., fenced) from grazing animals.

Well in advance of the anticipated planting dates, equipment and labor will have to be arranged. Equipment needs are relatively simple. If planting is to be done by hand, "sharp shooter" shovels (long narrow-bladed shovels), picks, small hand shovels (garden type), gloves, and some means of transporting water to the site (e.g., buckets, bottles, and hoses will be needed). Planting may also be done using motor-driven augers. Augers are effective for many sites but have difficulty in heavy soils and especially in rocky soils. If using augers, it is always wise to have two augers and extra parts available, primarily the tip of the auger bit, which can wear down in a matter of a day or two under normal working conditions.

3.5.3.3 Timing of Planting

Timing of planting is best when soils are moist and temperatures are favorable (i.e., not too hot; not too cold). In the Great Basin Desert, this may be in the early spring months (March to May) when soils may still be moist from winter snows and temperatures are generally above freezing. For warmer climates in the Mojave and Sonoran Deserts, transplanting may take place during the cool season, but summer plantings have also been shown to be effective for some species, particularly if plants are irrigated (Bainbridge et al., 1998).

3.5.3.4 Implementation

The implementation phase is as critical as any other phase of the planting process. Months, if not years, of effort are invested in quality plant material. It would be unfortunate at this stage of the process to make compromises to "just get the job done." To ensure that good planting techniques are followed, it is important that the planting crew be trained in all phases of the planting process. Safety issues should also be addressed. The size of the crew needed to perform the planting will vary depending on the size of the area, number of transplants, and site accessibility. The Nevada Division of Forestry runs a planting crew of 10 individuals that can plant approximately 500 plants/day or about 60 plants/hour. BN completed a planting project in

central Nevada using motor-driven augers and a crew of seven and planted approximately 100 plants/hour. The crew consisted of two auger operators, three planters, one person to water-in the plants, and a site supervisor, who helped, where needed, when available. The number of auger operators will vary depending on the difficulty in augering holes (Figure 3-19). For good non-rocky soils, one operator could drill enough holes for three to four planters. The crew may also need to include personnel to transport the plants to the planting area depending on the distance from the holding facility. With this baseline, the crew size can be adjusted to accommodate the number of plants to be planted and the time frame for planting. For example, if a site is small (i.e., 0.4-0.8 ha (1-2 acre), and density is about 2,470 plants/ha (1,000 plants/acre), then a minimum-size crew could probably plant the site in two days. If it is critical that all the plants be planted in one day, simply double the crew size.

Figure 3-19. Digging holes with a power auger (left) allows the operator to provide sufficient holes and keep ahead of the planting crew (right).

Using a motor-driven auger, a hole is excavated to a depth that will place the root portion of the transplant 1.25-2.5 cm (0.5 to 1.0 in) below the surface. The auger operator should not be more than a few holes ahead of the planters; otherwise, soil moisture is lost from the extracted soils. The plant should be carefully removed from the growing container so the root plug stays in tack. The root plug is placed in the hole and soil is packed firmly around it and on top of it (Figure 3-20). Care should be taken so there are no air pockets around the root plug and the top is covered to prevent water from wicking up through the plug. In rocky soils, care should be taken to not crush the roots between rocks.

Planting on steep slopes offers different challenges. Planting should begin at the top of the slope and work across and down. Position of plants on steep slopes is critical. Catchment basins, about 0.3 m (1 ft) in diameter, often help stabilize the slope, increase infiltration, and direct moisture to the new transplant. A shovel or "hoedad" (a hoe with an extra heavy and long blade) is used to scrape excess soil from where the plant is to be planted. A catchment basin is then formed and the hole is positioned near the outer edge of the basin, but below the lip.

Figure 3-20. Transplant is carefully lowered into the hole (left) to minimize root disturbance. The soil is firmed around the plant (right) to remove air pockets and ensure good contact of the soil with the roots.

If soil is not moist at the time of planting, plants should be "watered in" (Figure 3-21). The amount will depend on current soil conditions and time of planting. Usually less than 3.8 liters (1 gallon) of water is used at the time of planting per each plant.

Figure 3-21. Plants are watered soon after planting to settle the soil around the plant and to ensure that roots are not damaged by the adjacent dry soil.

3.5.3.5 Plant Protection

Protection of the new transplants is essential for plant establishment and long-term survival. Young transplants do not have the carbohydrate reserves to sustain grazing or trampling. They are typically more succulent and tender than plants in the native plant community, and during

times of drought, may be the only plant material available to animals. Protection from herbivores is almost always needed (Bainbridge et al., 1998), and frequently, from desiccating winds. This is discussed further in Section 3.6, "Grazing and Weed Control." For large plantings, protection may be for the entire site or for individual plants. Fencing around the entire site is more economical if it is possible. Sand (snow) fences can be strategically located to protect young transplants from moving sands, and mulches can be used in the immediate vicinity of the site to minimize soil erosion and the potential for moving sands. Individual plant protectors may be more labor intensive, but because of terrain or future use of the site, may be the only effective method of protecting the young transplants. Individual plant protection could include vexar (plastic) tubing (Hansen, 1989), wire cages, rocks, or plastic shelters (Bainbridge et al., 1998).

Protection from herbivores and grazing animals is simple compared to protection from desiccation. In arid regions, natural precipitation is notably variably and unreliable. After going to the effort to acquire quality plant material, the investment must be protected, which includes supplemental watering. Blanket irrigation of mass plantings is usually not feasible because of the remoteness of the site, cost of transporting large volumes of the water to the site, and the ineffective distribution of the water. Much of the water distributed in this manner is lost to evaporation or infiltration. Watering of individual plants is certainly the most cost-effective approach. San Diego State University scientists have evaluated many different methods of supplying water to new transplants (Soil Ecology and Restoration Group, restoration bulletin #6) and results of their work could be adapted to individual site conditions. The amounts, duration, and frequency of supplemental watering can probably only be determined by monitoring plant vigor. Ultimately, protection from herbivores and desiccation will be left to the plants. The time frame for this transition will depend on specific site conditions.

3.5.4 Special Considerations

Frequently plant materials (transplants) are available that are not adapted to the specific reclamation site. If plant materials are available, but are not adapted to site conditions (i.e., from seed native to the area), they can still be used; however, the potential for long-term survival and establishment may be diminished. Given sufficient lead time, another option is to make custom seed collections and have a nursery grow the plants from your site-adapted seed. The first step for this option is to find a nursery that has experience with native plants, has the proper facilities, and is willing. Establish a contract with them to produce the desired number of plants within a given time frame. The contract should include some level of standards for the transplants (i.e., stem diameter, height, evaluation of vigor). Next, procure seed native to the revegetation site (see Section 3.4, "Seeding") and provide it to the nursery. Stay in contact with the nursery by monitoring the status at key stages over the course of the period of performance. Do not wait until the plants are due for delivery and find out that none of them have germinated.

Another common method of obtaining native plant material is through salvage operations. Federal and state agencies often have land-disturbing activities from which plants may be salvaged usually on given days prior to the planned disturbance (typically a pipeline or right-of-way). Contact local offices to determine if they participate in plant salvage operations. Not all species tolerate salvaging and transplanting, so it is important that species that can be salvaged

are identified and time is not wasted trying to salvage species that will most likely die. Plants may also be salvaged from your sites prior to disturbances.

3.6 GRAZING AND WEED CONTROL

On many project sites, successful revegetation is not possible unless one controls grazing and weeds. Young seedlings or new transplants can be lost in a very short period of time without proper protection. Weeds, if allowed to persist, can out-compete the desirable species on a site and create problems for even the surrounding undisturbed areas. Understanding the potential for loss and implementing control techniques early is often a very important part of a successful revegetation project.

3.6.1 Objectives

The objectives of grazing and weed control are (a) to protect young plants and seedlings from herbivory, which is extremely damaging, until plants are well established and (b) to reduce competition for resources, particularly soil moisture, which is critical in arid environments.

3.6.2 Principles

Most resource managers recognize that large grazing animals can consume a tremendous amount of biomass. They can be particularly destructive to newly revegetated areas because the plants have not developed a good reserve of energy stored in their roots which would allow them to re-sprout after shoots are removed. Grazing of cattle may be limited on many DoD or DOE sites, but it is still common on BLM and private land holdings. There are other large herbivores such as burros, wild horses, deer, and antelope that also can create significant impacts to areas. In addition to these large mammals, less obvious animals such as rabbits, other small mammals, birds, and ants can cause tremendous impacts on revegetation. Grazing by rabbits and hares has been the single greatest cause for failure of seedings on some reclaimed sites (Kay, 1979; Kay and Graves, 1983). Small mammals such as kangaroo rats, deer mice, etc., can consume large amounts of seed. Reichman (1979) documented that rodents consumed over 80 percent of seed, either buried or on the surface, within 24 hours of seeding. Over a period of days, this can nearly eliminate all of the seed that is used at a site. Ants can also remove large quantities of seed that is on the soil surface, however, unlike rodents, they do not dig for seed that is buried. In the same study of rodents, Reichman (1979) found that ants took only 45 percent of the surface seed and none of the buried seed within the 24-hour study period. Birds are also known to gather seeds from the surface of the soil. In dry years when other food sources are limited, they may consume not only seed but also new seedlings as was documented in a newly seeded area at Fort Irwin, California, in 2002.

The effects of grazing have been documented for both transplanting and direct seeding. At the Nevada Test Site (NTS), fencing increased transplant survival twofold from 23 percent to 42 percent (Hunter et al., 1980). Survival increased even more in a study by Clary and Slayback (1984) in California with unprotected plant survival averaging only 10 percent while protected transplant survival averaged 75 percent. Studies on the effectiveness of rabbit fencing by DOE

Yucca Mountain at the NTS showed that species density was improved significantly increasing from <4 seedlings/m^2 on unfenced plots to >7 seedlings/m^2 on fenced plots (Winkel et al., 1999). Vegetative cover also showed a significant increase on fenced plots. One year after seeding, cover on the unfenced plots averaged 3.6 percent while the fenced plots averaged 8.5 percent. By the second year after seeding the unfenced plots averaged 9.9 percent cover while the fenced plots averaged 15.4 percent.

Our reclamation trials at Fort Irwin, California, showed that fencing was imperative to establish plants from seed. Density of unfenced plots averaged 1.7 plants/m^2 after two growing seasons while density of fenced plots averaged 6.7 plants/m^2 (Figure 3-22). Studies from central Nevada also show the impact of rabbit herbivory on seedling establishment (Figure 3-23). After 18 months, seedling density inside the fence averaged 52.7 seedlings/m^2 while outside densities averaged 21.0 seedlings/m^2. Living cover of plants inside the fence averaged 21.5 percent while living cover outside the fence averaged only 2.3 percent.

Weeds can compete with the native species trying to establish onsite. Weeds are very aggressive and often germinate early and remove water from the upper soil layers restricting or even prohibiting seed germination of seeded species (Hall et al., 1999). Even when you are planting containerized plants, seeds will often establish adjacent to the transplant and utilize valuable water and nutrients. Executive Order 13112, *Invasive Species*, states that federal agencies will develop strategies to limit invasive species on their lands. Aggressive invasive species can easily out-compete many native species in newly reclaimed sites. These can then spread to adjacent areas causing losses in productivity and diversity on a landscape scale. Weeds will invade

Figure 3-22. Construction of fenced plots at Fort Irwin, California, which resulted in greater plant density and cover than in unfenced plots.

Figure 3-23. Fenceline contrast illustrating the effect of controlling herbivory by rabbits in central Nevada after one year. The seeded area on the right averaged 21.5 percent cover while the seeded and unprotected area on the left averaged only 2.3 percent cover.

disturbed sites quite rapidly and if these sites are not revegetated promptly after being disturbed, weeds will become established and will be very difficult to eliminate.

SERDP has research projects to investigate new techniques to identify weed infestations through hyperspectral techniques and other remote-sensing techniques. They also have projects investigating biological and integrated control techniques to control weeds as well as to determine the susceptibility of areas to invasion of annual weeds and ways to predict and control future invasion (www.serdp.org/research/conservation.html; www.cnr.colostate.edu/RES/rel/serdp/index.html).

3.6.3 Techniques

3.6.3.1 Grazing Control

Grazing is most often controlled by fencing the revegetated area. For large animals, this may be a three-strand, barbed wire fence. For rabbits, 2.5-5.0 cm (1-2 in) mesh chicken wire (thin wire woven into hexagonal patterns) is most often used. This needs to be buried at least 15 cm (6 in) so that rabbits do not go under the fence and at least 1 m (3 ft) high to prevent them from jumping over the fence (Figure 3-22). In rocky soils not conducive for trenching, rocks can be placed on the bottom of chicken wire flared to the outside of the site.

Transplants can also be protected from grazing both by large animals and rabbits by protective tubes often called "tree shelters" (Figure 3-24). These tubes not only protect the plants from grazing but can also decrease damage due to windblown sand, reduce evaporation, and provide some shading. All of these factors act to improve the growing conditions for the plants and have been shown in the field to be effective (Bainbridge et al., 1998). Protective tubes may cause plants to have an abnormal growth habit because the shape of the tube causes the plants to grow vertically for 60-90 cm (2-3 ft) before horizontal growth is possible so plants tend to be rather spindly. Less expensive wire screen cages are also commonly used but are not as effective as protective tubes because they offer little protection against water loss and wind-blown sand damage. Commercial plastic mesh is also available and inexpensive. These have an added advantage that the plastic is photodegradable and will break into pieces in one to two years. All of these protectors need to be anchored with metal rebar or a wooden stake so that they remain upright and in place.

Figure 3-24. Transplant protector tubes at Fort Irwin, California.

There are several chemicals that can be used to protect transplants from being eaten. The effectiveness of these can vary depending on many environmental conditions. Generally, their use is not recommended unless herbivory is a severe problem.

One of the best techniques to avoid seed predation is to make sure that the seed is buried or covered with soil. Neither birds or ants will dig for seed. Some small mammals will dig for seed but their success is greatly reduced on buried seed as compared to seed on the surface. Small mammals may also bury seed in what is termed a "cache." These seed "caches" may germinate if they are not used by the small mammals prior to adequate precipitation for germination. Bainbridge et al. (1998) recommends spreading cracked wheat over the site as an alternative source of food for ants so that they will avoid the native seeds.

Drill seeding is useful in burying seed to a proper depth for germination. It is less effective if one is seeding a diverse mix of different sized seeds. In this case, broadcast seeding followed by a harrow to bury the seed works very effectively. This technique tends to bury seeds at various depths but often requires a slightly higher seeding rate to obtain acceptable seedling densities. The use of a mulch, either straw or gravel, can also help to hide seed from granivores as well as provide an alternative seed source since straw mulch generally contains some seed.

The timing of seeding or planting can also serve to lessen the impact from grazing or seed predation. In arid areas seed should be sown just prior to the time of the most reliable rains. This would be in November-March in the Great Basin Desert, in February-March in the Mojave Desert, and in August-September in the Sonoran Desert. Reducing the time the seed sits in the soil prior to germination reduces the chance of predation. We have tested pre-treating seed or seed priming to encourage the seed to germinate within hours of seeding. Combining seed pre-treatment with minimal irrigation greatly reduces seed predation.

3.6.3.2 Weed Control

Weeds are most often controlled by chemical herbicides. Herbicides are generally of two types, contact or pre-emergent. Contact herbicides are applied directly to the plant leaves or stems. The contact herbicides can be nonselective, which means they kill all plants regardless of species or they can be selective and designed to control specific weeds. For native rangelands, very few herbicides have been developed to treat specific weed species. Contact herbicides are applied with a liquid sprayer either pulled by a tractor for large areas or with an ATV or a hand-held sprayer for smaller spot treatments. They are usually applied in spring or when the plants are actively growing and when precipitation is not anticipated for several days since rain will wash the herbicide off the leaves of the plants. Because of the lack of species-specific herbicides and the costs of application, contact herbicides are not often used except on small problematic areas.

Pre-emergent herbicides may offer greater flexibility for control of annual weeds. Pre-emergent herbicides kill germinating seeds so they cannot be used at the same time when you are seeding with native species. They could be used the next season. They can also be used on a site the season before seeding, particularly if the site has a weed problem and there is adequate lead time. Pre-emergent herbicides are applied prior to germination, which is usually in the late winter or early spring (or early summer in the Sonoran Desert). Pre-emergent herbicides are generally applied with a mechanical spreader for large areas or hand spreaders for smaller areas. Rates of application vary by chemical and manufacturer or distributor. Mowing or disking a weedy site before the seed of the weeds mature can be an effective mechanical control technique. Often the best way to control weeds is to establish perennial vegetation on the disturbance as soon as

possible. The perennials will generally out-compete weedy species for resources once they are established.

Reducing fertilizers, particularly nitrogen levels, will reduce weed problems. Many weeds require higher fertilizer levels than most native species. Applying fertilizer will favor growth and development of the weeds at the expense of more desirable species. If fertilization is needed on the site, apply the fertilizer a year after seeding when it will benefit the native species, but not the weed species (e.g., just after the annual weedy species drop their seed) or use a fertilizer with a low level of nitrogen or a slow-release fertilizer.

3.6.4 Special Considerations

Fire is a major concern in many semiarid environments such as the northern Great Basin and Snake River Plains of Nevada, Idaho, and Oregon (Whisenant, 1990; Pellant, 1990) and is becoming more of a concern in the southern Great Basin and American Deserts, particularly when weeds such as cheatgrass (*Bromus tectorum*) and red brome (*Bromus rubens*) become established (Hunter, 1990; Young and Tipton, 1990). Both of these species have invaded many of the western ranges and invade new disturbances quite rapidly. Once established, they provide sufficient biomass to allow a fire to move between shrubs. Many of Nevada's desert shrub species are not adapted to fire and they do not re-sprout after a fire so they are quickly removed from fire-prone areas. Both brome species invade rapidly after fires and can out-compete many native species often forming monocultures that are very susceptible to fire. Thus, the fire frequency increases and continues to remove many native shrubs from the landscape (Figure 3-25). This is common in the sagebrush communities of central and northern Nevada

Figure 3-25. Conversion of sagebrush into annual grasslands dominated by red brome following fires on the Nevada Test Site.

and southern Idaho. It is becoming more common in the southern desert around Phoenix, Arizona, where creosote bush communities are being burned and replaced by invasive annual grasses. Many military operations and training programs have the capacity to ignite range fires. They can become serious problems unless the burned areas are revegetated and weed problems are dealt with early.

3.7 MULCHING

3.7.1 Objectives

The objectives of mulching are to: (a) create a suitable environment for seed germination and plant growth and (b) control erosion. The use of mulch to control erosion is discussed in Section 3.1.3.1.4, "Mulching." Because of the importance of mulch, particularly in arid ecosystems, special emphasis is being provided to ensure users understand and use mulches properly.

3.7.2 Principles

The primary purposes of using mulches on disturbed sites are twofold: control of erosion and conservation of moisture. On steep slopes or barren soils, mulch acts to protect the soil against rainfall and overland flow of water and protects the soils from wind erosion. On drier sites, mulch acts to conserve moisture and reduce evaporation. Where annual precipitation is under 30 cm (12 in), mulches are highly conducive to seedling establishment due to their moisture-holding characteristics. Many reclamation projects and test plots have demonstrated the effectiveness of mulch for improving seedling establishment (Winkel et al., 1999; Hansen and McKell, 1991). Yet others (Bainbridge et al., 1998) caution that in arid conditions mulches are "often unnecessary."

Improper use or applications of mulches can be detrimental, particularly if water is held by the mulch and not allowed to infiltrate into the soil or if the mulch has an abundance of seeds (e.g., weed and cereal seeds).

Analyses show that mulch is beneficial to revegetation in several ways:

- Trapping soil particles.
- Protecting the soil against impact of raindrops and intercepting surface runoff.
- Modifying soil temperatures.
- Maintaining soil moisture by retarding evaporation.
- Providing a substrate for soil microbes.
- Encouraging nutrient cycling.
- Aerating the soil and increasing water infiltration.

In areas that have been disturbed and much of the vegetation has been removed, soil erosion can become a severe problem. Under these conditions, movement of soil by wind in arid areas is very common. Mulching can act to catch soil particles by slowing down the wind speed at

ground level. Stubble mulches or crimped straw can be very effective at trapping soil (Figure 3-26). In our studies at Fort Irwin, California, on some heavily used sites, a crimped straw mulch was very successful at trapping blowing sand with accumulations of 10-15 cm (4-6 in) occurring on some sites. Mulching also can protect the soil from the impact of raindrops that causes soil particles to become dislodged and subject to water erosion.

Figure 3-26. Blowing sand captured by a crimped straw mulch and gravel mulch. From 10 to 15 cm of soil were trapped by the straw mulch at this site at Fort Irwin, California.

Mulches can slow overland flow of water and surface runoff, which will also reduce erosion. In arid environments perhaps the main advantage of mulch is that it tends to retain soil moisture by reducing soil temperatures and decreasing surface evaporation. Vogel (1987) reports that straw mulch at 2,240 kg/ha (2,000 lb/acre) can reduce soil surface temperature by 5-8°C (10-15°F). At Fort Irwin, California, small plots with three different surface mulches were compared for soil moisture and temperature. Probes were placed at four depths (3, 10, 25, and 55 cm [1, 4, 9, and 22 in]) and data were recorded on a data logger from March 2001 through June 2001. Analysis of the data showed that, at the 3-cm (1-in) depth, maximum temperatures were 3-9°C less on the straw mulch plots compared to the non-mulched plots. Minimum temperatures averaged 2-3°C more for the straw plots compared to the non-mulched plots. Straw tended to keep soil temperatures more uniform which may be a response to greater soil moisture.

Even gravel mulch tended to reduce maximum temperatures an average of 2-3°C less than the no mulch plots. Similar to the straw mulch plots, minimum temperatures of the gravel plots averaged 1-2°C higher than the non-mulched plots. Soil moisture at the 3-cm (1-in) depth was higher on the straw mulch plots than the non-mulched plots; however, at the 10-cm (4-in) depth soil moisture was less particularly after an irrigation event. The straw mulch appeared to hinder

movement of the water through the soil possibly by intercepting the moisture and allowing it to evaporate from the surface of the straw culms or because there were more plants (wheat from seed in the mulch) using the soil moisture.

There was no difference between the gravel and no mulch treatments for soil moisture. By mid-April, soil moisture in the surface 3 cm (1 in) was completely gone regardless of whether mulch was applied or not. Mulches are most beneficial during the early spring because they tend to retain moisture near the soil surface, which is where the seeds need to be to germinate and emerge successfully. Straw or other organic mulches are effective at decreasing soil temperatures. Studies at Fort Irwin, California, also showed that certain types of mulches could increase soil temperatures. Soil temperatures were increased 8-10°C when a plastic mulch was used compared to no mulch. This may be desirable for some species which require higher soil temperatures for germination.

Organic mulches can be very beneficial at enhancing the soil microbial populations, which enhance nutrient cycling and soil development (Bainbridge et al., 1998; Whitford 1988). Mulches should have a high carbon to nitrogen (C:N) ratio so they stimulate microarthropods rather than encourage weeds. Soil microbes are important for plant growth because they provide nutrients in a usable form. Generally, plants have a very limited capacity to incorporate organic nitrogen, phosphorus, or sulfur and rely on soil microbes to return the organic nutrients to a more usable state (Tate, 1985).

3.7.3 Techniques

There are many different kinds of mulch that have been developed to address specific erosion and water conservation problems under various conditions. Understanding which mulch to use under different conditions is important to maximize efficiency and minimize costs. The most commonly used mulches in arid areas are organic mulches from agriculture crop residues such as straw from wheat, barley, rye, or other cereal crops. Other commonly used mulches include hay and wood fiber and other wood residues (common in hydromulching). Mats and netting made from wood fibers and other organic and synthetic material are effective for controlling erosion in specialized uses such as steep slopes and drainage channels or culvert areas. The cost for these materials is prohibitive for general use at most areas (Vogel, 1987).

3.7.3.1 Criteria for Mulch Selection

Several factors need to be considered in selecting the proper mulch for the reclamation objectives and characteristics of the area to be mulched. Vogel (1987) identifies these factors as (a) the proposed land use; (b) climate and weather characteristics such as intensity and frequency of precipitation, temperature, and wind velocity; (c) topography and soils; and (d) availability and cost of mulching materials. An important component of the proposed land use is to evaluate what the strategy is to establish vegetation on the site. Mulch has a dual role of not only protecting the soil from erosion but of enhancing conditions for vegetation establishment. These goals can sometimes conflict. For example, an excessive amount of mulch on a site would be very effective at halting erosion but would prohibit seed germination by not allowing water to

infiltrate effectively or by creating a barrier so thick that the seedlings cannot grow through it. Perhaps the most important factor in the selection of mulch is the availability and cost of the material, the transportation costs and ease of application. Some mulches may have little initial cost but are not available locally so transportation costs are high and application requires specialized or costly equipment.

3.7.3.2 Mulch Application

Straw mulches are the most commonly used mulches in arid environments and can be used in many different situations to address specific erosion or revegetation problems. Mulches, particularly native grass hay mulch, can be a common source of weed seed in revegetation so the mulch should be inspected and certified by the state agricultural inspector to be free of weeds, particularly noxious weeds, before delivery is accepted. Straw and hay mulch should have a minimum fiber length of 20 cm (8 in) when crimping is specified. Long fiber length is necessary to ensure proper anchoring, when the mulch is crimped, netted or tacked. Mulch generally should be applied at a rate of 4,480 kg/ha (4,000 lb/acre). The mulch should also have a moisture content of no more than 20 percent, because mulch with a high moisture content is difficult to apply uniformly. Further, the specified application rate is not achieved due to the high water weight. Straw or hay mulch should be free of mold or other unspecified material.

Straw mulches are applied after seeding of a site but they could be applied before or after planting at a site depending on how the mulch will be held in place and the density or placement of the plants. If the mulch will be crimped, mulching should be done prior to planting so the equipment will not damage plants. If the mulch is held in place by tackifier or netting, planting should be done after mulching.

Straw and hay mulches are generally applied with a power blower (Figure 3-27). The blower breaks apart the straw or hay bales without shattering the fiber and blows the fibers out over the seedbed. The blower can spread mulch approximately 15 m (~50 ft.) or more depending on wind speed and direction. Straw and hay can also be spread by hand, particularly on inaccessible areas and steep slopes. Hand spreading generally requires more hay or straw 4,480-5,040 kg/ha (4,000 to 4,500 lb/acre) because the materials tend to clump as it is spread. On areas where equipment can traverse, straw mulch is best anchored by crimping. To get the maximum benefit from crimping the fiber length of the mulch should be at least 20 cm (8 in) and the soil uncompacted. The mulch should be crimped into the soil about 5 cm (2 in) in depth. Blunt-notched disks or specially designed rollers should be used for anchoring the mulch because round discs tend to cut the fibers instead of crimping them into the soil (Figure 3-28).

Field analysis of disturbed sites show that mulch should be used on all slopes greater than 3h:1v to reduce erosion (NPI, 1985a). On these sites netting or tacking is nearly always required to hold the mulch in place. Munshower (1994) states that netting is used to hold mulch in place, but it is very labor intensive and only used in critical erosion-prone areas. Chemical tackifiers (a dilute glue solution) are best applied with a hydromulcher (Figure 3-29). A recommended rate of 136 kg (296 lb) of tackifier with 333 kg (741 lb) of wood fiber mulch per hectare is mixed in a water slurry and applied evenly over the straw or hay mulch. Recommended rates may differ with various products and the manufacturers suggested rates should be applied.

Figure 3-27. Applying straw with a blower requires three people.

Figure 3-28. The crimper presses straw into the soil orienting the stems vertically.

Figure 3-29. Applying tackifier with a hydroseeder.

On critical sites or high-priority areas that are steep and subject to erosion, mulch with a plastic netting or "excelsior" blankets (fine wood shavings pressed into sheets and held together with plastic netting) appear to be the most cost-effective technique for reducing erosion while allowing for a stable vegetative cover to develop. The excelsior is rolled out over the seedbed and stapled at regular intervals to anchor the mat in place. When applying netting, a trench is made at the top of the slope and the ends buried to prevent water from running underneath the netting. The netting is stapled at meter intervals and half-meter intervals along the sides and bottom. A U-shaped metal staple is generally used ranging from 15-30 cm (6-12 in) in length. Shorter staples are used on rocky or non-topsoiled slopes. On extremely rocky or compacted soil surfaces, rocks or other objects may need to be placed on top of the netting to hold it in place.

In arid areas, hydromulching is generally not recommended (Bainbridge et al., 1998) unless the site will be irrigated. The fiber mulch has a tendency to dry very quickly and create a physical barrier to seedling growth. This makes it less suitable for revegetation although it would still be effective for erosion control. Nurse crops are also not recommended as viable mulches because they compete with the native seedlings for limited soil moisture.

3.7.4 Special Considerations

There are many different kinds of mulch that are useful for specific applications and their use needs to be considered in developing the reclamation plan. We have been evaluating the effect of various mulch treatments (gravel, straw, plastic, no mulch, and chemical stabilizer) on pretreated seed of some dominant arid land native species, creosote bush (*Larrea tridentata*), white bursage (*Ambrosia dumosa*), brittlebush (*Encelia farinosa*), and big galleta (*Pleuraphis*

rigida). Trials at two locations at Fort Irwin, California, have shown that plastic mulch in combination with irrigation or applied after a rain is very effective at increasing seed germination and establishment (Ostler and Sparks, 2001). Plastic mulch nearly eliminates evaporation from the soil surface and increases soil moisture and relative humidity in the upper 1 cm of the soil where most germination occurs. In addition, plastic mulch increases soil temperature, which is very favorable for species such as creosote bush and big galleta that have optimum germination temperatures near 30°C (86°F). These species do not often perform well in revegetation efforts because by the time soil temperatures warm sufficiently for germination, the soil is too dry for germination.

Plastic mulch increased germination of creosote bush in an early March seeding from an average of 2.7 seedlings/m^2 in the non-mulched plots to an average of 45.8 seedlings/m^2 in the plastic-mulch plots. In mid April, use of plastic mulch was even more effective averaging 37.5 seedlings/m^2 on the non-mulched plots and 137.2 seedlings/m^2 on the plastic-mulch plots. The use of plastic mulch appears to be a very promising technique to establish creosote bush and other dominant arid land species from seed during the early spring and perhaps the late fall.

Plastic mulch is applied as sheets that have to be buried along each edge to prevent the wind from getting under the plastic and blowing it away. This can be done mechanically using a tractor and plastic roller commonly used in the agricultural areas for such crops as strawberries and melons (Figure 3-30). The plastic mulch does not have to be on for very long, just until germination occurs. This may be from one to three weeks, depending on temperatures and seed pre-treatments. The plastic can then be removed and reused.

Figure 3-30. Equipment to apply plastic mulch developed for agricultural use could be adapted for use in arid land revegetation.

3.8 IRRIGATION

The factor limiting seed germination and plant establishment in the arid regions of the southwest is available water. These arid regions are characterized by extended periods of low precipitation and, even during average precipitation periods, the timing of the precipitation events may render the additional moisture ineffective for seed germination and plant growth. The strategy of supplemental irrigation is to ensure adequate water for seed germination and plant growth even during years of below-normal precipitation

3.8.1 Objectives

The goal of irrigation in reclaiming arid areas is to provide sufficient water for seed germination and plant establishment and not to provide a continuous supply of water to the site. Although perceived to be expensive, the efficiency of supplemental irrigation can be maximized by only providing water at critical times, thus allowing or forcing young seedlings to adapt to the natural conditions of the site and not artificial conditions that would result from continuous irrigation.

Irrigation may also be used to extend the typical seeding window (Winkel et al., 1999). The seeding window is defined by periods of high rainfall and optimum temperatures for seed germination and plant growth. When supplemental irrigation is used, optimum temperatures for seed germination and plant growth become the primary criteria for identifying the seeding window (Munshower, 1994; Winkel et al., 1999)

3.8.2 Principles

Supplemental irrigation is used to provide sufficient moisture for seed germination and plant establishment. Irrigation may be necessary to break seed dormancy by lowering soil temperatures during winter months (Ferraiuolo and Bokich, 1982) or to wash seeds of germination inhibitors (see Section 3.4, "Seeding"). Germination of seeds of some species is triggered when conditions are favorable for seed germination and plant growth. Cooler soil temperatures during winter months may be the result of higher soil moisture content, which in turn breaks seed dormancy for some species. Significant precipitation events may result in high soil moisture content over extended periods of time. These conditions are capable of washing germination inhibiting chemicals from seed coats. In the absence of such conditions naturally, supplemental irrigation can artificially create the same conditions.

When seed pre-germination requirements are met, there must be sufficient moisture available for germination to occur. If temperatures are optimum, seed dormancy is broken, or inhibitors removed, but there is not sufficient moisture available for germination, germination is unlikely to occur or, if it does, it is unlikely to be successful (i.e., a seedling established). Seeds may or may not need some form of pre-treatment in order to germinate, but in almost all cases moisture is required for germination. That moisture must be over an extended period of time so seeds can imbibe water, germinate, and have sufficient soil moisture for the developing seedling (Devitt, 1989; Ferraiuolo and Bokich, 1982). If water is not available naturally, supplemental irrigation can provide the water necessary for seed germination. Water must be available when optimum temperatures for seed germination exist, which may be different for each plant. Plants

may be grouped into warm season or cool season plants, indicating the general range of optimum temperatures for germination and growth.

Once seeds germinate, sufficient water is needed for seedling shoot and root growth. If young roots exhaust moisture and nutrient reserves without finding additional water, mortality is certain. Because of high evaporation rates and temperatures in arid areas, surface soils often dry out very rapidly and often do not provide proper moisture conditions for seed germination and early seedling growth. If evapotranspiration needs are not met, the flow of nutrients does not occur (Ferraiuolo and Bokich, 1982). Once seeds are germinated, moisture should be available in the soil profile so as to stimulate deep root growth (DePuit et al., 1982). Supplemental irrigation beyond the germination and plant establishment phase may result in plants dependent on supplemental watering, less developed root systems, and potential plant mortality if natural precipitation is not adequate for plant survival (DePuit et al., 1982; Munshower, 1994).

At times, there may be a tendency to reduce seeding rates when supplemental irrigation is used. The quality of the seed should not be compromised nor should the seeding rates. It is best to allow the young seedlings to thin naturally (Ries and Day, 1978).

An alternative strategy to supplemental irrigation is to repeat the seeding process until sufficient water is received naturally for seed germination and plant establishment (Munshower, 1994). This strategy may require several years to establish native perennial species at the site. If the site is not a high-priority site, this strategy may be possible. However, during the waiting period, other species, usually noxious weeds or other unwanted species, may invade the site and then compete with seeded species for water and nutrients.

3.8.3 Techniques

3.8.3.1 System Design

Irrigation systems can be designed to provide supplemental water for either transplants or seeded areas. Systems to irrigate transplants may include drip, trickle, or subsurface (deep pipe, clay-pot) irrigation (Bainbridge et al., 1998; Bainbridge, 2002). These systems are very efficient in providing given amounts of water to specific locations. They are designed to provide sufficient water for plant growth and long-term establishment.

Some methodologies for distributing the water are more efficient than other methods (Bainbridge et al., 1998; Bainbridge 2002), but all are more efficient than overhead sprinklers that are designed to distribute water over large areas. Materials for drip or subsurface irrigation systems are usually relatively simple (Figure 3-31); however, distribution of the water can be labor-intensive depending on the amount, frequency, and duration of irrigation events. Specifics on these systems have been shown to be effective in establishing transplants in arid regions of the southwest and reference is made to other researchers for details on this method of supplemental irrigation (Bainbridge et al., 1998; Bainbridge, 2002; Sparks, 2002).

Figure 3-31. Setting up irrigation system hardware.

The systems designed for transplants are generally not suited to provide water for seed germination unless the seeded area is relatively small. Overhead or sprinkler irrigation is designed to provide sufficient water for seed germination and early plant establishment over large areas. Either solid set or pivot sprinklers can be used (Keller and Bliesner, 1990), depending primarily on size of the area and availability of water. Materials and labor requirements for installation are higher, but once a system is in place the cost to operate the system is usually less intensive than drip or sub-surface irrigation. Sprinkler irrigation has been used successfully in several arid areas of the southwest (Hall and Anderson, 1999; Anderson and Ostler, 2002; Winkel and Boone, 1999; Limbach and Anderson, 1993; Hunter and Romney, 1975; Hunter et al., 1976).

A solid set sprinkler system was designed by Harward Irrigation Company (Spanish Fork, Utah) for the irrigation of approximately nine acres at the Double Tracks remediation site on the Tonopah Test Range in southwest Nevada. Water was pumped from two 37,854-liter (10,000-gallon) tanks through a series of 5-cm (2-in) and 2.5-cm (1- in) polypipe to superstands equipped with wobbler heads that distributed water in a relatively even, circular pattern at a rate of 8.3 liters (2.2 gallons) per minute per head (Figure 3-32).

Approximately 200 heads were used to irrigate the entire site. Sections of the system were assembled offsite. After the site was seeded, the sections were carefully transported onto the site and assembled. Water filters were installed to prevent small rocks and rust particles from

Figure 3-32. Portable irrigation system designed to provide supplemental water for plant establishment.

entering the system and plugging wobbler heads. Approximately two days of time for two laborers, two technicians, and a representative from Harward Irrigation were required for offsite installation and preparation. Another two days of time for the two laborers and one of the technicians was required to assemble the system onsite. Specifics on the materials and costs are addressed in Section 6.0, "Decision Tools for Selection of Reclamation Techniques."

One technician could operate the irrigation system with manual valves. A system could be designed with automatic valves thus eliminating the need for a technician. Besides a reduction in labor, automatic valves would facilitate the timing of irrigation to coincide with periods of low evaporation (e.g., during periods of light winds and low temperatures). These ideal irrigation periods do not usually coincide with normal working hours or when the controlled site is accessible. For this particular project, water was only available during normal working hours and a technician had to be onsite for security reasons, so manual valves were used.

When irrigation was completed, the system was disassembled and transported to a warehouse for storage. Two laborers disassembled the system in about three days. Another day was required to load the system on trucks and transport and unload it at the warehouse. It is important to remove the system from the field as soon as possible to avoid unnecessary exposure to the sun. Polypipe is not as affected by the sun's rays as is pvc (polychloride) pipe, which can become very brittle. The life of the fiberglass superstands and plastic wobbler heads can also be extended if exposure is minimized.

With slight modifications this same system has been used at other sites. Once at the NTS for about seven acres and another time at the NTC at Ft. Irwin, California, for about five acres.

Certain criteria were established for the design of the system. First was portability. It was important from a cost standpoint to be able to use the system multiple times so costs could be spread over several projects. Second, was even distribution of water. The superstand with a wobbler head, properly spaced, meets this requirement. The wobbler discharges a large water droplet in a manner very similar to natural rainfall. Flexibility in regulating flow rates and duration of application was also important. It is for this reason that the system was broken down into sections, with a given number of heads per section. A section could be turned on and off with a single valve, so time of application could be regulated. If water began to puddle on a section, the water could quickly be diverted to another section.

3.8.3.2 Amount of Irrigation

The amount of supplemental irrigation to apply to a site should mimic natural conditions, not agricultural conditions (Munshower, 1994). Local precipitation records are valuable in comparing years when good seed germination and plant growth were observed, with precipitation amounts and distribution (Hall and Anderson, 1999). The amount and distribution experienced during these good plant growth years could then become the goal for supplemental irrigation. The amount of supplemental irrigation would actually be the difference between natural precipitation and these predetermined goals. If the goal for the period October 1 to December 31 is 2.5 cm (1 in), and natural precipitation is 0.5 cm (0.2 in), a total of 2.0 cm (0.8 in) of supplemental irrigation should be applied. The amount can be altered based on current conditions. For example, if seeding and irrigation follow several dry years, the soil moisture levels may be low and increasing the amount of supplemental irrigation may be needed to recharge the soil. The opposite may also occur. If soils are moist, supplemental irrigation may be reduced. Supplemental irrigation on soils already saturated may not only be inefficient and costly, but can result in surface runoff (Devitt, 1989).

3.8.3.3 Timing of Irrigation

As observed under natural conditions, timing of precipitation is critical. Late summer storms, no matter what the amount, may not have any effect on the germination or growth of certain species. It is important to know the germination and growth requirements of the species used. High soil moisture may be necessary during winter months for some seeds to meet stratification requirements.

When seeds begin absorbing water and cotyledons and radicles emerge, soil moisture must be maintained. If soils dry, young seedlings seldom survive. Once established, it is important that the roots of young seedlings move downward where future water is most likely to be found. Excessive irrigation has been shown to decrease the development of root biomass and keep root systems near the surface (DePuit et al., 1982).

A typical supplemental watering scenario may include a fall application of an inch or less of water sometime after seeding is completed. As soil temperatures approach optimum seed

germination temperatures in the spring, supplemental irrigation should be applied as needed to keep the surface 2.5-5 cm (1-2 in) of soil moist. Supplemental irrigation during this period should occur over several days or weeks until germination is observed. Successful seed germination and seedling establishment is dependent on moisture. If soils dry out during germination, high plant mortality can be expected. As seedlings emerge and start growing, soil moisture is needed at deeper depths. The depth will depend on the soil type, but will probably be in the range of 38-61 cm (15-24 in).

This deep watering will provide needed water in future months for the establishment of the young plants, once supplemental irrigation is terminated. Additional supplemental watering, in the fall and later years, can be determined by the amount and timing of natural precipitation events, and by the condition of the young plants. There is a significant investment in each plant at this point in the revegetation process. An additional watering to protect this investment may be necessary and justified.

3.8.4 Special Considerations

The quality of the water used for supplemental irrigation should meet standards for plant growth and should not have a negative effect on soil physical properties. Water samples should be analyzed for salt content (Ludwig et al., 1976; Jurinak and Topper, 1989). The pH and sodium adsorption ratio should be determined as well as the concentration of elements that may be known to occur in the soil and may be detrimental to plant growth (Devitt, 1989). Alternative water sources should be identified and samples collected and analyzed simultaneously. All samples should be collected well in advance so there is sufficient time for laboratories to conduct the analyses and interpret the results.

Supplemental irrigation is commonly deemed too expensive (Munshower, 1994) even though it has been shown to be effective in increasing survival, productivity, plant density, species diversity and decreasing the effect of invading weedy species (DePuit et al., 1982; Ries and Day, 1978; Winkel and Boone, 1999; Hall and Anderson, 1999). The cost for materials as mentioned previously can be amortized over time and projects. Many materials are one-time costs or require only minimal upgrades (e.g., pumps, valves, and engines) (Figure 3-33). Others will eventually have to be replaced but if replaced over time costs can be minimized. In arid climates the distance to a water source has a significant effect on the cost of irrigation. The cost of getting water to the site may be greater than all other costs and is project specific (i.e., no amortization). Distance to water and the costs associated with getting it to the site are important considerations and should be investigated in detail before deciding whether it is a viable alternative.

3.9 SITE PROTECTION

Because training impacts have greater adverse impacts in arid and semiarid lands than in areas like grasslands and woodlands with higher precipitation, it is essential that mitigation measures be implemented to ensure sustainable use of these lands in the future. The implementation of erosion control measures and revegetation is a necessary and essential requirement for the preservation of site conditions--conditions that can continue to provide a reasonable degree of

Figure 3-33. Example of wobbler heads attached to flexible, portable polypipe.

realism and safety for training activities. Once costs and effort have been incurred for mitigation, it is imperative that some degree of site protection be implemented to protect this investment and ensure sustainable use in the future. A description of objectives, key principles, and recommended techniques follows for providing site protection.

3.9.1 Objectives

The overall goal of site protection is to ensure the sustainable use of DoD/DOE installations in a manner that reduces costs and downtime due to off-limits imposed on the area due to mitigation efforts. This goal is achieved by understanding the site mission, communicating with site management personnel, and implementing reasonable mitigation measures to minimize damage to revegetation and erosion control structures while permitting the sustainable use of the area for the defined training and operations of the site. Objectives include:

- To comply with DoD/DOE environmental stewardship responsibilities while minimizing any negative effects that such compliance may have on the military mission.
- To understand and work within the training mission or operations for the DoD/DOE installations.
- Provide adequate training and appropriate communications with site personnel.
- Reduce the amount of downtime or off-limits imposed on areas due to rehabilitation and mitigation activities.

3.9.2 Principles

Understanding a few basic principles can help facilitate the development and implementation of better site protection. Key principles that help guide the user in developing an effective site protection program include the following.

3.9.2.1 Understanding Special Regulations

Understand what the environmental regulations, permit stipulations, and site operating requirements are that pertain to protected species of plants and animals or their habitat that may occur at the site. If federal or state regulations provide special protection to plant or animal species (e.g., desert tortoise [*Gopherus agassizii*]) or their habitat (e.g., critical habitat or jurisdictional wetlands) then the user should be aware of permit stipulations and penalties. The distribution of such species or habitat warrants special protection and details of special site operating requirements described in the biological opinion that regulates training activities in lands containing these species. Examples of permit stipulation include environmental training of all personnel entering and using such areas and restrictions in use (spatial or temporal) of these areas. Mitigation projects in such areas may also require attention to permit stipulations (e.g., a Section 404 Permit for jurisdictional wetlands). Such species and habitat are protected with fines, penalties, and even prison terms for offenders, if convicted. The user's knowledge of these laws can help properly educate others at the installation and avoid costly mistakes.

3.9.2.2 Understanding the Site Mission and Training Activities

Understand what the mission and training activities are for the installation and work within the organization through effective communication. The user has a responsibility to understand the mission of the installation and what types of training activities may be required for the installation to effectively fulfill its mission. As part of this training, it is reasonable to assume that some activities will create adverse impacts. The user should contact site personnel and determine the types of training activities and schedule of activities (e.g., during day versus night) that are likely to create adverse land-disturbing impacts. The frequency, location, and physical and biological site conditions can help the user determine which, if any, mitigation measures are appropriate for specific sites. Areas that are too frequently or intensely used (e.g., travel corridors, trenching areas, live fire targets, or habitually used staging areas or camp sites) may have to be considered as "sacrifice" areas that may not receive mitigation in the short-term. The user should communicate with range control and other operation personnel on a regular basis and develop a good working relationship with such personnel. The more the user can understand about the operations and mission of the installation, the better informed will be the decisions. A well-informed user is generally better respected by management personnel and is more likely to be listened to.

3.9.2.3 Educating and Training Site Personnel

Educate and train site personnel as to the goals and objectives of the site protection program and what actions they can take to ensure compliance with this program. One of the first steps in

effective communication is the need to describe what you are trying to accomplish and why. This can be done during briefings or short training sessions that review the goals and objectives of the program, benefits to be achieved by complying with the program, and consequences for noncompliance. A brief 15-30-minute computer presentation (Microsoft PowerPoint®) or overhead presentation provides the opportunity to provide pictures, describe key points, and make a case for program compliance. Fliers, pocket-sized cards, and brochures provide excellent tools that can be given to those not attending briefing and training sessions. Users can work closely with installation personnel to ensure that the message is properly worded thus ensuring a "buy in" and support by management. Users should take advantage of every opportunity to interact and train site personnel. Do not forget to ask installation personnel how you can do a better job of protecting these valuable resources. Self-addressed questionnaires with prepaid postage (you only pay for those you receive back) may also provide opportunity to receive feedback by mail from visiting range users. Questions might request suggestions on how to better train and protect the mitigation features and revegetation.

3.9.2.4 Understanding Physical and Cultural Tools

Understand the physical and cultural tools available for ensuring site protection and their limitations. Users should become acquainted with the physical (e.g., barriers and berms) and cultural (e.g., signs, education, and training) tools that can be used to protect the site. Communicating with users at other installations and sharing ideas can help make the user more knowledgeable. To be effective as a deterrent, an obstacle needs to be recognized as such both during the day and at night. To be seen, this may require special reflective tapes and paints at regularly spaced intervals. Additionally, training and education may be needed to develop a culture in which personnel recognize and comply with signage and barriers. Above all, the user should recognize that no technique is fool-proof and that there are limitations to every technique. For example, study areas at four different sites in the NTC at Fort Irwin, California, were marked with regularly spaced fence posts with reflective tapes (thermal infrared and night light reflecting) in training areas. At each site approximately three dozen small white ceramic tiles, approximately 20-cm square, were placed within these marked areas using a regularly-spaced grid system of 30 m x 30 m. The original purpose for the placement of the tiles was to identify the corners of vegetation plots using aerial photographs. After 12 months, the tiles at the 4 sites were visited to determine the number that had been run over by vehicles within the protected area. The percentage of damaged tiles were 68 percent at Central Corridor, 17 percent at John Wayne Hill, 15 percent at Langford Impact Zone, and 58 percent at Red Pass. These statistics suggest that the method of protection was only partially successful and varied by site location. Unfortunately, no tiles were placed outside of the protected area for comparison, although it is the authors opinion that a far greater percentage of these tiles would have been damaged and fence posts did offer some protection to the sites.

3.9.2.5 Monitoring and Providing Adaptive Management

Monitor site conditions and provide adaptive management to ensure that goals and objectives are being met. Once the protective measures are put in place, it is essential to monitor their effectiveness. If techniques are not working properly then changes must be made in

management practices to ensure that the investments in erosion control and revegetation are not wasted or lost entirely. Monitoring should be done in a timely fashion. (See Section 4.0, "Monitoring and Remediation" for a more detailed discussion of monitoring.)

3.9.3 Techniques

The following techniques are presented as examples of those being used at Fort Irwin, California, and the NTS. These are only examples of possible techniques that can be used. The more important point is that the basic principles should be applied and modified as needed to achieve the goal of site protection through the use of protective features and techniques.

3.9.3.1 Working with Range Control

Those at the installation responsible for range control can be contacted and arrangements made to coordinate activities and utilize resources when possible. For example, personnel at range control can be supplied with Geographic Information System (GIS) themes, brochures, and other training information to help educate others. During their routine activities, they may have opportunity to advise personnel who are near or plan to have activities in restricted (e.g., tortoise habitat) or biologically sensitive areas (e.g., areas that may need temporary protection during mitigation phases). They may advise users of special problems they observe developing during site reconnaissance and clean-up operations.

3.9.3.2 Providing the Location of Protected Areas on Maps

Sensitive areas that need protection can also be identified on all maps that are provided to installation personnel so that they become familiar with the specific location of these areas. They can be appropriately marked with symbols or labels to inform personnel and reinforce information provided during training briefings. The global positioning system spatial coordinates can be provided to GIS personnel producing maps to ensure spatial accuracy. GIS themes can be prepared and shared with groups responsible for creating and printing site maps. Such maps should be reviewed and updated regularly to ensure that this information is current and accurate.

3.9.3.3 Posting Signs at the Site Perimeter

Signs may be posted at the perimeter of sensitive areas that need protection. Such signs should be properly elevated, visible both day and night (discernable using headlights or thermal-infrared imagery), and convey the necessary information to personnel who may enter the site. Signs may indicate a brief reason for the travel restriction and a contact telephone number or office name for those desiring further information, or provide a code that is readily interpreted. Signs should be sturdy enough to stand up to the rigors of high winds (e.g., speeds in excess of 160 kilometers per hour [kph] or 100 miles per hour [mph]), excessive heat (e.g., temperatures greater than 49°C [120°F]), and routine training activities. Signs should be monitored regularly and replaced when

they deteriorate to the point of losing key information. Examples used at Fort Irwin, California, are shown in Figure 3-34.

Figure 3-34. Siebert signs with night vision reflective tape.

3.9.3.4 Controlling Access Using Berms and Barriers

Access to mitigation and erosion control sites may be controlled through a variety of techniques. These include the construction of barriers (e.g., railroad ties, sections of telephone poles, or concrete jersey barriers), fences (with and without wires), earthen berms, or shallow ditches, and the placement of natural obstacles such as large boulders or rocks (Figure 3-35). The planting (by large transplants) or seeding of vegetation screens can also be used to direct traffic around sensitive areas.

An alternative to constructing barriers is to direct traffic by improving surface conditions on selected portions of traffic corridors (e.g., at intersections). If vehicle operators have a choice of several routes and one of those routes is more improved than the others, the operators will often take the improved route. Improvements may consist of grading the surface to increase smoothness and marking road edges with berms to direct traffic. Often a combination of these physical and biological techniques may be required.

3.9.4 Special Considerations

It is also important to consider potential adverse impacts from controlled access features to the safety of vehicles and personnel, and any undesirable potential disruptions to training operations that may result from these techniques to make sure that they do not pose any unwanted safety

Figure 3-35. Berms combined with transplants to direct traffic down established roads at Fort Irwin, California.

hazards (e.g., ditches should not be so deep as to create deathtraps to those who may enter them at night at high speeds as part of routine training).

Because training activities often occur at night, any signs should be clearly visible at night as well as during the day. Nighttime activities often use thermal-infrared vision sighting devices that may not detect the usual reflective surfaces. Routine monitoring of the signs will help determine the effectiveness of such protective techniques.

Instrumentation and other mitigation equipment may have to be protected (e.g., buried) or removed during certain periods of the rotation schedule to ensure that they are not damaged.

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4.0 MONITORING AND REMEDIATION

4.1 MONITORING

Monitoring is often the most overlooked of all aspects of a reclamation project and consists of conducting several site visits both during and after reclamation activities. It is important to consider monitoring at the very beginning of the project and adequately budget for monitoring activities not only during and right after reclamation activities but for several years after reclamation is completed.

4.1.1 Purposes of Monitoring

The main purposes of monitoring are to assess if reclamation objectives are on track or are being met, locate problems, develop recommendations for remediation, and evaluate the success or failure of all reclamation practices including determining why they succeeded or failed and their cost-effectiveness. Monitoring also serves to verify compliance with contract specifications, assure that adequate data are available to guide remedial actions (if necessary), and provide for future cost savings. An example of cost savings is illustrated by proper monitoring and early detection of an erosion control structure that is not functioning properly. If the problem is detected early and remedial action is implemented soon after detection, erosion and damage to the erosion control structure are minimized. This results in considerable cost savings in repairing damage created by the erosion. Monitoring activities should be formalized into a written monitoring plan and included as a section in the reclamation plan before implementation begins.

4.1.2 Key Elements of a Monitoring Plan

No single monitoring plan is applicable to all installations or areas. Monitoring plans should be "tailor-made" to fit the unique requirements of a given installation, area, or project site. However, there are some key elements that should be included in a monitoring plan:

- Clearly identify the reclamation objectives.
- Outline and describe the monitoring techniques to be used, including a monitoring schedule.
- Clearly define the success criteria.
- Identify the reference area, if needed.
- Summarize and report monitoring results.

4.1.3 Techniques

Two general monitoring techniques, qualitative and quantitative, are available for assessing reclamation results. Deciding which technique to use is primarily dependent on the reclamation objectives, reporting requirements, and budgetary constraints. One technique does not have to be used exclusively. In fact, it is best to use both monitoring techniques. For example, vegetation

at a site could be quantitatively monitored during the first, third, and fifth year following implementation and qualitatively monitored during the second and fourth year following implementation.

Monitoring activities usually focus on soil erosion and vegetation. However, other things may be monitored as well such as wildlife use and climatic variables (e.g., precipitation, wind speed and direction, soil moisture, and air and soil temperature). Elzinga *et al.*, (1998) provide a comprehensive approach to measuring and monitoring plant populations.

4.1.3.1 Qualitative Monitoring

Qualitative monitoring consists of making reconnaissance visits to a site, and is done to observe and document overall site conditions including the stability or erosion of soil surface materials, integrity and functionality of erosion control structures, anchoring of surface mulches, emergence of seedlings, evidence of stressed or dead seedlings, condition of transplanted plants, presence of unwanted weeds that could cause problems for plant survival, signs of herbivory or animal use, and integrity and functionality of site protective measures. It is very important to take good notes during the reconnaissance visit. A standardized checklist may facilitate note-taking. An example of a standardized checklist is found in Appendix 9.3. It is also recommended that color photographs be taken from standardized photo points. If possible, photographs should be taken prior to disturbance, during the implementation phase, and at various times after implementation to track site condition through time. Figure 4-1 shows the value of having photographic documentation of a site before and after reclamation. Also, a new technique for measuring perennial plant cover using aerial photographs has been developed by Hansen and Ostler (2002). This technique is valuable for comparing plant cover between reference areas and reclaimed sites. Video cameras may also be used to document site condition. This is extremely helpful, especially for remote sites for reviewing both visual and audible information from the site visit back in the office.

4.1.3.2 Quantitative Monitoring

Quantitative monitoring methods consist of taking measurements or counts. For revegetation evaluation, counts of living plants (seedlings or transplants) are made. Commonly used techniques include counting the number of plants in specific areas (density) such as samples from a length of row if seeded in rows by a mechanical seed drill or the number of plants in representative sample plots in areas such as a circle or quadrat if the seeds were broadcast. Where transplants have been planted in a random fashion, the total number of individuals, by species, should be determined in representative areas. Other vegetative parameters that may be measured include plant cover, frequency, biomass, species richness, and species diversity. Determining how many measurements or counts to take depends on the level of accuracy or precision you need or are required to provide, and the resources you have to do the monitoring. It is important to adequately budget for reclamation monitoring costs at the beginning of the project. Formulas for determining minimum sample sizes at different levels of statistical precision can be used and are described in detail by Bonham (1989).

Figure 4-1. Double Tracks clean-up site (Nellis Air Force Range, Nevada) before (A) and after (B) seeding.

The BLM has developed a rating and classification data form for evaluating soil erosion in the field (Table 4-1). For each of the four erosion indicators (i.e., Column A = Surface litter, B = Pedestalling, C = Rills < 9 in, D = Rills > 9 in), determine a numerical rating from one to five based on field observations of the site. Then total the four numbers in the total cell (A + B + C + D) and assign an erosion condition class based on the numerical rating scale. For example, if each indicator was given a value of three (3) the total numerical rating would be 12.0 (3 + 3 + 3 + 3) so the site erosion condition class would be moderate. Hand-held palmtop computers can also be used to enter data directly into an electronic data form. This speeds up the data entry and analysis process substantially and reduces transcription errors. Once quantitative data are collected, they should be analyzed and results interpreted. Depending on the reporting requirements and need for precision, detailed statistical analyses may be warranted. This is especially true if the field monitoring results are to be used in any legal proceedings or negotiations that require extensive and technically valid numbers.

Table 4-1. Example of a soil-erosion rating and classification form for assessing erosion status in the field.

Rating Value	A Surface Litter	B Pedestalling	C Rills < 23 cm (9 in)	D Rills > 23 cm (9 in)	Totals
1	Accumulating in place	No visual evidence	No visual evidence	No visual evidence	
2	Slight movement	Slight pedestalling	Rills in evidence at intervals > 3 m (10 ft)	Rills in evidence at intervals > 3 m (10 ft)	
3	Moderate movement	Small rock and plant pedestalling	Rills at 3 m (10 ft) intervals	Rills at 3 m (10 ft) intervals	**(A+B+C+D)**
4	Extreme movement	Pedestalling evident, plant roots exposed	Rills at 1.5 – 3 m (5 – 10 ft) intervals	Rills at 1.5 – 3 m (5 – 10 ft) intervals	
5	Very little remaining litter	Most plants and rocks pedestalled and roots exposed	Rills at < 1.5 m (5 ft) intervals	Rills at < 1.5 m (5 ft) intervals	
Example:	**Surface Litter** Rating: 3	**Pedestalling** Rating: 3	**Rills < 23 cm** Rating: 3	**Rills > 23 cm** Rating: 3	12.0*
* Number Rating for Totals:		**Total Rating Value** / **Erosion Condition Class** 0.0 – 4.0 ..... Stable 4.1 – 8.0 ..... Slight 8.1 – 12.0 ..... Moderate 12.1 – 16.0 ..... Critical 16.1 – 20.0 ..... Severe			

4.1.4 Frequency of Monitoring

Monitoring should occur during the implementation phase of reclamation to ensure that work is being carried out according to specifications, and for three to five years following implementation to ensure that reclamation objectives have been met (Hansen and McKell, 1991).

The frequency of monitoring (i.e., number of site visits per unit of time) should be determined by the reclamation project team. Some factors to consider include reclamation objectives, site accessibility, budgetary constraints, and time of year. Visits should be timed so that the maximum benefits can be obtained such as following a rainfall event to evaluate water management techniques or at the peak of the growing season to determine revegetation success. It is also recommended that seedling density counts be made during the first growing season following seeding to establish a baseline density that can be used to track plant survival over time. During the implementation phase, monitoring should focus on making sure that reclamation techniques are being implemented properly. Proper design and implementation will substantially reduce the need for remediation later. Nevertheless, the major emphasis of

monitoring activities is after the implementation phase. After implementation, monitoring during site visits should be focused on evaluating each reclamation technique to see if it is fulfilling its intended purpose. If any are not, remedial actions should be developed and implemented to correct the problem. Hansen and McKell (1991) recommend a minimum of two visits per year for the first two years following the reclamation of high-priority sites, at least one visit per year for low-priority sites, and one visit to all sites after three to five years to assess the longer term stability and plant survival. Generally, after this period, plant mortality is minimal. In areas receiving continual military training, monitoring should be increased commensurate with the degree of disturbance (e.g., monthly or quarterly).

4.1.5 Success Criteria

Success criteria are used to evaluate whether the reclamation objectives have been met or not. For example, if one of the reclamation objectives is to control wind erosion from a site, then the amount of soil lost to wind erosion needs to be measured (qualitatively or quantitatively) and specific values set to define when this reclamation objective has been achieved. If the success criteria are not met, then remedial actions should be planned and implemented.

Success criteria will vary among sites because reclamation objectives vary, and success criteria should be based on the reclamation objectives. An example of viable success criteria was developed by reclamation scientists as part of the Yucca Mountain site characterization studies in south-central Nevada (Dixon, 1998). She states, "Reclamation will be considered successful if the cover, density, and species richness (i.e., the number of perennial plant species in each site) of native-perennial vegetation is equal to or exceeds 60% of the values of these parameters in undisturbed reference areas." Their reclamation objective was to, "Return land disturbed by site-characterization activities to a stable ecological state with a form and productivity similar to the predisturbance state." Success criteria may also be dictated by state or federal regulations.

4.1.6 Reference Areas

Reference areas are used to determine or approximate the pre-disturbance state of a disturbed site. Data collected from reference areas are used to develop seed mixes and transplant needs for revegetation and for comparison with data from revegetated sites to see how close they approximate each other. Specific values on how close the disturbed site and reference area approximate each other after a certain period of time can be set to determine if revegetation has been successful or not. Values can also be set as benchmarks to ensure that revegetation is on track to meet the final success criteria.

Vogel (1987) lists essential criteria for comparing reference and revegetated areas:

- Individual site factors, including elevation, precipitation, slope, and aspect, are similar on both areas.
- Both areas are composed of the same plant life-forms and seasonal varieties of vegetation.
- Management of the reference areas during the revegetation phase is consistent with that proposed for the revegetated area.

- Certain edaphic characteristics are similar, though it is unlikely that both areas will have exactly the same soils.
- A revegetated area that is realistically comparable to the reference area (i.e., it can produce a similar kind and amount of vegetation).

The reference area does not need to be immediately adjacent to the revegetated area as long as the above criteria are met, but should be within about 32 kilometers (km) (20 miles [mi]) of the revegetated area. Sampling design should also be similar in the two areas for valid comparisons.

4.1.7 Summarize and Report Monitoring Results

In order to fulfill the main purposes of monitoring, it is imperative that monitoring results be summarized and communicated to the right people. Otherwise, monitoring efforts would not be effective. Results may be communicated via formal reports, informal reports, or in memoranda to the file. The following questions should be answered:

- Are reclamation objectives on track or have they been met?
- Are there any problems (e.g., signs of erosion, dead plants, etc.)?
- Are there any remedial actions required to maintain the integrity of the site and meet the reclamation objectives?
- What reclamation techniques were successful and why were they successful?
- What reclamation techniques failed and why did they fail?
- What was the cost-effectiveness of each reclamation technique?
- Were contract specifications met?
- Were there any inconsistencies between what was written in the reclamation plan and what actually occurred during implementation?

Answering these questions will provide valuable insight into the reclamation process and should make future projects more successful and more cost-effective.

4.2 REMEDIATION

Remediation is defined as the actions required to fix, correct, or repair problems associated with reclamation activities. Remedial actions are developed from information gathered during the site visits. The most important principle of remediation is to determine the root cause of the problem and then focus the remedial actions on the root cause. For example, if small rills are noticed on a revegetated slope, a possible action may be to fill and rake over the small rills. This may get rid of the small rills but the root cause of those rills may be improper water diversions, in which case the small rills will develop again after the next rainstorm. When possible, every effort should be made to implement the remedial actions as soon after monitoring as possible, especially if active accelerated erosion is taking place.

The most common remedial actions deal with inadequate or failed erosion control techniques and inadequate plant establishment. The same erosion control principles and techniques that were described in Section 3.1, "Erosion Control," should be used for remediating areas with erosion

problems. Some areas may need to be re-seeded or replanted after remedial erosion control practices have been implemented. Obviously, it is best to minimize the amount of disturbance to previously revegetated areas. Some level of erosion should be expected until the vegetation becomes established or the disturbed site is stabilized.

Causes of inadequate plant establishment may be due to a variety of factors that may include lack of sufficient water, poor soil fertility, poor soil aeration, competition from weedy species, herbivory by insects or other animals, absence of soil microbes, soil erosion problems, or any combination of these. Some possible remedial actions include supplemental watering, fertilizing, weed control, pesticides, fencing, or inoculation with microbes. Sometimes the best thing to do is wait, especially when seeding with native plants. In order for plants to germinate, it takes the right combination of climatic variables (e.g., moisture and temperature). In arid areas, the right conditions for germination do not occur every year. Seeds of many native plant species have adapted to this problem and remain viable in the ground for several years. The length of time to wait depends on the reclamation objectives, species used, and the climate. In some cases, it may be necessary to seed in consecutive years until the right climatic conditions result in germination.

Determining if erosion or inadequate plant establishment are serious enough to warrant remedial actions should be carefully thought out and the decision based on the reclamation objectives and the success criteria established to meet those objectives. Remediation can be costly. However, by the time remedial actions become necessary a lot of money has already been invested in reclamation activities and remediation costs are usually minimal compared to the total cost already invested. It is imperative to consider potential remedial actions at the beginning of the project and address these in the reclamation plan. It may not be necessary to conduct remediation in all areas. Priority areas may be designated where remedial actions can be focused. Proper selection and implementation of reclamation techniques are the best ways to minimize the need for remediation but do not necessarily guarantee success.

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5.0 COSTS

The cost of land reclamation can vary widely based on several factors including site conditions and size of the reclamation project. Difficult site conditions (e.g., wet soils, steep slopes, rocky terrain, remote locations, etc.) can greatly increase the cost of most activities.

Military installations present unique logistical challenges that may serve to reduce or increase reclamation costs depending on local circumstances. Material costs can be reduced if on-site materials are available (e.g., riprap). Using military engineer personnel and machinery when available may reduce labor and equipment costs. On the other hand, costs may be increased if training schedules limit access to the areas to be reclaimed or training damages ongoing reclamation efforts. Travel costs to the remote locations of many military installations may increase overall reclamation expenditures. Costs for various revegetation techniques in arid and semi-arid areas of the western United States can be found in Warren and Ostler (2002), Appendix 9-3. Summary information for the Mojave (including the northern Sonoran Desert) and Great Basin deserts are provided below. Costs were obtained by contacting various federal and state agencies and private companies in each region. Only cost data from 1990 through 2000 were used and data prior to 2000 were adjusted by an inflation rate of 3 percent per annum. Costs were generally reported for average-sized jobs done by experienced contractors, operators, and vendors. Most jobs have built-in mobilization costs that do not vary regardless of job size. Hence, costs per hectare are often less for large jobs and considerably higher for small jobs. Costs are provided for the eight categories discussed in Section 3.0, "Reclamation Techniques."

5.1 EROSION CONTROL

Section 3.1, "Erosion Control" discussed the many techniques, physical, chemical, cultural and biological, that can be used to control erosion. Physical techniques that are commonly used in arid environments include surface manipulations or diversion structures such as contour trenching, contour furrowing, pitting, imprinting, gouging, check dams, and dozer basins. Diversion structures may be used to divert water away from areas of concentrated flow, thus reducing the erosive energy of flowing water. Diversion trenches and dozer basins may also be used to divert water into areas where revegetation efforts are taking place in order to supplement the supply of water to the new plants. For the purposes of this cost analysis, diversion trenches are defined as shallow, linear excavations produced by a single pass of heavy equipment such as a road grader, although an experienced bulldozer or front-end loader driver can often accomplish a similar result. Average regional costs for the construction of diversion trenches are listed in Table 5-1. Costs are generally low and do not vary widely by region. There is generally as much or more variation within desert provinces than between them. Variability in cost per linear meter ($/lm) is attributable to mileage to and from the construction sites, and the size of the job.

Armoring in areas of high risk for erosion is also common. Armoring with large rocks or boulders is most commonly referred to as riprap. Runoff from storm events is a rare event in most deserts, however, when it occurs it is often very rapid and damaging to unprotected areas. Riprap is commonly placed in gullies or waterways to slow the flow of water and minimize its

Table 5-1. Regional average cost for supplemental erosion control practices.

Province	Estimate Type	Diversion Trenches ($/meter)	Riprap, Installed ($/m^3)
Great Basin Desert	Average	6	40
	Range	3-6	20-69
Mojave Desert	Average	6	48
	Range	3-12	26-87
COMBINED AVERAGE		6	44

erosive energy. Riprap is available in many different sizes depending on the expected flow of water. The size of the rock can greatly affect the cost. Most agencies do not record the costs of materials and labor separately. Hence, the values recorded in Table 5-1 include both labor and material.

In some areas of the Mojave and Sonoran Deserts, a natural armoring has developed (known as desert pavement) that protects sites from erosion. There have been a few sites where this technique has been attempted but it is generally very costly (~$2,000 ha). Gravel is applied using a modified spreader on a dump truck. Gravel should be less than 2-3 cm in thickness or it will inhibit seedling emergence. Hauling and application efforts are the major factors in costs of this technique.

Organic mulches are commonly used to control erosion but costs of these will be discussed in Section 5.7, "Mulching."

Chemical control techniques have been used to control erosion in arid lands; however, their use is generally restricted to dust control associated with mining roads and mine tailings. Hygroscopic salts are often used on mining roads and costs run $200-$1,000 each year depending on the number of applications. These are not compatible with revegetation because they increase the salt in the soil make plant growth difficult or impossible for most species. Organic tackifiers and water-soluble synthetic polymers are sometimes used to control erosion on highly erodible areas. We used an organic tackifier at Fort Irwin, California, on some revegetation trials and it was very effective at controlling erosion on some severely disturbed sites (Figure 5-1). It also performed well as a mulch treatment with pre-treated seed of creosote bush and white bursage. Costs for application of these chemical treatments (~$3,000/ha) are similar to hydromulching since they are generally applied with hydromulching equipment. Distance to a water source is a major factor controlling the cost of hydromulching.

5.2 SITE PREPARATION

Some form of mechanical site preparation is often needed prior to revegetation. This can be particularly true on DoD training areas where repeated passage of armored vehicles has caused significant soil compaction. Ripping, subsoiling, or chiseling are deep tillage operations specifically designed to break or shatter compacted soil layers that can inhibit germination, root

Figure 5-1. Soil crust developed from chemical soil stabilizer that was applied to severely disturbed and highly erodible soils at Fort Irwin, California.

development, and moisture infiltration. Chiseling is generally less expensive than ripping or subsoiling due to shallower depths of implement operation and reduced power requirements. Disking can be used to ameliorate shallow compaction and vesicular horizons and to remove unwanted vegetation. Disking may be accomplished with an offset disk or a tandem disk. Offset disking is generally more expensive than tandem disking, but does a better job of killing and mulching existing vegetation with a single pass of the implement. Harrowing is a much less intensive site preparation method used to break up superficial compaction or physical crusts. It can also be used to smooth the soil surface following ripping or disking, and is often used following broadcast seeding in order to help cover the seeds and ensure seed-soil contact necessary for germination. One other site preparation technique is known as slope chaining, sometimes called clod busting. It is used on slopes too steep for equipment to traverse but where there is access from the top of the slope. Slope chaining had average costs of $310/ha. The regional costs for the various site preparation practices are listed in Table 5-2.

Table 5-2. Regional average cost ($/hectare) for site preparation activities.

Province	Estimate Type	Site Preparation		
		Ripping	Disking	Harrowing
Great Basin Desert	Average	67	49	44
	Range	15-161	15-124	12-111
Mojave Desert	Average	213	106	126
	Range	15-741	15-383	15-366
COMBINED AVERAGE		140	78	85

Costs for site preparation treatments ranged widely within and between the two geographic regions (Table 5-2). Costs in the Mojave Desert province were higher due largely to costs reported for two military sites in the Mojave Desert. Costs for all three sites reported by the Natural Resources Conservation Service in a revegetation study conducted for the U.S. Navy on abandoned farmland in the Lahontan Valley, Nevada, were also high. Ripping costs were 4 to 10 times higher at Fort Irwin, California, than for any location other than Lahontan Valley, Nevada. Treatments at Lahontan Valley, Nevada and Fort Irwin, California were experimental in nature. Because mobilization costs remain relatively constant regardless of the size of the treated area, the higher costs per hectare are likely attributable to the small size of the treated areas and the remoteness of the locations. If these sites were eliminated from the data set, the average costs per hectare are in line with the other desert areas.

Topsoil salvage was discussed as a special consideration and where possible topsoil salvage is encouraged. The costs associated with removal and replacement of topsoil can range greatly depending on the depth of the topsoil, the equipment used, and the distance it has to be hauled. Average costs for short hauls (0.5 km) range from \$1.00-\$4.00/m^3. Direct hauling of topsoil from the removal location to the final placement is preferred over storage to reduce costs and retain the quality of the topsoil.

5.3 SOIL AMENDMENTS

Three kinds of amendments (synthetic polymers, organic materials, fertilizers) are used in arid areas to improve the soil and provide proper nutrients and water-holding capacity for good plant growth. Costs for synthetic polymers average \$1,110-\$1,860/ha depending on an application rate of 170-280 kg/ha. Our experience and that of others suggests that this rate is much higher than needed for a desert environment. Rates of 25 kg/ha have been shown to have a beneficial effect (Winkel et al., 1999) at a much reduced cost. These polymers are most effective if they are applied and then disked into the soil. Costs for application and disking would range from \$15-\$124/ha in the Great Basin area and \$15-\$383/ha in the Mojave Desert with an average price near \$80/ha (Table 5-2). Total costs for materials and application would range from \$1,200-\$1,940/ha.

Many organic materials also can have no or very low costs; however, the cost of this material is mainly influenced by transportation. If local sources are available, then application may be practical. Like synthetic polymers, organic materials need to be mixed into the soil, which is often best accomplished by disking. Typical costs of applying organic materials would consist of the initial cost of the materials (\$0-\$400/ha), transportation (\$10-\$100/ton), application onto the site (~ \$100/ha) and disking to incorporate the organic materials (\$80/ha). This technique can become quite expensive and is only viable where sources are close and have low or no cost.

Fertilization is not a common practice on rangelands or training lands in the arid West. Indeed, except where frequent and/or intense disturbance has resulted in the loss of organic matter and fine soil particles, fertilization can be counterproductive in trying to reestablish desert

ecosystems. Native perennial plants in deserts generally have low nutrient requirements while introduced annual plants generally have higher requirements. Hence, the addition of fertilizer will tend to favor exotic weeds at the expense of native plants.

The number of responses from the various agencies was quite low for both deserts. Labor and equipment costs were generally low in both deserts (Table 5-3). Overall, material costs were higher and more variable than labor or equipment costs. Variability in material costs is based on the type and amount of fertilizer required. These factors are, in turn, determined by existing nutrient status, soil type, organic matter content, clay mineralogy, salinity, alkalinity, site history, etc. Overall, it appears that the cost of fertilization was very similar in both deserts.

Table 5-3. Regional average cost ($/hectare) for broadcast fertilization.

Province	Estimate Type	Broadcast Fertilization	
		Labor/Equipment	Materials
Great Basin Desert	Average	35	217
	Range	10-111	62-371
Mojave Desert	Average	30	217
	Range	17-111	62-371
COMBINED AVERAGE		33	217

The costs included in Table 5-3 are for broadcast fertilization only as this is the most common method of application for revegetation projects. When planting tubelings or containerized plants, fertilizer pellets are occasionally used. Only one agency reported information on fertilizer pellets. They estimated the cost for using fertilizer pellets to be $1 per plant for materials and $0.50 to $2 per plant for labor. Other sources (NPI Reclamation Services, 1985b) report fertilizer tablet costs around $0.10 per plant. These costs should not change significantly based on region.

5.4 SEEDING

On large disturbances, such as fires or major construction projects, reestablishment of vegetative ground cover is most often accomplished by broadcast or drill seeding. Broadcast seeding is a process of spreading seed onto the soil surface. Prior seedbed preparation is not always required or even desirable. Broadcasting is often the least expensive seeding alternative in terms of labor costs. This is due primarily to the fact that more ground surface can be seeded with a single pass of the seeding equipment (particularly with aerial seeding) than with drill seeding. However, because the seed is left on the soil surface, seed-soil contact may not be adequate for good germination success. Hence, it may be necessary to seed at a higher rate or to drag an implement over the site following seeding to help cover the seed with a thin layer of soil. Seeding at a higher rate (some studies suggest 50-100 percent) will increase the cost of broadcast seeding tremendously. It is generally a better option from a cost standpoint to combine the broadcast seeding with a blanket harrow or other technique that covers the seed if access to the site is possible.

Drill seeding is a process of placing seeds directly in the ground at a specified depth. Depending on the condition of the soil surface and the nature of the seed drill, some form of seedbed preparation may be necessary. Seed distribution is generally improved by drilling. Many seed drills can be adapted to place seeds at variable depths depending on their germination requirements. Seed drills are also often equipped with press wheels or drag chains to help cover the seeds with soil and improve seed-soil contact. Where rough or steep terrain limits the access of drilling implements, broadcasting or hydroseeding may be required. Hydroseeding is a process of spraying seed onto the soil via liquid slurry. It is much more expensive than drill seeding or broadcasting due to the cost of equipment and the cost of transporting large quantities of water.

For both deserts, broadcast seeding had the lowest labor and equipment costs (Table 5-4). The average cost of drill seeding was almost double the cost of broadcast seeding. However, these estimates do not include the potential cost of using an additional implement to cover the seed in the case of broadcast seeding or the possible added cost of seedbed preparation in the case of drill seeding. Higher average costs for broadcast and drill seeding were reported from the Mojave Desert Province. As in the case of seedbed preparation practices, the higher per hectare costs here were attributable to the mobilization costs for treating small areas and the remoteness of the sites treated. Average per hectare hydroseeding costs were uniformly high and exceeded broadcasting and drilling by an order of magnitude. There are fewer contractors equipped to do hydroseeding and many hydroseeding contractors travel throughout the West.

Table 5-4. Regional average cost ($/hectare) for seeding practices.

Province	Estimate Type	Labor & Equipment Cost		Seed Cost	Hydroseeding (includes labor, equipment, seed, fertilizer, mulch, and tackifier)
		Broadcast	Drill		
Great Basin Desert	Average	35	59	531	5103
	Range	10-99	15-161	148-988	3529-14085
Mojave Desert	Average	111	138	425	5103
	Range	49-148	25-297	148-988	3529-11752
COMBINED AVERAGE		73	99	478	5103

The rate of seeding, and hence the cost of seed, was assumed to be constant regardless of the equipment used. Executive Order 13112, issued February 3, 1999, requires federal agencies to prevent the introduction of invasive species and work toward the restoration of native species. Hence, seed costs were estimated based on using only mixtures of native species despite the fact that such a strategy may increase the cost of reseeding by as much as an order of magnitude in some cases. Seed costs were slightly lower in the Mojave Desert. Seed costs can vary widely within and between years based on supply and demand; low supplies or high demand can greatly increase the cost of seed. Some seeds are not available commercially but can be custom-collected. This will generally increase the cost of seed but does provide seed that is site-adapted and generally performs very well.

Handling of seed and short- or long-term storage can also increase costs. Seed cannot be left out in hot, wet weather without causing significant loss of viability. While pre-treating seed will incur additional cost, it can increase germination tremendously. Thus, one can reduce the seeding rates which should more than offset any increase in cost to do the seed pre-treatments.

5.5 PLANTING

Where reclamation plans call for trees and shrubs, it is sometimes more effective to utilize live plants rather than seeds particularly in arid environments. Planting provides plant material on a site rather quickly to solve erosion or other aesthetic issues. Planting is often done for high-priority projects that have larger budgets. However, the availability of suitable containerized trees and shrubs for transplanting in desert regions is often limited. When available, they are most often supplied as tubelings or containerized plants. Bare rootstock is used by some agencies, but is comparatively rare in dry regions due to the higher risk of desiccation of the tender roots during and after the planting process. Costs of bareroot stock are generally half the costs of tubelings. Relatively few agencies in the region were able to provide cost estimates for the use of live plants. Estimates were limited to commonly available native species (estimates for unusual species can run as high as $200 per plant). Costs are reported in Table 5-5.

Table 5-5. Regional average cost ($/plant) for live plants.

Province	Estimate Type	Tubelings			Containerized Plants (3.8 l)		
		Labor	Material	Labor and Material	Labor	Material	Labor and Material
Great Basin Desert	Average	2	2	5	10	14	17
	Range	1-3	1-3	3-24	7-25	5-29	6-36
Mojave Desert	Average	2	2	4	10	8	10
	Range	1-3	1-3	2-6	2-18	2-11	2-36
COMBINED AVERAGE		2	2	4	10	11	14

The cost of using tubelings was markedly less than containerized plants in both deserts. Planting tubes are smaller (0.5 liters) and cost less than most other containers. Because of their small size, space requirements for growing and transporting are minimized. For containerized plants, the reported costs reflect 3.8-liter (1-gallon) containers. The use of larger container sizes tends to increase expenses dramatically due to the higher cost of transportation and the fact that the plants in larger containers tend to be older and have required more effort to grow. Labor costs are estimated for hand planting in normal soils; where soils are hard or rocky, labor costs can be expected to increase. Some agencies procure labor and materials through separate contracts.

This has a tendency to increase the overall cost when compared to contracts that procure labor and materials jointly (Table 5-5). This is especially true for large contractors who grow their own plants or who can take advantage of volume discounts by securing plant materials for multiple contracts simultaneously.

Salvaging of plants from areas that will be disturbed is also possible. The cost of salvaging plants is probably not much different from purchasing containerized plants since the labor cost would be incurred for removal of the plants from the salvage area and transplanting to the new area. Labor costs are generally equal to material costs. Salvaging plants may provide species that are not available from commercial nurseries or that are very expensive. Salvaging plants should be restricted to those species, such as cacti and succulents, that do well when transplanted.

Although inoculation of woody plant roots with mycorrhizal fungi can significantly enhance survival and growth of many woody species, it is not widely used. Only one agency reported costs of inoculation. These averaged less than $1 per plant including labor and materials.

5.6 GRAZING AND WEED CONTROL

Two techniques (fencing and protective tubes) are commonly used to control herbivory on a site being reclaimed. Fencing is effective but is also costly particularly for large areas. Two types of fencing are often used, normal barbed wire to exclude large grazing animals and chicken wire fencing to control rabbits and other smaller mammals. Costs for barbed wire fence average $2,000 per km including materials and labor for installation. This can vary widely based on the rockiness of the soil and remoteness of the location. Chicken wire fence is less expensive, however it does require special care in installing the fence because 30 cm of fence needs to be buried to keep rabbits from going under the fence. Cost of the material is $500/linear km and installation will range from $1,500-$1,700.

In areas that are receiving transplants, it is desirable to use translucent tubes to protect the young plants from sunscald and herbivores while providing a greenhouse-like microenvironment. Such tubes for containerized plants or tubelings cost an average of $2 (range $1-$3) each when purchased in bulk, regardless of region. Installation of the tubelings costs an average of $2 per plant (range $1-$2). For small plantings, this is a very useful technique; however, for large areas with many transplants a perimeter fence may be more cost-effective.

Weeds are often controlled by herbicides particularly in areas near facilities. Herbicides are generally not very expensive but the application can be since many areas require a person certified in the proper handling and use of the herbicides. Herbicides cost about $100-200/ha and the application cost ranges from $200-$500/ha. Weeds should be treated early to avoid their spread thus creating large and more serious problems later on.

5.7 MULCHING

Germination and survival of plants in reseeded areas can be enhanced by the addition of mulch. Mulch helps conserve soil moisture and adds organic matter to the soil. Commonly used materials include straw, hay, and commercial fiber mulch. Hay is often more expensive than straw because of its alternative value as winterfeed for livestock. Straw ranges from $600-$740/ha while hay ranges from $740-$1,230/ha. Transportation of the material to the site can increase these costs tremendously. Straw and hay can be hand-spread or blown on with special equipment designed for that purpose. The labor cost for applying mulch is the same for

straw and hay, although the material cost can vary widely both within and between regions (Table 5-6). Costs for straw blowing generally range from $300-$400/ha. Straw and hay are both susceptible to being blown off of the site unless they are anchored in some way. Hence, crimping or tackifying may be necessary to hold it in place. Crimping generally ranges from $105-$185/ha, while tackifying is much more expensive since hydromulching equipment is needed and costs may range from $1,000-$2,000/ha. Costs are much less than actual hydromulching because less material and particularly less water are required. Most contracts that call for mulching do not separate the costs of materials and labor. Hence, Table 5-6 reflects average regional costs for the entire process. The cost of mulching is much lower in the Great Basin Desert than the Mojave Desert in part due to the proximity of numerous farms and ranches at higher elevations within this region where cooler temperatures and irrigation systems provide a setting more conducive to hay and straw production.

Table 5-6. Regional average cost ($/hectare) for mulching with straw or hay.

Province	Estimate Type	Material, spreading and crimping
Great Basin Desert	Average	734
	Range	321-1129
Mojave Desert	Average	2320
	Range	-
COMBINED AVERAGE		1527

Fiber mulch is generally used only in conjunction with hydromulching or hydroseeding. The combined cost of labor and materials for hydromulching is generally much higher than mulching with straw or hay. Estimated costs of hydromulching generally range from $3,000-$4,500/ha. The cost of materials is around $400/ha for the wood fiber mulch applied at a rate of 1,100 kg/ha and $190/ha for the tackifier. The major cost is the application of the material that includes equipment, water, and labor. Distance to water is the major factor particularly in arid areas.

There are also other mulches such as jute netting, excelsior mats, and plastic mesh that are used for areas that are more susceptible to erosion or where runoff accumulates. These mulches are often very expensive. Excelsior mats range from $8,155 to $10,626/ha for materials and $2,224 to $4,448 for installation. Plastic netting is slightly less ranging from $6,920 to $7,166/ha and approximately $2,000 for installation. These mulches are seldom used in arid areas because the erosion potential is not as great as more mesic areas and the mulches often do not allow precipitation to get into the soil.

5.8 IRRIGATION

Supplemental watering of young seedlings or transplants can also enhance survival. The practice, however, is not common. Two agencies reported the cost of supplemental watering of transplants at $16 and $28 per plant. This can be twice the cost of the plants themselves (Table 5-5), and likely accounts for the fact that the practice is uncommon. It does increase the survival of the transplants tremendously, particularly in dry years. In the Mojave Desert, survival rates with irrigation range from 25-97 percent with a mean value of 67 percent.

Survival was dependent on species, time of planting, soil erosion, and herbivory. There are several ways to apply water to transplants efficiently including basins, buried perforated pipe, and driplines. The focus of these is to apply water only to the area immediately surrounding the plant roots. Field data from Fort Irwin, California, show that although basins are initially less expensive to construct and to water, lower survival rates make this technique more costly than perforated pipes or driplines on a per living plant basis.

Portable irrigation systems can be used effectively on seeded areas to enhance or ensure germination. Irrigation levels should not be higher than normal wet years that may naturally occur at these sites, otherwise species die-out will occur once the irrigation is removed. Since portable systems can be used multiple times, the major cost of irrigation is in the transport of water to the site. A 15,000-liter (4,000-gallon) water truck with a driver may cost approximately $300 to $400/day. To put 2.5 cm (1 in) of water on 0.4 ha (1 acre) would require seven truckloads, which would take about one day to apply if the water source was fairly close.

5.9 SITE PROTECTION

Several techniques are identified that are effective at protecting reclaimed sites until they have grown sufficiently to withstand minor disturbances. Most important of these is proper signage of the areas. Signs are inexpensive compared to the total cost of reclaiming the site, yet without them the whole revegetation effort could be decimated by continual access. Signs should be used to make personnel aware that the areas are undergoing rehabilitation and are protected.

5.10 COST EFFECTIVENESS

Many variables (most previously discussed) can effect the cost of reclamation projects. These costs are important in selecting reclamation techniques for a reclamation plan. It is important that reclamation costs are tracked to develop realistic budgets for future reclamation efforts. It is also important that one achieves the best results from the money spent. To do this one has to assess the cost effectiveness of various techniques. This can only be done by comparing costs with results (i.e., achieving some goal or objective such as density of plants with the cost of that effort). This yields a cost per live plant. This cost per plant can then be compared for the various techniques and becomes a standard for comparison. For example, one can assess the cost effectiveness of fencing a site by the increase in the density of plants that have established within that fenced area compared to an unfenced area. If the cost of seeding a 1-ha site was $1,000 and the density after one year was one plant/m^2, the cost of each live plant would be $0.10 (the cost [$1,000] divided by 10,000 plants [10,000 m^2] in a hectare, each meter containing a single plant). On an adjacent 1-ha site, a fence is built to keep out herbivores. The fence costs $1,000 to build so the total cost of the revegetation effort is $2,000. The density on this site increased to 3 plants/m^2 because many plants were not eaten. The comparable cost on a per-live-plant basis is $0.067 (30,000 plants at a cost of $2,000). The fence was cost-effective. The need for a fence will not be the same for every site (some areas are not grazed) so data must be gathered from your site or in sites that are similar if the data are to be used appropriately in this analysis.

One cannot conduct this kind of analysis without monitoring success. One cannot get the most for the reclamation dollar spent without conducting a cost-effectiveness analysis. This is why monitoring of costs and success of reclamation projects are so important. Gathering this type of data and making cost-effective decisions are often processes that will take several years depending on how many sites are reclaimed on your installation. Given that there is often a high turnover of personnel particularly at DoD sites, it is important that these efforts are well documented so they can be passed on to the next people who will be responsible for reclamation at the installation. Good record keeping cannot be overemphasized.

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6.0 DECISION TOOLS FOR SELECTION OF RECLAMATION TECHNIQUES

This manual is designed to give the user an understanding of the various techniques that are available, and when and where their use is appropriate. The user can then evaluate and select techniques based on the specific needs, budgets, and constraints of their sites. This section provides decision tools that help guide the user through the planning process to ensure that all applicable reclamation techniques are properly considered.

6.1 OBJECTIVES

The objective of this section is to provide decision tools that will assist the user in deciding what needs to be done to achieve successful reclamation. The reclamation techniques were described in Section 3.0, "Reclamation Techniques," however, not all techniques are applicable to every site, therefore, a flow diagram and table of techniques are provided to direct the user back to specific techniques that may be applicable. Techniques included in the flow diagram and table are identified under different priority and slope combinations to help focus the applicable techniques. Every site has unique conditions and characteristics so that a site-specific plan needs to be developed for each area with the input of individuals who are most familiar with the site. These decision tools help direct the development of a site-specific plan.

6.2 PRINCIPLES

It is intended that this manual will provide principles that will lead to sound ecosystem management. Reclamation in arid areas is a difficult and often slow process. Many reclamation projects are not successful in part because proper principles are not followed. Even with the best techniques, success is not guaranteed particularly if irrigation is not used. Wallace et al. (1980) report that precipitation is adequate in only 3 out of 10 years for natural revegetation to occur. Using current techniques, we have been able to improve on that percentage but failures particularly during drought periods will still occur. Utilizing correct principles, a resource manager can develop a program that will ensure sustainable use of their area without environmental degradation and loss of valuable soil resources.

Figures 1-2 and 1-3 (figures previously cited) show the costs associated with allowing a site to degrade to a point where recovery is very difficult and costly. The best thing that a resource manager can do is to not allow a site to be degraded to the point that resistant plants and soil resources are being lost (Phase IV, V in Figure 1-1). Several techniques (such as the ATTACC methodology used by the Army) have been developed to monitor and predict impacts of various activities. The Army has also developed the ITAM program that is designed to evaluate conditions of the training ranges and mitigate impacts so the ranges can support sustainable use.

6.3 FLOW DIAGRAM

Figure 6-1 provides a flow diagram of decision making that will assist a user of this manual to determine which revegetation and erosion control techniques should be considered for a site.

Many sites that have minor degradation can recover very quickly with adequate precipitation or protection from further disturbance (Figure 6-2). Conversely, sites that will be used continuously with no protection should not be revegetated since the source of the impact is still present.

In evaluating the need for reclamation of a site, the first question to ask is, "Is the site heavily disturbed?" (Decision 1). Based on our experience in the Mojave Desert, a site is heavily disturbed if vegetative cover is under 6 percent or if you are losing many of the resistant species on the site. At Fort Irwin, California, the resistant species include creosote bush, white bursage, and desertsenna (*Senna armata*) while the more sensitive species included rabbit thorn (*Lycium pallidum*) and burrobrush. Appendix 9-2 of the Diagnostics Users Manual (Hansen and Ostler, 2002) provides a valuable technique to assess sensitivity of species to disturbance for your sites. Cover values may be higher in the Great Basin and Sonoran Deserts and resistant species will certainly differ at other sites. If the site is heavily disturbed, proceed to Decision 3. If the site is not heavily disturbed, a second question is asked, "Is erosion a problem?" (Decision 2). If the answer to that question is no, then the site can be allowed to revegetate naturally (Box A). These sites should be monitored periodically to see if their status has changed. If the site experiences further degradation, it may fall back into the heavily disturbed category. If erosion is a problem, proceed to Decision 3. This decision asks the question, "Will future intensity of use allow revegetation?" If the site is still being heavily used, revegetation is not practical, but one needs to assess if erosion is a problem on the site (Decision 4). If erosion is not a problem, then the site can be used continually and may be considered as a short-term sacrifice area (Box B). If erosion is a problem for the site, then the user needs to select appropriate erosion control techniques (Box D) from Section 3.1, "Erosion Control" and Table 6-1 to minimize erosion. If the answer to Decision 3 is yes, the user should select the appropriate revegetation techniques (Box C) from Figure 6-1 and Sections 3.0, "Reclamation Techniques." The techniques can then be implemented and evaluated for effectiveness (Box E).

6.4 TABLE OF TECHNIQUES TO BE CONSIDERED

Table 6-1 is a table of techniques that should be considered under varying levels of priority and slope. This table will not present all of the options available under each technique, rather it presents the more common options and those that would be generally recommended. It is intended to assist the user, but not be the absolute answer for what must be done on a site. Two factors, priority and slope, are important when evaluating which techniques to use.

6.4.1 Priority

The priority level is determined by the user or often the users commander or manager who directs them to reclaim a site. Examples of factors that influence priority are visibility, erosion

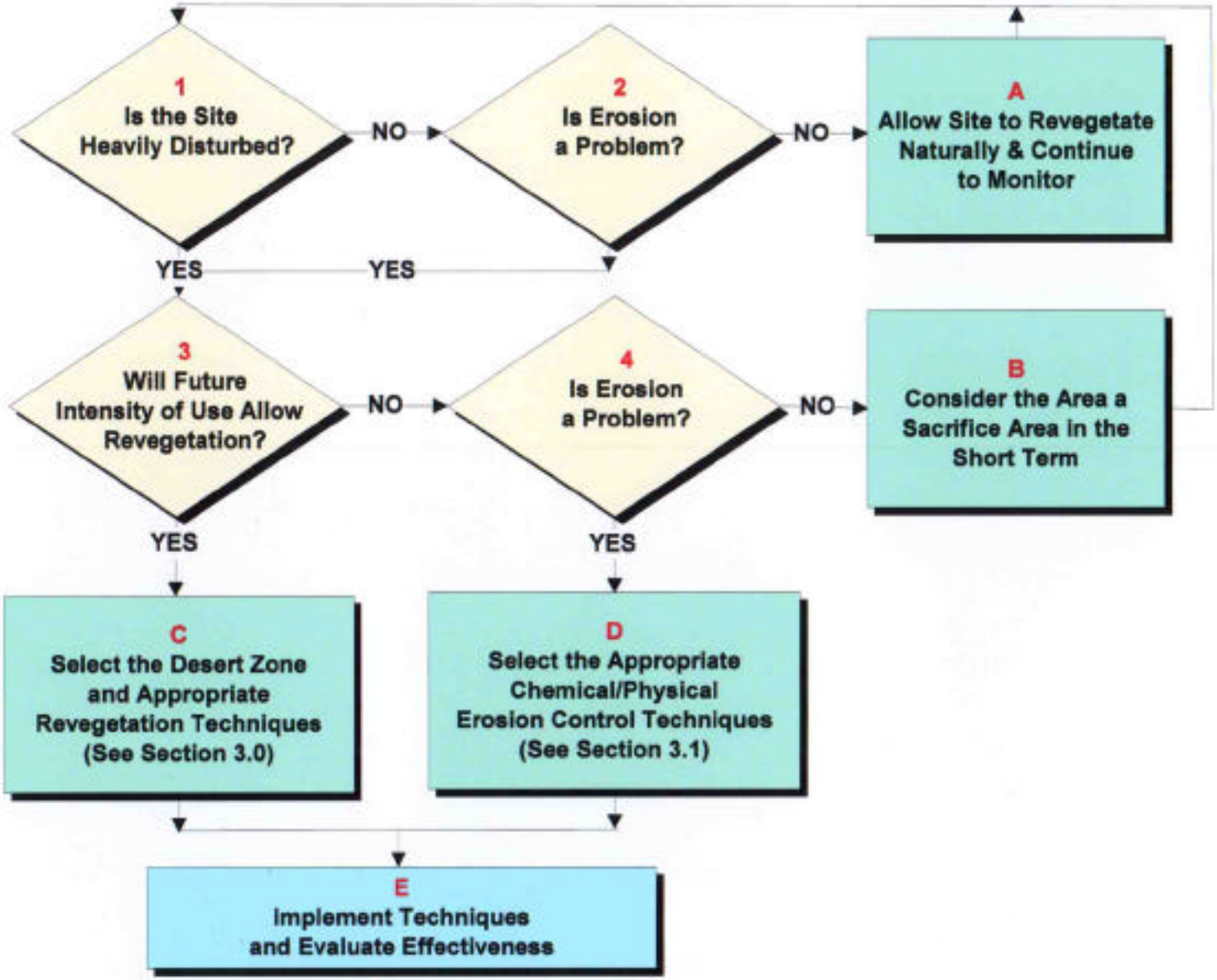

Figure 6-1. Flow diagram of decision making for erosion control and revegetation techniques.

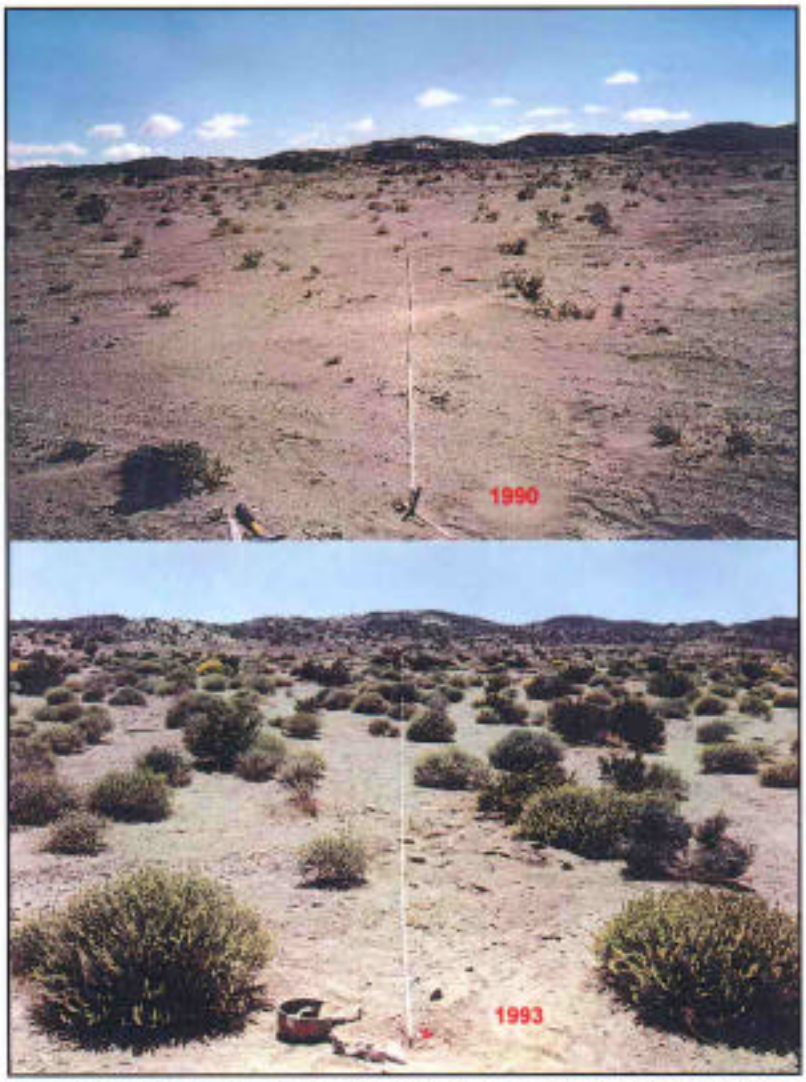

Figure 6-2. Site recovery in 1993 at the National Training Center from a heavily disturbed area (1990) after three years of good precipitation.

problems affecting operations, erosion problems causing violations (Clean Air or Clean Water Acts), and sensitive or protected species habitat. Many other factors can influence the priority on your site. We have arbitrarily recognized only two levels, high and low, within the priority category. Prioritizing sites is very useful particularly if one has limited budgets and resources.

6.4.2 Slope Steepness

The second factor in assessing appropriate techniques is the steepness of the slopes at the site. This factor is important because it impacts the use of many types of reclamation equipment.

Table 6-1. Table of techniques showing recommended considerations by priority and slope steepness.

	Section	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0
Priority	**Slope Steepness**	**Erosion Control**	**Site Preparation**	**Soil Amendments**	**Seeding**	**Planting**	**Weed Control & Animal Control**	**Mulching**	**Irrigation**	**Site Protection**	**Monitoring & Maintenance**
High	**> 3horizontal:1vertical (steeper slopes)**	ARM, BIO, CHEM, CT, CULT, DIV, ECB,	SC	FERT	BS,HS; COM,CC; PTS	TU,CON, SPEC; CG;WI	HA, F, PT	BSM-T, BSM-N, EM	DL	Ed, RC, Sign, Map	QUAL, QUAN
	< 3horizontal:1vertical (flatter slopes)	ARM, BIO, CHEM, CULT, CF, DIV, MUL, PIT, WB	CHIS, DISK, HAR, RIP	FERT, ORG, POLY,	DS,BCS; COM,CC; PTS	TU,CON, SPEC; CG; WI	MA, F, PT	BSM-C, PM	DL,DT,PS	Ed, RC, Sign, Map, B/B	QUAL, QUAN
Low	**> 3horizontal:1vertical (steeper slopes)**	BIO, CULT, DIV			BS,HS, AS;COM	TU, CON; WI		BSM-T		Ed, RC, Map	QUAL
	< 3horizontal:1vertical (flatter slopes)	BIO, CULT, DIV	CHIS, DISK, HAR, RIP		DS,BSC,AS; COM	TU, CON; WI		BSM-CGB		Ed, RC, Map	QUAL

Technique Abreviations:

Erosion Control
ARM = Substrate armoring
BIO = Permanent vegetative cover
CF = Contour furrowing
CHEM = Chemical soil stabilizers
CT = Contour trenching
CULT = Cultural techniques
DIV = Diversion structures, barriers, water channeling
ECB = Erosion control blanket
MUL = Mulching
PIT = Pitting, impringing, gouging or dozer basins
WB = Windbreaks

Site Preparation
CHIS = Chiselling
DISK = Disking
HAR = Harrowing
RIP = Ripping
SC = Slope chaining

Soil Amendments
FERT = Fertilizer
ORG = Organic material
POLY = synthetic polymer soil conditioner

Seeding
AS= aerial seed
BCS= broadcast cover seed
BS=broadcast seed
CC=custom collected seed
COM=commercial seed
DS=drill seed
HS=hydroseed
PTS=pre-treated seed

Planting
CG=contract grown
CON=Copntainers
SPEC=specimen-size
TU=tubelings
WI=water in at planting

Weed/Animal Control
F= Fence
HA = Hand apply herbicide
MA = Machine apply herbicide
PT = Protective tubes

Mulching
BSM-CGB = blow straw mulch & crimp (in Great Basin only)
BSM-N = Blow straw mulch & net
BSM-T = Blow straw mulch & tackify
EM = excelsior mat
PM = Plastic mulch

Irrigation
DL=drip line
DT=deep tubes
PS=portable sprinkler (for seeded areas)

Site Protection
B/B = Berm or barrier
Ed = Education of Personnel
Map = Locations placed on map
RC = Communication w/Range Control
Sign = Signs posted

Monitoring & Maintenance
QUAN = Quantitative monitoring
QUAL = Qualitative monitoring

Two levels are recognized; slopes greater (i.e., steeper) than 3h:1v and slopes less than 3:1 (i.e., flatter). Generally heavy equipment, tractors, etc., cannot operate on slopes greater than 3:1; this alters tremendously which techniques can be used. Some operators are much more experienced than others and can work slopes up to 2:1 but these are generally exceptions. Increased slope also increases the potential for water erosion and techniques that need to be implemented to ensure that erosion does not become a problem.

6.4.3 Techniques to be Considered

The continuing columns of the table include those techniques that should be considered given the site priority, slope steepness, and other site characteristics. These are listed and identified in the order they are presented in Section 3.0, "Reclamation Techniques." Techniques are identified by codes due to space concerns. Abbreviations are listed alphabetically within each technique. The techniques identified in the matrix should be considered and evaluated under the various conditions. They do not all have to be implemented but are listed so the user who knows the site can make a more informed decision on what is available and what will be best for that site.

6.5 LIMITATIONS AND SPECIAL CONSIDERATIONS

Information on technique selection presented in the table is useful as general guidance. Limitations may occur based on site conditions such as soils, which may make suggested techniques less desirable. Experienced site personnel informed with all the options will generally make the best decisions regarding which techniques are most effective. An effective technique used in one year may not be the best in every subsequent year if site conditions, climate, or soils change. It is useful to continue to evaluate new techniques (on a small scale) every year to expand the options available to the user and to search for more cost-effective techniques.

7.0 RECOMMENDATIONS

Based upon findings from many years of experiments during this project and from practical experienced gained in actually using techniques, several conclusions can be drawn and the following recommendations are made:

7.1 RECLAMATION PLANNING

- Failure to develop and implement a suitable reclamation plan is the most common reason for failure of reclamation projects in arid lands. A reclamation plan should be developed that clearly states the goals and land-use objectives of the reclamation effort.

- The reclamation plan should be complete and specific for your site. It should include land-use objectives, constraints, subcontracting, scheduling, site assessment, site preparation, species selection, technique selection, monitoring, and remediation.

- The planning process should be started early, preferably at the inception of the project development activities, and should include, where feasible, input on concerns and priorities from stakeholders.

7.2 EROSION CONTROL

- Soils that are impacted by training activities are subject to erosion by wind and water. This erosion creates adverse impacts that affect training, safety, revegetation success, and operational costs. In order for training activities to be sustainable, erosion must be controlled.

- Uncontrolled erosion removes soil resources such as soil fines, organic matter, nutrients, and microorganisms are essential for plant establishment and growth. Areas where erosion is severe should be evaluated and prioritized to determine if they should be considered sacrifice areas. Techniques should then be implemented by priority as soon as possible to reduce damage to the site.

- The main principles of erosion control are understanding the erosion process and factors contributing to erosion, dissipating the energy of wind and flowing water, controlling where water flows, reducing saltation by wind, controlling sediment transport and deposition, protecting soil resources, and protecting plants from mechanical damage.

- Users should become familiar with physical, chemical, and biological techniques for controlling erosion and the costs and limitations of these techniques.

- Earth-disturbing activities, such as trenching, new road building, and encampments, that totally remove vegetation from the soil surface have the greatest impact on site stability. If possible, directing these activities to previously disturbed, existing sites will minimize erosion and reduce mitigation costs dramatically.

7.3 SITE PREPARATION

- Sites that have been disturbed have soil conditions such as compaction and erosive surfaces that are not conducive for controlling erosion and revegetating these areas. Such areas must be prepared before mitigation efforts can be successful and effective.

- The sites are treated with various techniques to control erosion, provide safe sites for seed and transplants, enhance plant growth to make them more resilient to adverse training activities, reduce competition between desirable perennial plants and undesirable short-lived weeds that increase the risk of fire, provide proper soil aeration, good water infiltration and retention, and proper soil structure. Users should become familiar with site preparation techniques, such as ripping, disking, and harrowing, to mitigate undesirable site conditions.

- UXO may affect site preparation activities. Users should communicate frequently and thoroughly with installation personnel before earth-altering activities are implemented. If necessary, the site should be cleared by experts before beginning such site preparation techniques.

- Proper planning before site preparation begins will ensure that biological resources, such as beneficial soil microorganisms, salvageable plant materials, and topsoil, are identified and, where feasible, salvaged to accelerate the recovery of severely disturbed sites.

7.4 SOIL AMENDMENTS

- Soil provides a medium that encourages seed germination and proper plant growth. Heavily disturbed soils may be lacking in water, nutrients, aeration, proper structure, and tolerable temperatures. Soil amendments may be added to ameliorate these adverse soil conditions.

- Soil amendments include the use of synthetic polymer soil conditioners, adding organic matter, and fertilization. The user should become familiar with the alternative soil amendments and their costs and limitations.

- Soil chemistry may not always be conducive to revegetation, especially under saline, sodic, or acid soil conditions. Users should utilize a reasonable program of soil mapping and testing to determine soil characteristics, nutrient deficiencies, and other potential adverse soil conditions that may necessitate the use of soil amendments.

- Site experimentation on a small scale can help the user evaluate the cost effectiveness of using soil amendments, especially in the long-term. The concept of control areas and proper documentation should be used to facilitate the evaluation of specific soil treatments.

7.5 SEEDING

- Plant species used for seeding should be species native to the revegetation site. Other species may be considered if they are adapted to site-specific environmental conditions or are known to have occurred at the site in the past.

- Direct seeding is a commonly used method to introduce viable seed into disturbed soils. Direct seeding carries risks because it relies heavily on natural processes for seed stratification, germination, and plant growth.

- Direct seeding can be successful if quality seed is used, appropriate seed mixes are developed, seeding is completed during the seeding window, there is good seed to soil contact during seeding, and there is sufficient soil moisture for seed germination and plant establishment.

- Broadcast seeding is appropriate for hard to access sites, such as steep slopes or rocky soils. It requires larger quantities of seed and usually requires special equipment.

- Drill seeding is commonly used on level terrain accessible to revegetation equipment such as tractors, disks, drill seeders, etc. Seeding rates for drill seeding are usually about half of the rates used for broadcast seeding. Rangeland drill seeders are commonly used to distribute the seed. Drill seeders equipped with multiple seed bins can accommodate different seed shapes, sizes, and weights.

- Native seed is available from numerous seed companies located in the western United States. If seed is not available commercially and the particular species is considered essential to the success of the revegetation project, some seed companies can also perform custom seed collections. Custom collections of native seed may require special seed collecting equipment, seed cleaning equipment, and special seed storage facilities. Permits may also be required, particularly from federal or state land management agencies.

7.6 PLANTING

- For greatest long-term success, plant materials should be adapted to site conditions. If plant materials are not available commercially, it may be necessary to make custom seed collections and contract with local nurseries, experienced in growing native plants, to grow the plants.

- All plant material should be hardened before leaving the nursery. This may require several weeks or even months. If plant materials are not hardened, the shock of moving from greenhouse conditions to the revegetation site may result in low survival rates.

- Plant materials should be protected from wind and sun when delivered to the site. Plants should be watered and not allowed to dry out prior to planting. When planting, roots should be covered and native soil firmly packed around them to avoid drying. If soil moisture is not adequate at the time of planting, transplants should be watered-in.

- Young transplants should be protected once they are in the ground. Provide adequate protection from herbivory and desiccation.

- Salvaging plants from land-disturbing activities in the vicinity of the reclamation site should be considered. Federal and state agencies frequently allow salvage of native plant materials prior to a predetermined land disturbance (i.e., pipeline, road, etc.).

7.7 GRAZING AND WEED CONTROL

- Grazing by large or small herbivores can have devastating effects on revegetation efforts. Where these herbivores are problematic, control techniques, such as fencing or tree shelters, should be implemented to protect revegetated sites.

- Seed that is sown in disturbed areas is also subject to predation by rodents, ants, and birds. Seed needs to be buried at a proper depth so it is less available to seed-eaters. Also, it should be sown at the proper time to minimize the time prior to germination.

- Weeds can become serious problems if areas are disturbed and left unvegetated for a long time. Weeds will compete with desirable species during revegetation and will often out-compete these species for needed resources, particularly water. Areas infested with weeds may need to be treated prior to revegetation efforts. If weeds are a problem during revegetation, they should be treated with a selective herbicide or pre-emergent herbicide. Reducing fertilizers, particularly nitrogen, during revegetation implementation will help avoid weed problems.

- Weeds can lead to serious fire problems and create conditions that increase fire frequency. Control weeds early before they become major problems. Seed with desirable species in burned areas to discourage invasion of weeds.

7.8 MULCHING

- Mulch acts to control erosion on disturbed sites. Mulch slopes and other erosion-prone areas retain soil resources or capture blowing sand.

- Mulch acts to conserve soil moisture and improve depleted soils. Organic mulches, such as straw, that are crimped are recommended for most disturbed areas. They not only provide for soil protection but organic mulches provide a substrate for soil microbes, encourage nutrient cycling, aerate the soil, and increase infiltration.

- Other types of mulches are useful for particular applications and purposes. Plastic mulches have been shown to be effective at conserving moisture and increasing soil temperatures, both of which enhance germination of some Mojave Desert species.

7.9 IRRIGATION

- Supplemental irrigation should be considered if natural precipitation is low, unreliable, and unpredictable. Seeding success is dependent on sufficient soil moisture for seed germination

and plant establishment. If there is not sufficient soil moisture available naturally, then supplemental irrigation should be considered.

- Supplemental irrigation should be applied when optimum soil and air temperatures occur for seed germination and plant growth. Supplemental irrigation can be used to reduce soil temperature and extend the seeding window if necessary.

- The amount of supplemental irrigation should be the difference between the amount of natural precipitation received and the amount required for good seed germination and plant growth. Prolonged irrigation may result in poor root development and overall poor adaptation to natural environmental conditions.

- The quality of the water used for irrigation should be analyzed for salts and other elements potentially harmful for plant growth.

7.10 SITE PROTECTION

- Environmental regulations and permit stipulations may dictate practices to ensure that sensitive plant and animal species are protected. Users should familiarize themselves with these stipulations and ensure that others are properly educated.

- It is imperative that reclamation technicians understand the site mission and training activities. Users should seek to understand these requirements and work harmoniously with others to achieve the desired objectives.

- Proper communication with installation personnel will help ensure success in achieving the reclamation objectives. Users should seek opportunities to communicate and educate site personnel about reclamation objectives.

- A variety of physical and cultural (social) tools are available to ensure site protection. Users should experiment with the best techniques and realize the limitations of each tool.

- Monitoring effectiveness of site protection measures will help provide needed feedback to alter future management practices. Users should be committed to monitoring in a timely fashion to ensure that investments are not wasted and to foster adaptive management practices.

7.11 MONITORING AND REMEDIATION

- The main purpose of monitoring is to assess if reclamation objectives are being met, locate problems, and evaluate success. All reclamation projects should be monitored and results documented. Funds should be allocated for monitoring. This will save money in the long run by documenting what techniques have been successful and cost-effective.

- Monitoring should include photographs or video of the sites from standardized photo points.

- Standardized checklists will facilitate evaluations.

- Quantitative monitoring should be performed at key times, (i.e., one year, two years, and five years).

- Success criteria should be established as part of the reclamation plan.

- Reference areas or pre-disturbance conditions should be established. Monitoring results should be compared to these reference areas or pre-disturbance conditions to evaluate if success criteria have been met.

- Document the results of your monitoring. It is imperative that results are summarized and communicated to the right people. Document what was done, what were the problems, what worked, and what did not work. This will help you or your successor the next time.

- Remedial actions need to be taken to fix or correct problem areas before the problem gets worse. Every effort should be made to implement remedial actions as soon as possible, especially if active accelerated erosion is taking place.

7.12 COSTS

- All projects have limited budgets and reducing costs is an important goal. To accomplish this, costs of various reclamation treatments should be documented as well as their success. These monitoring results should be compared on a standardized basis, such as cost per established plant, not on the overall costs of the projects.

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9.0 APPENDICES

9.1 SAMPLE SEED MIX MATRIX. SEEDING RATE GOAL IS 20 LBS/ACRE.

9.2 PRE-TREATING SEED TO ENHANCE GERMINATION OF DESERT SHRUBS

9.3 REGIONAL COST ESTIMATES FOR RECLAMATION PRACTICES ON ARID AND SEMIARID LANDS

9.4 POST-CLOSURE MONITORING CHECKLIST

9.5 INTERNET WEB SITES FOR HABITAT RESTORATION

APPENDIX 9.1 SAMPLE SEED MIX MATRIX. SEEDING RATE IS 20 PLS LBS/ACRE.

Scientific Name	No. Pure Live Seed /lb [A]	Recommended Rate (PLS lbs/a) [B]	Factors to consider in determining the recommended seeding rate				Cost B*No. Acres*C
			Density (plants/ft^2) in Reference Area	Ease of Establishment	Cost/PLS lb [C]	No. PLS/ft^2 A*B/43,560	
SHRUBS							
Atriplex confertifolia	64,900	4.8	0.09	Good	$ 15	7.2	$ 72
Ephedra nevadensis	19,875	2.7	0.03	Good	$ 15	1.2	$ 41
Ericameria nauseosa	693,200	0.2	0.02	Good	$ 10	3.2	$ 2
Eriogonum fasciculatum	450,000	0.3	0.0[2]	Good	$ 40	3.1	$ 12
Grayia spinosa	166,765	0.6	0.01	Fair	$ 30	2.3	$ 18
Hymenoclea salsola	110,000	2.4	0.04	Fair	$ 45	6.1	$ 108
Krascheninnikovia lanata	112,275	4.7	0.11	Good	$ 32	12.1	$ 150
Lycium andersonii	194,000	0.2	0.01	Poor	$ 55	0.9	$ 11
Picrothamnus desertorum	4,000,000	0.1	0.09	Fair	$ 400	9.2	$ 40
GRASSES							
Achnatherum hymenoides	161,920	2.6	0.09	Fair	$ 15	9.7	$ 39
Achnatherum speciosum	172,000	0.0[1]	0.02	Fair	$ -	0.0	$ -
Elymus elymoides	191,555	1.2	0.03	Good	$ 25	5.3	$ 30
FORBS							
Sphaeralcea ambigua	500,000	0.2	0.02	Good	$ 46	2.3	$ 9
TOTALS		**20.0**	**0.6**			**62.4**	

Cost/Acre:	$ 532

[1] = Seed not available

[2] = Species not in reference area but adapted to site

APPENDIX 9.2 PRE-TREATING SEED TO ENHANCE GERMINATION OF DESERT SHRUBS

APPENDIX 9.3 REGIONAL COST ESTIMATES FOR RECLAMATION PRACTICES ON ARID AND SEMIARID LANDS

DOE/NV/11718—715

Pre-treating Seed to Enhance Germination of Desert Shrubs

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Keywords: Creosote bush, white bursage, Mojave Desert, seeding, germination, revegetation, restoration, seed priming

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Abstract

Creosotebush [Larrea tridentata (D.C.) Cav.] and white bursage [Ambrosia dumosa (A. Gray) W.W. Payne] seeds were subjected to pre-treatments of rinsing and soaking in water and thiourea to enhance germination in laboratory experiments. The effects of darkness, temperature, seed source, and soil moisture were also evaluated in the laboratory. The best pre-treatment from the laboratory experiments, rinsing with water for 36 hours followed by drying, was field-tested at Fort Irwin, California. Two sites and two seeding dates (early March and mid April) were determined for each site. Five mulch treatments (no mulch, straw, gravel, chemical stabilizer, and plastic) were evaluated in combination with the seed pre-treatments. Field emergence was greatly enhanced with the seed pre-treatment for white bursage during the March (18-42% increase in germination) and April seedings (16-23% increase in germination). Creosotebush showed poor germination during March (2-5%) when soil temperatures averaged 15°C, but germination increased during the April trials (6-43%) when soil temperatures averaged 23°C. The seed pre-treatment during the April trials increased germination from 16-23%. The plastic mulch treatment increased germination dramatically during both the March and April trials. The plastic mulch increased soil temperatures (8-10°C) and maintained high humidity during germination. Both the chemical stabilizer and the gravel mulches improved germination over the control while the straw mulch decreased germination. These results suggest that seed pre-treatments combined with irrigation and mulch are effective techniques to establish these two dominant Mojave Desert species from seed.

Introduction

Creosotebush [*Larrea tridentata* (D.C.) Cav.] is a dominant or co-dominant member of most plant communities in the Mojave, Sonoran, and Chihuahuan deserts. Creosotebush occurs on 14-18 million hectares in the Southwest (Cable 1973). Creosotebush is a native, drought-tolerant evergreen shrub that averages about 2 meters (m) in height and width but can grow up to 4 m under proper conditions. White bursage (*Ambrosia dumosa* [A. Gray] W.W. Payne) is a dominant or co-dominant member of most plant communities in the Mojave and Sonoran deserts. White bursage is a native, drought-deciduous shrub growing from 0.2-0.6-m tall in a compact hemispheric shape. These two species often occur together and form the creosote-white bursage association that covers approximately 70 percent of the Mojave Desert (MacMahon 1988, Shreve 1942).

Creosotebush is unpalatable to livestock and most browsing wildlife, but it is an important source of habitat and food for many small mammals and reptiles (Baxter 1988, Boyd et al. 1983, Hoagland 1992, and Monson and Kessler 1940). White bursage is moderately palatable to cattle and sheep and more palatable to wild horses and feral asses (Hanley and Brady 1977). Transplants and seedlings of white bursage are often browsed and the seeds are often eaten by desert rodents (Reichman 1976).

Some of the earliest germination requirements research of creosotebush was conducted over 30 years ago (Barbour 1968, Graves et al. 1975). There has been valuable research conducted over the past three decades on revegetation of arid environments, particularly using native species (Clary 1983, McKell 1979, McMullen 1992, Sabo et al. 1979, Wallace et al. 1980, and Winkel et al. 1999) and pre-treating or priming methods (Ansley and Abernathy 1984, Kay et. al. 1977a,b). Yet despite this, there is much that is unknown and revegetation by direct seeding of creosotebush and white bursage has not been very successful. Reclamation scientists have generally recommended transplanting these species (Graves et al. 1975). Survival rates of transplants of these species have been good (60-80%) when planted and irrigated properly the first year (Clary and Slayback 1985, Miller and Holden 1993, and Tipton and Taylor 1984). However, transplanting is much more expensive than direct seeding. White bursage and, to a lesser extent, creosotebush will naturally invade disturbances given adequate time and precipitation, but this may take tens to hundreds of years (Angerer et al. 1994 and Webb and Wilshire 1980).

Arid lands are currently being used much more for both recreational and military training than they have in the past. This use creates disturbances and loss of vegetation that if not mitigated leads to soil erosion and loss of wildlife habitat. Federal agencies have recognized their role as land stewards and are focusing on ecosystem management principles to assist with this role (Robertson 1992 and U.S. Department of Energy [DOE] 1996). The goal of our research work is to mitigate the impacts of U.S. Department of Defense and DOE activities in arid lands.

The objectives of this study were to (1) determine if pre-treating seed could enhance germination of creosotebush and white bursage in the laboratory,

(2) evaluate suitable pre-treatments under field conditions, and (3) assess the impact of environmental conditions (temperature, soil moisture, mulch, and soils) on seed germination of these two species.

Methods and Materials

Seed Procurement

Seed for this study was purchased from commercial seed companies specializing in native seed. Creosotebush seed was collected in Arizona for the laboratory experiments and in southern California for the field trials. White bursage seed was collected mainly from Arizona (some from California) for the laboratory experiments and from northern Arizona for the field trials.

Laboratory Experiments

Three separate experiments were conducted from October 2000 to February 2001. The first experiment tested four major seed pre-treatments: rinsing with running water, rinsing followed by drying of seed, soaking in water, and soaking in thiourea. Seeds were (1) placed in running water for 24, 36, 48, and 140 hours and then placed in petri dishes or (2) treated as above and then dried for 12 hours and placed in petri dishes. Seeds were soaked in water for 24 or 48 hours prior to placement in petri dishes. Other seed was soaked in thiourea for 5 minutes prior to placement in petri dishes. One hundred seeds of creosote and 100 seeds of white bursage were treated and placed in petri dishes to assess germination with each treatment being replicated three times. Seeds where counted as germinated when a radicle 2 millimeters in length had emerged from the seed. Germination was recorded for 2 weeks.

The second experiment utilized three seed pre-treatments (control-no rinse, 30-hour rinse with water, and 40-hour rinse with water) to assess the effects of darkness, seed source, drying, and chilling of seeds on germination. Again 100 seeds of both creosote and white bursage where used and each treatment had three replications. The dark treatment consisted of two levels, total darkness and 12 hours of light followed by 12 hours of darkness. Two different seed lots were used of both creosotebush (both from Arizona but separate locations) and white bursage (one from Arizona and one from California) to assess the impact of seed source. The drying treatment had two levels, no drying and 12 hours of drying. The chilling (refrigeration at 35° C) of seeds following pre-treatment had two levels, no chilling and chilling for 158 hours. After treatment, all seeds for both species were placed in petri dishes and germination was recorded for three weeks. The total number of seeds germinated for each treatment was used for comparisons.

The third experiment tested seed treatments in a soil matrix at varying temperatures and soil moisture contents. The four-seed pre-treatments consisted of a control (untreated) seed, seed that was rinsed for 48 hours, seed that was rinsed for 48 hours followed by 12 hours of drying, and seed that was soaked for 48 hours. (For creosotebush, a fifth treatment of soaking for 96 hours was included.) After the seed was treated, it was sown into pots containing a

sand matrix. Three temperature regimes were tested: average daytime temperatures of 22°C with nighttime temperatures averaging 18°C, daytime temperatures of 13°C with nighttime temperatures of 9°C, and daytime temperatures of 8°C with nighttime temperatures of 4°C. Pots were instrumented with thermistor soil cells (Cambell Scientific) and moisture data were recorded regularly. Four moisture levels, 90%, 80%, 60%, and 40%, were evaluated. Pots were watered and allowed to dry until the particular treatment moisture level (90-40%) was reached at which time the treatment pots were watered and the process was repeated. Germination was recorded for 3 weeks and the total number of seedlings of creosotebush and white bursage were recorded for each treatment and was used for analysis.

Field Trials

The laboratory experiments helped significantly in refining the field trials. Trials occurred at two locations (Fig. 1) with separate desert soil types (site 1 - Gravesummit loamy sand and site 2 - Rositas loamy sand). Treatments were arranged in a split-plot design with the mulch treatments as main plots and the seed pre-treatments (control and rinsing seeds for 36 hours followed by drying for 2 hours) arranged in a completely randomized factorial as subplots. Because of the need to conserve moisture and protect the soil from erosion, five mulch treatments [no mulch, gravel, straw, stabilizer (M-binder®), and plastic] were evaluated. Also, two seeding dates (early March and mid April) were evaluated. Each treatment consisted of a 2 x 2-m plot with three replications of each seed pre-treatment within each mulch type. Site preparation included tilling of the site to reduce compaction. Plots were raked slightly and then hand-seeded with a mix of five species common in the areas at rates shown in Table 1. Following seeding, the plots were lightly raked and rolled to ensure good seed-to-soil contact. Mulch treatments were then applied. Irrigation was applied to the site 1 for 10 days following seeding with a total of 4.65 centimeters (cm) of water being applied during that period. Site 2 received irrigation for 6 days following seeding with a total of 2.95 cm being applied. Soil temperatures averaged near 15°C during the March seeding with the straw mulch plots being 2-3° C lower and the plastic mulch plots being 8-10° C degrees warmer. The second seeding occurred on 16 April with site preparation, seeding rates, and the species mix the same as that of the March trials. Irrigation was applied to both sites for 4 days following seeding with a total of 5.9 cm of water being applied. Both sites received an additional 2.3 cm of irrigation during 23-26 April for a total of 8.2 cm at each site. Soil temperatures averaged 22°C with the straw mulch plots being 2-3° C lower and the plastic mulch plots being 8-10° C warmer. Fences were put up around the sites to exclude rabbits.

Sampling and Data Analysis

Sampling of field plots occurred on 9, 10, 13, 15, and 27 March; 14, 18 April; and 14, 17 May 2001. Sampling consisted of recording seedlings by species from a 1-m^2 quadrat placed in the center of the 2 x 2-m plot. Data were

placed in an Excel® spreadsheet and were graphed and inputted into Systat® for statistical analysis.

Results

Laboratory Experiments

Results of the first experiment for creosotebush showed the best germination was from running water for 140 hours with or without drying. A problem with this treatment that would make it unsuitable for use in the field is that many of the seeds had root radicles that had already emerged during the treatment prior to placement in petri dishes. This would make the seeds quite susceptible to damage during the seeding process. The treatments show that the best germination for white bursage was rinsing for 36 and 48 hours. Drying of the seeds after 48 hours of rinse greatly decreased germination of white bursage; however, drying after a 36-hour rinse improved germination. With both species the soak (water or thiourea) treatments were not effective.

Results of the second experiment showed that for creosotebush, those seeds that were rinsed and placed in darkness germinated better than those that were processed in a 12-hour light/12-hour dark alternating environment. The seeds in the 30-hour rinse showed a slight increase in germination under continuous darkness, increasing from 42.7 to 47.7%, while the seeds from the 40-hour rinse showed an even greater increase under continuous darkness (46 to 62%). The pattern for white bursage was slightly different. The 40-hour rinse was similar to creosote with an increase under continuous darkness. The difference was in the 30-hour rinse where the continuous darkness treatment was less than the alternating light and dark treatment (43.3%, 51.7%, respectively).

Results of the analysis for seed source showed that seeds from two different sources showed a positive response to seed pre-treatment. The difference in germination between the controls for the two seed lots most likely reflects simply a difference in initial seed viability. For white bursage, there was a 10% difference in germination between the two seed lots tested. Despite this initial difference, the rinsing treatments still increased germination over the control. From 14.0-18.7%. For seed lot 1, the 30-hour rinse increased germination from 33% in the control to 51.7%. The 40-hour rinse was not as effective but germination still increased to 47.0%. For seed lot 2, the 30-hour rinse increased germination from 43.3% in the control to 59.7%. The differences were not as dramatic for creosotebush with the control seed lots being very similar (33.3 and 35.3%). Again, the rinse treatments improved germination over the controls from 6.0-12.7%. The 30-hour rinse for seed lot 1 increased germination to 43.3% while the same treatment increased germination in seed lot 2 to 41.3%. The 40-hour rinse for seed lot 1 increased seed germination even more (46.0%).

The influence of drying of seeds that had been rinsed showed consistent results. Regardless of the rinse treatment, seed source, or species tested, drying of the seed for 12 hours following treatment tended to reduce germination by

6.4 to 21% for white bursage and 2.6 to 10.0% for creosotebush. Results from experiment 1 showed mixed effects of drying, but these tests all show consistent declines with drying.

The final parameter tested in experiment 2 was the effect of chilling the seeds following treatment. If one could hold the seed in a refrigeration unit following treatment, the seeds could be removed when conditions were right and seed the area of interest without having to wait for the seeds to be treated. Likewise, if more seed was treated than was actually needed, the residual seed could be held until a latter date. The results of this treatment for white bursage showed a large decline in germination of seeds that were refrigerated prior to placement in petri dishes for both the 30-hour rinse (34% decline) and the 40-hour rinse with a 12-hour dry period (18% decline). This same pattern of decline held for creosotebush for the 30- and 40-hour rinse treatments (8 and 20%, respectively).

The results of the third experiment for temperature effects on germination of white bursage are shown in Figure 2. No germination occurred at the 8°C treatment. Germination of white bursage was delayed generally by 10-14 days at the 13°C treatment. Total germination was also much reduced. However, even with these changes, the basic pattern of improved germination with rinsing of seeds was evident. Unlike the previous tests in petri dishes, drying of the seed did not decrease germination but actually increased it slightly although not significantly. ANOVA for the data from the 22°C white bursage tests showed that there was a significant difference among the seed treatments ($p=0.008$) but no difference among the moisture treatments ($p=0.387$). Fisher's Least Significant Difference (LSD) showed that the rinsed treatments (with or without drying) had significantly greater germination that the control or soaked treatments.

For creosotebush, only the 22°C temperature treatment had any germination after 30 days when the experiment was concluded. ANOVA results of the data for creosotebush again validated the increase in germination with rinsing of the seed (Fig. 2). Soaking of the seed for 96 hours also showed improved germination. The main effect, seed treatment, was significant with a p-value of 0.018 while the moisture treatment was not significant with a p-value of 0.806. Fisher's LSD showed that only the 48-hour rinse with 12-dry was significantly greater than the control.

March Field Trials

Site 1. The first emergence of seedlings occurred on 9 March, ten days after seeding and occurred primarily in the plots with pre-treated seed and gravel mulch. All of the seedlings were white bursage. Emergence continued rapidly and peaked 29 days following the initial seeding. Four weeks after seeding the pre-treated seed of white bursage averaged 165.6 seedlings m^{-2} (~79% germination) while control plots averaged only 77.2 seedlings m^{-2} (~37% germination). Creosotebush germination was poor overall with the pre-treated seed averaging 23.5 seedlings m^{-2} (~5% germination) and the control seed treatments averaging 18.1 seedlings m^{-2} (~4% germination) (Fig. 3). Creosotebush germination improved in the plastic mulch treatment which

averaged 57.5 seedlings m^{-2} (~12% germination) where soil temperatures were 10° C warmer (Fig. 4). Germination of white bursage also increased under the warmer conditions facilitated by the plastic mulch (Fig. 4). Germination on all surface treatments peaked with the 27 March sampling with the plastic mulch yielding the greatest germination followed by the stabilizer and gravel treatments.

Site 2. The first sampling of seedlings occurred on 13 March. Similar to Site 1, the first species to germinate was white bursage and it occurred primarily in the plots with pre-treated seed and plastic mulch. Emergence continued rapidly and peaked 24 days following the initial seeding. The advantage of the pre-treatment of seed continued to be evident in field trials for white bursage where the pre-treated seed averaged 91.5 seedlings m^{-2} (~44% germination) while the control plots averaged only 54.7 seedlings m^{-2} (~26% germination), both of which are lower than comparable treatments at Site 1. Creosotebush germination was poor overall with the pre-treated seed averaging 11.3 seedlings m^{-2} (~2% germination) and the control seed treatments averaging 8.5 seedlings m^{-2} (<2% germination) (Fig. 3). Creosotebush germination improved in the plastic mulch treatment which averaged 34.0 seedlings m^{-2} (~7% germination) where soil temperatures were 10° C warmer (Fig. 4). The other surface treatments were very similar with the exception of straw treatment which was lower than the rest.

April Field Trials

Site 1. The first sampling occurred at this site on 23 April one week following seeding. At that time germination of white bursage had occurred on all treatments but was best in the plastic (pre-treated and control seeds) and stabilizer treatments with pre-treated seeds. Creosotebush was germinated in only the plastic mulch treatments (better with pre-treated seed than control seed, 40 seedlings m^{-2} and 5.3 seedlings m^{-2}, respectively) and in the stabilizer treatment with pre-treated seed (12.7 seedlings m^{-2}). Germination peaked during the 27 April sampling. Pre-treated seed of both white bursage and creosotebush outperformed control seed (Fig. 5). Pre-treated seed of white bursage averaged 106.5 seedlings m^{-2} (~51% germination) while the control plots averaged 58.4 seedlings m^{-2} (~28% germination). Germination of creosotebush was much better during the April trials than the March trials and averaged 65.7 seedlings m^{-2} (~13% germination) for the pre-treated plots and 28.5 seedlings m^{-2} (~6% germination) for the control plots.

Creosotebush had excellent germination on the plastic mulch treatment, particularly with pre-treated seed averaging 214 seedlings m^{-2} (~44% germination) while the control seed averaged 104.7 seedlings m^{-2} (~21% germination) (Fig. 6). Even with this later seeding date, creosotebush germination improved with the greater soil temperatures generated under the plastic mulch. This was also true for white bursage where germination in the pre-treated seed plastic mulch plots averaged 206 seedlings m^{-2} (~99% germination) while the control seed in the plastic mulch plots averaged 152 seedlings m^{-2} (~73% germination). Germination was also excellent in the stabilizer and gravel mulch treatments with pre-treated seed.

Site 2. The first sampling occurred at this site on 23 April one week following seeding. At that time germination of white bursage had occurred on all treatments but was best in the plastic with control seeds and stabilizer treatments with pre-treated seeds. Creosotebush had germinated in essentially only the plastic mulch treatments (better with pre-treated seed than control seed, 139.3 seedlings m^{-2} and 53.3 seedlings m^{-2}, respectively). Germination peaked during the 26 April sampling. Pre-treated seed of both white bursage and creosotebush outperformed control seed (Fig. 5). Pre-treated seed of white bursage averaged 88.9 seedlings $m-^{2}$ (~43% germination) while the control plots averaged 55.7 seedlings m^{-2} (~27% germination). Germination of creosotebush was much better during the April trials compared to the March trials and averaged 91.9 seedlings m^{-2} (~19% germination) for the pre-treated seed plots and 29.2 seedlings m^{-2} (~6% germination) for the control plots (Fig. 5).

Creosotebush had excellent germination on the plastic mulch treatment, particularly with pre-treated seed averaging 216 seedlings m^{-2} (~45% germination) while the control seed averaged 112.7 seedlings m^{-2} (~23% germination). Even with this later seeding date, creosotebush germination improved with the greater soil temperatures generated under the plastic mulch (Fig. 6). This was not true for white bursage where germination in the pre-treated seed plastic mulch plots was greatly reduced averaging 51.3 seedlings m^{-2} (~25% germination) while the control seed in the plastic mulch plots averaged 40.7 seedlings m^{-2} (~20% germination). Germination was best in the stabilizer treatment with pre-treated seed averaging 144 seedlings m^{-2} (69%). Germination of white bursage was much lower during the April seeding than the March seeding at this site unlike creosotebush which performed much better during the April trials.

Discussion and Conclusions

Under laboratory conditions, Barbour (1968) found optimal germination conditions for creosotebush to be; a temperature of 23°C, leaching with running water, total darkness, wetting and drying cycles, exposure to cold temperatures prior to sowing, and a near-zero osmotic pressure low in sodium chloride. Kay et al. (1977b) found the optimal temperature for germination to range from 15 to 25°C. Field studies validate that warmer temperatures tend to increase germination of creosotebush. The warmer temperatures during the April trials (average 22°C) increased germination of creosotebush from 3% during the March trials (average 15°C) to 11%. The plastic treatment during the April seeding had highest temperatures (average near 30°C) and germination increased to 34.5%. In field observations at Death Valley, Went and Westergaard (1949) found that when temperatures were greater than 30°C or less than 10°C no germination occurred. Our data agree with those observations regarding the colder temperature limit, but we did have good germination at the upper temperature limit when soil moisture and humidity remained high.

Kay et al. (1977a) suggest that an inhibitor in the hull may limit germination and removal of the hull or rinsing of the seed increased germination.

Graves et al. (1975) and Miller and Holden (1993) found that rinsing of seeds (5-12 hours) increased germination. While rinsing did improve germination, our data show that a longer time period (30-40 hours) is required to optimize germination.

Our data also support Barbour's finding (1968) that darkness increased germination. Barbour reported that seeds in the light treatment had germination rates of 47% compared to that of the dark treatment. Our data compared light and dark treatment only in combination with rinsing treatments. With a 30-hour rinsing, the light treatment was 92% of the dark treatment while with a 40-hour rinsing the light treatment fell to 73% of the dark treatment. Both of these conditions show less of an impact of darkness than that reported by Barbour (1968).

Kay et al. (1977a) report that white bursage has optimal germination between 15 and 25°C with no germination at 2 or 5°C. Our laboratory and field data support that temperature range. In the laboratory, we did not see any germination in the treatment, with average temperatures of 8°C and poor germination at 13°C. The field data showed little differences between the March trials with average soil temperature of 15°C and the April trials with average temperatures of 23°C. The April trials at Site 1 under plastic mulch treatment with temperatures near 30°C showed a tremendous decline in germination. This was not seen at Site 2 where germination under plastic was the best mulch treatment.

Graves et al. (1975) found that germination of white bursage increased about 10% with activated carbon or stratification in moist sand for 30 days. Activated carbon is known to absorb chemical inhibitors. Young et al. (1986) also found that a moist stratification at 17°C markedly improved germination. We found that inhibitors do exist on the seed coat and that rinsing with water for 30-40 hours also removed this inhibitor and improved germination 31-57% in the laboratory and 67-115% in the field.

The field trials show that pre-treating of seed of creosotebush and white bursage can improve germination. It not only decreases the time required for initial germination but also enhances the number of seeds germinated at a site by almost 100%. The field trials demonstrate that mulches can be used effectively to improve germination of seed, particularly plastic mulches that increase soil temperature and humidity. Combining the pre-treatment of seed with irrigation (during the germination process) and mulch appears to be a viable technique for establishing creosotebush and white bursage in the Mojave Desert.

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Table 1. Seeded species and rates used for field trials

Common Name	Scientific Name	% of Mix	Pure Live Seed m^{-2}
Creosote bush	*Larrea tridentata*	48.6	491
White bursage	*Ambrosia dumosa*	20.7	209
Big galleta	*Pleuraphis rigida* Thurb.	12.8	129
Anderson's wolfberry	*Lycium andersonii* Gray	9.4	96
Goldenhills	*Encelia farinosa* Gray ex Torr.	8.5	86
TOTAL		100.0	1,011

Figure 1. Map of Fort Irwin study plots

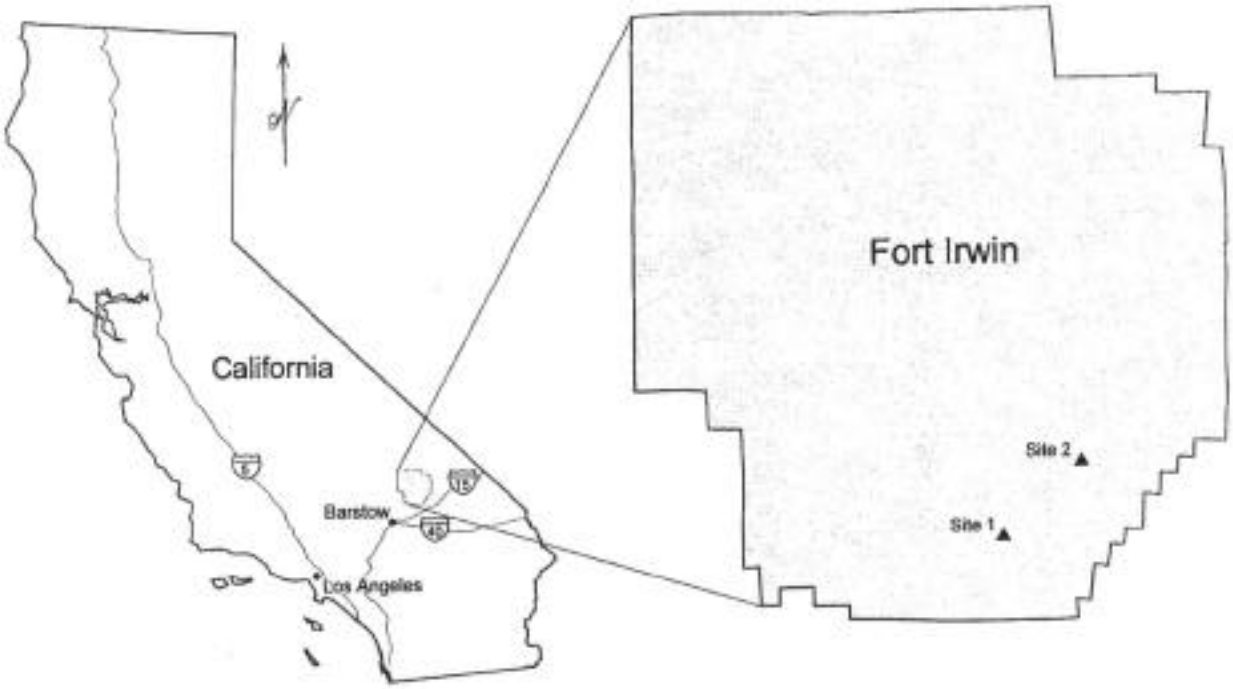


Figure 2. Temperature impacts on germination of creosotebush and white bursage

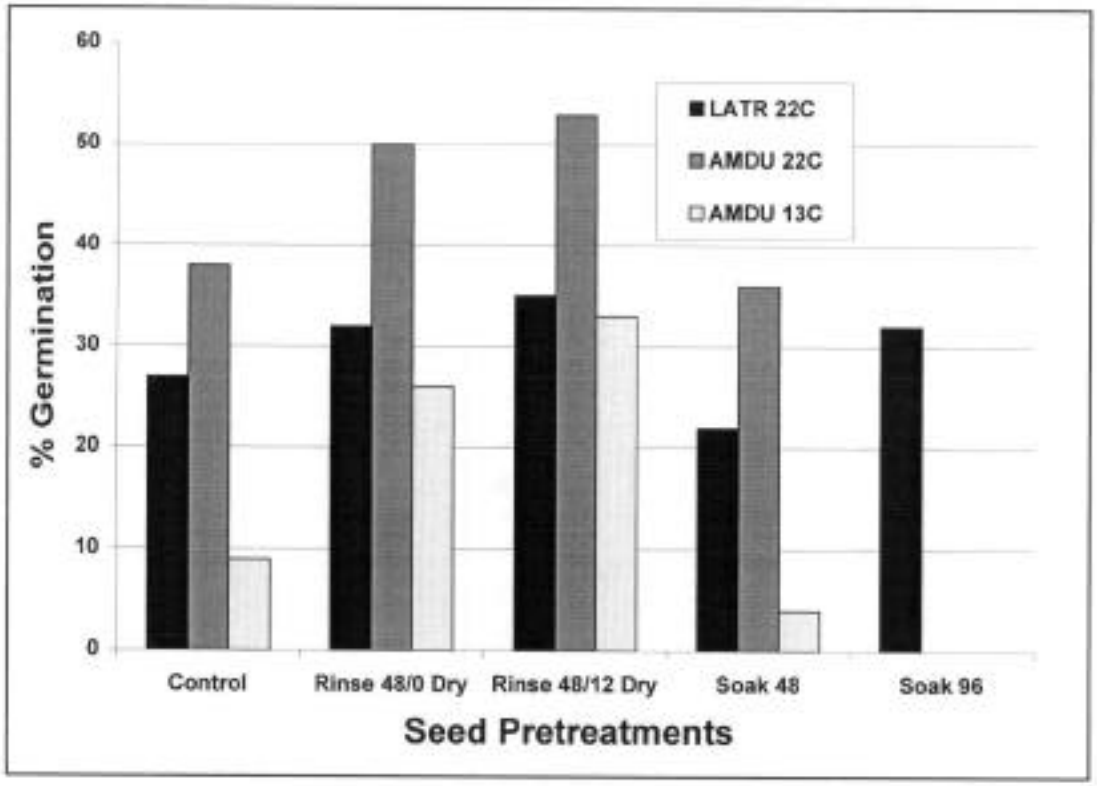


Figure 3. Effect of seed treatments on white bursage and creosotebush during March trials

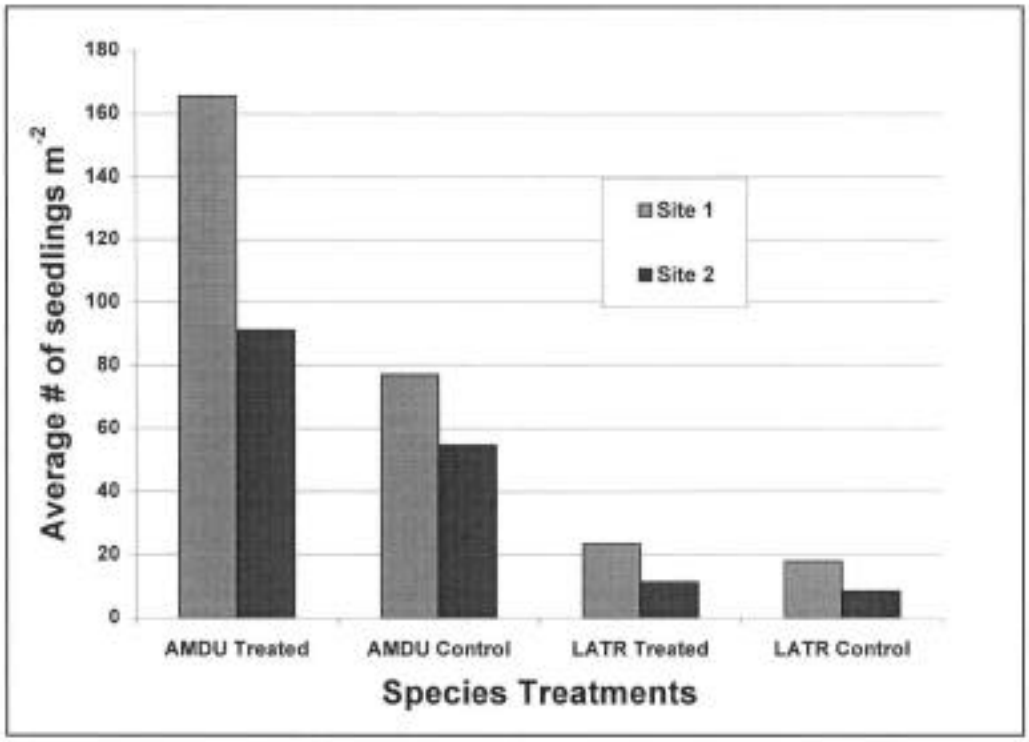


Figure 4. Effect of mulch treatments on germination of white bursage and creosotebush during March trials

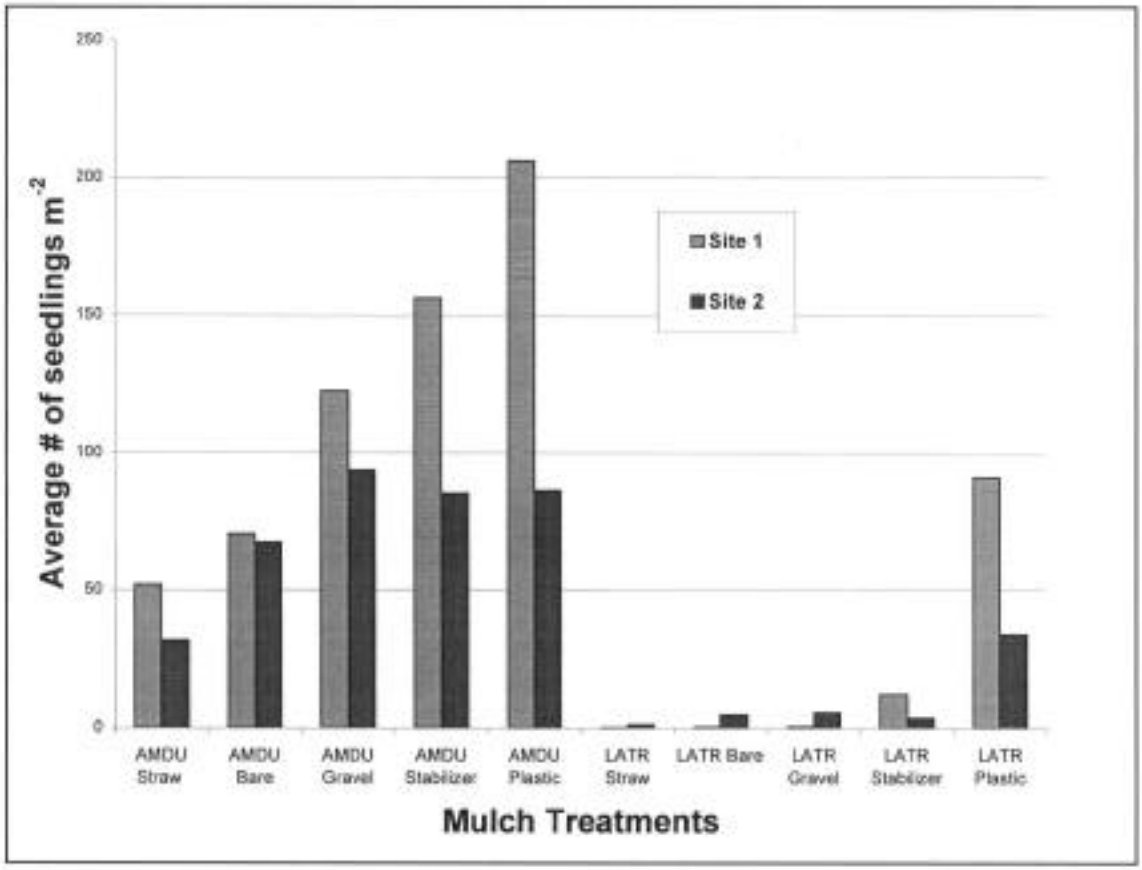


Figure 5. Effect of seed treatments on white bursage and creosotebush during April trials

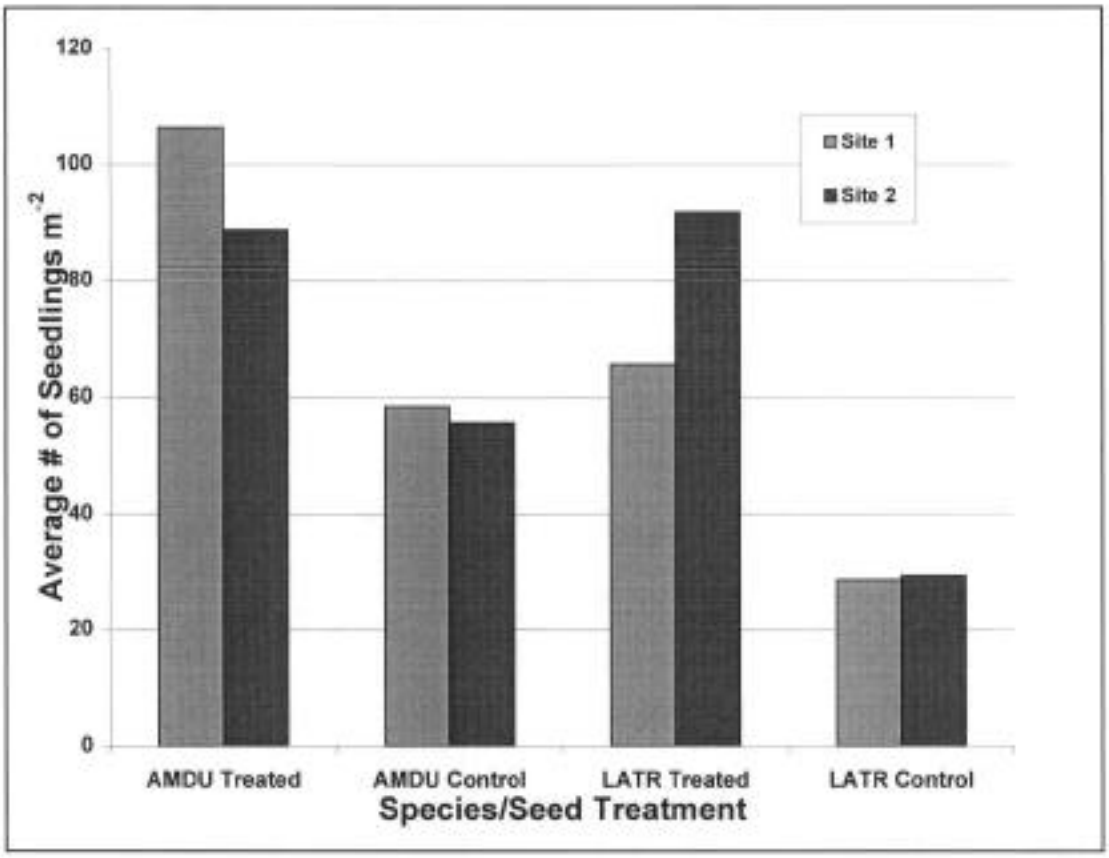
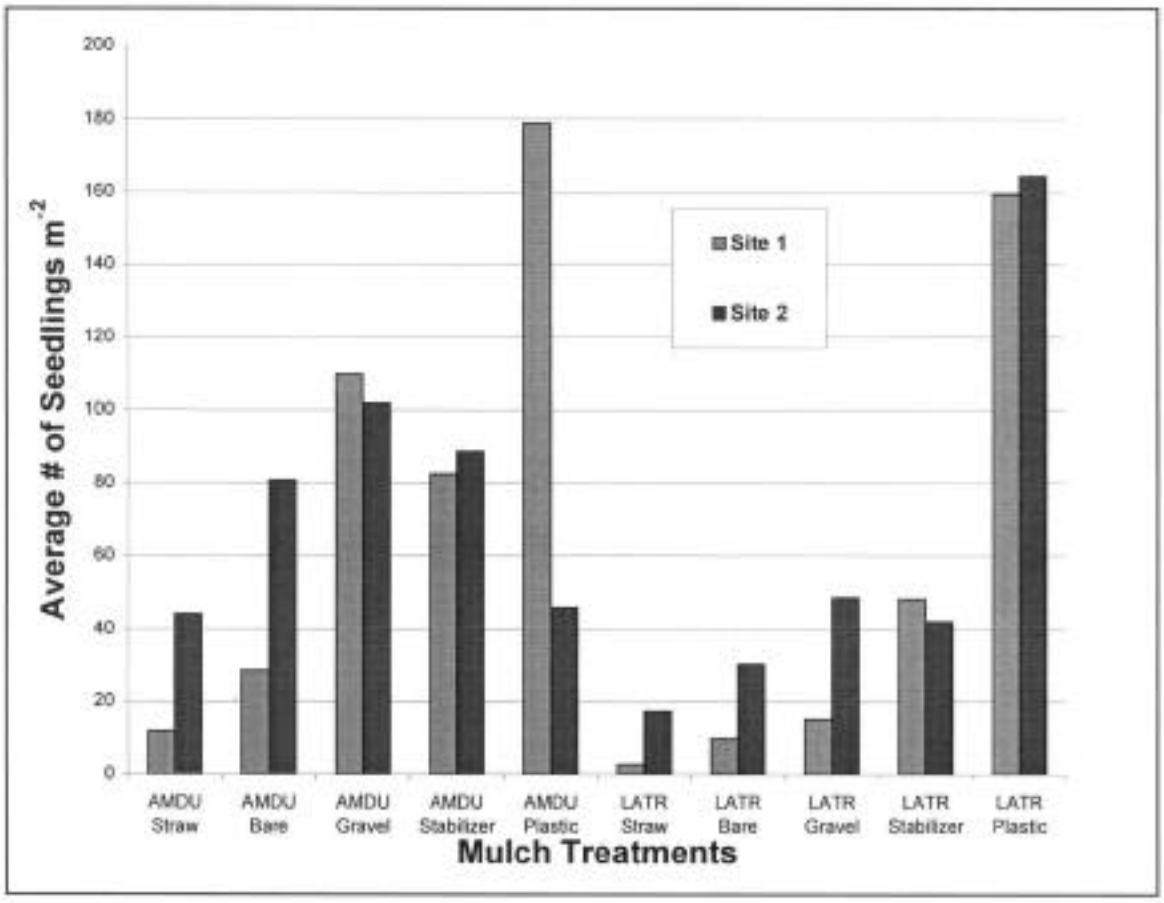


Figure 6. Effect of mulch treatments on germination of white bursage and creosotebush during April trials



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DOE/NV/11718--698

REGIONAL COST ESTIMATES FOR RECLAMATION PRACTICES ON ARID AND SEMIARID LANDS

February 2002

Prepared for the U.S. Department of Energy, National Nuclear Security Administration Nevada Operations Office. Work performed under Contract No. DE-AC08-96NV11718

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REGIONAL COST ESTIMATES FOR RECLAMATION PRACTICES ON ARID AND SEMIARID LANDS

February 2002

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Diagnostic Tools and Reclamation Technologies for
Mitigating Impacts of DoD/DOE Activities in Arid Areas

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ABSTRACT

The U.S. Army uses the Integrated Training Area Management program for managing training land. One of the major objectives of the Integrated Training Area Management program has been to develop a method for estimating training land carrying capacity in a sustainable manner. The Army Training and Testing Area Carrying Capacity methodology measures training load in terms of Maneuver Impact Miles. One Maneuver Impact Mile is the equivalent impact of an M1A2 tank traveling one mile while participating in an armor battalion field training exercise. The Army Training and Testing Area Carrying Capacity methodology is also designed to predict land maintenance costs in terms of dollars per Maneuver Impact Mile. The overall cost factor is calculated using the historical cost of land maintenance practices and the effectiveness of controlling erosion. Because land maintenance costs and effectiveness are influenced by the characteristics of the land, Army Training and Testing Area Carrying Capacity cost factors must be developed for each ecological region of the country. Costs for land maintenance activities are presented here for the semiarid and arid regions of the United States. Five ecoregions are recognized, and average values for reclamation activities are presented. Because there are many variables that can influence costs, ranges for reclamation activities are also presented. Costs are broken down into six major categories: seedbed preparation, fertilization, seeding, planting, mulching, and supplemental erosion control. Costs for most land reclamation practices and materials varied widely within and between ecological provinces. Although regional cost patterns were evident for some practices, the patterns were not consistent between practices. For the purpose of estimating land reclamation costs for the Army Training and Testing Area Carrying Capacity methodology, it may be desirable to use the "Combined Average" of all provinces found in the last row of each table to estimate costs for arid lands in general.

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TABLE OF CONTENTS

Abstract ..... *iii*
Acronyms, Abbreviations, and Symbols ..... *vii*

1.0 Introduction 1
2.0 Methodology 2
  2.1 Regions 2
  2.2 Cost Estimating 4
3.0 Results 5
  3.1 Seedbed Preparation 5
  3.2 Fertilization 6
  3.3 Seeding 7
  3.4 Planting 8
  3.5 Mulching 9
  3.6 Supplemental Erosion Control 10
4.0 Conclusions 11
5.0 Published Sources of Information 12

LIST OF TABLES

Table 1 Regional average cost ($/hectare) for seedbed preparation activities 5
Table 2 Regional average cost ($/hectare) for broadcast fertilization 6
Table 3 Regional average cost ($/hectare) for seeding practices 8
Table 4 Regional average cost ($/plant) for live plants 8
Table 5 Regional average cost ($/hectare) mulching with straw or hay 9
Table 6 Regional average costs for supplemental erosion control practices 10

LIST OF FIGURES

Figure 1 The arid and semiarid regions of the Western United States 2

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ATM.....ATTACC Training Model
ATTACC.....Army Training and Testing Area Carrying Capacity
°C.....degrees Celsius
DoD.....U.S. Department of Defense
DOE.....U.S. Department of Energy
ES.....Erosion Status
°F.....degrees Fahrenheit
ft.....feet
gal.....gallon
in.....inches
l.....liters
lm.....linear meter
m.....meters
MIM.....Maneuver Impact Mile
m^3.....cubic meters
mm.....millimeters
$.....cost

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REGIONAL COST ESTIMATES FOR RECLAMATION PRACTICES ON ARID AND SEMIARID LANDS

1.0 INTRODUCTION

The U.S. Army uses the Integrated Training Area Management program for managing training land. One of the major objectives of the Integrated Training Area Management program has been to develop a method for estimating training land carrying capacity and then to incorporate this concept into training land management decisions. Training land carrying capacity is generally defined as the amount of training that a given parcel of land can accommodate in a sustainable manner. The Army Training and Testing Area Carrying Capacity (ATTACC) methodology is used to estimate carrying capacity by relating training load, land condition, and land maintenance practices.

The ATTACC methodology measures training load in terms of Maneuver Impact Miles, or MIMs. One MIM is the equivalent impact of an M1A2 tank traveling one mile while participating in an armor battalion field training exercise. The impacts of all mission activities are converted to MIMs using data from the ATTACC Training Model (ATM) in combination with Training Impact Factors. The ATM includes prescribed tactical vehicle mileage by vehicle, unit, and event and is derived from the Battalion Level Training Model and Programs of Instruction. Training Impact Factors are multipliers that express the relative severity of impact of events and vehicles and are derived largely using subject matter experts and tactical vehicle characteristics. Using MIMs allows the impact of all mission activities to be aggregated and expressed as a single training load. MIM values for a given mission activity remain constant across the Army, regardless of location.

Land condition is measured by the ATTACC methodology in terms of the Erosion Status, which is the ratio of predicted erosion rates to tolerable erosion rates. Erosion Status values greater than 1.0 indicate that more soil is being lost than can be replaced naturally, and values less than 1.0 indicate that there is not a net soil loss. Erosion rates are estimated using the Revised Universal Soil Loss Equation, a scientifically accepted method utilizing percent vegetative cover, climate, soil type, topography, and conservation practices. The effects of training load and land maintenance practices on erosion rates are captured in the Revised Universal Soil Loss Equation by adjusting values of the percent vegetative cover, slope length and steepness, and conservation practice factor accordingly.

The ATTACC methodology is designed to predict land maintenance costs in terms of dollars per MIM. The overall cost factor is calculated using the historical cost of land maintenance practices and the effectiveness of the various practices in influencing elements of the Revised Universal Soil Loss Equation calculation. Because land maintenance costs and effectiveness are influenced by the characteristics of the land, ATTACC cost factors must be developed for each ecological region of the country.

The U.S. Department of Defense (DoD) Strategic Environmental Research and Development Program has funded a research project entitled "Diagnostic Tools and Reclamation Technologies for Mitigating Impacts of DoD/DOE Activities in Arid Areas." As part of that project, an effort was made to quantify the costs of various land reclamation practices in the arid regions of the continental United States. This report summarizes those findings.

2.0 METHODOLOGY

2.1 Regions

For the purposes of this report, the arid and semiarid regions of the Western United States have been divided into ecosystem provinces based on similarities in climate, soils, and vegetation (http://www.fs.fed.us/land/ecosysmgmt/ecoreg1_home.html). These include the Intermountain Semidesert Province, Intermountain Desert Province, American Desert Province, Colorado Plateau Semidesert Province, and Chihuahuan Desert Province (Figure 1).

The **Intermountain Semidesert Province** consists of the Columbia and Snake River Plateaus and the Wyoming Basin. Average annual precipitation ranges from 130 mm (5 in.) in parts of the Wyoming Basin to 510 mm (20 in.) on the eastern part of the plateaus. Precipitation is fairly evenly distributed throughout the year except during the summer months when there is little rain. Average annual temperature ranges from 4–11°C (40–52°F). The primary vegetation type, sometimes called sagebrush steppe, is made up of sagebrush or shadscale mixed with short grasses. Occasional alkaline flats support alkali-tolerant greasewood. This province has extensive alluvial deposits in the floodplains of streams and in the fans at the foot of mountains.

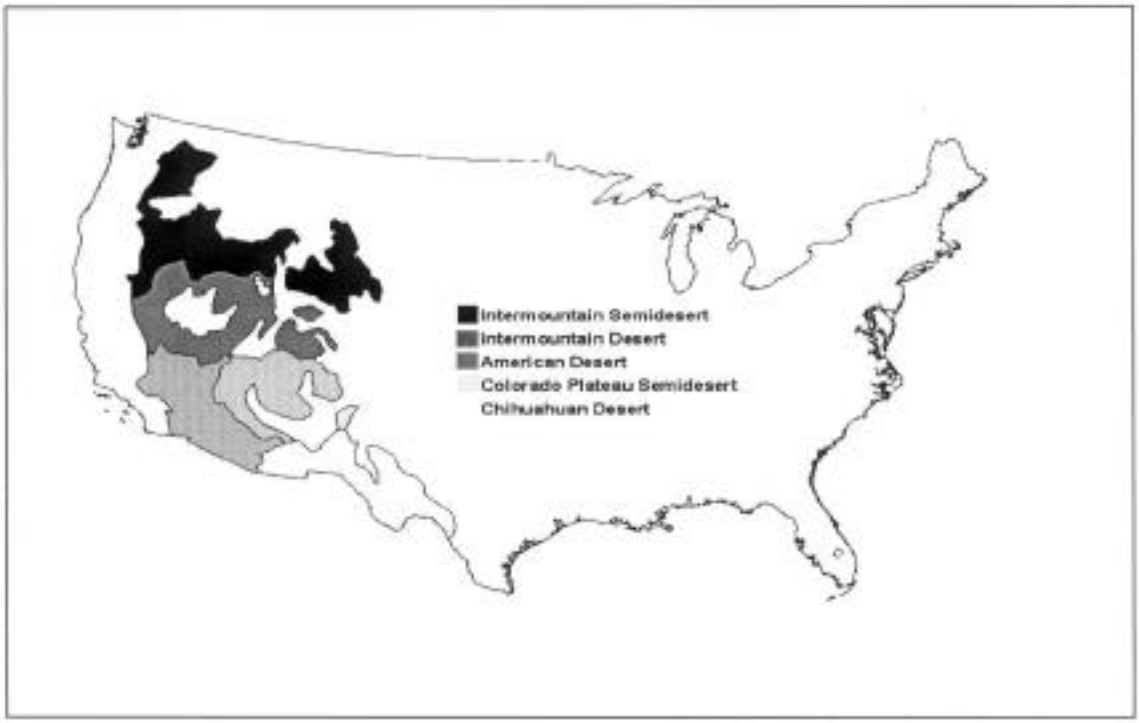

Figure 1. *The arid and semiarid regions of the Western United States.*

Dry lakebeds are numerous, and there are extensive eolian deposits, including both dune sand and loess. Aridisols dominate all basin and lowland areas of the plateaus; Mollisols are found at higher elevations. Soils in the Wyoming Basin are alkaline Aridisols, often containing a layer enriched with lime and/or gypsum, which may develop into a caliche hardpan.

The **Intermountain Desert Province** covers the physiographic region called the Great Basin and the northern Colorado Plateau in Utah. Summers in this province are hot, and winters are only moderately cold. Annual precipitation averages only 130–490 mm (5–20 in.), often falling as winter snow. Almost no rain falls during the summer months except in the mountains. Average annual temperature ranges from 4–13°C (40–55°F). Much of this province is made up of basins with interior drainage; only a small part of the province drains to the sea. The lower parts of many basins have heavy accumulations of alkaline and saline salts. Streams are rare and few are permanent. Sagebrush dominates at lower elevations. Above the sagebrush belt lays a woodland zone dominated by pinyon pine and juniper. Aridisols dominate all basin and lowland areas. Salt flats and playas without soils are extensive in the lower parts of basins with interior drainage.

The **American Desert Province** includes the Mojave and Sonoran Deserts. Its topography is characterized by extensive plains, most gently undulating, from which isolated low mountains and buttes rise abruptly. Elevations range from 85 m (280 ft) below sea level to 1,200 m (4,000 ft) in valleys and basins, with some mountain ranges reaching as high as 3,400 m (11,000 ft). Summers are long and hot. The average annual temperature is 15–24°C (60–75°F). Though winters are moderate, the entire province is subject to occasional frosts. Winter rains are widespread and usually gentle, but in summer they are usually thunderstorms. In the Mojave Desert of southeastern California, there are virtually no summer rains. Average annual precipitation is 50–250 mm (2–10 in.) in the valleys but may reach 610 mm (25 in) on mountain slopes. Vegetation is usually very sparse with bare ground between individual plants. Cacti and thorny shrubs are conspicuous, but many thornless shrubs and herbs are also present. The most widely distributed plant is the creosote bush, which covers extensive areas in nearly pure stands. Cholla, mesquite, paloverde, ocotillo, saguaro, and bitterbrush are common in the Sonoran Desert; various saltbush species are common in the Mojave Desert. The Joshua tree is prominent along the northern edge of the province. Juniper and pinyon pine also occur in the north. Interior basins characterized by ephemeral shallow playa lakes are a conspicuous feature of the Mojave Desert. Entisols occur on the older alluvial fans and terraces and in the better-drained basins. Aridisols dominate throughout the rest of the province.

The **Colorado Plateau Semidesert Province** is characterized by deeply dissected plateaus in northern Arizona and New Mexico and in southeastern Utah. Elevations of the plateaus range from 1,500–2,100 m (5,000–7,000 ft), with local relief ranging from 150 to more than 900 m (500–3,000 ft) in some of the deeper canyons. Due to the region's generally high altitude, the climate is characterized by cold winters. Summer days are usually hot, but nights are cool. Annual average temperatures are 4–13°C (40–55°F). Average annual precipitation is about 510 mm (20 in.) although some parts of the province receive less than 260 mm (10 in.). Summer rains are thunderstorms with ordinary rains arriving in winter. Thus, this province differs from the Intermountain Semidesert Province, which generally lacks summer rains. Vegetation zones are conspicuous but lack uniformity. In the lowest zone, there are arid grasslands, but the shortgrass sod seldom covers the ground completely leaving many bare areas. Xeric shrubs often grow in open stands among the grasses, and sagebrush is dominant over extensive areas. A profusion of annuals and perennials blooms during the summer rainy season. At low elevations in the south, several kinds of cacti and yucca are common. The woodland zone is the most extensive, dominated by open stands of two-needle pinyon pine and several species of juniper, often termed a

pygmy forest. The montane zone extends over considerable areas on the high plateaus and mountains, but it is much smaller in area than the pinyon-juniper zone. Entisols occur along the floodplains of major streams. Aridisols cover plateau tops, older terraces, and alluvial fans.

The **Chihuahuan Desert Province** is mostly desert. The area has undulating plains with elevations near 1,200 m (4,000 ft), where somewhat isolated mountains rise 600–1,500 m (2,000–5,000 ft). Extensive dunes of silica sand cover parts of the province. In scattered areas, small beds and isolated buttes of blackish lava occur. Summers are long and hot. Winters are short but may include brief periods when temperatures fall below freezing. Average annual temperatures range from 10–18°C (50–65°F). The climate is distinctly arid; spring and early summer are extremely dry. Localized summer rains may be torrential. Average annual precipitation is in the range of 200–260 mm (8–10 in.). The northern part of the province also receives winter rains, which are more gentle and widespread. A number of shrubs, most of them thorny, are typical of the Chihuahuan Desert. They frequently grow in open stands but sometimes form low, closed thickets. Extensive arid grasslands cover most of the high plains of the province. On deep soils, honey mesquite is often the dominant plant. Yucca and cacti are also abundant. Open stands of creosote bush cover large areas especially on gravel fans. In the western and northern portions of this province, the soils are primarily Aridisols. Both Aridisols and Entisols are present in the south.

2.2 Cost Estimating

Within each of the defined ecological provinces, various federal and state agencies and private companies were contacted by E-mail and telephone to obtain the required information. Agencies included state departments of transportation and state offices of the Natural Resources Conservation Service and the Bureau of Land Management. Some agencies provided published documentation; most populated a simple spreadsheet. Most agencies provided recent data; others provided historical databases. Only information since 1990 was considered relevant. For databases prior to 2000, an inflation rate of 3 percent per annum was assumed and costs were adjusted accordingly.

It was hoped that labor, equipment, and material costs could be obtained and reported separately. However, few institutions record data in that fashion. More often the values represent installed costs, which include labor, equipment, and materials. Hence, in many cases it was impractical to report labor, equipment, and material costs separately.

Costs were generally reported for average-sized jobs done by experienced contractors, operators, and vendors. Most jobs have built-in mobilization costs that do not vary regardless of job size. Hence, costs per hectare are often less for large jobs and considerably higher for small jobs.

The cost of land reclamation can vary widely based on site conditions. Difficult site conditions (e.g., wet soils, steep slopes, rocky terrain, remote locations, etc.) can greatly increase the cost of most activities. Hence, costs are reported here as ranges as well as averages. Costs will be on the higher end of the spectrum for sites with difficult conditions and on the lower end for ideal conditions.

Military installations represent unique logistical opportunities that may serve to reduce or increase reclamation costs depending on local circumstances. Material costs can be reduced if on-site materials are available (e.g., riprap). Labor and equipment costs may be reduced by using military engineering personnel and machinery when available. On the other hand, costs may be increased if heavy training

schedules limit access to the areas to be reclaimed. Travel costs to the remote locations of many military installations may increase overall reclamation expenditures.

3.0 RESULTS

3.1 Seedbed Preparation

Some form of mechanical seedbed preparation is often needed prior to reseeding. This can be particularly true on Army training areas where repeated passage of armored vehicles has caused significant soil compaction. Ripping, subsoiling, or chiseling (here referred to collectively as ripping) are deep-tillage operations specifically designed to break or shatter compacted soil layers that can inhibit germination, root development, and moisture infiltration. Chiseling is generally less expensive than ripping or subsoiling due to shallower depths of implement operation and reduced power requirements. Disking can be used to ameliorate shallow compaction and vesicular horizons and to remove unwanted vegetation. Disking may be accomplished with an offset disk or a tandem disk. Offset disking is generally more expensive than tandem disking but does a better job of killing and mulching existing vegetation with a single pass of the implement. Harrowing is a much less intensive seedbed preparation method used to break up superficial compaction or physical crusts. It can also be used to smooth the soil surface following ripping or disking and is often used following broadcast seeding in order to help cover the seeds and ensure seed–soil contact necessary for germination. The regional costs for the various seedbed preparation practices are listed in Table 1.

Table 1. Regional average cost ($/hectare) for seedbed preparation activities.

Province	Estimate Type	Seedbed Preparation		
		Ripping	Disking	Harrowing
Intermountain Semidesert	Average	54	42	37
	Range	15–183	15–136	17–92
Intermountain Desert	Average	67	49	44
	Range	15–161	15–124	12–111
American Desert	Average	213	106	126
	Range	15–741	15–383	15–366
Colorado Plateau Semidesert	Average	35	25	17
	Range	15–72	12–59	10–25
Chihuahuan Desert	Average	42	37	–
	Range	15–72	15–59	–
	Combined Average	124	64	57

Costs for all seedbed preparation treatments ranged widely within geographic regions (Table 1). Overall, it appears that costs in the American Desert province were highest. This province includes both the Sonoran and Mojave Deserts. The higher costs in this province are largely due to those reported for two military sites in the Mojave Desert. Costs for all three seedbed practices reported by the Natural Resources Conservation Service for a revegetation study conducted for the U.S. Navy on abandoned farmland in the Lahontan Valley, Nevada, were high. Ripping costs were 4–10 times higher at Fort Irwin, California, than for any location other than Lahontan Valley. Treatments at Lahontan Valley and Fort Irwin were experimental in nature. Because mobilization costs remain relatively constant regardless

of the size of the treated acreage, the higher-per-acre costs are likely attributable to the small size of the treated areas and the remoteness of the locations. If these sites were eliminated from the data set, the average-per-acre costs are in line with the other desert ecosystem provinces. After the American Desert province, costs for all site preparation activities were highest in the Intermountain Desert, followed sequentially by the Intermountain Semidesert, Chihuahuan Desert, and Colorado Plateau Semidesert. No agency in the Chihuahuan Desert could provide cost estimates for harrowing.

3.2 Fertilization

Fertilization is not a common practice on rangelands in the arid West. Indeed, except where frequent and/or intense disturbance has resulted in the loss of organic matter and fine soil particles, fertilization can be counterproductive in desert ecosystems. Native perennial plants in deserts generally have low-nutrient requirements, while introduced annual plants generally have higher requirements. Hence, the addition of fertilizer may favor exotic weeds at the expense of native plants.

The number of responses from the various agencies was quite low for all provinces. Because fertilization is so rarely used, no agency in the Colorado Plateau Semidesert province was able to provide information on material costs, although they were able to estimate labor and equipment costs. Labor and equipment costs were generally low in all desert ecosystem provinces but somewhat higher in the Intermountain and American Desert provinces (Table 2). Overall, material costs were higher and more variable than labor and equipment costs. Variability in material costs is based on the type and amount of fertilizer required. These factors are, in turn, determined by existing nutrient status, soil type, organic matter content, clay mineralogy, salinity, alkalinity, site history, etc. Overall, it appears the cost of fertilization is highest in the Chihuahuan Desert followed by the American and Intermountain deserts. Costs were lowest in the Intermountain Semidesert province.

The costs included in Table 2 are for broadcast fertilization only, as this is the most common method of application for reseeding projects. When planting tublings or containerized plants, fertilizer pellets are occasionally used. Only one agency reported information on fertilizer pellets. They estimated the cost for using fertilizer pellets to be $1 per plant for materials and $0.50–2 per plant for labor. These costs should not change significantly based on region.

Table 2. Regional average cost ($/hectare) for broadcast fertilization.

Province	Estimate Type	Broadcast Fertilization	
		Labor and Equipment	Materials
Intermountain Semidesert	Average	10	106
	Range	5–22	49–185
Intermountain Desert	Average	35	217
	Range	10–111	62–371
American Desert	Average	30	217
	Range	17–111	62–371
Colorado Plateau Semidesert	Average	12	–
	Range	7–22	–
Chihuahuan Desert	Average	17	304
	Range	10–22	124–482
	Combined Average	35	151

3.3 Seeding

On large tracts of nonagronomic land, broadcast or drill seeding most often accomplishes reestablishment of vegetative ground cover. Broadcast seeding is a process of spreading seed onto the soil surface. Prior seedbed preparation is not always required or even desirable. Broadcasting is often the least expensive seeding alternative in terms of labor costs. This is due primarily to the fact that more ground surface can be seeded with a single pass of the seeding equipment than with drill seeding. However, because the seed is left on the soil surface, seed–soil contact may not be adequate for good germination success. Hence, it may be necessary to seed at a higher rate or to drag a second implement over the site following seeding to help cover the seed with a thin layer of soil. Drill seeding is a process of placing seeds directly in the ground. Depending on the condition of the soil surface and the nature of the seed drill, some form of seedbed preparation may be necessary. Seed distribution is generally improved by drilling. Many seed drills can be adapted to place seeds at variable depths depending on their germination requirements. Seed drills are also often equipped with press wheels or dragged chains to help cover the seeds with soil and improve seed–soil contact. Where rough or steep terrain limits the access of drilling implements, broadcasting or hydroseeding may be required. Hydroseeding is a process of spraying seed on the soil in a liquid slurry. It is much more expensive than drill seeding or broadcasting due to the cost of equipment and the cost of transporting large quantities of water.

Across all ecological provinces, broadcast seeding had the lowest labor and equipment costs (Table 3). The average cost of drill seeding was almost double the cost of broadcasting. However, these estimates do not include the potential cost of using an additional implement to cover the seed in the case of broadcast seeding or the possible added cost of seedbed preparation in the case of drill seeding. The highest average costs for broadcast and drill seeding were reported from the American Desert Province. As in the case of seedbed preparation practices, the higher-per-acre costs here were attributable to the mobilization costs for treating small acreages and the remoteness of the sites treated. Average per-acre hydroseeding costs were uniformly high and exceeded broadcasting and drilling by an order of magnitude. There are fewer contractors equipped to do hydroseeding, and many hydroseeding contractors travel throughout the West.

Table 3. Regional average cost ($/hectare) for seeding practices.

Province	Estimate Type	Labor and Equipment Cost		Seed Cost	Hydroseeding (includes labor, equipment, seed, fertilizer, mulch, and tackifier)
		Broadcast	Drill		
Intermountain Semidesert	Average	20	32	200	5,444
	Range	7–37	10–138	47–618	3,529–14,085
Intermountain Desert	Average	35	59	531	5,103
	Range	10–99	15–161	148–988	3,529–14,085
American Desert	Average	111	138	425	5,103
	Range	49–148	25–297	148–988	3,529–11,752
Colorado Plateau Semidesert	Average	15	35	628	5,182
	Range	10–20	12–138	148–1142	3,529–14,085
Chihuahuan Desert	Average	17	40	524	4072
	Range	10–20	15–138	148–618	1,853–14,085
Combined Average		36	49	353	5,320

The rate of seeding, and hence the cost of seed, was assumed to be constant regardless of the equipment used. Executive Order 13112 issued February 3, 1999, requires federal agencies to prevent the introduction of invasive species and work toward the restoration of native species. Hence, seed costs were estimated based on using only mixtures of native species despite the fact that such a strategy may increase the cost of reseeding by as much as an order of magnitude in some cases. Seed costs were lowest in the Intermountain Semidesert province. This was apparently due to the fact that agencies in that province tend to use mixtures of grasses and shrubs, while agencies in other provinces tend to add more wildflowers to their seed mixtures. Grass seed is generally less expensive overall, and shrubs are generally seeded at low rates. Seed costs tended to be marginally highest in the Colorado Plateau Semidesert, although the reason for the trend was not apparent. Seed costs can vary widely within and between years based on supply and demand; low supplies and/or high demand can greatly increase the cost of seed.

3.4 Planting

Where land rehabilitation prescriptions call for trees and shrubs, it is often more cost effective to utilize live plants rather than seeds. This is due to the higher cost and lower availability of tree and shrub seeds, as well as generally low-germination and -seedling survival rates. The choice of woody plants for desert regions is limited. When available, they are most often supplied as tublings or containerized plants. Bare rootstock is used by some agencies but is comparatively rare in dry regions due to the higher risk of desiccation of the tender roots during and after the planting process. Relatively few agencies per region were able to provide cost estimates for the use of live plants. Estimates were limited to commonly available native species (estimates for unusual species can run as high as $200 per plant). Costs are reported in Table 4.

The cost of tublings was markedly less than containerized plants in all ecological provinces. Planting tubes are smaller and cost less than most other containers. Because of their small size, space requirements for growing and transporting are minimized. For containerized plants, the reported costs reflect 3.8 *l* (1 gal.) containers. The use of larger container sizes tends to increase expenses dramatically due to the higher cost of transportation and the fact that the plants in larger containers tend to be older

Table 4. Regional average cost ($/plant) for live plants.

Province	Estimate Type	Tublings			Containerized Plants (3.8 *l*)		
		Labor	Material	Labor and Material	Labor	Material	Labor and Material
Intermountain Semidesert	Average	2	1	3	9	15	11
	Range	1–3	–	2–4	6–14	3–30	3–36
Intermountain Desert	Average	2	2	11	10	14	17
	Range	1–3	1–3	4–24	7–25	5–29	6–36
American Desert	Average	2	2	4	10	8	10
	Range	1–3	1–3	2–6	2–18	2–11	2–36
Colorado Plateau Semidesert	Average	2	2	4	11	18	18
	Range	1–3	1–3	2–6	7–14	14–21	7–36
Chihuahuan Desert	Average	–	–	–	9	15	13
	Range	–	–	–	6–14	2–2	3–36
Combined Average		2	2	9	11	12	13

and have required more effort to grow. Labor costs are estimated for hand planting in normal soils; where soils are hard or rocky, labor costs can be expected to increase. Some agencies procure labor and materials through separate contracts. This has a tendency to increase the overall cost when compared to contracts that procure labor and materials jointly (Table 4). This is especially true for large contractors who grow their own plants or who can take advantage of volume discounts by securing plant materials for multiple contracts simultaneously.

In some areas it is desirable to use translucent tubes to protect young seedlings from sunscald and herbivores while providing a greenhouse-like microenvironment. Such tubes for containerized plants or tublings cost an average of $2 (range $1–3) each when purchased in bulk, regardless of region. Installation of the tubes costs an average of $2 per plant (range $1–2). Although inoculation of woody plant roots with mycorrhizal fungi can significantly enhance survival and growth of many woody species, it is not widely used. Only one agency reported costs of inoculation. These averaged less than $1 per plant including labor and materials. Supplemental watering of young seedlings can also enhance survival. The practice, however, is not common. Two agencies reported the cost of supplemental watering at $16 and $28 per plant. This can be twice the cost of the plants themselves (Table 4), and likely accounts for the fact that the practice is uncommon.

3.5 Mulching

Germination and survival of plants in reseeded areas can be enhanced by the addition of mulch. Mulch helps conserve soil moisture and adds organic matter to the soil. Commonly used materials include straw, hay, and commercial fiber mulch. Straw and hay can be spread by hand or blown on the soil with special equipment designed for that purpose. The labor cost for applying mulch is the same for straw and hay, although the material cost can vary widely both within and between regions (Table 5). Hay is often more expensive than straw because of its alternative value as winter feed for livestock. Straw and hay are both susceptible to blowing. Hence, crimping or tackifying may be necessary to hold it in place. Most contracts that call for mulching do not separate the costs of materials and labor. Hence, Table 5 too reflects average regional costs for the entire process. The cost of mulching was highest in the American Desert province followed closely by the Chihuahuan Desert and Colorado Plateau Semidesert provinces.

Table 5. Regional average cost ($/hectare) mulching with straw or hay.

Province	Estimate Type	Material, Spreading, and Crimping
Intermountain Semidesert	Average	610
	Range	237–1,001
Intermountain Desert	Average	2,734
	Range	321–1,129
American Desert	Average	2,320
	Range	–
Colorado Plateau Semidesert	Average	2,246
	Range	793–4,942
Chihuahuan Desert	Average	1,638
	Range	793–4,942
	Combined Average	1,366

Mulching was far less expensive in the Intermountain Desert and Semidesert provinces, possibly due to the proximity of numerous farms and ranches at higher elevations within those regions where cooler temperatures and irrigation systems provide a setting more conducive to hay and straw production. Fiber mulch is generally used only in conjunction with hydromulching or hydroseeding. The combined cost of labor and materials for hydromulching is much higher than mulching with straw or hay. As labor and equipment expenses remain relatively constant for hydraulic applications regardless of the materials used, estimated costs of hydromulching alone can be approximated from Table 3 by subtracting the costs of seed and fertilizer from the cost of hydroseeding.

3.6 Supplemental Erosion Control

At some locations, revegetation alone may not be adequate to control soil erosion. Some form of supplemental erosion control may be necessary. Common erosion control practices include diversion trenches and riprap. Diversion trenches may be used to divert water away from areas of concentrated flow thus reducing the erosive energy of flowing water. Diversion trenches may also be used to divert water into areas where revegetation efforts are taking place in order to supplement the supply of water to the new plants. For the purposes of this report, diversion trenches are defined as shallow, linear excavations produced by a single pass of heavy equipment such as a road grader, although an experienced driver of a bulldozer or front-end loader can often accomplish a similar result. Average regional costs for the construction of diversion trenches are listed in Table 6. Costs are generally low and do not vary widely by region. There is generally as much or more variation within provinces than between them. Variability in cost per linear meter ($/lm) is attributable to mileage to and from the construction sites and to the size of the job. Riprap is commonly placed in gullies or waterways to slow the flow of water and minimize its erosive energy. Riprap is available in many different sizes depending on the expected flow of water. The size of the rock can greatly affect the cost. Most agencies do not record the costs of materials and labor separately. Hence, the values recorded in Table 6 include both labor and material. The cost of riprap varies widely both within and between provinces. On average,

Table 6. Regional average costs for supplemental erosion control practices.

Province	Estimate Type	Diversion Trenches ($/lm)	Riprap Installed ($/m^3)
Intermountain Semidesert	Average	3	27
	Range	3–6	13–50
Intermountain Desert	Average	6	40
	Range	3–6	20–69
American Desert	Average	6	48
	Range	3–12	26–87
Colorado Plateau Semidesert	Average	6	41
	Range	3–6	28–86
Chihuahuan Desert	Average	6	90
	Range	3–6	28–348
	Combined Average	6	53

costs per cubic meter ($/m^3) of material were much higher in the Chihuahuan Desert than in the other provinces. The higher costs there may be attributable to the long distances between sources of riprap and construction locations.

4.0 CONCLUSIONS

Costs for most land reclamation practices and materials covered by this report varied widely within and between ecological provinces. Although regional cost patterns were evident for some practices, the patterns were not consistent between practices. Due to the wide intra-provincial variability in costs and frequent small number of cost estimates per province (i.e., 1–13), it is impossible to conclude with any degree of certainty that differences in average costs between provinces are statistically significant. For the purpose of estimating land reclamation costs for the ATTACC methodology, it may be desirable to use the "Combined Average" of all provinces found in the last row of each table to estimate costs for arid lands in general.

5.0 PUBLISHED SOURCES OF INFORMATION

Gebhart, D.L. and S.D. Warren. 1995. Regional cost estimates for rehabilitation and maintenance practices on Army training lands. Technical Report 96/02. US Army Corps of Engineers, Construction Engineering Research Laboratories.

RS Means Company, Inc. 2000. Site work and landscape cost data 2000. 19th edition. Kingston, MA. 614 pp.

Tranel, J.E., R. Sharp, N. Dalsted, and P. Gutierrez. 1994. 1993 custom rates for Colorado farms and Ranches. Colorado State University Cooperative Extension and Department of Agricultural and Resource Economics, Fort Collins, Colorado.

United States Department of Agriculture, Forest Service. 1994. Cost estimating guide for road construction. Region 4, Division of Engineering.

University of Wyoming. 1994. Custom rates for farm/ranch operations in Wyoming 1992–93. Bulletin B-703R. Cooperative Extension Service.

U.S. Department of Agriculture, Forest Service. 1995. Description of the ecoregions of the United States. Compiled by Bailey, R. G. Web Site (http://www.fs.fed.us/land/ecosysmgmt /ecoreg1_home.html) [Date of Access: October 2000].

DISTRIBUTION

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APPENDIX 9.4 POST-CLOSURE MONITORING CHECKLIST

POST-CLOSURE MONITORING CHECKLIST

Date of Last Inspection:	Reason for Last Inspection:
Responsible Agency:	Project Manager:
Inspection Date:	
Inspector (name, title, organization):	
Assistant Inspector (name, title, organization):	

A. GENERAL INSTRUCTIONS

1. All checklist items must be completed and detailed comments made to document the results of the site inspection. The completed checklist is part of the field record of the inspection. Additional pages should be used as necessary to ensure that a complete record is made. Attach the additional pages and number all pages upon completion of the inspection.
3. Any checklist line item marked by an inspector in a SHADED BOX, must be fully explained or an appropriate reference to previous reports provided. The purpose of this requirement is to provide a written explanation of inspector observations and the inspector's rationale for conclusions and recommendations. Explanations are to be placed on additional attachments and cross-referenced appropriately. Explanations, in addition to narrative, will take the form of sketches, measurements, annotated site maps.
4. The site inspection is a walking inspection of the entire site including the perimeter and sufficient transects to be able to inspect the entire surface and all features specifically described in this checklist.
5. A standard set of color 35mm photographs is required. In addition, all anomalous features or new features (such as changes in adjacent area land use) are to be photographed. A photo log entry will be made for each photograph taken.
6. This unit will be inspected biannually with formal reporting to the Nevada Division of Environmental Protection to be done annually. The annual report will include an executive summary, this inspection checklist with field notes and photo log attached, and recommendations and conclusions.

B. PREPARATION (To be completed prior to site visit)	YES	NO	EXPLANATION
1. Site as-built plans and site base map reviewed.			
2. Previous inspection reports reviewed.			
a. Were anomalies or trends detected on previous inspections?			
b. Was maintenance performed?			
3. Site maintenance and repair records reviewed.			
a. Has site repair resulted in a change from as-built conditions?			
b. Are revised as-builts available that reflect repair changes?			

C. SITE INSPECTION (To be completed during inspection)	YES	NO	EXPLANATION
1. Adjacent off-site features within watershed areas.			
a. Have there been any changes in use of adjacent area?			
b. Are there any new roads or trails?			
c. Has there been a change in the position of nearby washes?			
d. Has there been lateral excursion or erosion/deposition of nearby washes?			
e. Are there new drainage channels?			
f. Change in surrounding vegetation?			
2. Security fence, signs.			
a. Displacement of fences, site markers, boundary markers, or monuments?			
b. Have any signs been damaged or removed? (Number of signs replaced: _____)			
c. Were gates locked?			

APPENDIX 9.4 POST-CLOSURE MONITORING CHECKLIST (CONT)

POST-CLOSURE MONITORING CHECKLIST			
3. Waste Unit cover.	YES	NO	EXPLANATION
a. Is there evidence of settling?			
b. Is there cracking?			
c. Is there evidence of erosion around the cap (wind or water)?			
d. Is there evidence of animal burrowing?			
e. Have the site markers been disturbed by man or natural processes?			
f. Do natural processes threaten the integrity of any cover or site marker?			
g. Other?			
4. Vegetative cover.			
a. Is perimeter fence or mesh fencing damaged?			
b. Is there evidence of horses or rabbits on site?			
c. Is organic mulch adequate to prevent erosion?			
d. Are weedy annual plants present? If yes, are they a problem?			
e. Are seeded plant species found on site?			
f. Is there evidence of plant mortality?			
5. Photo Documentation			
a. Has a photo log been prepared?			
b. Number of photos exposed (one, attached to report)			
D. FIELD CONCLUSIONS			
1. Is there an imminent hazard to the integrity of the unit? (Immediate report required) Person/Agency to whom report made:			
2. Are more frequent inspections required?			
3. Are existing maintenance/repair actions satisfactory?			
4. Is other maintenance/repair necessary?			
5. Is current status/condition of vegetative cover satisfactory?			
6. Rationale for field conclusions:			
E. CERTIFICATION			
I have conducted an inspection of the Bomblet Pit, at the TTR in accordance with the Post-Closure Monitoring Plan (see Closure Report) as recorded on this checklist, attached sheets, field notes, photo logs, and photographs.			
Chief Inspector's Signature:	Printed Name:		
Title:	Date:		

APPENDIX 9.5 INTERNET WEB SITES FOR HABITAT RESTORATION

Notable sites for habitat restoration are those listed in: William R. Jordan III, 1998. World Wide Web. Restoration & Management Notes Volume 16, Number 1, Summer 1998. A condensed list follows, but less than 50 percent of the websites listed in this publication were still active at the time this report was published. Listing of these web sites does not constitute or imply its indorsement, recommendation by the U.S. Government or agency thereof or its contractors or subcontractors. Surviving Web sites include:

9.5.1 Non-profit Organizations and Projects

California Ecological Restoration Projects Inventory: http://ice.ucdavis.edu/CERPI

Environmental Law Institute: http://www.eli.org

Estuarine Research Federation: http://erf.org/

Glen Canyon Institute: http://www.glencanyon.org

9.5.2 Nurseries, Equipment Suppliers, and Consulting Firms

Bitteroot Restoration, Inc.: http://www.montana.com/BRI

Carino Nurseries: http://www.carinonurseries.com

Ecogroup: http://www.ecomgmt.com

Environmental Concern: http://www.wetland.org

Ernst Seeds: http://www.ernstseed.com

Freshwater Farms: http://www.freshwaterfarms.com/

Granite Seed Company: www.graniteseed.com

Lewis Environmental Services: http://www.lewisenv.com/

LSA Associates: www.lsa-assoc.com

Plant Health Care: http://www.planthealthcare.com

Plants of the Southwest: www.plantsofthesouthwest.com

Reforestation Technologies International: http://www.reforest.com/index2.html

S&S Seeds: www.ssseeds.com

9.5.3 Government Sites

EPA Adopt Your Watershed: http://www.epa.gov/adopt/

EPA Ecological Restoration: A Tool to Manage Stream Quality: http://www.epa.gov/adopt

Native Plant Conservation Initiative: http://www.nps.gov/plants/austin99/

SERDP: www.serdp.org/research/conservation.html

U.S. Forest Service National Headquarters: http://www.fs.fed.us

U.S. Army Cold Region Research and Engineering Laboratory: www.crrel.usace.army.mil/gcd/curr-research.htm

Wetland Science Institute: http://www.pwrc.usgs.gov/wli/default.htm

VegSpec: http://ironwood.itc.nrcs.usda.gov/Netdynamics/Vegspec/pages/HomeVegspec.htm

9.5.4 University Sites

Biological Control of Weeds Working Group: http://bioweed.ifas.ufl.edu/

Colorado State University, Dept. of Rangeland Ecosystem Science: www.cnr.colostate.edu/RES/rel/serdp/index.html

9.5.5 Journals, Newsletters, Publishers

Native Plants Journal: http://nativeplants.for.uidaho.edu

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