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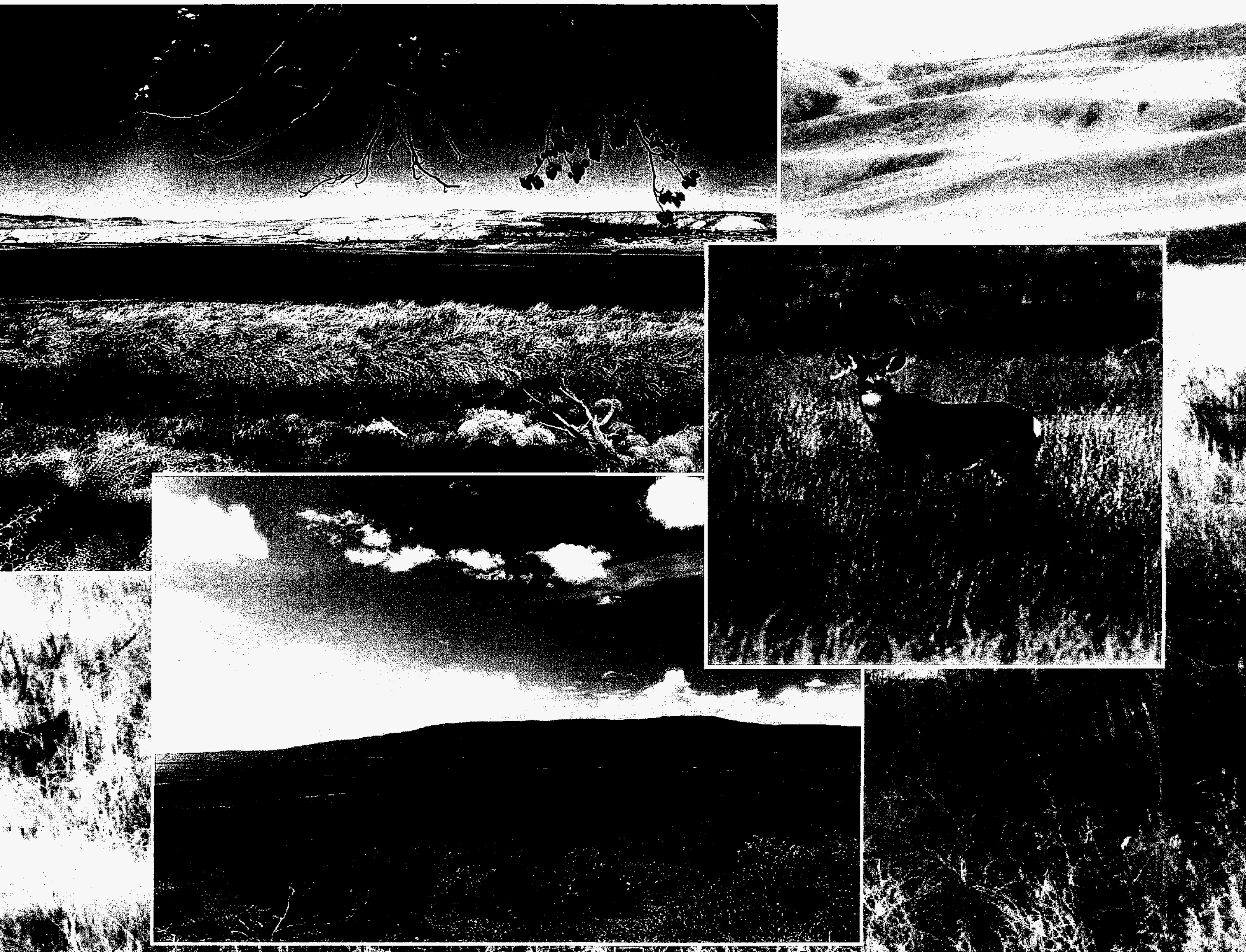
Rev. 0

Revegetation Manual for the Environmental Restoration Contractor



Prepared for the U.S. Department of Energy
Office of Environmental Restoration

Bechtel Hanford, Inc.
Richland, Washington

DISCLAIMER

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Revegetation Manual for the Environmental Restoration Contractor

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TABLES

1.0 EXECUTIVE SUMMARY

The purpose of this manual is to provide guidance and general guidelines for the revegetation of remediated waste sites and other disturbed areas on the Hanford Site. Specific revegetation plans will be developed using guidance from this manual. Locations, resources, and funding will dictate the specific revegetation design at each disturbed area.

Disturbances have occurred to some of the ecological communities of the Hanford Site. Many of these disturbances are the result of operations of the Hanford facility, including *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) waste sites on small portions of the Hanford Site. There were, however, extensive disturbances to the native vegetation prior to operations of the facility. These resulted from cultivation, grazing, fire, and the introduction of exotics. Revegetation planning must take into account these early disturbances, as well as the later ones.

There are three primary goals in land rehabilitation: revegetation, reclamation, and restoration. Revegetation and reclamation are practical and achievable goals, in most cases. This manual concentrates on these goals and how to achieve them. Restoration is much more difficult; it implies that the site be returned to its pre-disturbance condition. In an absolute sense, this is not possible.

Late-successional ecosystems are very complex systems involving linkages among plant, animal, microbial, soil, and atmospheric subsystems that take biologically long periods of time to develop. Under natural conditions, this process of ecological recovery in the climate of Hanford might take on the order of 200 years to complete. Although we can not return to pre-disturbance conditions in a pure sense, we can restore a site to conditions similar to pre-disturbance conditions in much shorter periods of time, and these procedures are presented in this manual. Section 2.0 discusses these goals of revegetation, reclamation, and restoration, as well as the objectives associated with them.

Revegetation, reclamation, and restoration involve many ecological processes. Understanding these processes and using them to help accomplish our goals greatly reduces the time, effort, and money required to achieve the objectives. Ignoring these ecological principles and conducting projects contrary to the natural processes will greatly increase the probability of failure. A successful revegetation program must be built on a sound ecological basis. Section 3.0 discusses the ecological basis for revegetation.

Section 4.0 presents an general overview of the methods used in revegetation and ecological restoration. These are the tools that are available to use to accomplish our objectives. Section 4.0 also discusses the proper use of these tools and their potentials and limitations.

The specific recommendations for revegetation projects at Hanford are presented in Section 5.0. The first step is to define the objective. This is accomplished by selecting, from a decision matrix menu (Section 5.3), the appropriate combination of site (5 selections), desired community type (3 selections), time line (5 selections), and use or impact level (2 selections). Based on the selection made in this decision matrix, one of 22 specific revegetation scenarios is recommended (Section 5.4). For each scenario, pre-planting, propagation, and post-propagation procedures are presented, along with expected vegetation dynamics, evaluation procedures, and discussions of relative costs and ecological considerations. Guidelines for selection of plant material are presented in Section 5.5, along with 14 recommended seed mixtures.

A fundamental consideration of any revegetation project is subsequent evaluation. Did it succeed or did it fail? Evaluation criteria to be used to quantitatively answer this question are presented in each of the 22 recommended revegetation scenarios and a general discussion is presented in Section 6.1. Measurement concepts and specific designs and methods for evaluating the scenarios are presented in Section 6.2.

This document is produced as a working document, one that will change over time as new information becomes available and as goals and objectives change. It is based on current scientific knowledge and the personal experience of the authors. A continuing review process is essential for its continued usefulness. The final section of the manual presents a procedure for review and update.

2.0 DEVELOPMENT OF RESTORATION GOALS AND STRATEGIES

2.1 GOALS

There are three primary goals in land rehabilitation: revegetation, reclamation, and restoration. The goals are not exclusive, but they are different and have important differences for Hanford needs that should be recognized from the beginning. A successful rehabilitation project must clearly state which goal applies. This goal then provides the guidance and limits to the project.

The purpose of revegetation is to establish some type of vegetative cover to the site. Various types of vegetation or levels of cover may be specified, but the purpose is to get plants growing on the site. The first objective in most rehabilitation projects is to stabilize the site. Site stabilization is the primary objective in most revegetation projects.

Revegetation projects may be relatively simple or they may be very complex. The endpoints of a simple revegetation project may be (1) to establish any type of plant community on the site, and (2) to ensure that some type of plant community succession continues on the site. A more complex revegetation project might require that a specific type of plant community (e.g., big sagebrush shrubland) be established on the site and that it continue to exist on the site after management ends.

Reclamation implies more that just revegetation. It implies that a site has been significantly disturbed and that the site must be returned to ecological conditions similar to surrounding sites that were not subjected to the disturbance. Reclamation projects include revegetation of the site, but they also include amelioration of the effects of the disturbance. Whereas revegetation accepts the conditions left by the disturbance and proceeds from that point to establish vegetation on the site, reclamation first attempts to ameliorate the effect of the disturbance, then proceeds to establish vegetation.

Restoration is the most difficult of the three goals. The word "restoration" implies that the site be returned to its pre-disturbance conditions. Most often, this is not possible in an absolute sense. To achieve complete restoration, the entire ecosystem must be reconstructed; this, in most cases, is beyond our current ability. However, partial restoration, or restoration of certain components of the ecosystem, is often possible and many times practical.

2.2 OBJECTIVES AND STRATEGIES

Once the project goal has been defined, objectives can be defined to attain the goal and strategies can be developed to accomplish the objectives. Revegetation is an acceptable and achievable goal for many rehabilitation projects. If site revegetation is the goal, objectives are generally defined on the basis of (1) what type of plants are acceptable, (2) how much cover is acceptable, and (3) how long the process is to take. Revegetation objectives can be defined, and evaluated, solely on the plant community: what type, how much, and how long. Strategies can then be developed to accomplish the objectives (Section 5.0).

Both plant and abiotic objectives are included in reclamation projects. Abiotic objectives address how well the effects of the disturbance have been rectified and what is necessary for the establishment of the target plant community. Examples include altering pH, moving the rooting zone away from contamination by adding topsoil, and recontouring the surface to remove artificial obstructions to surface water flow. The plant objectives may then be similar to revegetation objectives (i.e., what plant community, how much, and how long).

There is only one objective to a pure restoration project: restoration of the complete pre-disturbance ecosystem. The first step of this process is to define the pre-disturbance plant community. This definition must include composition, structure, and functional aspects (Section 3.2.1). These values should be based on field data from nearby reference sites. Reference sites are areas dominated by the same plant community that is supposed to have been the pre-disturbance community on the site undergoing restoration. "Nearby" is a relative term, the definition of which will vary based on ecological conditions, especially microclimate. Normally, reference sites should be within < 1 km from the target site, and must have topographic, edaphic, and biotic characteristics similar to those of the supposed pre-disturbance target site.

Once the pre-disturbance plant community is defined, a soil profile similar to the reference site must be established. It must include similar physical, chemical, and biological components. The more similar the restored profile is to the reference site profile, the more likely it will be that the pre-disturbance plant community can be established on the site and that it will be self-perpetuating. Conversely, the less similar the restored profile is to the reference profile, the less likely the pre-disturbance community can be restored to the site or that it will perpetuate itself after establishment. The restoration of the soil profile includes the re-establishment of surface topography similar to pre-disturbance conditions.

Once the soil profile and surface topography have been restored, the plant community can be established. The target composition is generally easier to establish than recreating the soil structure and surface topography. It can be established from seeds, tublings, transplants, or various combinations of the three. Structural restoration (e.g., height of plants, depth of rooting) requires more time, because the plants must grow to maturity both above- and belowground. Structural restoration may take several years in grasslands, several decades in shrublands, and several centuries in forests.

Functional restoration is the last of the objectives to be accomplished. Functional restoration requires (1) the proper composition of plants to be present on the site, (2) the proper structure of the community to be present, (3) the re-establishment of pre-disturbance animal community characteristics, and (4) the re-establishment of complex ecological linkages among plant, animal, microbial, and abiotic components. Functional restoration, if possible at all, may require 50-100 years in grasslands, 100-200 years in shrublands, and 200-500 years in forests.

3.0 BACKGROUND INFORMATION

3.1 DESCRIPTION OF THE HANFORD SITE

3.1.1 Geographical and Historical Setting

The Hanford Site occupies 1,450 km^2 in semi-arid southeastern Washington. The site has been administered by the U.S. Department of Energy (DOE) since 1943, when the area was acquired by the U.S. government as a national security area for producing plutonium used in nuclear weapons. A total of nine reactors were constructed and operated through the 1960s. Eight reactors were phased out in the 1960s and early 1970s. One reactor, the dual-purpose (i.e., plutonium production and electrical generation) N Reactor, remained in operation after February 1971. The Fast Flux Test Facility reactor was brought into operation in 1980 for the testing of reactor technologies. Both facilities were closed in 1988, and the Hanford Site mission changed to nuclear waste management, environmental restoration, research, and technology development (Cushing 1992).

Major buildings are confined to a few widely-spaced clusters along the Columbia River (the 100 Areas and the 300 Areas) and the Hanford Site interior (the 200 Areas). These clusters are connected by roads, railroads, and electrical transmission lines that together occupy about 6% of the land area.

The Hanford Site is part of the Columbia Basin physiographic province, which is underlain by the massive Columbia River basalt flows. Topography of Hanford varies considerably, with elevations ranging from 1100 m at the crest of Rattlesnake Mountain to 110 m along the Columbia River. A number of long anticlinal ridges run through or within Hanford, including Rattlesnake Mountain and the Rattlesnake Hills, Yakima Ridge, Umtanum Ridge, Saddle Mountain, and Gable Mountain.

The Columbia River flows mostly east and southeast through the Hanford Site. This portion of the Columbia, known as the Hanford Reach, is regarded as one of only two remaining free-flowing stretches of the Columbia River in the United States. The Hanford Reach provides one of the only remaining native spawning beds for fall chinook salmon on the main stem of the Columbia. Adjacent to the north and east sides of the river are the steep White Bluffs, which rise in places to over 180 m above the river. North and east beyond that, the Wahluke Slope rises gently before reaching the steeper slopes of the Saddle Mountains.

In 1967, a 260 km^2 area of Hanford was designated as an environmental research area. This relatively undisturbed piece of land, which is located in the southwestern sector of the Hanford Site, has been designated as the Fitzner-Eberhardt Arid Land Ecology Reserve. In 1977, the entire Hanford Site was designated a National Environmental Research Park (NERP) by DOE for use as an outdoor laboratory for ecological research. In 1978, the Hanford Reach of the Columbia River was re-opened to public access. Although Hanford Site land lying south and west of the Columbia River is still restricted to public access, ecological research by university personnel and Hanford Site contractors is encouraged.

The Hanford Site contains one of the few relatively undisturbed remnants of the shrub-steppe habitat in the state of Washington. However, a number of land disturbances have occurred on the Site since the advent of cultivation agriculture in the northwest. Areas of the Site located near sources of water (such as the Columbia River, Rattlesnake Springs, Snively Springs, and artesian wells in the northwest corner of the Site) were cultivated from the turn of the century to 1943. Subsequent disturbances have resulted from nuclear-related operations. These disturbances have included construction, excavation, and materials/spoils disposal. Most disturbances have been confined to the vicinity of the reactors along the Columbia River and within the 200 Areas of the central plateau. However, few areas of the Site remain totally unaffected at the present time, as a result in part of the widespread groundwater monitoring network, road and power line construction, excavation of numerous gravel and soil borrow pits, long firebreak lines, and off-road vehicle traffic.

3.1.2 Climatic Data

The meteorological data base maintained by the Hanford Meteorology Station consists of hourly data, taken from the ground surface and from a 125-m (410-ft) tower. The data has been collected continuously from 1953 to the present.

The Hanford region is classified as a mid-latitude semi-arid desert. The climate is strongly influenced by the Cascade Range to the west, which forms a barrier to eastward-moving Pacific Ocean storm fronts. The mountains form a rain shadow, producing mild temperatures and arid climatic conditions.

The mean annual temperature and precipitation at the Hanford Meteorological Station site (over the period from 1961 to 1990) are 11.8° C and 159 mm, respectively (Hoitink and Burk 1996). Eighty-one percent of the precipitation falls from October through May, the portion of the year in which most plant growth occurs. During the 35-yr period of 1961 through 1995, precipitation during the October-May period averaged 130 mm. In four of these years (1964, 1966, 1968, and 1977) less than 76 mm of precipitation was received October-May. The driest period, 1976-1977, had only 47 mm of precipitation. The three wettest years on record were 1995 (313 mm), 1949 (291 mm), and 1983 (281 mm). The three driest years on record were 1976 (76 mm), 1967 (83 mm), and 1965 (93 mm).

The monthly distribution of precipitation shows three major biological periods of the year (i.e., fall-winter growth, spring growth, and summer dormancy). October through January is the time of fall-winter growth, when precipitation exceeds evapotranspiration and soil water storage occurs. February through May is the period of spring growth, when most of the plant growth occurs and stored soil water is depleted most actively by shoot transpiration. June through September is the period of lowest precipitation, a stressful time of the year for both plants and animals. Most of the plants reduce water losses by dropping some or all of their leaves, or else the shoots die back to near ground level. The relative humidity is highest from October to January. The average is 71%, compared to only 37% in the period from June through September.

Although much of the land area of the Hanford Site is gently rolling, the Rattlesnake Hills rise to 1100 m. This increase in altitude is accompanied by an increase in precipitation. The annual precipitation at Rattlesnake Spring, situated at an elevation of 210 m, averages 167 mm. Upper Snively Field, elevation 553 m, averages 260 mm.

Snowfall has occurred every year since measurements began in 1946, with a 30-year (1961 to 1990) annual average of 35.1 cm (Hoitink and Burk 1996). However, total annual amounts have ranged from 0.8 cm (in 1957-58) to 142.5 cm (in 1992-93). Eighty-three percent of snowfall occurs in the period from October through January, peaking in December. Snowfall differs from rainfall in that, once deposited, it can be redistributed by wind. In this way, soil water storage can be lessened in soils that are swept free of snow by wind and increased in soil upon which the snow is deposited.

Solar radiation ranges from a low of 89 langleys per day in December to 647 in July. Only 15% of the solar radiation input is received in the October-January period of the bioclimatic year, while 50% is received in the period from June through September. However, most of the primary production takes place from February through May, which receives only 35% of the annual solar radiation input. Clearly, primary production is not synchronized with the period of the year in which sunlight is most intense. It is also equally clear that maximal photosynthetic activity is performed during the few weeks when soil water is most available and when air temperatures are moderate.

January is the coldest month, with a mean monthly temperature of -0.4° C (over the period from 1961 to 1990), and December is the wettest month, with a mean monthly precipitation of 26.2 mm (from 1961 to 1990) (Hoitink and Burk 1996). July is the hottest and driest month with mean (1961-90) monthly temperature and precipitation of 24.6° C and 4.6 mm.

Wind plays a major role in the dispersal of seeds and pollen, as well as the re-distribution of snow once it is deposited on the ground. Wind is a chronic force in soil erosion, and it is very important in the spread of wildfire. The prevailing wind directions are from the northwest and west northwest. However, peak gusts are from the southwest or south-southwest. Wind speeds tend to be lowest during the fall and winter months (October through January). June has the highest mean wind velocity at 4.1 m/s, and December has the lowest at 2.7 m/s.

3.1.3 Soils of the Hanford Site

The Pacific Northwest shrub-steppe, encompassing large areas in the upland regions of eastern Washington, eastern Oregon, and southern Idaho, includes a diversity of soils. However, the soils of the shrub-steppe are typified by those existing on the Columbia Plateau, bordered by the northern Rocky Mountains on the east, the Cascade Mountains on the west, the Okanogan Highlands on the north and the Blue Mountains on the south. The plateau functions as a large inland basin comprising a series of small basins. The surface of the plateau was modified initially by glacial abrasion and redistribution, and later by wind and water events. A significant portion of the basin section has developed on a mantle of loess and Pleistocene outwash sediments. The soils of the Columbia Plateau supporting shrub-steppe vegetation are principally in the drier upland regions of 120 to 1060 m in eastern Washington, northwestern Idaho, and northern Oregon.

Hajek (1966) classified the soils of the Hanford Site. The following is a description of the 15 soils identified and described by Hajek (1966).

<u>Ritzville Silt Loam (Ri)</u>. This mapping unit consists chiefly of dark-colored silt loam soils which have developed midway up the slopes of Rattlesnake Hills. These soils developed under bunch grass from silty wind-laid deposits mixed with small amounts of volcanic ash. Ritzville soils are characteristically greater than 150 cm deep; in places, however, bedrock may occur at less than 150 cm, but greater than 75 cm.

<u>Rupert Sand (Rp)</u>. This mapping unit represents one of the most extensive soils on the Hanford Site. Rupert soils developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits that were mantled by wind-blown sand. Relief characteristically consists of hummocky terraces and dune-like ridges. Active sand dunes are present.

<u>Hezel Sand (He)</u>. Hezel soils are similar to Repert sands. The surface soil is very dark brown and was formed in wind-blown sands that mantled lake-laid sediments.

<u>Koehler Sand (Kf)</u>. Koehler soils are similar to the other sandy soils found on the Hanford Site. They developed in a wind-blown sand mantle. This soil differs from the other sands in that the sand mantles a lime-silica cemented layer or a hardpan.

<u>Burbank Loamy Sand (Ba)</u>. This is a dark-colored, coarse-textured soil underlain by gravel. The surface soil is usually about 40 cm thick, but can be 75 cm thick. The gravel content of the subsoil may range from 20 to 80 volume percent.

<u>Kiona Silt Loam (Ki)</u>. This soil occupies steep slopes and ridges. The surface soil is very dark-grayish brown and about 10 cm thick. The subsoil contains basalt fragments 30 cm and larger in diameter. Many basalt fragments also are found in the surface layer. Normally, this shallow stony soil occurs in association with Ritzville and Warden soils.

<u>Warden Silt Loam (Wa)</u>. This is a dark-grayish brown soil with a surface layer that is about 22 cm thick. The silt loam subsoil becomes strongly calcareous at about 50 cm. Granitic boulders are found in many areas. Usually, the soil is greater than 150 cm deep.

<u>Ephrata Sandy Loam (El)</u>. This is a dark-colored, medium-textured soil underlain by gravelly material that may continue for a number of meters. This soil is associated with the Burbank soil, and the topography is generally level.

<u>Ephrata Stony Loam (Eb)</u>. This soil is similar to Ephrata sandy loam. It differs in that many large hummocky ridges, made up of debris released from the melting ice of glaciers, are present. Areas between hummocks contain many boulders several feet in diameter.

<u>Scootney Stony Silt Loam (Sc)</u>. This soil has developed along the north slope of the Rattlesnake Hills, usually confined to floors of narrow draws or small fan-shaped areas where

draws open onto plains. The soils are often severely eroded with numerous basaltic boulders and fragments being exposed.

Pasco Silt Loam (P). This is a poorly-drained very dark-grayish brown soil formed in recent alluvial material. The subsoil is variable, consisting of stratified layers. Only small areas of this soil are found on the Hanford Site and they are located in low areas adjacent to the Columbia River.

Esquatzel Silt Loam (Qu). This is a deep dark-brown soil formed in recent alluvium derived from loess and lake sediments. Esquatzel soils are associated with Ritzville and Warden and often seem to have developed from sediments eroded from these two series.

Riverwash (Rv). These are wet, periodically-flooded areas of sand, gravel, and boulder deposits which are adjacent to the Columbia River and make up overflowed islands in the river.

Dune Sand (D). This unit represents a miscellaneous land type which consists of hills or ridges of sand-sized particles drifted and piled up by wind and is either actively shifting or so recently fixed or stabilized that no soil horizons have developed.

Lickskillet Silt Loam (Ls). This soil occupies the ridge tops of Rattlesnake Hills and slopes above the 760 m elevation. The soil is similar to the Kiona series except that the surface soils are darker. Lickskillet soils are shallow over basalt bedrock. Numerous basalt fragments are present throughout the profile.

3.1.4 Pre-Disturbance Vegetation

Daubenmire (1978:204-205) placed the Hanford area in the northern section of the Agropyron spicatum Province. This vegetation is often described as sagebrush-steppe (Bailey 1995). Prior to European settlement, this area was a shrubland dominated by big sagebrush (Artemisia tridentata), with small amounts of green rabbitbrush (Chrysothamnus viscidiflorus), spiny hopsage (Grayia spinosa), or bitterbrush (Purshia tridentata). The overstory shrubs were widely-spaced, 0.5-2.0 m tall, and with canopies covering 5-20% of the ground surface. An understory layer of mostly bunch grasses, 30-40 cm tall, consisted primarily of bluebunch wheatgrass (Agropyron spicatum), Idaho fescue (Festuca idahoensis), Sandberg bluegrass (Poa sandbergii), and Thurber needlegrass (Stipa thurberiana) (Daubenmire 1978). Other authors believe that the pre-European era vegetation was bluebunch wheatgrass grassland, rather than shrubland. Tisdale (1994) described the bluebunch wheatgrass type of land as dominated by bluebunch wheatgrass, with lesser amounts of Sandberg bluegrass and with virtually no shrubs. Shelford (1974) suggested that the original vegetation of the region might have contained shrubs scattered at 3-8 m intervals, with an understory of bluebunch wheatgrass, Sandberg bluegrass, needle-and-thread (Stipa comata), and squirreltail (Sitanion hystrix).

Fire reduces sagebrush frequency since the shrubs are largely killed by hot fires (Humphrey 1962, Cline et al. 1977). Big sagebrush stands often require several decades to a century to recover from fire in the area. Until the big sagebrush becomes dominant again, perennial grasses dominate the site (unless invaded by annuals). Bluebunch wheatgrass has been found to recover from fire especially fast (Blaisdell 1953). If fire was relatively frequent across the area (< 50 years), the area most likely was dominated by perennial grasses with only scattered individuals or small patches of big sagebrush on microsites where the fire did not burn. On the other hand, if fire was less frequent, the area was probably dominated by big sagebrush with a strong perennial grass understory composed primarily of bluebunch wheatgrass and Sandberg bluegrass.

At lower and more xeric elevations, gray rabbitbrush (Chrysothamnus nauseosus) largely replaced big sagebrush and green rabbitbrush (Daubenmire 1978), and sand dropseed (Sporobolus cryptandrus) and purple threeawn (Aristida purpurea) were locally abundant understory species (Tisdale 1994). At higher elevations, antelope bitterbrush (Purshia tridentata) was more abundant than big sagebrush, and junegrass (Koeleria cristata) was a significant associate with bluebunch wheatgrass (Findley 1994). Shrubs were infrequent on particularly thin soils (< 25 cm) over non-fractured basalt along ridges. These sites were dominated by Sandberg bluegrass (Johnson 1994).

3.1.5 Current Vegetation

Four factors have significantly modified the pre-European settlement vegetation of the Hanford Reservation: (1) grazing by livestock, (2) cultivation, (3) alteration of fire regime, and (4) disturbances associated with the Hanford operations. The first three are general to the area, while the fourth is specific to the Hanford Site.

Livestock grazing in the nineteenth and early-twentieth centuries most likely reduced the vigor of the perennial grasses of the area. This probably increased the relative amounts of shrubs because (1) the shrubs were not grazed by livestock as heavily as were grasses, and (2) the shrubs had less competition from the grasses under grazing than under ungrazed conditions.

Cultivation caused several types of disturbances to the native vegetation. First, late-seral communities on many areas (especially those of relatively level topography and near the river) were physically destroyed by plowing. This fragmented the natural vegetation landscape, somewhat reducing its ability to return to pre-disturbance characteristics after cultivation. Second, non-native plant species such as cheatgrass (Bromus tectorum) and Russian thistle (Salsola iberica) were also introduced, often accidentally via contaminated crop seed (Mack 1981). These exotics made successional recovery on abandoned cropland more difficult, and they also invaded adjacent stands of native vegetation. Third, the physical, chemical, and biological characteristics of the cultivated sites were altered by cultivation, resulting in sites that were ecologically different after cultivation ended. These changes included increased erosion, altered hydrological properties, decreased soil organic matter, and modified nutrient pools.

Settlement also altered the fire regimes in the area. Some sites probably burned more frequently than before settlement because of deliberate actions of farmers or accidental fires, while some areas burned less frequently because of increased fire control. Shrubs probably decreased in areas that were burned more frequently, and increased in those areas that were burned less frequently. The presence of certain exotic species, such as cheatgrass, also altered post-fire dynamics, resulting in much slower recovery following fire.

These three factors occurred throughout the area prior to the establishment of the Hanford Site, but they did not occur uniformly or at the same intensity. By the early 1940s, some areas had been severely impacted, while others had been much less impacted. A few areas similar to the pre-settlement native vegetation may have remained. The point must be made that many of the changes in the vegetation at the Hanford Site were not caused by the Hanford facility, but by activities occurring prior to its establishment.

The Hanford operations have resulted in disturbances similar to those occurring previously, as well as new types of disturbances associated with the development and production of nuclear weapons. These include large-scale physical disturbances such as removal of vegetation by scraping, placement of artificial surfaces (e.g., rock, asphalt, and concrete), digging of pits and trenches, placement of pipelines and underground storage structures, and deposition of large quantities of cinders and other waste materials.

The vegetation of the Hanford Site now consists of a mosaic of disturbance types and islands of mid-seral shrubland surrounded by areas of late-seral shrubland. Vegetation on the disturbed areas includes none (i.e., bare ground), annual forbs [primarily Russian thistle, and tansey mustard (Descurainia and Sisymbirum spp.)], cheatgrass, and various combinations of early- and mid-seral perennial grasses and shrubs (Cline et al. 1977, Cline and Uresk 1979). Common examples of the last category are squirreltail (Sitanion hystrix) and rabbitbrush. On undisturbed or less-frequently-disturbed sites, remnants of sagebrush shrubland continue to exist (Rickard and Schuler 1988).

3.1.6 Animal Communities

Forty species of mammals have been documented on the Hanford Site since its inception. Four species of large mammals have been observed at Hanford: elk (Cervus elaphus), mule deer (Odocoileus hemionus), white-tailed deer (O. virginianus), and pronghorn antelope (Antiolocapra americana). Elk colonized the Hanford Site in 1972 (Rickard et al. 1977); the population increased from about eight individuals in 1975 to about 250 individuals in 1993 (Downs et al. 1993b). Mule deer occur throughout the Site, but most commonly along the Columbia River. River islands provide important fawning habitat. White-tailed deer were first reported onsite in 1970 (O'Farrell and Hedlund 1972). Since then, additional sightings have occurred in close association with riparian habitats along the Columbia River. The pronghorn antelope is uncommon in Washington. They were originally introduced into eastern Washington in 1940 through transplants of Oregon stock (Larrison 1970). Nine pronghorns were observed on the Wahluke Slope Wildlife Recreation Area (WRA) and the Saddle Mountain National Wildlife Refuge (NWR) of the Hanford Site in the winters between 1978 and 1980. However, pronghorns have not been seen at Hanford since the winter of 1980-81, probably reflecting habitat conversion to irrigated farmland, which may have forced them to other locations.

Four families of carnivores are represented at Hanford: the Felidae, Canidae, Mustelidae, and Procyonidae. Within the Felidae, only one representative, the bobcat (Lynx rufus) has been documented on site. Bobcats have been observed on Rattlesnake Mountain, Gable Butte, and Gable Mountain, but no detailed studies of bobcat have been conducted at Hanford. The coyote (Canis latrans) is common at Hanford and has been studied since the mid-1970s. The coyote is the only representative of the Canidae family at Hanford. Within the Mustelidae family, there are six species represented at Hanford. These species include: badger (Taxidea taxus), striped skunk (Mephitis mephitis), otter (Lutra canadensis), mink (Mustela vision), long-tailed weasel (M. frenata), and short-tailed weasel (M. erminea). Although none of these species has been studied on the Hanford Site, general observations have been made on their distributions and relative abundance. One representative of the Procyonidae family, the raccoon (Procyon lotor), occurs throughout the Site, primarily around water. This species occurs mostly along the Columbia River and near ponds on the Saddle Mountain NWR and on the Wahluke WRA.

Other mammals found at the Hanford Site include two shrews: Merriams' shrew (Sorex merriami) and the vagrant shrew (S. vagrans); six species of bats: the hoary bat (Lasiurus cinereus), pallid bat (Antrozous pallidus), silver-haired bat (Lasionycteris noctivagans), California myotis (Myotis californicus), little brown myotis (M. lucifugus), and the Yuma myotis (M. yumanensis); three Leporidae: Nuttall's cottontail (Sylvilagus nuttallii), the white-tailed jackrabbit (Lepus townsendii), and the black-tailed jack rabbit (L. californicus); twelve species of small rodents; and four species of medium- to large-sized rodents (Downs et al. 1993b).

Small rodents that inhabit the Hanford Site include the deer mouse (Peromyscus maniculatus), Great Basin pocket mouse (Perognathus parvus), western harvest mouse (Reithrodontomys megalotis), grasshopper mouse (Onychomys leucogaster), montane meadow mouse (Microtus montanus), house mouse (Mus musculus), sagebrush vole (Lagurus curtatus), least chipmunk (Eutamias minimus), Norway rat (Rattus norvegicus), bushy-tailed woodrat (Neotama cinerea), northern pocket gopher (Thomomys talpoides), and Townsend ground squirrel (Spermophilus townsendii). Medium- to large-sized rodents that are known to occur at Hanford include the yellow-bellied marmot (Marmota flaviventris), beaver (Castor canadensis), porcupine (Erithizon dorsatum), and muskrat (Ondatra zibethica) (Downs et al. 1993b).

There are relatively few species of reptiles and amphibians at the Hanford Site, although they are important as prey for nesting raptors, especially Swainson's hawks (Buteo swainsoni). The reptile and amphibian species inhabiting the Hanford Site include the garter snake (Thamnophis sirtalis), yellow-bellied racer (Coluber constrictor), Great Basin gopher snake (Pituophis melanoleucus), western rattlesnake (Crotalus viridis), desert night snake (Hypsiglena torquata), striped whipsnake (Masticophis taeniatus), side-blotched lizard (Uta stansburiana), sagebrush lizard (Scleoporus graciosus) short-horned lizard (Phrynosoma douglasii), Pacific treefrog (Hyla regilla), Great Basin spadefoot (Scaphiopus intermontana), and Woodhouse's toad (Bufo woodhousei) (Downs et al. 1993b).

Birds may be the most visible and readily recognized wild animals at the Hanford Site. Some birds serve as indicators of environmental change. For example, an increase in starlings (Sturnus vulgaris) reflects the presence of human-manipulated habitats, and a decrease in sage sparrows (Amphispiza belli) reflects the loss or alteration of sagebrush-dominated habitats. A total of 238 bird species have been observed at Hanford (Landeen et al. 1992).

3.2 ECOLOGICAL BASIS FOR RESTORATION

3.2.1 Characteristics of Ecological Communities

Definitions. An ecological community is the total of all organisms that inhabit a specific area (Smith 1966, Ricklefs 1997). The specified area is critical to the definition, as is generally taken to be a contiguous area dominated by the same plant species. For example, a stand of big sagebrush surrounded by previously cultivated areas now dominated by cheatgrass would define a community. The surrounding cheatgrass areas would be included in a second community. A stand of big sagebrush on the other side of the cheatgrass from the first sagebrush stand would be in a third community. The two sagebrush communities would be of the same type (i.e., big sagebrush), but would be separate communities because they are not contiguous.

Although the dominant plant species commonly defines the area included in the community, the community includes much more than just the dominant plant species. The community includes all the organisms present: plants, animals, and microbes.

An ecosystem is an ecological community and its abiotic factors treated together as a functional unit (Odum 1971, Whittaker 1975). These abiotic factors include all non-living factors associated with the ecosystem: climatic, edaphic, physiographic, and pyric.

The organisms define the community, but the abiotic factors generally set the overall limits to the potential characteristics of the community. For example, sufficiently low annual precipitation (a climatic factor) results in deserts rather than forests or grasslands. Soil high in clay content (an edaphic factor) often support grasslands in regions where there is sufficient precipitation to support woodlands or forests. North-facing slopes of mountains (a physiographic factor) often support communities characteristic of cooler and more moist conditions than south-facing slopes. Shrublands subjected to frequent burning (a pyric factor) often develop into grasslands.

Community Attributes. Ecological communities have three primary attributes: composition, structure, and function. Composition refers to what species are present in the community. Those species that are present on a site are those that have (1) reached the site, (2) successfully tolerated the environmental conditions at the site, and (3) successfully exploited the resources available at the site.

Not all species are of the same ecological importance at a given site. A few species, and sometimes only one, are most abundant and/or productive in a given community. These are called dominant species. Their removal from the community would change the fundamental characteristics of that community. An example would be big sagebrush in a big sagebrush shrubland.

Most species are not as important individually as dominants, but are very important as a group. The removal from the community of any one of these species would not fundamentally alter the characteristics of the community, but their removal as a group would. They are called sub-dominants. An example would be the perennial grasses in a big sagebrush shrubland. Other species have only minor ecological importance within a given community, even as a group. An example would be annuals in a mature, late-seral big sagebrush shrubland.

It is important to note that the importance of a particular species varies from community to community. Cheatgrass, for example, is a minor species in a late-seral big sagebrush shrubland, but is the dominant species in an early-seral cheatgrass community on abandoned cropland.

Species richness is also an aspect of composition. It refers to how many species are present in an area, without respect to the abundance of each species. Species richness and site heterogeneity increases as the size of the area being sampled increases.

The second attribute of communities is structure. Structure refers to how the community is arranged. Structural attributes include height (or depth, if below ground), cover, and distribution (or pattern). Communities can have similar composition, but may differ significantly in structure. For example, big sagebrush may be the most abundant species in both a mature sagebrush shrubland and a recently revegetated disturbance site, but the sagebrush on the revegetated site may be small seedlings or transplants. Conversely, communities may have similar structural characteristics, but differ in composition or richness. For example, structural characteristics of a rabbitbrush shrubland may be similar to a sagebrush shrubland, but their composition is quite different. In general, communities that are similar structurally have similar functional characteristics.

Community structure modifies the effect of climate and influences use by the animal community. For example, wind speed and wind erosion are decreased by the height and density of shrubs. Shading of the soil surface increases as canopy cover increases, thereby reducing surface temperature and evaporation.

Distribution refers to the arrangement pattern of a species within a community or across the landscape. Species are distributed in relation to the distribution of resources. Few species are uniformly distributed within a community or across a landscape, because few resources are uniformly distributed. These non-uniform distribution patterns of most species are often important in determining ecological characteristics of the community.

The third general attribute of communities is function. Function refers to how the community operates. Community function is determined by how energy flows and nutrients are cycled through the various species in the community. Function determines the ecological productivity of the system. Ecological processes control this flow and cycling.

Ecological communities are dynamic with respect to both space and time. This is because the individual species are dynamic. As the availabilities of resources change, species success changes. Availabilities of resources change because environmental conditions change and resources are used as communities mature.

Community Subsystems. All communities have plant, animal, and decomposer subsystems. The plant community (i.e., the plant subsystem) is most distinct because it is used to define the ecological community. The animal subsystem consists of all animals that spend time in the ecological community. Some animals spend their entire lives within one ecological community, while other species migrate among two or more communities. These communities may be adjacent, or they may be very distant from each other (as in the case of migratory species). In general, the larger the animal or the higher it is up the food chain, the less likely it will be confined to a single plant community. In these cases, the ecological impacts of the animals are distributed among the various communities on the basis of amount of use in each.

Animals require plant communities as sources of food, direct or indirect, and shelter. In turn, animals affect plant communities in a number of ways (e.g., as herbivory, physical disturbance, pollination, seed dispersal, and nutrient redistribution). Decomposer subsystems are very complex assemblages of macrofauna, microfauna, and microbes that are active in the decomposition of dead plant and animal tissue deposited in the community.

3.2.2 Abiotic Control Factors

Climate: Precipitation and Moisture. Moisture is the single most important factor affecting the productivity and distribution of plant species and communities. Moisture is supplied to terrestrial ecosystems by precipitation and by stream/river flow. Stream/river flow is important in riparian communities, but the moisture available to most terrestrial ecosystems comes from precipitation.

Ecologically, the most important aspects of precipitation are (1) type, (2) amount, (3) variability, and (4) intensity. Type of precipitation refers to the state the water is in when the precipitation occurs. Rain, the liquid state, is most immediately useful to vegetation. Snow becomes useful to vegetation once it melts. Snow can also be very important in temperature relations and as a physical restriction to movement of some animals. Other forms of precipitation (sleet, hail, fog, dew) are generally of limited importance, but can be significant in some areas.

The single most important aspect of precipitation is the amount of precipitation received at a site, because it sets the upper limit to site productivity. Forests require relatively high amounts of precipitation; woodlands, shrublands, and grasslands require intermediate amounts; and deserts occur in areas of low precipitation.

Variability of precipitation occurs seasonally and annually. Seasonal variability can be important, because it relates to moisture supply during the growing season. Two areas receiving similar amounts of precipitation annually may have significantly different vegetation, because one area may receive most of its precipitation in the winter and the second area may receive most in the summer.

The annual variability of precipitation can be a very important ecological factor. Above- and below-average precipitation years are common in many areas, especially in arid and semiarid regions. Stable plant communities are able to tolerate some drought years, but if the droughts become too frequent or too severe, significant changes in the communities may occur.

The intensity of precipitation, especially rainfall, can also be very important ecologically. Intense rainfall events supply a large amount of moisture to a site, but much of it is lost to the site through runoff because the soil is not able to absorb the water fast enough. In addition, these intense rainfall events can cause significant soil erosion and physical damage to the plant communities.

Surface water is useful to many animal species and is necessary as a source of drinking water to many animals. It is of little use to most plants, however, until it enters the soil. Most plants receive their water from the soil. Only the water that enters the soil following a precipitation event, or following snow melt, can be stored for future use by plants. Once stored in the soil, water is removed by surface evaporation and by plant transpiration. Together, these are called evapotranspiration.

Climate: Heat and Light. If temperatures get too high, heat stress followed by physiological damage occurs in organisms. Some species are more resistant than others, and this differential response contributes to the dynamics of the ecosystem. Most plants can minimize heat stress, as long as there is adequate soil moisture, by increasing their rate of transpiration and thereby removing excess heat by evaporation of water. When soil moisture is not available, plants must be able to tolerate heat stress (e.g., desiccation, dormancy, and internal moisture conservation) or suffer physiological damage. Animals generally minimize heat stress by increasing water intake, increasing evaporative or conductive cooling, or by moving to a cooler location (often in the shade of underground). Similarly, cold stress, freeze damage, and physiological damage can occur in species if temperatures get too cold.

Sunlight is also ecologically important as a signal mechanism. Initiation of growth, flowering, and dormancy in plants is often triggered by photoperiod (i.e., the relative lengths of daylight and dark). Activity levels, reproductive statuses, and dormancy in many animals are also controlled by photoperiod.

Climate: Other Factors. Other climatic factors are also important, but generally less so than precipitation and temperature.

Humidity, the atmospheric moisture content, is important because it helps regulate evapotranspiration. Evapotranspiration is driven by the moisture gradient between the water surface (e.g., in the stomatal cavity or in the soil) and the atmosphere. Water evaporates, and plants transpire more rapidly, in dry air than in humid air, causing an increase in water use.

Wind can be very important ecologically for a number of reasons. Wind moving across leaf surfaces, or animal bodies, decreases the boundary layer between the tissue surface and the atmosphere away from the tissue. This increases the rate of water loss. Therefore, as wind speed increases, water loss increases. This can cool an organism by evaporative cooling, as long as water supply can keep up with water loss. But if water supply lags behind water loss, damage from desiccation (i.e., wind burn) will occur.

Wind can cause physical damage to a community by blowing over trees or shrubs and by striking tissues with wind-born particles. Wind erosion can remove soil from a site, causing detrimental effects to occur to the community. Wind can also be an effective means of spreading some plant seeds and can affect animal movement.

Soil. Soil is produced by the modification of parent material by climate and organisms, influenced by slope, over time. Parent material is any material from which a soil is formed. Examples include rock, sand, mud, clay, landslide debris, and volcanic ash. Soils develop over time along with the ecological communities that they support. Both the soil and the community affect the development of the other.

Soil is ecologically important for several reasons. First, it is the storage reservoir for nutrients and water used by plants. Second, it is the physical matrix in which most plants anchor themselves. The deeper and more solid the matrix, the more secure the anchoring. Third, many plants require mutualistic support from various soil organisms such as mycorrhizal fungi. The characteristics of the soil affects the types, and activity levels, of soil organisms that can exist within it. Fourth, soil provides the matrix in which decomposer animals and microbes live. Decomposition and mineralization are critical for supplying nutrients to the plant community. Fifth, soil provides protection from desiccation and freeze damage for many animals and perennial plant parts.

Soil Properties. Each soil has a specific combination of physical, chemical, and biological properties. Soils occur as layers or stratas, called horizons, beginning at the surface and extending downward to the parent material. Each horizon is a product of the soil-forming process and has at least one significant difference in physical, chemical, or biological properties from the horizon above and the horizon below it. Each horizon is composed of mixtures of mineral particles, organic matter, organisms, plant roots, and openings between the particles. The openings are called pores, and they are filled with a combination of water and air.

In general, the most important soil physical property is texture. Soil texture refers to the relative amounts of sand, silt, and clay particles the soil has. Sand particles are the relatively large particles (0.05-1.00 mm in diameter), clay particles are the smallest soil particles (< 0.002 mm), and silt particles are intermediate-sized (0.002-0.05 mm) (Foth and Turk 1972).

Soil texture has a significant effect on many ecological characteristics of soils. Sands are generally less fertile than adjacent loams and clays, have low moisture-holding capacities (but easily release what moisture they do have), warm up and cool down rapidly, and have rapid infiltration rates. Soils high in clay have high nutrient-holding capacities, have high moisture-holding capacities (but much of the water is held too tightly for plant use), warm up and cool down slowly, have slow infiltration rates, and are difficult for some plant roots to penetrate. Loams are soils of intermediate textures and have properties intermediate between those of sands and clays.

Water is necessary for plant growth, microbial activity, and the availability of nutrients (as nutrients are absorbed by plants in an aqueous solution). Air (i.e., oxygen) is necessary for respiration by roots and soil organisms. The pore space in soil can be filled with air, water, or some combination of both. As the moisture content increases, the air content decreases. Sands are well-aerated, but have lower water-holding capacities than fine-textured soils. Clays are poorly-aerated, but can hold more water than sands. Hanford Site soils are predominantly sandy soils.

Fertility is a chemical property of the soil. It refers to the amount of nutrients in the soil and is determined by parent material, texture, precipitation regime, soil depth, and past use. Sands are generally less fertile than adjacent clays. High precipitation tends to reduce fertility by washing the nutrients out of the soil profile. Shallow soils have less total available nutrients than deeper soils because they have less soil volume in which to store the nutrients.

Another soil chemical property, pH, is a measure of the inverse of the negative log of the hydrogen ion concentration. The lower the value, the more acidic the soil is; the higher the value, the more basic (7 = neutral). Each plant species is generally best adapted to a soil pH range of about one unit. Soil solute pH affects nutrient availability and biological activity. Soils with extreme pH values (< 5 and > 9) can be toxic to plants.

Salinity refers to high levels of soluble salts. Saline soils are difficult for most plants to grow in because the salts have a high affinity for water, causing physiological drought in saline soils even when moisture content is relatively high. Successful revegetation of saline areas requires the use of salt-tolerant plants or the reduction of salts in the soil, the latter of which can be very expensive.

Organic matter is the soil profile consists of small particles remaining from the decomposition of surface litter, plant roots, and vegetative material moved downward by animal activity. Most soils have 1-2% organic matter in their upper horizons, although Hanford Site soils generally have less organic matter than this. Soil organic matter improves water-holding capacity, tilth, and fertility of a soil.

Soils contain very complex assemblages of organisms. These include plant roots, large and small animals, and a large number and diversity of microbes. Soil animals include large and small burrowers that feed on plant roots, other soil animals, a combination of both, soil microbes, or on material they bring below ground. Examples of soil animals include gophers, Townsend ground squirrels, Great Basin pocket mice, deer mice, snakes, ants, termites, nematodes, and a variety of insects and insect larvae. Soil animals are ecologically important because they mix the soil profile and transport aboveground plant material below ground.

The microbial community can be divided into three very general functional categories. Autotrophic organisms, such as algae, live near the soil surface and produce their own food by photosynthesis. Saprophytic organisms, such as many bacteria and fungi, feed on dead organic matter at and beneath the soil surface. Mutualistic microbes live in association with plant roots, receiving carbohydrates from the host plant and providing nutrients in return. Examples include symbiotic nitrogen-fixing bacteria in root nodules of legumes and mycorrhizal fungi on roots of many plant species. The former supply nitrogen to the host plant, and the latter help their host plants absorb phosphorus and water. Many of these microbial-plant mutualistic relationships are known to be very important to the plant community.

<u>Soil Development</u>. Well-developed soils are important components of mature and productive ecosystems. Soil development is a relatively slow process, influenced primarily by climate and organisms. Plant roots are important vectors allowing for soil development throughout their rooting depth. Chemical changes take place along root channels, and moisture regimes change as roots penetrate into the parent material. Dead roots add organic matter to the lower profile, thereby altering its chemical and biological properties. Soil animals and freeze-thaw cycles mix the upper and middle portions of the soil profile. As soil moisture moves downward, clay particles, organic matter, and soluble ions are moved downward also. These processes alter the chemistry and texture of the soil profile.

As these soil-developing processes continue, the upper part of the parent material is continually being transformed into soil. However, soil erosion may be operating at the surface, either through water or wind movement. If the rate of soil development exceeds the rate of erosion, as it does in most natural systems, the soil and its component horizons become thicker. But if the rate of soil erosion exceeds the rate of soil development, as is often the case after the plant community is removed or disturbed, the soil becomes thinner.

<u>Physiography: Elevation</u>. As elevation increases, temperature decreases and precipitation increases. The decrease in temperature is caused by the thinner air, which can hold less heat. The increase in precipitation is caused by the fact that the cooler air can hold less moisture; therefore, as the air masses rise, they are not able to hold as much moisture, and this difference falls as snow or rain. This fact also explains why most mountains have a wet side and a dry side (i.e., the rain shadow effect). The wet side, which generally faces the nearest ocean, is the side where the air masses most often rise. The dry side is the side where the air masses most often drop, since as they drop they warm and warm air holds more moisture than cool air. The dry side is referred to as the rain shadow of the mountain. This phenomenon helps explain why the Hanford Site is arid in comparison to western Washington state.

Physiography: Aspect. In the northern hemisphere, north-facing slopes are cooler and wetter than adjacent south-facing slopes. This is caused by the angle of incidence to the sun. South-facing slopes face the sun for more hours during the year than do north-facing slopes. This increases their temperature and, therefore, their evapotranspiration rates. This effect increases with slope and with latitude.

Aspect can be an important ecological factor. Sauer and Rickard (1979) found that total vegetative cover on north-facing slopes of ravines along the Columbia River adjacent to the Hanford Site averaged 71%, compared to 25% on south-facing slopes. Sandberg bluegrass and bluebunch wheatgrass dominated the north-facing slopes, and cheatgrass dominated the south-facing slopes. Soil depth on north-facing slopes was four times that of south-facing slopes (33.9 cm and 8.6 cm, respectively), and organic matter was twice as high on north-facing slopes than south-facing slopes (1.1% and 0.5%, respectively).

Physiography: Slope. As slope increases, surface stability, soil moisture, and the amount of incident solar radiation received decrease. Surface stability decreases because of the effect of gravity. Soil moisture decreases because of greater runoff and because less precipitation is received per unit surface area. (Precipitation occurs somewhat perpendicular to a horizontal surface; with increased slope, the angle from horizontal increases.) Incident solar radiation on north-facing slopes also decreases because of the angle shift from perpendicular.

Fire. Fire is a natural ecological factor. It has been a significant factor for ecosystems in which there is sufficient fuel to carry a fire. These include forests, woodlands, grasslands, and many shrublands. Natural fires remove undergrowth and litter before they can build up to levels that would cause crown fires. Ecological effects of fire depend on the type of plant community, amount of fuel load, type of fuel load, wind speed, temperature, moisture content (of fuel and soil), and physiography.

Fire affects species composition, community structure, seed germination, rate of nutrient cycling, and disease and parasite effects. For areas in which the climate can support either grasslands of shrublands, fire generally shifts the vegetation from shrubland to grassland. At the Hanford Site, fire decreases the abundance of big sagebrush and increases the abundance of perennial grasses (Cline et al. 1977).

Fire generally decreases the structural complexity and increases the productivity of ecosystems. These are characteristics most often associated with earlier, rather than later, successional stages. Natural fire cycles are probably very important in maintaining the productivity and composition of those ecosystems that burned naturally. Altering these natural fire cycles can have significant long-term effects on ecosystem dynamics.

3.2.3 Ecology of Disturbed Lands

Ecological systems are dynamic with respect to time. They are constantly changing. This is true of natural ecosystems, as well as those altered by human impacts. Failure to recognize this fundamental property limits our ability to develop and manage successful restoration programs, because we fail to recognize the effects of background ecological factors and processes.

This dynamic property of ecosystems is the result of ecological populations and processes responding to changes in environmental factors. These changes may be rapid (for example, with fire or the introduction of an exotic species), or may be slow (as in response to climate change or long-term shifts in soil chemistry). The factors or mechanisms causing these changes are numerous; some are internal to the community, and some are external. Since these factors and mechanisms are themselves dynamic, no community is static.

Repeated measurement of any community attribute (e.g., annual productivity of a species, death rate of a herbivore, decomposition rate of lignin, or total community phytomass) over time results in a variance for that attribute, as well as a mean. This variation occurs because the attribute is affected by variation in one or more control factors, such as precipitation, temperature, sunlight, nutrient supply, or predation rate.

If the mean remains relatively constant over time the attribute is considered to be stable with respect to time within the time frame included in the measurements. And if most attributes of the community, and especially the attributes of the dominant species, are stable with respect to time, the community is a late-seral community. However, since the attributes have variances, and because their values fluctuate over time, late-seral communities are relatively, not absolutely, stable.

Fluctuations in community attributes may occur on a periodic (i.e., regular) basis, or they may occur on a non-periodic (i.e., stochastic) basis. Seasonal variation is an example of a periodic pattern. Other, less obvious, periodic fluctuations may also be common in many ecosystems. Natural fires may have occurred in the western United States at periodic intervals before European settlement (Madany and West 1983, Swetnam and Betancourt 1990). And there is mounting evidence that 50- and 100-year cycles in global climatic patterns, which may have significant effects on ecosystems, exist (Neilson 1987, Chumbley et al. 1990, Scuderi 1993). In contrast, other climatic events (such as major storms and, perhaps, droughts) appear to be non-periodic in their occurrence.

In addition to frequency of occurrence, ecological fluctuations may also be regular or stochastic as to intensity (i.e., magnitude) of fluctuation. In temperate regions, for example, there is a strong periodic pattern to temperature, with warm temperatures occurring in the summer and cold temperatures in the winter. This pattern appears to be relatively constant for at least millennia. However, the magnitude of the summer warming and winter cooling varies significantly from year to year. In contrast, photoperiod also varies seasonally, but its summer maxima and winter minima are constant. Photoperiod has a periodic frequency and a periodic intensity, whereas temperature has a periodic frequency but a stochastic intensity. Precipitation may have a strong or weak periodic frequency (depending on location), but has a stochastic intensity in most regions.

Optimum and Tolerance Ranges. Community attributes affected by ecological factors such as photoperiod, temperature, and precipitation reflect the periodic and stochastic patterns of these driving variables. The result of these, and all associated, interactions are the fluctuations that are a normal characteristic of any ecosystem. Because of these fluctuations, each species in the ecosystem is adapted to a range in values for each environmental factor. Each species has a relatively narrow optimum range for each factor and a wider range of values that the species can tolerate.

The closer the fluctuations in factor values are to the optimum range for the species, the more the species benefits. The more the factor fluctuates away from the optimum for the species, the more the species is placed under stress. If the environmental factor fluctuates past the tolerance limit for the species for a certain length of time or at a certain frequency, frequently enough, the species cannot complete its life cycle. In addition, inter-specific competition has a restrictive effect on these limits, generally narrowing the mono-specific optimum and tolerance limits for a given species.

The ecological community also has optimum and tolerance ranges for each environmental factor. These ranges are the integration of the ranges for the individual species, weighted in favor of the ecological dominants. If environmental variation remains within these tolerance limits, the attributes of the community will vary, but the community will continue to exist at the site. The result is relative ecological stability. If variation exceeds the tolerance limits of the community, however, instability results.

Instability can be in either direction (i.e., toward greater community development or toward lesser community development). The former is referred to as succession (Section 3.2.5), and the latter as retrogression. Succession is generally gradual and is often directional. Retrogression generally occurs more rapidly and may or may not be directional. Most commonly, retrogression in an ecosystem is caused by a change in a single environmental factor. The event causing the environmental change is called a disturbance, and may be either natural or anthropogenic.

Stress Disturbances. Stress disturbances occur when one or more environmental factors shift past the tolerance level of the dominant species of a community for a sufficiently long period of time. Stress disturbances commonly occur gradually, as opposed to more catastrophic physical disturbance events. The ecological change to the community in response to stress disturbances may be rapid or relatively slow, depending upon the magnitude of the environmental stress.

Climate. A common cause of stress disturbance in ecosystems is change in climate. Climate-induced stress occurs because of drought, flooding, extreme fluctuations in temperature, storms, and changes in gas and particulate concentrations in the atmosphere. These climatic changes may be short-term or long-term.

The most common climate-induced disturbance is probably drought. All terrestrial communities can tolerate some reduction in mean precipitation, either annual or seasonal. But when precipitation decreases below the tolerance level for that community too frequently, or decreases too far below the tolerance level, detrimental effects occur in the community.

Long-term changes in precipitation may also occur, and the effects of these changes may be much more difficult to observe that those associated with short-term events. The increase in shrubs on southwestern rangelands during the past 100-150 years is generally attributed to overgrazing of the grasslands by livestock. Overgrazing has certainly occurred, and this most likely has contributed to the increase in shrubs. However, shrubs have also increased on areas protected from grazing (Hennessy et al. 1983, Collins et al. 1987). This suggests that a factor other than grazing is also involved. There is significant evidence that the area has undergone climate fluctuations during the past 1000 years (Neilson 1987). These fluctuations appear to have involved shifts from cooler-moister periods to warmer-drier periods and back again. For the past 200 years, the region has appeared to be warming and becoming drier. These climatic changes may also be involved in the increase in shrubs.

Fire. Fire is a natural part of most terrestrial ecosystems. Consequently, the communities that develop on a site are in balance with the normal pyric environment of that ecosystem. Whenever changes occur in this normal pattern, however, pyric disturbances are possible. Fires may not burn through a forest frequently enough to remove understory vegetation and dead litter on the forest floor; for example, this might occur following a period of above-average precipitation or because of fire suppression by humans. When fire does return to the forest, the fine-fuel buildup might be sufficient to cause a fire that is much hotter than normal and spreads to the tree canopies, resulting in a destructive crown fire.

There is a relatively delicate balance between grasses and shrubs on many grasslands. As fire frequency increases, shrub abundance decreases and grass abundance increases. As fire frequency decreases, shrubs increase and grasses decrease. This is because grasses, in general, tolerate removal of aboveground tissue better than do woody plants. These areas are climatic shrublands or woodlands (i.e., in the absence of fire, shrublands or woodlands rather than grasslands would be the late-successional community). However, fire keeps the shrubs or trees from increasing in abundance to the point of dominating the site. Fire keeps the site at a mid-seral grass-dominated stage.

Herbivory. All ecosystems contain herbivores, and all late-seral communities have established in the presence of herbivory. All plants can tolerate some level of herbivory stress by at least some types of herbivores: mammals, birds, insects, nematodes, micro-organisms, or some combination of these. It does not follow, however, that natural disturbances cannot occur because of herbivory. Natural populations of herbivores can, and sometimes do, increase to levels that exceed the carrying capacity of the site. Overgrazing results. This might be on the local level, or it may be widespread. It may be aided by climatic conditions, sudden changes in predator populations, or by human intervention, but overgrazing by native herbivores can cause ecological disturbance.

Overgrazing by domestic livestock is a primary cause of disturbance in many ecosystems. Overgrazing alters species composition by applying selective stress to forage species. Productivity of the system is eventually effected and, if overgrazing is sufficiently severe, erosion may occur. Overgrazing by native species also occurs. When the ecological processes that are important in the natural balancing of herbivore numbers are disrupted, native herbivores increase in numbers to levels that can become destructive to the plant community. For example, if natural predators of elk or deer are eliminated and artificial means of population regulation are not applied, elk or deer herds can increase to numbers well above the carrying capacity of the area. The herbivory pressure these populations apply to the plants can exceed the tolerance levels of the plants, resulting in an overgrazing-induced disturbance.

It should also be pointed out that the lack of a natural herbivore in a system can also cause ecological shifts. For example, if the native plant community developed under grazing by elk, and elk are no longer a part of the ecological community, successional changes will occur that may cause significant compositional changes. This may be particularly important in the restoration of some sites. Attempts to establish a target plant community without regard to its associated natural animal community may result in failure to establish the desired community.

Pathogens and Parasites. There are periodic and stochastic outbreaks of pathogens and parasites in natural populations. Where these outbreaks are great enough to significantly affect the dominant species, ecological disturbance can occur. Such an outbreak may be occurring currently to big sagebrush in some lower elevations of the Hanford Site.

Exotic Species. The introduction of non-native species is a major stress-disturbance vector. These exotic species compete with native species for finite resources. Over time, the exotic species may be able to displace native species and either dominate a site or at least reduce native species richness.

Physical Disturbances. The preceding discussion centered on natural disturbances resulting when dominant species are gradually stressed beyond their tolerance limits. The other major type of disturbance occurs when the community is physically altered directly by the disturbance vector.

Natural physical disturbances are common, although they vary considerably as to size of area and degree of disturbance. Water is a common physical disturbance vector. Floods can cause significant physical modifications of ecological communities through uprooting and scouring by rapidly-moving water and water-borne materials and through deposition of debris. This is common in mesic regions and along water courses. However, it can also be significant in arid and semiarid regions.

Infrequent, high-intensity events such as thunderstorms or the very rapid melting of snowpacks can cause significant erosional damage in dry regions, especially on the local and landscape scales.

Wind also can have tremendous effects on ecological communities. A frequent effect is the abrasion and drying that occurs as winds blow across a site. This can have a very significant detrimental effect on revegetation efforts, because of physical damage to and desiccation of seedlings and transplants.

Fire, especially catastrophic fires, can be a major disturbance vector in forest and shrubland communities. The ecological effect of fire is often magnified when combined with wind and water erosion. Shrublands suffering crown fires are highly susceptible to wind and water erosion until the surface becomes stabilized, often by a stand of perennial grasses.

Biotic vectors can be important in physical disturbance. Migration of herds of hoofed mammals, large flocks of migratory birds, or large populations of insects can cause considerable large-scale damage. Local damage often occurs from activities of large herbivores, and small-scale physical disturbance from ants and burrowing mammals is widespread.

Some of these biotic physical disturbances are so much a part of the landscape that we often fail to recognize them as such. For example, gophers and ground squirrels are found in sagebrush communities. Their burrowing activities constantly create small-scale disturbed sites throughout the late-successional shrubland. These disturbed sites become suitable habitat for the establishment of early-seral species such as cheatgrass and Russian thistle. Thus, the rodents provide refugia for the early-seral species, maintaining their long-term ecological presence in an otherwise late-successional landscape.

Summary. Natural stress and physical disturbance vectors are integral parts of most ecosystems. They are part of what defines the characteristics of the systems. Restoration efforts must take these natural vectors into consideration. Without them, we should not expect the established community to function precisely as the pre-disturbance community functioned. Indeed, it might not be possible to restore the target community without these factors, since they helped to shape and maintain it.

Conversely, some of these factors may cause restoration to proceed at a very slow pace unless artificially modified. For example, drought may be a natural aspect of arid and semiarid ecosystems. However, below-average precipitation may cause the failure of revegetation efforts. Natural revegetation may occur in these regions only during years of above-average precipitation, and these may occur under natural conditions only a few times each century. However, unless we are willing to wait centuries for natural recovery to take place, we may want to consider supplemental water in the early stages of revegetation efforts during drought years. Likewise, the use of surface mulches may reduce wind and water erosion on a newly-seeded site, thereby significantly decreasing the time required to establish a target community on the site.

Ecosystems are dynamic. We can ignore this fact and work against these vectors. In doing so, we will make the processes of revegetation and restoration much more difficult, perhaps even impossible. Or we can try to understand these vectors, incorporate the concepts in our programs, and use them to benefit our efforts. This will increase the probability of success and reduce the costs involved.

3.2.4 Ecological Recovery: Secondary Succession

Secondary succession is the natural process of ecological recovery following disturbance. It is a process of species replacement over time. When a disturbance occurs at a site, species composition is altered. If the disturbance event is severe enough, the entire site may be denuded. Under less-severe conditions, earlier-seral species may replace the late-seral species that dominated prior to disturbance. In either case, secondary succession begins as soon as the disturbance event ceases.

Change in species composition over time is the most obvious characteristic of secondary succession. A disturbed site is first dominated by annuals, which are replaced in time by herbaceous perennials, either perennial grasses or perennial forbs followed by perennial grasses. On many moist sites, the herbaceous perennials are eventually replaced by woody species, either shrubs or shrubs followed by trees. On most arid sites, xeric shrubs and succulents dominate the final communities. Each ecological community in this progression from early- to late-succession at a site is called a seral stage.

In addition to composition of the plant community, other changes occur during secondary succession. There are changes in composition of the animal and the decomposer subsystems of the seral communities, changes in microclimate, and changes in the soil. Each seral stage forms an ecological community. Significant differences exist between it, each seral stage that preceded it, and each stage that followed. These differences can be as great as differences among different late-seral communities across a landscape.

<u>Rates of Secondary Succession</u>. The rate at which disturbed sites return to late-seral conditions varies, dependent on the type of late-seral community involved, the ecological harshness of the site, the severity of the disturbance, and the type of use following disturbance. Physically-disturbed grassland communities may return to late-seral conditions in 40-60 years under mesic conditions, or may take 100 years in semiarid climates. Shrublands may require 100-200 years, and temperate forests may require 200-500 years. In each case, the rate of seral change is most rapid early in secondary succession, and then decreases as succession reaches mid- and late-seral conditions.

<u>Convergent and Divergent Succession</u>. It is often assumed that late-seral communities that eventually develop on disturbed sites will be similar to the pre-disturbance communities. This is one type of convergent succession (i.e., the succession converges to the pre-disturbance community). This assumption, however, is not necessarily true. If macro-environmental conditions (e.g., site macro-relief, climatic regime, soil conditions, and herbivory characteristics) remain approximately the same after disturbance, and if an adequate seed source of late-seral plants is available for establishment on the site, the post-disturbance late-seral community may be similar to its

pre-disturbance counterpart. If however, macro-environmental conditions have changed or the supply of late-seral species is limited, the post-disturbance late-seral community may differ significantly from the pre-disturbance community. This is an example of divergent succession.

The second type of convergent secondary succession is where two or more sites of equivalent late-seral communities in a landscape experience the same type of disturbance and then develop similar seral communities during secondary succession. This assumption is made in many ecological studies involving disturbance chronosequences. Secondary succession may produce similar patterns within the same community over time. However, if environmental conditions have changed between disturbances or are different across the landscape, secondary succession may produce different patterns within the same community, a second case of divergent succession. Differences in propagule availability and the presence of exotic species are common factors that may cause this type of divergent succession.

Control Mechanisms of Secondary Succession. Seral patterns, the changes in species composition over time, are caused by the succession process. Specific combinations of species, and their interactions, do not occur randomly. They are the result of the interaction of biotic and abiotic factors operating at the site over time. There are both deterministic and stochastic aspects to the interaction, but the interaction causes the pattern. An important management application of this concept is that it may not be possible to recreate the pattern without recreating the biotic and abiotic conditions that caused the pattern.

An adequate understanding of the process of succession is much more difficult than simply recognizing the patterns. However, if we can understand the process, we should be much more successful in development of revegetation and restoration programs. To understand the process, we must understand the mechanisms that control it.

Migration, Establishment, Growth Rate, and Resource Requirements. The first secondary succession control mechanism is migration and establishment. Not all species are equally mobile. Species that dominate early-seral communities are widely-distributed species that quickly arrive at disturbed sites. These early-seral species also have rather broad establishment envelopes (i.e., they can establish in a wide range of habitats). Mid- and late-seral species either are slower to arrive at the site or, if they are present from the early stages, have much slower establishment rates than early-seral species.

Early-seral species also have relatively rapid growth rates and short lifespans. Early-seral plants are commonly annuals with high potential growth rates. These species are able to rapidly exploit the resources available in vacant niches associated with disturbed sites. They are good exploiters. However, these species also have high resource requirements associated with their rapid growth rates. As long as resources are abundant, these growth potentials can be realized and early-seral species, both plants and animals, become very productive over a short period of time.

The combination of high productivity and short lifespans results in a rapid depletion of available resources. This depletion then functions as a control mechanism, regulating how long these early-seral species can dominate a site. Before long, available resources are depleted to a level too low to support these high rates of production, and the early-seral species can no longer dominate the site.

Nitrogen Availability. Nitrogen availability has been found to be a primary control mechanism in secondary succession in ecosystems as diverse as forests, grasslands, shrublands, and deserts (Ettershank et al. 1978, Lamb 1980, Heil and Diemont 1983, Aerts and Berendse 1988, Carson and Barrett 1988, Hunt et al. 1988, Fisher et al. 1988, McLendon and Redente 1991, Miller et al. 1991, Seastedt et al. 1991, McLendon and Redente 1992, Klein et al. 1996, Paschke et al. 1996). The rapid incorporation of nitrogen into tissue of rapidly growing early-seral species depletes available soil nitrogen within 2-3 years. This nitrogen limitation continues until supplies can be replenished through decomposition of litter and mineralization of the incorporated nitrogen. This may take 3-5 years in many ecosystems. During this period of nitrogen limitation, species with relatively low tissue nitrogen requirements have an advantage. Perennial grasses have low tissue nitrogen requirements and generally dominate the seral stages following those dominated by annuals. Perennial grasses continue to dominate the site as decomposition and mineralization gradually release the nitrogen incorporated in litter, because the root systems of the perennial grasses are present to absorb these supplies as they become available (McLendon and Redente 1994).

Competitive Displacement and Differential Tolerance. Secondary succession is a species replacement process. Seral replacement of species A by species B results from (1) abiotic environmental conditions changing in such a way that they become intolerable for the continued success of species A, but not for species B, or (2) species B, through accumulation of sufficient biomass or by modification of environmental conditions, denies resources to species A and thereby reduces the ecological success of species A. The first case is differential tolerance, and the second case is competitive displacement. In either case, changes in availability of at least one required resource of at least one of the species is involved.

Lifespan and Nutrient Conservation. To be successful, a species must be able to accumulate sufficient resources to supply its minimum requirements for survival, growth, and reproduction. There are two primary strategies whereby species accomplish these accumulations. The first is to secure limited available resources more rapidly than competitors do. The second is to keep secured resources longer than competitors, therefore accumulating reserves of these resources that are available to you, but not to your competitors. Both strategies are followed by some species in all seral communities, but the first is most common to early-seral dominants and the second to late-seral dominants.

As lifespan increases, the potential to accumulate resources increases. Perennials can carry some resources from one year to the next. Annuals can carry over resources only as seeds. Therefore, perennials can both store resources and develop more elaborate structures, such as deep root systems or tall canopies, to use to secure additional resources. Likewise, longer-lived perennials have greater potential to accumulate greater amounts of limited resources and to develop greater structure than do shorter-lived perennials. Late-seral dominants have longer lifespans and greater structural development than mid- or early-seral dominants.

3.2.5 Ecology of Selected Seral Species

Early-Seral Species.

Cheatgrass (Bromus tectorum)

Cheatgrass is an introduced annual grass, now widely distributed throughout the western United States. It was introduced into the Northwest about 1890 (Mack 1981). It is one of the two ecologically most important early-seral species in the Hanford area. Together with Russian thistle, cheatgrass dominates the early successional dynamics on disturbed sites. In many sagebrush regions of the western United States, cheatgrass dominates disturbed sites for 3-5 years, then becomes a subdominant or secondary species as it is replaced by perennial grasses and shrubs (West and Hassen 1985, McLendon and Redente 1991, 1992). In the Hanford area, however, cheatgrass can quickly dominate a disturbed site and remain dominant for over 50 years (Rickard 1973).

Cheatgrass is a cool-season species that begins growth early in the growing season (e.g., February) or germinates in the fall and makes limited growth throughout the winter. This early-growth ability provides cheatgrass with a significant ecological advantage against seedlings of most native perennials. This largely explains why cheatgrass stands are so long-lived in the arid regions of the Northwest, but are relatively short-lived in the eastern and southern regions of its range.

Most precipitation in the Northwest occurs during the winter. Cheatgrass has access to the resulting soil moisture before the slower-germinating perennial seedlings do. Cheatgrass is also able to rapidly produce a moderately deep root system. For example, Hulbert (1955) found that cheatgrass that germinated at Lewiston, Idaho on 5 October had 18-cm deep (7-in. deep) roots one month later (on 4 November) and 43-cm deep (17-in. deep) roots two months later (on 9 December). Mature plants were sampled on 10 June and found to have roots as deep as 107 cm (42 in.). Maximum reported root depth at Hanford is 24 in. (Downs et al. 1993a).

As cheatgrass roots extend downward, they deplete the soil of moisture, making moisture unavailable to seedlings of the later-growing perennials. Dense cheatgrass stands can deplete 80% of available soil water by mid-April on lower elevation, sandy-soil sites in the Hanford area (Rickard 1985a, Link et al. 1990). Even when seedlings of cheatgrass and perennials germinate at the same time, cheatgrass root elongation may be more rapid, and may therefore give the annual first access to moist soil. Harris (1967) found that cheatgrass seedlings had 50-90% deeper root penetration than bluebunch wheatgrass seedlings when both species began growth at the same time, even when bluebunch seedlings were four times as dense as cheatgrass seedlings. Link et al. (1990) reported that cheatgrass successfully competed against established Sandberg bluegrass (Poa sandbergii) for soil moisture throughout the growing season.

Cheatgrass matures in early summer (i.e., May-June). Therefore, moisture that becomes available during late spring and the summer is more available to perennials than to cheatgrass, provided that the perennials can extend their growth cycle past that of cheatgrass. At least one native perennial, Sandberg bluegrass, apparently cannot (Link et al. 1990). The eastern and southern regions of the range of cheatgrass receive significant proportions of their annual precipitation during late spring and summer. Therefore, cheatgrass has less of an ecological advantage there than in the Northwest. Likewise, established perennials have more of a competitive advantage over cheatgrass than their respective seedlings, because the mature perennials have established root systems. These roots can absorb soil moisture before annual cheatgrass roots can reach the mid- and lower rooting depths. In this scenario, the perennials can deny cheatgrass soil moisture. In addition, the presence of established perennial roots has been shown to limit lateral development of cheatgrass root systems (Bookman and Mack 1982).

Growth of most annuals is increased by higher levels of available nitrogen more than is growth of most perennials (McLendon and Redente 1994). Cheatgrass production is favored by higher levels of nitrogen and phosphorus, but not to the degree of most annuals. McLendon and Redente (1994) reported that cheatgrass had the lowest tissue nitrogen concentration of any species except one (prickly pear) encountered in disturbed big sagebrush shrublands at high and moderate soil nitrogen levels in a study in northwest Colorado, but not at low soil nitrogen levels. Eckert and Evans (1963) found that crested wheatgrass (Agropyron cristatum), an introduced perennial grass widely used in revegetation programs, produced more above- and below-ground biomass than cheatgrass at higher nitrogen levels (224 and 448 ppm), but that cheatgrass produced more at lower nitrogen levels (14 and 56 ppm). Link et al. (1995) reported that cheatgrass productivity was increased by additions of water and nitrogen together, but was not increased by either water or nitrogen separately.

Cheatgrass is moderately sensitive to shading. Pierson et al. (1990) reported a 30% and 60% reduction in aboveground biomass when sunlight was reduced by 60% and 90%, respectively. Root biomass was reduced even more (38% at 60% shading and 76% at 90% shading). This sensitivity to shading may partially explain why cheatgrass does not dominate disturbed big sagebrush sites in northwest Colorado until the initial stand of Russian thistle decreases (McLendon and Redente 1991).

Russian Thistle (Salsola iberica)

Russian thistle (tumbleweed) is an introduced annual forb, now widely distributed throughout the western United States. It is an early-seral species that often forms near monocultures on disturbed sites the first 2-3 years after disturbance. Commonly, it decreases in abundance after 2-3 years, but remains a major component of the vegetation until dominance by perennials is re-established. Controversy remains as to why the species declines after its early dominance. The most common explanations are (1) alleopathy (Lodhi 1979), although work by Schmidt and Reeves (1989) casts doubt on this mechanism, and (2) reduced nutrient availability (McLendon and Redente 1991).

Russian thistle has the potential for making very rapid growth on disturbed sites. Fowler and Hageman (1978) reported aboveground production of 870 g/m^2 (7800 lbs/ac) at Las Cruces, New Mexico (28 cm [11 in.] irrigation plus rainfall; 140 days) from a planted monoculture. McLendon and Redente (1994) reported aboveground production of 235 g/m^2 on a disturbed site undergoing natural secondary succession in northwest Colorado (32 cm of precipitation; second growing season). This high potential production allows the species to quickly dominate a disturbed site. The production of relatively high levels of plant biomass significantly decreases the availability of site resources (water, nitrogen, space, sunlight) to other species.

Russian thistle also responds favorably to increased nitrogen availability. McLendon and Redente (1994) reported a 68% increase in aboveground production under field conditions (32 cm precipitation) when fertilized with 10 g N/m^2. Redente et al. (1992) compared growth rates and response to nitrogen of Russian thistle to several native species (squirreltail, prairie junegrass, rubber rabbitbrush, big sagebrush). They found that at very low nitrogen levels (1 ppm N), production (above and below ground) was about equal among species. At moderate nitrogen levels (7 mg/L/2 d), Russian thistle production was equal to that of junegrass and sagebrush, but less than that of squirreltail. At high levels (59 mg N/L/2 d), Russian thistle production was three times the level of junegrass and sagebrush and twice that of squirreltail.

Russian thistle has a very high water-use efficiency. Data from Dwyer and Wolde-Yohannis (1972) indicate a water-use efficiency of 145 (units of water required to produce one unit of aboveground dry biomass). This compares to values of 1000-1200 for perennial grasses (Sims and Singh 1978) and about 4000 for shrubs (Dwyer and Wolde-Yohannis 1972). Allen (1982b) found that, under dry conditions (30 ml/d), Russian thistle produced three times as much aboveground biomass than seedlings of either blue grama (Bouteloua gracilis) or western wheatgrass (Agropyron smithii), on the same amount of water and nutrients. However, the three species produced approximately equal amounts at high moisture (60 ml/d).

Although Russian thistle has a relatively low root-to-shoot ratio, 0.06-0.22 (Dwyer and Wolde-Yohannis 1972, Redente et al. 1992), the species can have a relatively deep tap root. Allen and Knight (1984) found Russian thistle roots at a depth of 112 cm (44 in.), which was twice as deep as any associated annual. Klepper et al. (1985) reported Russian thistle roots to a maximum depth of 173 cm (68 in.) at Hanford.

Russian thistle is a C_4 species (Allen 1982a). As such, it should have its greatest ecological efficiency, and therefore competitive advantage, during the warmer parts of the growing season (Allen 1982a). Conversely, it should have greatest competitive disadvantage against cool-season species, especially perennials. Most of the native perennials at the Hanford Site are cool-season species.

Late-Seral Species.

Big Sagebrush (Artemisia tridentata)

Big sagebrush is a native shrub that is widely distributed in the western United States and southwestern Canada. It is the most abundant dominant in the Great Basin region. It is a long-lived shrub that can reach heights in excess of 3 m (10 ft), with canopy covers of 3.7 m^2 (40 ft^2; Van Epps et al. 1982). Size of mature big sagebrush plants is primarily dependent on genetic characteristics and available moisture (Van Epps et al. 1982, Barker and McKell 1986). Densities of mature plants within established stands may approach one per square meter. Big sagebrush densities at low elevation sites at Hanford may range from 10-20 m^2 per plant (200-400 plants/ac), with mean canopy cover of 10-25% (Rickard and Sauer 1982, Rickard 1988).

For revegetation projects, big sagebrush can be established from seed or from tublings. Young et al. (1990) reported that seedbed microtopograhy and seasonal precipitation were the most important environmental factors affecting emergence of big sagebrush seedlings. Seedlings can reach heights of 45-60 cm (18-24 in.) in one growing season, with maximum growth rates in excess of 3 cm (1.5 in.) per week (Booth et al. 1990). Barker and McKell (1986) reported shorter heights (18-25 cm [7-10 in.]) for 1-year-old plants in Utah and Wyoming. Vegetative growth of big sagebrush begins at Hanford in March or early April and continues until November, if moisture is available (Sauer and Uresk 1976). Highest productivity rates in established stands generally occur in late spring, with productivity declining, but not ceasing, in the summer in response to decreasing soil moisture (DePuit and Caldwell 1973, Rickard 1985b). Flowering begins in early summer and continues until winter dormancy (Sauer and Uresk 1976, Pitt and Wikeem 1990).

Big sagebrush is a drought-tolerant shrub, but is not particularly water efficient (DeLucia and Schlesinger 1991). Its production is highly dependent on available water. Fetcher and Trlica (1980) found that annual production of the species in northwest Utah was most highly correlated with spring precipitation and early-spring temperature. However, data presented by Rickard (1985b) for the Hanford area showed poor correlation between annual precipitation and leaf production. Barker and McKell (1986) grew big sagebrush seedlings for one year at field capacity, at 5% below field capacity, and at 10% below field capacity. Mean height of plants grown at field capacity was 18 cm (7 in.), those grown at 5% below averaged 13 cm (5 in.), and those at 10% below averaged 5 cm (2 in.). Seed production is increased by above-average precipitation (Sauer and Uresk 1976), as is seed emergence (Young et al. 1990). Anderson and Holte (1981) found that increases in big sagebrush abundance in southeast Idaho were correlated with years of above-average precipitation.

Drought tolerance in big sagebrush is apparently the result of two factors: (1) its ability to secure adequate moisture through its deep and extensive root system, and (2) its ability to regulate moisture demands by leaf loss. The species produces two types of leaves (DePuit and Caldwell 1973). One set is normally abscissed in the summer in response to drought, while the second set of smaller leaves remains on the plant throughout the winter (Black and Mack 1986). Although big sagebrush rapidly sheds up to 75% of its leaf area in response to drought, transpiration remains high via the remaining small leaves; this allows the species to flower during the summer when most other perennials are dormant (Black and Mack 1986).

Apparently, the drought tolerance of big sagebrush is the result of its ability to secure adequate moisture. The species has been shown to be very competitive for belowground resources when competing against bluebunch wheatgrass (Caldwell et al. 1991a) and Thurber needlegrass (Miller et al. 1991). In addition, the deep root system of big sagebrush gives it added competitive advantage. In mixed shrub-grass stands, big sagebrush has been shown to access significant amounts of soil moisture from the soil profile at depths below those occupied by most grass roots (Sturges 1993). These deep-profile amounts may contribute as much as 50% of the daily water budget for big sagebrush during dry periods (Caldwell et al. 1991b).

The maximum reported rooting depth for big sagebrush is 3.4 m (11 ft; Weaver and Clements 1938). Maximum depth reported at Hanford is 2.8 m (9 ft; Waugh et al. 1994). Welch and Jacobson (1988) reported greenhouse-grown seedlings of big sagebrush to have average root lengths of 45 cm (18 in.) after 40 days and 90 cm (36 in.) after 174 days. These results suggest that first-year big sagebrush plants should be able to effectively exploit most of the soil profile containing available moisture on most Hanford sites. At 10% available moisture content (field capacity--permanent wilting), the upper 45 cm (18 in.) of the profile should hold about 46 mm (1.8 in.) of plant available moisture. Root growth in big sagebrush seedlings appears to be less sensitive to available nutrient level than is aboveground production (Johnson and Lincoln 1991, Redente et al. 1992).

Compared to potential competitors at Hanford, first-year big sagebrush plants probably have comparative root systems, at least in depth. Hulbert (1955) reported cheatgrass roots at 43 cm (17 in.) within 60 days of germination, whereas Welch and Jacobson (1988) reported big sagebrush roots at 45 cm (18 in.) after 40 days. The respective authors reported end-of-growing-season lengths of 107 cm (42 in.) for cheatgrass (240 days) and 91 cm (36 in.) for big sagebrush (174 days). Harris (1967) reported a 107-cm (42-in.) depth for cheatgrass (156 days) and a 98-cm (39-in.) depth for bluebunch wheatgrass (156 days). Allen and Knight (1984) reported a 112-cm (44-in.) root depth for Russian thistle at the end of the growing season, and Klepper et al. (1985) reported a 173-cm (68-in.) depth.

Although these reports were from different areas and mixed field and greenhouse studies, they do give a relative comparison of potential root architecture among competing species. Such a comparison suggests that first-year big sagebrush plants should be quite competitive against cheatgrass and Russian thistle for belowground resources, provided that each species begins growth at the same time. However, this is not the case. Cheatgrass begins growth earlier, and therefore has a temporal advantage. However, this temporal advantage can be offset by proper timing of irrigation. After the first year, big sagebrush should have a significant competitive advantage, because its root system is perennial.

Experimental data relative to the response of big sagebrush to nitrogen fertilization is conflicting. Doescher et al. (1990) and Miller et al. (1991) reported that big sagebrush responds favorably to nitrogen fertilization. They fertilized established big sagebrush plants in southeastern Oregon (11.6 in. precipitation) at a rate of 4 g N/m^2 (40 lb N/ac), and found that fertilized shrubs had twice as many leaves and 3-5 times as much leaf biomass as unfertilized shrubs. Similarly, Redente et al. (1992) found that increasing nitrogen from 3 mg/L to 22 mg/L (applied at 2-day intervals) increased mean aboveground biomass of 75-day-old big sagebrush seedlings by 160% and belowground biomass by 200%. Johnson and Lincoln (1991) found that increased nitrogen increased aboveground, but not belowground, biomass production in 84-day-old seedlings. However, McLendon et al. (1996a) found that nitrogen fertilization did not increase aboveground biomass of 3-year-old big sagebrush plants in a common garden experiment in northeastern Colorado [38 cm (15 in.) mean annual precipitation].

Innoculation with vesicular-arbuscular mycorrhizae (VAM) has been shown to increase production of big sagebrush seedlings by up to 80% in the first growing season (Call and McKell 1985). When grown under field conditions, however, big sagebrush does not require artificial inoculation; it may actually benefit competitively from lower mycorrhizal levels early in succession (McLendon et al. 1996b).

Big sagebrush is a non-sprouting species; therefore, it is susceptible to fire (Humphrey 1962). Big sagebrush must re-establish from seed following fire; this process may take 20-40 years (Humphrey 1984, McLendon and Redente 1994) or longer if perennial grasses do not dominate the site within several years, or if sagebrush seed plants are not near.

Big sagebrush is a major browse species for deer and elk throughout its range. Kufeld et al. (1981) reported crude protein contents of 9-11% and dry measure digestibilities of 46-56% for winter big sagebrush browse in western Colorado. Big sagebrush does not tolerate heavy, sustained browsing (Bilbrough and Richards 1993). The shrub is also subject to significant insect herbivory at times (Gates 1964, Rickard and Warren 1981). Level of herbivory by grasshoppers is dependent, in part, on nutrient content of the leaves (Johnson and Lincoln 1991).

4.0 METHODS OF ECOLOGICAL RESTORATION

4.1 SITE STABILIZATION

4.1.1 Protection From Wind and Water Erosion

Soil erosion relates to the movement and resistance of soil to the forces of water and wind. Wind erosion occurs where the soil is exposed to the dislodging force of moving air. The degree of erosion by wind varies with soil structure; surface roughness; slope; cover of the soil surface; and the velocity, angle of incidence, and duration of air movement. A 40-km/h wind has four times the power to pick up soil as does a 20-km/h wind. As soil particles are moved by air, they have an abrasive action that dislodges more soil. Control can be attained by decreasing exposure to wind with tillage practices and/or mulches, or by planting vegetation that covers the soil and adds organic matter to promote improved soil structure.

Soil erosion by water is a complex natural process that is affected by numerous interrelated factors. Land disturbances result in a landscape that is devoid of vegetation and more vulnerable to the action of erosive agents. There are two forms of erosion resulting from runoff. The first, sheet erosion, is a combination of raindrop dispersion and the movement of water in shallow layers more or less uniformly across the soil surface. If raindrops are large, their force is delivered in blows that dislodge soil particles and splash them in all directions. When the raindrops are small, little dislodgment of soil particles occurs. On level land with rain falling vertically, splash is equal in all directions and there is little net loss of soil; the greater the slope, the more downhill the creep of material will be. Splash erosion destroys soil structure, places particles in suspension, and mixes water and soil. As muddy water infiltrates the soil, the suspended particles tend to plug the soil pores, sometimes completely preventing further infiltration of water. When the sealed layer dries, it forms a crust and surface runoff tends to increase.

The second form of water erosion is rill or gully. The overland flow of water transports soil materials dislodged by raindrops and further loosens soil particles by abrasion. Beginning sheet erosion may not be noticed, but it results in the concentration of water and increased scouring action that is evidenced by rills. The deeper water-cut channels become gullies, the worst of which often occur toward the bottom of a slope. Gullies gradually work headward as soil sloughs from the steep sides and is carried away. Deposition and sedimentation are the end results of these erosion processes.

The slope of the land makes a great difference in the erosion rate. Multiplying the slope by four roughly results in 2 times the velocity of flow, 4 times the eroding power, 32 times the material carried, and 64 times the size of material that can be moved. The force of running water is dependent on volume and rate of flow, which are related to intensity and duration of rainfall.

A number of treatments are applicable for erosion control on disturbed lands. Minor grading and shaping of the soil surface, when used in combination with erosion control treatments, are effective in controlling soil erosion and sedimentation processes and help in the establishment of a permanent plant community. The following treatments are used for the prevention and control of erosion on disturbed lands in semi-arid and arid regions.

<u>Mechanical Treatments</u>. Mechanical structures can provide both temporary and permanent measures for erosion control by reducing and modifying the energy involved in the erosion process. Their main emphasis should be on prevention of erosion, rather than cosmetic treatment. Structural measures include diversions, waterways, buried outlets, terraces, berms, rip-rap, gabions, and silt fences. Erosion control measures should be aimed at slope stability and soil moisture conservation to facilitate effective plant establishment for erosion control. Design and field layout of the mechanical structures for erosion control should be part of the initial reclamation plan for the disturbed area. Mechanical structures should be properly maintained for their effectiveness in erosion control.

Mulches. Different types of mulches and soil binders have been used to stabilize the soil surface against erosion. Soil stabilization through the use of mulches is mostly temporary and often provides effective erosion control until plant establishment. Organic and inorganic mulches applied to the soil surface protect the soil against the raindrop impact and wind, intercept surface runoff, protect the seed, moderate soil temperature, and reduce evaporation. Their application is well known for temporary erosion control measures on disturbed lands. A description of mulch types that are commonly used to protect the soil from wind and water erosion is provided below.

Straw. Straw is one of the most common mulches used. It consists of stems of cereal grains such as wheat, barley, or oats. Application rates are normally about 4.5 Mg/ha. It is critical that the stems be as long as possible (65% by weight should be 25 cm or longer) to increase the life expectancy of the mulch and to improve its effectiveness when crimped. Straw mulch may commonly contain seed of the parent crop or noxious weeds. Care should be exercised when selecting a mulch to make sure that its seed content is minimal and the grain will not readily volunteer on the site.

Straw can be spread by hand over small areas, or with a pneumatic blower for large areas. The mulch must be secured in place to prevent loss due to high winds or overland flow of water. Straw mulch can be anchored to the soil by crimping. A crimper is a machine that pushes part of the straw into the soil; the remaining portion of the straw protrudes from the soil and acts like stubble. This stubble shades the ground, reduces wind velocity at the soil surface, and improves infiltration. Straw can also be secured in place with the use of tackifiers that are sprayed on top of the mulch, or with plastic netting that is placed over the straw and secured in place with long metal staples.

Native Hay. Native hay is very similar to straw in its effectiveness, its application procedure, and in methods of anchoring the material in place. One advantage that native hay has over straw is that the stems of hay are usually longer; this results in longer mulch life and better results from crimping. Native hay contains large amounts of seed; this may or may not be desirable depending upon the species composition of the hay and the presence of weedy species. If the species are desirable, then a native hay can result in an increased diversity of the established community.

Hydromulching. Hydromulching is the application of a wood fiber or paper mulch in a water slurry, using a specialized machine known as a hydromulcher or hydroseeder. This type of mulch is most useful on steep slopes, where access is limited, or where crimping straw or hay is not possible. Mulch manufactured from alder and aspen fibers is the best material for hydromulching, because longer fibers create an effective mat that adheres to the soil and is fairly resistant to wind and water erosion. Mulch that is manufactured from corrugated boxes or other recycled paper products is not as effective as wood fiber.

Hydromulch should be applied at a rate of approximately 3.4 Mg/ha. A tackifier can be added to the mulch to improve its adherence to the soil. The evidence supporting the use of a tackifier along with the hydromulch is limited, however; therefore, the use of a tackifier is not recommended (Kay 1978). A hydromulcher/hydroseeder can be used to apply seed, fertilizer, and mulch separately or in any combination. Combining these materials into one operation is not recommended, however, unless the probability of adequate precipitation is high (USDA 1979). Applying fertilizer and seed together is not recommended, because fertilizer (especially N) in direct contact with the seed can reduce the germination of seed by creating a salt effect, thus reducing water absorption by the seed. This is normally not a problem for broadcast methods that do not involve hydromulch. It is important to note that the application of seed and fertilizer as part of a hydromulching operation may be as much as four times more expensive than applying seed and fertilizer with a drill or centrifugal-type broadcaster.

Wood Residues. This category of mulch includes such products as wood chips or bark fragments. These products make an excellent mulch and are inexpensive if a local source can be found. The application rate for wood residues is usually about 2 to 6 times the application rate of straw or hay. These materials can be spread by hand over small areas, or with a pneumatic blower over large areas. Wood residues last longer than all other mulches except gravel. One limitation in using wood residues is that they are not effective on sloping terrain, because they will wash off a site with any overland flow. Therefore, their use should be restricted to flat or gently sloping areas. If wood residue is left on the soil surface, there is little concern about nitrogen immobilization. However, if the mulch is incorporated into the soil, additional N should be added to compensate for the N that will be immobilized by microbial activity during decomposition. Approximately 6 kg of N/ha should be added per 1 Mg/ha of wood residue mixed into the soil.

Fabrics and Mats. There are many erosion control blankets available on the commercial market. The two most effective mulches in this category are jute netting and excelsior mat (a core of straw or wood fiber surrounded by two layers of plastic netting). Both are produced in large rolls that are simply rolled onto the site and secured in place with metal staples. During application of these mulches there are two general rules to follow: (1) there must be good contact between the mulch and the soil, and (2) the edges of the mulch must be secured to the soil to prevent strong winds from lifting the mat from the soil surface. Erosion control blankets are expensive, so their use should be limited to sites with high erosion potential.

Rock and Gravel. Rock or gravel mulch is permanent and usually introduces no seed, and is extremely effective in controlling erosion. It also improves moisture and temperature relationships for initial germination and establishment, as well as for long-term growth and survival. The use of this mulch is limited by availability and costs associated with transportation and application. Spreading of this mulch can be done with end dump trucks with cyclone-type spreaders. Rocks should be about 20 mm in diameter, and the mulch should be applied in a thickness of approximately 2.5 cm or at a rate of about 300 Mg/ha.

4.1.2 Protection From Invasion of Exotics

The invasion of exotic plants on to disturbed and revegetated sites is problematic, because (1) the presence of exotic species reduces the abundance of desirable species, (2) exotic species may spread into surrounding undisturbed communities, and/or (3) exotic species may be considered noxious weeds because of their aggressive and undesirable natures. In most instances, the invasion by exotics is addressed after their establishment through mechanical, chemical, or biological control procedures, or with the use of prescribed fire. It is more cost-effective and ecologically sound to address the invasion of toxic plants by preventing their establishment, rather than by controlling their spread or attempting to eliminate their presence.

There are basically two approaches that can be used to protect an area from the invasion of exotic species. The first is to establish and maintain a vigorous plant community that has enough species and lifeform diversity so that all resources (both in space and time) in the community are used. Competition for limited resources has a great deal of influence on the presence and abundance of species in a community, and determines their spatial arrangement. One or more of the following factors may occur when plants compete for resources: (1) time to reproductive maturity may be increased; (2) growth rates of plants may be decreased; and (3) susceptibility to density-dependent and density-independent mortality may be increased. These are important factors determining the outcome of revegetation efforts. In formulating seed mixtures, information on overlap in plant resource requirements and acquisition strategies may help to determine (1) which species are likely to be in direct competition and, therefore, inherently incompatible, (2) which species may effectively partition site resources to minimize competitive exclusion and, therefore, promote coexistence and diversity, and (3) which species may modify site characteristics to facilitate succession and establish additional species. The intensity, frequency, and periodicity of competitive interactions among plants may vary substantially on a seasonal and annual basis, in accordance with the stage of life cycle, patterns of physiological activity, and resource availability.

Plant mixtures for revegetation should be developed based on sound ecological evidence that species can coexist. Successful coexistence, in many cases, will depend on morphological or physiological attributes that enable various species at key stages in their life cycle to partition site resources effectively in space (vertical and horizontal, above and below ground) and in time (seasonal or phenological). In other cases, coexistence can occur if a species exploits a resource more effectively when the resource is limited, even though another species has the advantage when the resource is abundant.

In addition to establishing desirable species that can coexist and use available resources, a second approach to protecting a site from the invasion of exotics is to manipulate the availability of resources to favor the establishment of some plants and inhibit the establishment of others. The availability of soil nitrogen (N) has been shown to be a controlling factor in the establishment of early seral and undesirable weedy species. High levels of available soil N promote the establishment and continued growth of rapidly growing early-seral and exotic species, while low levels of soil N inhibit the establishment of early-seral and exotic species and promote the establishment of mid- and late-seral species. The manipulation of soil N can be a method for protecting areas from exotic invasion. Any carbon-based material that is low in N (such as sucrose and wood waste products) could be used as a soil amendment to immobilize N in microbial biomass. This would create conditions under which early seral exotic species will be less likely to invade, without inhibiting the establishment and growth of desirable species.

4.2 SOIL PREPARATION

4.2.1 Physical Characteristics

There are a number of physical characteristics of fill material and topsoil that are important to revegetation success. Severe limitations in these soil properties or improper soil preparation procedures can lead to failure in the revegetation effort. Those physical properties that are most likely to limit revegetation success include soil texture, soil compaction, and aggregate stability.

Soil Texture. Soil texture has a direct influence on such properties as infiltration, hydraulic conductivity, water-holding capacity, and cation exchange capacity. There is no optimum texture for all purposes and all plants because requirements vary greatly. But a growth medium with enough sand to allow for aeration and looseness to permit plant root growth and development, and enough clay for adequate nutrient and water-holding capacity, would be ideal for most situations.

Soils with a high percentage of clay size particles (less than 0.002 mm in diameter) have relatively high water-holding capacities and plant-available nutrients. However, these soils are often harsh and hard when dry, and sticky when wet. They are often poorly drained and aerated. In addition, some clay soils have a high shrink-swell potential that may be damaging to plant roots. Conversely, soils with a high percentage of sand-size particles (0.5 to 2.0 mm) have relatively low water-holding capacity and limited plant available nutrients, but they are well-drained and aerated and remain friable when dry.

Restoring soils that are extreme in their texture is challenging, because texture modification is not easy. Soil texture can be modified by mixing materials of different textures together. This approach is not commonly used, because of the problem of finding a suitable source of soil for mixing and the associated costs that are involved with transportation. Typically, the addition of an organic amendment to either sand, clay, or silt soils is effective in overcoming the physical limitations associated with texture. Organic matter additions to sandy soils will improve water-holding capacity, cation exchange capacity, and nutrient availability. Adding organic matter to clay soils will improve infiltration, drainage, and aeration, and will reduce the effect of soil surface crusting. Sources of organic matter include composted sludge, leaves, straw, hay, sawdust, and wood chips. Even shredded paper can be used under some conditions.

Soil Compaction. Soil compaction may be defined as the act of moving soil particles closer together by external forces. These forces range from natural ones (such as falling raindrops) to unnatural ones (such as trampling or vehicle activity). A certain amount of compaction or firmness may be beneficial (for example, to establish seed-soil contact for proper germination), but when compaction is excessive, it may result in deleterious effects to the soil and to the growth of plants. Fine-textured soils that have a bulk density greater than 1.6 g/cm^3 (dry weight) and coarse-textured soils that have a bulk density greater than 1.8 g/cm^3 (dry weight) may inhibit infiltration and root penetration and should be physically manipulated to reduce compaction (Brady 1974).

The most common approach to alleviate problems associated with compaction is through physical manipulation of the soil by deep ripping, chiseling, or disking. Other approaches include the addition of amendments (such as organic materials) or chemical treatments (such as gypsum).

Aggregate Stability. Soil aggregates, which are composed of two or more cohering primary soil particles, are the building blocks of soil structure. Both clay content and organic matter content are positively correlated with aggregation. A breakdown of aggregates by the disruptive forces of erosion, cultivation, and compaction results in the loss of structure, a reduction in infiltration, and crusting of the soil surface. If a soil has been compacted and also suffers from reduced aggregate stability, the use of ripping, chiseling, or disking may reduce bulk density, but may not improve infiltration. The problem of reduced infiltration may need to be addressed by resolving the aggregate stability problem through the addition of organic matter, or by allowing the problem to be resolved naturally through plant growth processes. As a plant community develops, root and shoot growth and decomposition will add organic matter to the soil and improve aggregate stability slowly over time.

4.2.2 Chemical Characteristics

Chemical characteristics of fill material and topsoil that are most likely to limit revegetation success include pH, soluble salts, and plant nutrients. Each of these characteristics can be modified through soil amendments that are commonly used in restoration of arid and semi-arid sites.

Soil pH. The soil pH may influence nutrient absorption and plant growth in two ways: (1) through the direct effect of the hydrogen ion, or (2) indirectly, through its influence on nutrient availability and the presence of toxic ions. In most soils, the latter effect is of greater potential significance. Although the direct toxic effect of the hydrogen ion can be demonstrated at extreme pH values, most plants are able to tolerate a wide range in the concentration of this ion as long as a proper balance of other elements is maintained. Unfortunately, the availability of several of the essential nutrients is drastically affected by soil pH, as is the solubility of certain elements that are toxic to plant growth.

Several essential elements tend to become less available as the pH is raised from 5.0 to 8.0. Iron, manganese, and zinc are good examples. Molybdenum, on the other hand, is affected in the opposite way; it becomes more available at the higher pH levels. Phosphorus is never readily soluble in the soil, but it seems to be held with the least tenacity in a pH range centering around 6.5. Phosphorus availability declines as pH increases to 8.5, and increases at pH levels above 8.5. Generally, nitrogen availability is highest in soils with a pH in the 6 to 8 range, and decreases in the range of 8 to 9. Both nitrogen and phosphorus availability decrease at pH levels below 6.

At pH values below about 5.0, aluminum, iron, and manganese may be soluble in sufficient quantities to be toxic to the growth of some plants. At very high pH values, the bicarbonate ion is sometimes present in sufficient quantities to interfere with the normal uptake of other ions, and thus is detrimental to optimum plant growth.

Microbial populations and processes are also influenced by pH. At soil pH values below 5.5, fungi are most active, but at pH values of 6.0 and higher, actinomycetes and bacteria are more prominent. The effect on populations of organisms in turn influences microbial processes that are important in nutrient cycling (such as nitrification, mineralization, and nitrogen fixation).

The most common approach to increasing pH of acid soils is through the addition of finely-ground limestone. Application rates are based on specific soil tests (i.e., acid-base accounting) that determine lime requirement and are associated with the buffering capacity of the soil. If the soil pH is highly alkaline (pH > 9), the soil should be treated with elemental sulfur. Elemental sulfur converts to sulfuric acid in moist soils through the action of certain bacteria (e.g., Thiobacillus). Soil tests are available for determining application rates for sulfur.

Soluble Salts. Saline soils are common features of arid and semi-arid environments. These soils are associated with climates in which annual evapotranspiration greatly exceeds annual rainfall; therefore, essentially no water percolates through the soil under normal conditions. The result is that, although the lack of water reduces the intensity of soil mineral weathering, the products of the weathering that do occur (e.g., salts) tend to accumulate in the soil. Because water is the vector for salt, salt accumulation in soil commonly reflects the relief and geomorphological conditions of the area.

A salinity hazard exists when there is sufficient soluble salt in a soil to interfere with the growth of desired vegetation (soil EC $\geq$ 4.0 mmhos/cm). The major adverse effect of soil salinity is to reduce the availability of soil water to plants. Briefly, this is because the presence of salt in water increases the work that the plant must do to extract water from the soil solution. This work is referred to as the "osmotic potential," and is additive to the work required by the plant to extract water from a nonsaline soil solution (i.e., the "matric potential"). The sum of the two potentials, osmotic plus matric, is called the "soil-water potential." Plant species have different abilities to make osmotic adjustments in the direction of maintaining a constant water potential gradient between the plant and the soil solution. Plants that are able to make the physiological changes associated with this adjustment are plants considered to be salt tolerant.

Salinity-stressed plants exhibit no distinctive symptoms. The most common effect of salinity stress is a general reduction or stunting of plant growth. Under severe conditions, plant leaves may have a purple, dark-green color and a waxy appearance. Salinity damage is most prevalent during germination and early seedling establishment.

At low to moderate salinity levels, fertilization can, to a limited degree, ameliorate the adverse effects of salinity. At the same time, some forms of fertilizer (e.g., most inorganic N fertilizers and chloride salts of K) have a relatively high salt index and may aggravate the salinity problem. The most common approaches to mitigating salinity problems are (1) to add organic matter to the soil to improve infiltration and natural leaching, (2) irrigation to leach salts out of the root zone, and (3) planting salt tolerant species.

Nutrient Limitations. Nitrogen (N) and phosphorus (P) deficiencies on disturbed lands are generally one of the most limiting factors to restoration success. Nitrogen deficiencies result from either low levels of plant-available N created by a disturbance, or a lack of microorganisms to convert various compounds to N forms used by plants. The re-establishment of an active biological cycle of N turnover is a key to restoration success on disturbed sites that have been severely impacted.

Phosphorus deficiencies occur primarily because of the insolubility of P, as well as the fixation of P by clay minerals in the soil. When P is deficient, seedlings have a difficult time establishing, due to restricted root development, a limiting ability to access adequate amounts of P.

Nitrogen and P deficiencies can be overcome with inorganic or organic fertilizer. The primary concern is to limit the amount of N added, because of the stimulation it causes in the growth of annuals (if annuals are a potential problem). Special attention needs to be given to formulating recommendations to fertilize with N. Soil tests should include analysis for total N, NO_3-N, and NH_4-N. The values from these results should be compared to soil N levels in undisturbed soils adjacent to the area to be restored. Nitrogen amendments should then be applied in very conservative amounts, if needed. Phosphorus is not known to stimulate weed growth and can be applied in more liberal amounts. Plant-available P should be analyzed in the disturbed soil before making recommendations. In general, soils with available P levels of 7 ppm are adequate for successful restoration.

4.2.3 Organic Matter Characteristics

Organic matter plays a direct role in the formation of a fertile soil, because it provides plant nutrients that become available during mineralization. Organic matter also has a fundamental effect on the physical properties of soil, such as water-holding capacity, structure, and heat regime. Additionally, it also influences such physiochemical properties as cation exchange capacity and buffering capacities. These properties influence nutrient uptake, water and nutrient availability, and the deleterious effect of soil acidity and alkalinity.

Soil organic matter directly or indirectly influences the physical environment of the soil (Allison 1973). As the percentage of organic matter decreases in a soil, the bulk density increases, with an associated reduction in porosity. The combination of increased bulk density and reduced aeration restricts root growth, impairs normal root absorption, and inhibits microbial activity.

Soil structure greatly influences fertility (Kononova et al. 1966). Organic matter is one of the most important factors in soil structure development. Soils with good structure provide the best conditions for supplying water and nutrients to plants. The conversion of humic substances into a soil aggregate is irreversible under natural processes. The formation of humic substances that bind soil crumbs is slow and requires specific environmental conditions. Similarly, increased stability of aggregates usually accompanies an increase in organic matter. Thus, to maintain good soil structure, there must be an absence of soil disturbance and a source for newly-formed humus substances (normally associated with plant growth and decomposition) on a regular basis.

Organic material itself, without biological transformation, has little effect on soil structure. Without organic matter as a source of energy, microorganisms are ineffective in producing soil aggregation. Fungi and actinomycetes produce mycelia and have metabolic processes that synthesize complex organic molecules. Decomposition products remain in the soil, and the sum of these effects is the production of stable soil aggregates.

Organic matter usually improves infiltration, reduces evaporation, improves drainage in fine-textured soils, and encourages more extensive and deeper root systems. Collectively, these actions should improve water available to plants. Organic matter increases infiltration by helping to hold water on the soil's surface long enough for it to enter the soil, and by improving the physical condition of the soil. Organic matter also reduces crust formation, which increases the rate of infiltration. Similarly, if organic matter is mixed into a soil, eventually improving soil aggregation and soil structure, percolation increases.

One of the most important chemical properties of soil is its ability to retain and exchange positively charged ions on colloidal surfaces. The primary controlling factors of cation exchange are the amount and type of clay and the quantity of organic matter in the soil (Smith et al. 1987). The organic matter in most mineral soils accounts for about 30 to 65% of the total cation exchange capacity (Campbell 1978). In sandy and organic soils, more than 50% of the cation exchange capacity is due to the organic component of the soil.

A buffer solution is one that resists changes in pH upon the addition of acid or base. Soils behave like buffers. Most of this ability is a result of their colloidal properties associated with the humus and clay minerals, which hold H, Al, and other cations (Campbell 1978). Resistance to pH change is low in soils with lower levels of organic matter, but higher in soils with higher levels of organic matter.

A wide range of chemically stable organic anions is capable of binding metal cations into weakly ionized forms. These substances, known as chelating agents, occur naturally in soils. They are associated with the solid organic fraction, as well as with soluble organic materials in the soil solution. Organic matter can hold metallic ions both by cation exchange and by chelation. In soils having metal ion concentrations that are toxic to plants, chelation may hinder adverse effects through the immobilization of the metal ion.

The optimum level of organic matter for a disturbed site may already be expressed in the adjacent undisturbed area. But one important consideration is the fact that disturbed systems are in the process of arriving at a balance. Thus, adding organic matter may expedite that balance or delay it, depending on the particular set of soil-forming factors in the area. In the surface horizons of undisturbed land, equilibrium organic matter levels generally vary with temperature, rainfall, vegetation cover, soil texture, physiographic position, and land use management. Equilibrium organic matter levels in surface horizons of native soils in nonmountanous areas of the West range from 0.5 to 3.4%. Generally, equilibrium organic matter levels increase with increasing precipitation and decrease with increasing temperature. Furthermore, with all other conditions being equal, organic matter levels generally decrease with decreasing clay and/or silt content. That is, the content of the organic matter of clay is greater than that of loam, which is greater than that of sand. Finally, more concave or depositional physiographic positions have higher organic matter levels in the upper horizons, because of the additional organic matter-enriched runoff received from upslope surfaces or increased plant production facilitated by additional moisture.

In revegetating subsoil and unweathered geologic material without topsoil, organic matter can play an important role in nutrient supply, soil structure, and water-holding and buffering capacities. In non-topsoil materials, minor elements usually are adequate for plant growth, but there may be nitrogen, phosphorus, and potassium deficiencies. Organic matter is a viable nutrient source enhancing revegetation efforts. Furthermore, applications of organic matter increase microbial growth, creating a more fertile environment for plants that can enhance restoration of relatively infertile, biologically-inactive subsoil materials. The amount of organic matter applied should be consistent with the intended effects on seedling establishment and long-term plant community productivity. If the purpose is to provide nutrients for plant growth, rather sizable amounts may be required. If the purpose is to improve physical conditions of the soil, smaller amounts may suffice.

4.2.4 Microbial/Decomposer Subsystem

Many of the transformations that occur during the cycling of nutrients are accomplished mainly or entirely by microorganisms. In fact, if it were not for the activities of bacteria and fungi, many element cycles would be drastically altered and the productivity of ecosystems much reduced.

The soil microbial community in a mature ecological system consists of a highly interrelated complex of organisms with equally complex trophic and life cycle characteristics. This microbial system is closely coupled with the plant community, and is negatively affected when the plant community is disturbed. Numerous types of macrofauna and microfauna feed on litter, changing its chemical composition and reducing its size. Saprophytic bacteria and fungi further alter the organic matter chemically and physically, eventually reducing the most resistant portion into humus and converting the remainder into their living biomass, CO_2, and various soluble components released into the soil matrix. Microfauna (i.e., protozoa, amoebae, nematodes, and microarthropods) and macrofauna predators feed on the saprophytes, mycorrhizal fungi, and on each other, increasing food web complexity. Mycorrhizal fungi exist in mutualistic association with plant roots, utilizing exudates for their energy supply and providing the host plant with increased amounts of water and soil nutrients.

The complex structure of the decomposer subsystem is a product of succession, as is the plant community. It progressively develops over time in response to the dynamics of the biotic and abiotic variables of the site. The rhizospheres of maturing plant communities become centers for processes other than decomposition of organic matter. These include nitrogen fixation, chelation and binding of metals, material transfer among plants through mycorrhizal hyphae, and creation and maintenance of soil structure through production of humic compounds and polysaccharide glues. In many species, mycorrhizal infection of the roots significantly increases absorption of phosphorus and water.

Since the plant and decomposer subsystems are closely-linked components of the same community, disturbance of one will effect the other (Doerr et al. 1984, Biondini et al. 1985, Reeves and Redente 1991, Klein et al. 1995, Klein et al. 1996, McLendon et al. 1996b). A significant reduction in primary production will deprive the belowground system of its energy source. Immediate responses occur in those populations most directly linked to plants for energy, the mycorrhizal fungi and other organisms dependent upon root exudates (Biondini et al. 1988). Severed from their energy supply, these fungi are replaced by saprophytes or go dormant. Root exudates, along with the most soluble portions of litter, provide the most readily available supply of energy to decomposers. Reduction in supply results in a corresponding decrease in overall belowground productivity. Predators that feed primarily on mycorrhizal fungi, or on mycorrhizal predators, must find alternative food sources, thereby decreasing trophic complexity and increasing competition. A decrease in the food source results in a decrease in consumers.

From the above discussion, it should be evident that disturbances to a plant community will adversely affect the functioning of the belowground system. Severe disturbances that remove the plant community and physically alter the soil may result in complete removal of the microbial population or the disruption of microbial structure and function. Under these severe conditions, it may be very difficult to reestablish a late seral plant community without restoring the microbial subsystem or providing a readily available source of nutrients to support plant growth, while the microbial community recolonizes the site.

The best way to reestablish a soil microbial community is to apply topsoil to the disturbed site that contains a diverse and viable population of microbes. It is essential that the microbial population has an adequate energy source (i.e., carbon) to function properly. This may require the addition of organic matter and some inorganic nitrogen to satisfy their energy and nutrient needs. Other microbial sources include manure and sewage sludge that could be applied at low application rates to provide an inoculum from which a microbial population can establish.

4.3 PLANT PROPAGATION

4.3.1 Methods: Seeding, Vegetative, Transplants

Seeding Rates. It is important to use enough seed to get a good stand, but not more than necessary. Too much seed may produce a stand of seedlings so thick that individual plants may compete with each other to the detriment of the majority of individuals. On the other hand, seeding rates that are too low will not provide adequate erosion control or competition against undesirable invading species.

The number of seeds placed in a unit area of soil is called the seeding rate. The total seeding rate is the sum of the individual species seeding rates. Seeding rates are normally expressed as the number of seeds per unit area or kg/ha. Many different seeding rates for the same species can be found in the literature. The primary reason for these differences is that some rates are for monocultures and other rates are for diverse mixtures.

Seeding rates should be developed on the basis of number of seeds per unit area (e.g., the number of seeds per square meter). Once this number is determined, it can be converted to weight per unit area (e.g., kg/ha). Since each species produces seed that weighs a different amount, the development of seeding rates based purely on weight per unit area will produce erroneous rates that will tend to over-emphasize small-seeded species and under-emphasize large-seeded species. For example, blue grama seed is typically about 320,000 seeds per kg, while Indian ricegrass is 80,000 seeds per kg (Fulbright et al. 1982). If seeding rates were calculated simply on the basis of weight per unit area, without recognizing the fact that a pound of blue grama seed has four times the number of seeds per pound as Indian ricegrass, it would be very easy to over-plant blue grama and under-plant Indian ricegrass.

Seeding rate may be calculated from an expected field emergence for each species and the desired number of plants per unit area. For purposes of calculation, field emergence for small-seeded grasses and forbs is assumed to be around 50% if germination is greater than 80%. Field emergence is assumed to be around 30% if germination is between 60 and 80%. The Natural Resource Conservation Service recommends a seeding rate of 200 to 300 pure live seeds per square meter (i.e., 20 to 30 pure live seeds per square foot) as a minimum number of seeds when drill seeding in areas with an annual precipitation between 15 and 45 cm. Two hundred and fifty pure live seeds per square meter, with an expected field emergence of 50%, should produce an adequate number of plants on the seeded area to control erosion and suppress annual invasion. This seeding rate is primarily for favorable growing conditions such as a weed-free seedbed, soils that are not extreme in texture, gentle slopes, north, or east-facing aspect, good moisture, and adequate soil nutrients. When conditions are less favorable or when the seed is broadcast, seeding rates should be increased up to a level that is two times the drill rate for favorable conditions.

When determining the seeding rates of specific species in a mixture, there are several factors that need to be considered. The first relates to the composition of the desired community. If the desired community is a shrubland or a shortgrass steppe dominated by cool-season grasses, the seeding rate needs to reflect this composition. Unfortunately, there are no simple recipes available to combine species to achieve a particular outcome. Most seeding rates for mixtures of plants are based on years of experience or specific experimentation with a specific set of species in a specific environment.

Pure Live Seed. Each state has a seed certifying agency, and certification programs may also be adopted by seed growers. Certification of a container of seed assures the customer that the seed is correctly identified and genetically pure. The state agency responsible for seed certification (in Washington, this is the Washington State Department of Agriculture) sets minimum standards for mechanical purity and germination for each species of seed. When certified, a container of seed must be labeled as to origin, germination percentage, date of the germination test, percentage of pure seed (by weight), other crop and weed seeds, and inert material. The certification is the consumer's best guarantee that the seed being purchased meets minimum standards and the quality specified.

When developing seed mixtures and when purchasing seed, the designation of pure live seed (PLS) must always be used. Percent pure live seed is expressed as follows:

$$\%PLS = \frac{\%\ \text{Germination} \times \%\ \text{Purity}}{100}$$

In the above equation, percent germination is the percent of the seeds in a unit weight that are viable (i.e., seed that produces a shoot and root when tested). Purity is 100 minus the percent trash plus the percentage of weed seed.

Seeding. The primary concern of seeding is to place the seed in the soil at the depth most favorable for its germination and establishment. The optimum depth of seed placement differs for each species. In general, the smaller the seed, the more shallow the placement in the soil, and the larger the seed, the deeper the placement. This general rule of thumb is directly linked to the amount of food reserves the seed contains to produce a coleoptile long enough to penetrate the soil surface. In addition, light stimulates germination of some species, and darkness is needed for others. Because of the specific requirements that each species has, one planting depth or seeding technique may not be optimum for all the species being planted in a mixture. For example, Sandberg bluegrass can be planted at depths up to 2.5 cm (1 in.; Evans et al. 1977). However, optimum depth for bluebunch wheatgrass is 0.6 cm (0.25 in.; Plummer 1943) and minimal coverage is optimum for big sagebrush (Jacobson and Welch 1987).

Drill Seeding. Drill seeding uses an implement that places the seed at a specified depth in the soil. Since location of the seed in the soil profile should optimize its potential for contact with water, seeding depth will vary with soil water holding capacity, soil texture, site exposure, and other aspects that influence soil moisture. Drills should be set at deeper depths in light sandy soils or on southern exposures. On finer-textured soils, high moisture conditions, or northern exposures, drills should be set at shallower depths.

Very small seed or seed with smooth seed coats will quickly move to the bottom of the seed box during the drilling operation. These kinds of seed should be placed in separate boxes to achieve a more uniform distribution. Fuzzy or hairy seeds, or seeds with long awns, will form large bunches that interfere with the movement of seed into the seed tubes. This problem can be overcome by adding a carrier to the seed mixture (e.g., rice hulls, ground corn cobs, or even sand) to improve the flow of seed from the seed box to the seed tubes, or by using seed drills with large-diameter seed tubes and mechanical agitators in the seed box.

The primary advantage of drill seeding is seed placement at a uniform depth and in direct contact with the soil (USDA 1979). Drills also provide uniform distribution of seed at accurate seeding rates. The primary disadvantage of drill seeding is that the presence of site conditions such as steep slopes, saturated soils, or extremely rocky soils may restrict access with a drill or reduce their ability to properly function (USDA 1979).

Broadcast Seeding. Any method of seed dispersal that drops seed upon the ground and does not place it in the soil is referred to as broadcast seeding. Since the seed is deposited on the soil surface and not placed in the soil, some sort of device (e.g., a harrow or chain) is pulled over the site after seeding to cover the seed with soil.

Centrifugal-type broadcasters, also called end gate seeders, are commonly used for broadcast seeding. These broadcasters generally have an effective spreading width of about 6 to 12 m. Hydroseeding is a form of broadcast seeding in which the seed is dispersed in water under pressure. If this technique is used, seed should not be combined with hydromulch or any other type of tackifier, because the seed will be suspended above the soil and will become desiccated as the mulch or tackifier dries. The only exception to this rule is in areas where precipitation is abundant and the probability of extended periods (2 to 3 weeks) of rainfall are high.

Aerial seeding is the dispersal of seed by a fixed-wing aircraft or helicopter. If properly conducted, this is a very efficient way to broadcast seed over large areas, steep slopes, or areas inaccessible to ground transportation.

The primary advantage of broadcast seeding is that site conditions do not pose access problems (USDA 1979). Since broadcast seeding can be done on the ground or aerially, physical site conditions are less of a concern than with drill seeding. In addition, broadcast seeding is also more economical than drill seeding, because of lower equipment costs and less time required to distribute seed. However, these cost savings can be eliminated when seed costs are high, because broadcast seeding will use twice the amount of seed as drilling. Broadcast seeding is ineffective if the seedbed is not roughened prior to seeding, or if the seed is not covered following broadcasting (USDA 1979).

Broadcast seeding is commonly done in concert with land imprinting in arid regions of the southwestern United States (Dixon and Simanton 1977, Dixon 1983). Imprinting is a mechanical process in which the soil surface in indented or embossed when a sharp angular object is forced downward into it. Natural imprintation is performed primarily by the hoofs of ungulates, whereas artifical imprints can be made by various types of mechanical devices. The most common device consists of a large metal drum that can be filled with water and has angle-iron welded to the face of the drum in various geometric designs. Adding water to the drum provides ballast and the angle-iron creates the indentations across the soil surface. Imprinters do not uproot or kill existing herbaceous vegetation; therefore, they permit the interseeding of desirable species into existing, but incomplete, plant communities. Current designs use 8-pointed stars with either 45° or 90° tooth points, and octagonal rings with broken corners. The star design is normally operated up and down slopes, and octagon designs are typically pulled along the contour. Imprinting is most effective in arid regions where moisture conservation and rainfall harvesting is absolutely critical for revegetation success. However, imprinting is not effective on sandy or rocky soils, because imprints do not remain in sand and cannot be created in soils with high rock content at the surface.

Seeding Legumes. Legumes (nitrogen-fixing plants with Rhizobium) are often included in seed mixtures to improve the nitrogen status of the soil and to add diversity to the plant community. These species need host specific bacteria present in order to establish a symbiotic relationship. Therefore, when legumes are being planted, an inoculum should be added to the seed to assure that the proper Rhizobium species is present. When dry seeding, the inoculant can be mixed with lightly moistened seed just before planting. Moistening the seed with sugar mixed with water helps bond the inoculum to the seed and extends the longevity of the Rhizobium. When seeding with a hydroseeder, the inoculant can be added to the slurry just before spreading. If fertilizer is added to the slurry, there may be a concern with the generation of acid conditions in the slurry and potential mortality of the bacteria. The pH of the slurry should never be allowed to drop below 5.0 when Rhizobium is present. Inoculum should be stored in a cool location and should not be used if the expiration date on the package has passed.

Season of Seeding. The time of seeding or planting is influenced by such factors as climate, seasonal weather patterns, and the seasonal growth patterns and moisture requirements of the planted species. Usually, the best times for planting precede or coincide with periods of precipitation that are of sufficient duration to allow the planted vegetation to become established.

Late fall seedings are common and are referred to as "dormant fall seedings." Seed is placed in the ground as late in the season as possible. The seed undergoes vernalization in the soil and is ready to germinate when temperature and moisture conditions are optimum in the spring. In general, cool-season species tend to perform better when planted in the early fall, and warm-season species tend to do better when planted in the spring or summer, depending upon the region. This is because cool-season species experience their greatest growth during the cool spring months, and warm-season species grow best during the warmer summer months. Weather conditions in the spring tend to be more unpredictable than in the fall for most areas, and this adds some problems with respect to scheduling the seeding activity.

Planting Whole Plants. Whole plants or plant parts may be transplanted. Whole plants can be transplanted as bareroot stock, container-grown stock, or wildings (i.e., plants excavated from their natural settings and transplanted to the disturbed environment). Bareroot stock are grown in a protected or enclosed area. When the plants reach a predetermined size, they are hardened by reducing moisture, temperature, nutrients, and day length. During the hardening period, plants increase their carbohydrate reserves and go dormant. Once the plants are dormant, they are removed from the growth medium, their stems and roots are trimmed, and they are packaged. These plants are then held in a cool, dark, moist environment until transplanted. The success of bareroot stock depends on keeping the plants inactive until planted and minimizing water stress when planted in the field.

Containerized stock are grown in a greenhouse in some sort of container. These plants are encouraged to grow very rapidly. Care should be exercised when purchasing them to make sure that good root development has occurred. Containerized stock are normally actively growing when purchased and transplanted, so the season of planting is a primary concern to prevent frost damage. To extend the planting season, containerized material can be "hardened" before transplanting.

Wildings are excavated from their natural setting and transplanted to the degraded site. Both trees and shrubs have been successfully moved by this technique, and plants that sprout from roots or underground stems seem to do best with this approach. Transplanting should be done when plants are dormant; otherwise, aboveground shoots should be pruned before transplanting to reduce transpiration and water stress on the plants. Wildings guarantee that genetic diversity is maintained, and provide instant cover and food for wildlife species.

Planting Plant Parts. Cuttings, root pads, or sprigging are techniques for establishing grasses, shrubs, and trees. Cuttings consist of woody roots or pieces of stems that include nodes. Stem and root buds develop from the meristematic tissue in the root, or at the plant nodes, and grow into complete plants. For a thorough description of methods for preparing cuttings, the publication by Hartmann and Kester (1975) is recommended. It is common to treat the cuttings with a growth hormone to stimulate root development. Growth hormones that have been found to be most reliable in stimulating adventitious root production in cuttings are indolebutyric acid and naphthaleneacetic acid. Indolebutyric acid is considered to be the best growth hormone for general use, because it is non-toxic over a wide concentration range and is effective in promoting rooting in a large number of species (Hartmann and Kester 1975). These chemicals are available in commercial preparations, dispersed in talc or liquid formulation that can be diluted with water, or in more concentrated forms (Hartmann and Kester 1975).

Root pads and sprigging are techniques for grass, forb, and shrub transplanting. Species that are root sprouting or rhizomatous are best suited for this approach. Equipment is available for lifting the root systems of plants following a close trimming of shoots to ground level. These sprigs are then spread over the site to be restored and covered with soil and lightly compacted.

Propagation of plants by rhizomes for local species, such as scurf pea (Psoralea lanceolata), can be done by harvesting rhizomes by hand digging or with the use of commercial sod cutters. Once the rhizomes are removed from the soil, they should be cut into sections, ensuring that each segment has at least one lateral bud. Rhizomes can be stored in polyethylene bags at temperatures from - 0.5 to + 4.5 C for as long as four months. Rhizomes should be planted at the start of the growing season, immediately prior to the period of greatest precipitation. Rhizomes should be spread over the soil surface and covered with at least 2.5 cm of soil or lightly rototilled into the soil.

4.3.2 Selection of Species

The selection of species for restoration must consider climatic conditions, soil characteristics, elevation, exposure, ecological and management goals, and ecological characteristics of the species themselves. Plant species selected for restoration should have contrasting patterns of aboveground and belowground growth to enhance the partitioning of resources and enhance species diversity. Mixtures of tall-, mid-, and short-height species with C_3 versus C_4 photosynthetic pathways offer an array of combinations that have potential for enhancing productivity, diversity, and coexistence via vertical and temporal stratification of resources.

On highly disturbed sites with poorly developed nitrogen cycles, legumes can be selected as early colonizers. Once a viable nitrogen cycle has been established, the importance of these legumes may diminish and they may be out-competed by the plants whose establishment they facilitated.

Shrubs encompass an array of morphological and physiological traits that can contribute to the vertical stratification of resources with grasses and forbs. Woody plants play a key role in creating islands of fertility and providing habitat for wildlife.

As a guideline for species selection, McKell et al. (1982) developed a conceptual model that consists of a hierarchy of criteria by which available plant species are evaluated for their suitability for a disturbed site. The criteria consider site characteristics, including the native vegetation, that are evaluated by sampling the environment. The criteria for the model are presented in Table 4.1.

4.3.3 Selection of Source of Plant Material

Once a potential list of species has been developed, the availability of the species must be explored. Seed or plants may be available for each species selected for restoration. However, an appropriate cultivar or ecotype must be selected for each species to ensure that the source of material is adapted to the site conditions. The availability of a specific cultivar or ecotype may be limited or non-existent.

When commercial cultivars are not available or not desired, seed may be collected from local populations. This seed may be used directly, sent to a seed grower for increase, or used to produce transplants. In all instances, when seed is collected from native stands, the original seed is selected from a plant population(s) that evolved on a particular soil under specific environmental conditions. When such an ecotype is used in restoring a disturbance, the original seed source should have been found close to the site of the disturbance. An ecotype can perform satisfactorily only if it is seeded at approximately the same elevation and exposure, and if it is moved no more than 180 km north or 100 km south of the point of origin of the seed (Cooper 1957, Thornburg 1982). East or west movement may be more or less, depending upon changes in elevation and precipitation.

All of these distances represent general recommendations and should not be taken as absolutes, however. Any successful movement will depend upon the equivalence of such environmental conditions as soil type, temperature extremes, and moisture conditions. It should be noted that these restrictions do not apply to commercial cultivars, because they have been genetically selected for specific attributes within a specified range of soil and climatic conditions. Seed produced from a cultivar produced in one environment may be

Table 4-1. A Hierarchy of Criteria Specified by McKell et al. (1982) for Selecting Species to be Used in the Restoration of a Specific Disturbed Site.

1. Capability for propagation and establishment under local stresses
    - A. Ease of obtaining seed or other vegetative material
    - B. Ease of propagation
    - C. Ease of planting
    - D. Immediacy and certainty of establishment

2. Value for animal nutrition
    - A. Forage value
        - Palatability
        - Nutritive value
        - Tolerance to grazing
        - Dependability of production
        - Length of green period
        - Accessibility of forage
    - B. Growth rate
        - Aboveground growth rate
        - Belowground growth rate
        - Cover
        - Season of maximum growth

3. Adaptability of climatic extremes
    - A. Tolerance to drought
    - B. Tolerance to temperature extremes
    - C. Tolerance to strong winds

4. Adaptability to soil conditions
    - A. Soil-water relations
    - B. Tolerance to salinity
    - C. Tolerance to unfavorable pH
    - D. Tolerance to nutrient deficiencies
    - E. Tolerance to toxicities
    - F. Tolerance to wetness

5. Protection of watershed
    - A. Belowground growth rate
    - B. Rate of spread

6. Suitability for miscellaneous conditions
    - A. Persistence
    - B. Self-renewal
    - C. Compatibility with other species
    - D. Disease and pest resistance
    - E. Fire resistance
    - F. Value for aesthetic purposes
    - G. Minimum maintenance costs

grown in a variety of other environments and still retain its genetic complement, and will perform adequately under the limitations originally described for the cultivar.

There are three potential sources of plant materials available for restoration work at the Hanford Site. The first source of materials is to collect seed or vegetative material from within the Hanford Site or in similar ecological zones in close proximity to Hanford. This material, if collected in a large enough quantity, would then be used in the restoration process.

The second option is to collect seed, as noted above, and use this material in a seed increase program or to produce transplants. A seed increase program involves contracting with a seed producer to plant the seed in a seed production field to increase the available seed for restoration. The increased seed would represent first-generation progeny and would have very similar genetic characteristics to those of the original parent plants.

The third option is to obtain seed or vegetative plant parts from commercial sources. This material might represent improved varieties, or may come from native collections from environments similar to that found at the Hanford Site.

4.4 EARLY COMMUNITY MAINTENANCE

4.4.1 Irrigation

In dry regions, irrigation may be required for plant establishment. Irrigation should only be considered as a temporary measure for plant establishment, as opposed to a long-term management practice. The development of perennial plant communities must eventually occur under natural climatic conditions. It is important to avoid establishing a level of plant density or production that is too high for natural environmental conditions to support.

The decision to irrigate, and the detemination of the amount of irrigation water to apply, should be based on several factors. These are the amount and distribution of precipitation, soil texture, plant density and production desired, water requirements of plants, use of cultural practices such as mulching, and ecological and management goals for the site. In general, regions that receive 250 mm or less of annual precipitation should be considered as prime candidates for irrigation to promote plant establishment (DeRemer and Bach 1977, Ries and Day 1978). Irrigation should also be given serious consideration during periods of drought, when the season of seeding or planting needs to be extended, or when establishing woody species that need additional water for establishment.

There are potential negative and positive effects associated with irrigation. When irrigation is done improperly, the result can be the production of a plant community that is too productive for the natural carrying capacity for the site. Under these conditions, when water is removed, that plant community may experience a dramatic decline in production or an increase in plant mortality. When water is applied as small irrigation events, plants will produce shallow root systems that have a low density. These plants will not be drought tolerant, or will be unable to use water stored deep in the soil profile. Improper timing and amounts of irrigation may also retard phenological development and result in plants that have a low reproductive output. Finally, irrigation may favor the growth of rapid-growing species to the extent that slower-growing species are not able to establish or are excluded from the plant community through competition for space, light, and nutrients.

When irrigation is conducted properly, there are potential positive effects to be achieved. Irrigation improves the reliability of plant establishment, extends the season of planting, and promotes the more efficient use of plant nutrients. The use of supplemental water may serve a critical role in meeting specific germination and establishment requirements of certain species. For example, certain warm-season species produce adventitious roots approximately 14 days following germination. If adequate soil moisture is not available at this time, the secondary root system of the plant will not develop and drought hardiness will be lost. The use of irrigation to meet specific growth requirements of plants provides a tool to manipulate species composition and actually increase species diversity. Finally, when supplemental water is applied in amounts that wet the entire soil profile, deep root development is encouraged and drought-resistant plants are established.

Three types of irrigation systems are commonly used in restoration projects: drip, sprinkler, and spraying. The selection of an irrigation type will depend upon the goals of restoration, the size of an area, the quality and quantity of water available, and cost factors. The following presents a summary of the advantages and disadvantages of sprinkler and drip irrigation systems.

Drip Irrigation. Drip irrigation systems are low-pressure, low-volume systems that place water directly where the plant is growing. This technique is well suited for steep slope restoration and for woody plant establishment. Drip systems require high quality water and are labor intensive because of high maintenance requirements. However, drip systems are less expensive to install than sprinkler systems, and water can be supplied by gravity-flow from storage tanks that are periodically filled by water trucks.

Sprinkler Irrigation. Sprinkler irrigation systems are high-pressure, high-volume systems that spray water over the entire revegetated area. These systems lead to the establishment of higher plant density compared with drip systems. Sprinkler systems are able to use lower quality water and have fewer maintenance requirements than drip systems. However, sprinkler systems are more expensive to install than drip systems, and sprinkler systems require higher pressure. If storage tanks are being used to supply the water, pumps must be used to provide the pressure.

Spray Irrigation. Spray systems use either hoses or booms mounted on vehicles to apply water directly to the revegetated area or to individual plants or clusters of plants. Hand-held hoses are mounted to water trucks or water tanks. Water is applied by gravity flow, or a pump can be attached to spray the water over larger distances. Major advantages of this method are that low quality water can be used, maintenance requirements are minimal, and costs are low, especially if the irrigation is required for a short period of time (e.g., < 2 years).

Storage tanks have the advantage over trucks in that tanks are relatively inexpensive and there is a minimum of physical impact to the vegetation by truck traffic. The major disadvantage of storage tanks is that they are immobile. For larger areas to be irrigated from tanks, either multiple tanks or long hoses must be used.

The major advantage of trucks is their mobility. A single truck can be used to irrigate numerous revegetation areas, and the water can be taken to the specific location without having long hoses dragged across the revegetated area. A potential disadvantage is damage to plants from vehicle traffic. Such damage can be minimized using only established paths between revegetated strips when driving trucks. Water is applied from the truck to the strips via either hoses or spray booms. The purchase, maintenance, and operation of the trucks are the major costs associated with this method of irrigation. However, if storage tanks are used in other systems (e.g., drip systems), trucks will likely be needed to fill them.

4.4.2 Nutrient Availability

Nutrients are found in the soil in different pools. Part of the total soil nutrient pool is readily available to plants. This available pool is found in soil solution. A second portion of the total nutrient content of a soil is complexed in one form or another and slowly becomes available to the plant. These nutrients may be in organic form or on the cation exchange. The third, and usually the largest, soil nutrient pool is insoluble and not available to plants. Only as soil minerals weather does this insoluble portion of the soil nutrient supply move into one of the other pools. Fertilizers are usually added to soils as additions to the available pool, or to the pool of nutrients that is slowly becoming available.

In the vast majority of restoration projects in the western United States, the three nutrients most often found to be deficient are nitrogen, phosphorus, and potassium. Of these three, nitrogen is most commonly found to be limiting on disturbed lands. Micronutrients are rarely deficient on disturbed lands in the western United States, but soil testing should be conducted on disturbed and undisturbed reference soils to determine the need for nutrient additions. Micronutrient availability is greatly influenced by soil pH. Cobalt, copper, iron, manganese, and zinc may have reduced availability to plants when the pH is greater than 7.5 (Brady 1974).

Nitrogen. Nitrogen (N) is typically the most limiting nutrient in disturbed soils. If plant available forms of N (i.e., NO_3-N and NH_4-N) are deficient, the effect on plant growth will be seen within the first couple of weeks after a seedling has emerged. It is relatively easy to overcome N deficiency during the short term. Inorganic forms of N, such as ammonium nitrate, are readily available to plants and can be applied to the soil surface, allowing natural leaching to move the nutrient into the root zone. However, because N is so highly mobile, it can be lost to the system by leaching below the root zone or may be lost through natural processes such as volatilization and denitrification. Nitrogen applied as inorganic fertilizer can be applied just prior to seeding or after initial emergence. If N is applied in an organic form, or applied with a wood waste product, the N should be mixed into the rooting zone prior to planting.

Providing a long-term source of N is more difficult and must include a source of organic matter. The best method available for providing a long-term source of N is to use topsoil with organic matter and a healthy microbial population. However, if topsoil is not available, the next best approach is to add composted sludge or wood waste in combination with inorganic nitrogen. The soil microbial community will decompose the wood waste material and immobilized N from the fertilizer during the process. This N will then be released slowly through the process of mineralization. Approximately 6 kg of N should be added for 1 Mg of wood waste applied. The establishment of N-fixing plants should also be considered as another source of N that will have long-term benefits.

Nitrogen fertilization has been shown to stimulate the establishment and growth of annual species, and to reduce species diversity by favoring rapid growing early seral species that competitively displace slower growing late seral plants (McLendon and Redente 1991, 1994). Because of these effects, caution must be used when fertilizing with N. Undisturbed soils should be sampled for inorganic forms of nitrogen (i.e., NH_4-N and NO_3-N) to establish reference values for fertilizer recommendations on disturbed sites.

Phosphorus. Phosphorus (P) is most likely the second most limiting nutrient on disturbed lands, although it has not been reported to be deficient in Hanford Site soils. If P is limiting, it will be very difficult for most perennial seedlings to establish because of limited root development. Phosphorus is a highly immobile element and does not leach in the soil. In order for a plant to access P, it must come into contact with labile forms of P through root growth or limited P diffusion. Since young seedlings have very limited root development, growth on P-deficient soils will be difficult.

Phosphorus fertilizer is commonly applied in an inorganic form such as triple super phosphate (0-46-0). Because of its immobility, it must be incorporated into the root zone prior to planting for maximum effectiveness. Phosphorus can be added to the soil in large amounts to provide a long-term source of P without fear of loss due to leaching. However, P will become fixed to clay particles over time or incorporated into organic matter, thus reducing its availability until the soil particle weathers or the organic material is mineralized.

Potassium. Potassium (K) tends to be limited on coarse-textured soils, but its deficiency is not as common as that of N or P, and it has not been shown to be deficient in Hanford Site soils. The mobility of K is less than that of N, but greater than that of P. Loss of K to leaching is generally not a concern, except in sandy soils or soils subject to flooding.

One of the more common forms of K that can be commercially purchased is potassium chloride. This product is sold under the commercial term "muriate of potash" and contains about 60% K_2O. Potassium is most effective when incorporated into the root zone prior to seeding, but it will slowly move into the soil if surface applied after plant growth has begun.

Fertilizer Calculations. Of the three numbers printed on a fertilizer container, the first represents the percent N, the second is percent P_2O_5 (phosphorus pentoxide), and the third is percent K_2O (potassium oxide). A fertilizer bag with the formula "20-10-5" indicates that the mixture contains 20% nitrogen, 10% P_2O_5, and 5% K_2O. Nitrogen is calculated as a straight percentage. In other words, a 100-lb bag

20-10-5 contains 20 lbs of N, and a 100-lb bag of 33-0-0 contains 33 lbs of N.

Phosphorus, however, is calculated differently. A 100-lb bag of 0-46-0 contains 46 lbs of P_2O_5. The formula for calculating the percent P is $\%P_2O_5$ X 0.43. Therefore, the 100-lb bag of 0-46-0 contains only 20 lbs of P (0.46 X 0.43 = 0.20; 20% of 100 = 20).

A 100-lb bag of 0-0-35 contains 35 percent K_2O. Percent K is calculated by multiplying $\%K_2O$ times 0.83. Therefore, in this example, 0.35 X 0.83 = 0.29 K. This bag of fertilizer, therefore, has 29 lbs of K.

Organic vs. Inorganic Fertilizers. Quick-release inorganic fertilizers are recommended in this manual, because this will meet the revegetation goals stated in this manual. Slow-release inorganic fertilizers are more expensive and best suited for humid environments, especially when planting bare-root or containerized materials. Slow-release organic fertilizers have less loss due to leaching, and lower risk of burning roots of young seedlings, than quick-release inorganic fertilizers. Since leaching and root burning are not concerns at the fertilizer rates recommended in this manual, the use of slow-release fertilizers is not justified.

Organic fertilizers are not recommended for use at the Hanford Site. The best sources of organic fertilizer are sewage sludge and manure. However, these materials have a nitrogen content of only about 1%, and application rates of 4.5 Mg/ha would be needed to supply 20 kg/ha of nitrogen. The cost of transportation and application in the field would far exceed the cost of inorganic fertilizer, and the benefits to plant establishment and growth would not be noticeably different.

4.4.3 Weed Control

Weed control is usually an integral part of restoration, because of the aggressive nature of many noxious weeds and our inability to establish plant communities that are able to fully utilize all resources. Most weed control treatments do not remove entire populations of undesirable species. Thus, treated areas are constantly disposed to reinvasion. When only partially controlled, remaining plants respond dynamically by taking advantage of the environmental potential released by the reduction in plant density (Young and Evans 1974, Roundy et al. 1981). Depending upon the species and growing conditions, undesirable plants may rapidly increase their densities by crown or root sprouting, or by seedling recruitment from new or persistent seedbanks. Vegetation manipulation treatments create a temporary shift in plant succession. Once desirable perennial species gain dominance in the manipulated community, they should suppress seedlings of undesirable plants, but they may not eliminate them from the community.

Undesirable species can be controlled by chemical, mechanical, prescribed burning, or biological control methods. Each method has advantages and disadvantages, depending upon site conditions, undesirable species present, and the degree of infestation.

Herbicide use is a management technique for the elimination of undesirable plants or for the elimination of an entire species from one area. Herbicides can play a role in succession management where individual species are targeted for elimination and a specific plant community development pathway is desired. Increasingly strict regulations regarding the toxicity and secondary ecological effects of herbicides have limited the numbers of new herbicides coming on the market. However, new methods of herbicide application, which are constantly being developed, strive to deliver higher selectivity and lower environmental contamination.

Mechanical vegetation manipulation methods vary considerably in their effectiveness to control herbaceous and woody species. Equipment is generally designed either to remove the top growth of undesirable plants (e.g., by mowing, roller chopping, and rotobeating) or to remove plants by completely uprooting them (e.g., by grubbing, bulldozing, chaining, root plowing, and disk plowing). Uprooting is associated with the control of undesirable woody plants and has less applicability at the Hanford Site than mechanical procedures using top removal, such as plowing or mowing.

The responses of plants to top removal, and the responses of surrounding plants when the tops of neighbors are removed, are critical to restoration success. Differential abilities of species to use stored carbohydrate in structures at the soil surface or below ground are important in community development after top removal. In addition, top removal may involve a radical change in the population structure of plants. This is especially true for plants with vegetative reproduction, because cutting tends to reduce apical dominance and also releases dormant buds on residual plant structures. Finally, top removal can suddenly change the availability of resources to other plant species, thereby allowing seedling establishment of increased growth.

Prescribed burning is when fires are intentionally set to create a designed disturbance to control colonization or to control species performance. Responses of individual species to fire are a function of various plant traits or adaptations that interact with fire. Many species are adapted to fire and may even require fire for regeneration. On the other hand, some plant species (e.g., big sagebrush) are not fire-adapted and would thus not regenerate after fire.

Biological methods of manipulating undesirable species range from the use of natural enemies (i.e., insects and pathogens) to selective grazing by large herbivores. Biological control has had its greatest success when both the species to be controlled and the predator have been introduced. Weeds usually arrive without their natural population controls; hence, they thrive and often become more aggressive pests than in their original habitats. No sound basis exists for selection of insects to introduce for biological control. The predator and host can be matched closely in terms of climate and competitors, but success or failure must be determined by actual testing and introduction. There is no shortcut in finding the ideal enemy for an undesirable plant. Some of the characteristics of an effective natural enemy are (1) high searching ability, (2) high degree of host specificity, (3) a reproductive capacity as great as the host, (4) adaptability to the host environment, (5) permanence where the host appears annually, and (6) environmental safety. Effective biological control usually results in low host numbers, rather than complete eradication. As the weed population declines, so does the predator, but small amounts of the host support a permanent population of the predator.

Grazing animals (such as goats and sheep) are commonly used to control undesirable species. However, in order to be effective, planned grazing prescriptions must be followed so that favorable results are not left to chance. In the last two decades, research has shown that food imprinting with training near weaning time, social learning from mothers and other adults, and individual learning from post-ingestive consequences describe three ways by which young domestic animals learn and can be trained to select certain foods (Provenza and Balph 1988, Provenza et al. 1992). Thus, the possibility exists that they can be trained to graze certain noxious plants.

4.4.4 Herbivory Control

Protective management practices may be necessary during the first few years after revegetation to protect vegetation and soils from the effects of excessive herbivory. Although such protection may be difficult to achieve on certain types of disturbances, in many cases inadequate control of herbivory may nearly destroy reestablished vegetation. Livestock grazing may be controlled with judicious fencing; however, control of large and small wild herbivores is more difficult to attain. Unusual practices (such as application of chemical grazing repellents, specialized fencing techniques, or perhaps, introduction of carnivores to control smaller herbivores) may become necessary if wildlife herbivory becomes too excessive.

4.5 INTERMEDIATE- AND LONG-TERM MANAGEMENT

4.5.1 Short-Term and Intermediate Management Options

The dynamics of reclaimed systems may be influenced by the application of various types of management following initial revegetation inputs. While effects of initial manipulations of site and biotic factors may persist, such manipulations are applied only at the outset of the reclamation process. In contrast, management options may be applied repeatedly over time. Broad goals of management, therefore, are to further accelerate and direct ecosystem recovery following initially applied treatments.

Despite the recognized importance of management, relatively little research on the ecological effects of varied managerial practices has been conducted on disturbed lands in the semi-arid west. Certainly, many potentially effective practices exist during the intermediate time frame following revegetation. For example, ecosystem processes such as plant species interactions and nutrient cycling may be influenced by the management practices of mowing, prescribed burning, or spraying with selective herbicides. Deferred interseeding or interplanting may be managerial approaches to induce plant species compositional changes after sites have undergone sufficient autogenic modification to allow the establishment of later successional species.

Interseeding is the method of introducing or reintroducing desirable plant species into an existing plant community when it is either impractical or undesirable to remove the existing vegetation or to implement complete seedbed preparation. Interseeding consists of seedbed preparation in strips to remove perennial and annual competition, and seeding or planting more desirable species. Interseeders are available commercially. They typically have furrow openers that remove a strip of sod from each row, a seeding unit for each row, adequate control of furrow depth and seeding depth within the furrow, packer wheels, and seed hoppers or a seedbox. The furrows provide temporary elimination of existing vegetation and conserve moisture by holding water within the furrows, especially when constructed on the contour.

Herbivory can have a major influence on the development and maintenance of ecosystems in the intermediate period of time following revegetation. New seedlings need protection from large herbivores if the potential for use is considered to be high. Seedlings should be allowed to become firmly rooted, to produce significant secondary growth, and to produce a seed reserve prior to heavy animal use. The length of protection in semi-arid regions is usually two years, but it depends upon site conditions, species seeded, competition from undesirable species, and initial stand development.

Vegetation manipulation treatments, primarily the application of selective herbicides, may be required if undesirable species invade and reduce the productivity of desirable species. Before application of a manipulation treatment, possible changes in competitive interactions should be considered. In most situations, if the seeded species establish at the same time or ahead of undesirable annual species, vegetation manipulation is not needed.

The use of fertilizers to increase seedling establishment and growth in semi-arid regions is questionable. If nutrient requirements are met at the time of revegetation, it is unlikely that fertilization will be required after revegetation is complete.

Irrigation should be considered as a short-term management practice if the region receives less than 250 mm of annual precipitation, or if an extended period of drought occurs. The use of irrigation reduces the risk of revegetation failure, but must be properly applied to gain the most benefit for seedling establishment and species diversity. Irrigation is normally applied for one or two growing seasons after seeding, and is not considered to be a long-term management practice.

4.5.2 Long-Term Community Stability

The successional process tends to drive recovering ecosystems toward a state of dynamic equilibrium, during which changes in structure and species composition decline and nutrient cycling becomes more closed. While such trends have in fact been observed in successional studies on reclaimed lands (Mackey and DePuit 1985, DePuit and Redente 1988), results have indicated that full stabilization may not occur over short time frames (i.e., years and decades) under either natural or manipulated succession.

Approaches to accelerate progression toward stabilization involve many of the management practices, previously described, that are applied to influence competition. However, the ultimate ramifications of these techniques on ecosystem stabilization are largely unknown.

5.0 DEVELOPMENT OF RESTORATION PLAN

5.1 INTRODUCTION TO THE SELECTION PROCESS

Five types of sites have been identified as possible restoration/revegetation sites. At each site, a combination of three factors determines the revegetation option to be used to achieve the desired objective. These factors are (1) the type of plant community that is desired, (2) the time period in which the objective is to achieved, and (3) the intensity of use the site will be exposed to during the revegetation process. The specific objective of a revegetation project can therefore be defined by combining the choices of site, community, time, and use.

In consultation with personnel from Bechtel-Hanford, Inc. (BHI), three potential communities, five time periods, and two use levels were defined (Section 5.3). When combined with the five site types, this results in 150 potential objective scenarios (5 sites x 3 communities x 5 times x 2 use levels). However, most of these scenarios are either not ecologically possible or not cost effective from a management standpoint. For example, one of the site types is a gravel site, where all topsoil has been removed; only the gravel substrate remains. Natural revegetation on this site would involve primary, not secondary, succession. The pre-disturbance community was a big sagebrush shrubland. One of the community types is late-seral and one of the time periods is 2-5 years. It is not ecologically possible to restore a late-seral shrubland on this type of a site in 2-5 years. Plants can be established within that time period, but to redevelop a complex plant-soil-animal interactive system that is a late-seral community takes much longer, even if topsoil has been returned to the site.

The set of 150 potential objective scenarios (site-community-time-use combinations) were reduced to 22 ecologically- and management-significant scenarios (Table 5.1, Section 5.3). A specific revegetation plan is presented for each of the 22 scenarios, and a decision matrix approach is used to provide the user with rapid access to the most appropriate revegetation methodology to meet the defined objective.

5.2 DEFINING THE OBJECTIVE

The revegetation objective is defined by selecting one of the possible values for each of the four factors: site, community, time, and use (impact) level. Descriptions of the four factors are presented in this section. The decision matrix is presented in Section 5.3, and the individual revegetation scenarios are presented in Section 5.4.

5.2.1 Definitions of the Five Site Types

Sand Sites. These are in 200, 300, and 600 Areas with Quincy sands, Hezel sands, or Burbank loamy sands. These sites may be mixed with small amounts (< 10%) of small gravel (< 2 mm). Native vegetation was big sagebrush shrubland, with significant amounts of perennial grasses. These sites are bare of vegetative cover after an environmental cleanup action, and wind erosion is significant.

Gravel Sites. These are in 100, 200, 300, and 600 Areas. All topsoil has been removed at these sites leaving only the Pasco gravel formation parent material. Some have a thin subsoil consisting of sand mixed with the gravel and stones.

Sterilized Sites. These are primarily 100 Area sites, although there are small sterilized sites within the 200 and 300 Areas. The sterilized sites consist of Ephrata stony loams, Ephrata sandy loams, Quincy sands, and Burbank sandy loams above waste sites. They have been kept clear of vegetation by the application of herbicides. Prior to the mid-1980s, the herbicides were long-lived herbicides such as Ureabore. Since then, they have been treated with pre-emergent products such as diuron/bromacil, tebuthiuron, and oryzalin. Revegetation on these sites will begin after the hazardous and radioactive contaminated soils are exhumed. At that time, the non-radioactive, herbicide-treated soil will be used as a subsoil, and will be covered with adjacent surface soil mixed with Pasco gravel or stony loam soils.

Fine Soil Sites. These are in 600 Areas on northeast-facing slopes of Rattlesnake mountain and south-facing slopes of the Saddle Mountain area. Soils include Warden, Ritzville, and Lickskillet silt loams. These sites are generally more mesic than most other Hanford sites, and they have received less extensive soil disturbance than the previously mentioned sites.

Riparian Sites. These are areas along the banks of the Columbia River that are influenced by shallow groundwater or intermittent flooding in the 100, 300, and 600 Areas. The primary disturbances on these sites are physical disturbances related to construction, site excavation along the river, and old reactor discharge lines. These sites vary in microtopography from steep, short banks to long, gradual sloping areas. The lower elevations are infrequently saturated. It is crucial to maintain or restore stability to these sites, and to minimize erosion and subsequent soil loss into the Columbia River.

5.2.2 Definitions of the Four Community Types

Introduced. An introduced community is a perennial plant community composed of introduced (i.e., not native to the area) species. In most cases, these species will be perennial grasses. Introduced grasses are often less expensive to establish than native grasses, and are usually easier to establish agronomically. In addition, introduced grasses often show superior growth, compared to natives, under disturbed or heavy-use conditions. This is because they have been genetically selected to perform well under the disturbed conditions associated with cultivation. This community type option would result in the establishment of a perennial grass community that would stabilize the site for at least 20 years. After that time, some native species would likely establish on the site, resulting in a mixed introduced-native community of perennial grasses and shrubs. Although this introduced option results in a community compositionally different from the pre-disturbance native communities, it stabililizes the site and it is structurally similar to some of the native communities in the area (i.e., a grassland).

The introduced community type is not a useful option for the riparian sites. Native species can be established on this mesic site as easily as introduced species. Therefore, there is no advantage to using introduced species. In addition, planting non-native species along a plant invasion corridor, such as a river bank, would lead to regulatory violations in the future if the seeded species was later deemed to be noxious.

Native. The native option is appropriate on all sites. This objective is to establish a perennial plant community composed of native species, primarily grasses. It is similar to the introduced option, except that native perennial species are used instead of introduced species. This increases the costs somewhat because (1) seed of native species is more expensive than seed of introduced species; (2) at present, the Hanford Site Natural Resource Trustee Council for CERCLA actions is requesting locally derived, native seed; and (3) most native species are more difficult to establish than many introduced species. The advantage of the establishment of native species establishment rather than introduced species is twofold. First, native species are generally better adapted to long-term ecological conditions at a site than are introduced species. Ecological conditions can vary greatly on decade and century time scales, especially in arid and semiarid regions, and native species can tolerate most of these fluctuations. Introduced species may be well-adapted to initial conditions, especially following disturbance, but may not be well-adapted to the long-term fluctuations. Second, there is considerable social and regulatory pressure to use locally-derived native species, rather than introduced species, and this pressure from stakeholder groups is likely to increase in the future.

The native species used in this option are mostly perennial grasses, because these establish more quickly than shrubs. However, some shrub and forb seed is included in the mixtures. The community initially established will be a grassland. Over time, however, other native species (primarily shrubs) will invade the site and slowly shift it from a grassland to a shrubland.

Late-seral. Establishing a late-seral native community on the site is the most difficult and expensive of the three options to accomplish. Late-seral communities must have late successional characteristics related to composition, structure, and function of the plant community. Provided adequate soil conditions exist, target plant composition can generally be achieved by planting the proper mix of species. However, late-seral structure is also important, and it takes time for the plants to grow to maturity (10-20 years for some shrubs). Costs are higher for this option than for the other options, because some of the late-seral species cannot establish under disturbed conditions, or can only do so very slowly. Since critical late-seral conditions must be re-established before the plant community can be re-established. One primary example is soil. A number of late-seral species may require a significant layer of topsoil to be present, or significant redevelopment of parts of the soil microbial system, before the plants can adequately function on the site.

It is probable that, over time, the other options will develop late-seral communities, if the sites are not re-disturbed. However, this process may take 100-200 years. In addition, the late-seral communities that may result from this secondary succession may be significantly different than the desired late-seral community, especially in the case of the introduced option. The purpose of the late-seral option is to establish the appropriate late-seral community on the site in a relatively short period of time.

The late-seral option is appropriate on all sites.

5.2.3 Definitions of the Five Time Periods

The five time periods are (1) 2-5 years, (2) 5-10 years, (3) 10-20 years, (4) 20-50 years, and (5) 50-100 years. A range of values is given in each case. The lower value is the estimated time in which the revegetation objective could be reached under ideal conditions (e.g., above average precipitation, excellent germination, little herbivory or pathogenic attack). The upper value is the estimated time in which it could be reached under adverse, but not necessarily worst-case, conditions. Under normal conditions, something slightly less than the lower value should be expected.

These time lines define the period in which it is desired to achieve the stated revegetation objective. For example, the community option chosen for a sand site might be a native community. This objective might be planned for accomplishment in 2-5 years or in 5-10 years. The revegetation procedures (scenario) would be different for the two time periods. It will take more resources to achieve the same objective in a shorter period of time.

The shorter the time period selected for a given revegetation option, the more extensive the procedure and the higher the costs. Conversely, if time is not as important, the same revegetation option can generally be achieved at a lower cost if the time period is longer. In the latter case, the natural process of secondary succession can be used to help the revegetation process. Whenever management objectives can be matched with natural ecological processes, there will be a cost savings.

Only the 2-5 year time option is available for the introduced community option, for much the same reason. Introduced species, and their related establishment procedures, are well adapted to post-disturbance conditions and can be successfully applied in short periods of time. A major advantage of the introduced over the native option is that the introduced species can be established more quickly than the native. If time periods greater than 5 years are used, the introduced option loses much of its advantage.

The native option is limited to the 2-5 and 5-10 year periods, except for the sand site, where it can also have a 10-20 year period. Like the introduced option, the native option establishes a grassland. These grass species can be established within 10 years on most sites. Longer establishment times generally do not provide any management advantage.

Late-seral communities require more time to develop than do early- or mid-seral communities, even with extensive anthropogenic inputs. No 2-5 or 5-10 year time options are available for the late-seral community option, because the woody late-seral plants require at least 10 years to reach maturity, even under good conditions. Revegetation to late-seral conditions should be most rapid on the mesic riparian sites. Here, the moist conditions should allow the willow and late-seral grasses to reach maturity within 10-15 years. Therefore, only the 10-20 year time option is available for this community option in this community type.

The gravel site will remain an extremely xeric site for a considerable period of time. Extensive inputs will be required to establish a late-seral community on this site, and this level of effort should allow a shrubland to be established within 10-20 years. Further successional development will be slow and can occur through natural means as rapidly as with human inputs. Therefore, time options past 20 years are not included for this site.

Late-seral conditions should be attainable within 50 years on the upper elevation and sterilized sites. Extending this time period to 100 years does not significantly decrease the revegetation costs, but it would significantly increase risks associated with erosion and weed control. Therefore, only 10-20 and 20-50 year time options are presented for these two site types.

Initially, late-seral species may be difficult to establish on the sand sites, but once succession has adequately stabilized the site, complex and productive late-seral communities are possible. Establishment of a late-seral community on these sites might be possible in 10-20 years, but it would take very high inputs of resources. Establishment of the same community in 20-50 years is much more feasible. Therefore, the 10-20 year time option has not been included for this site.

5.2.4 Definitions of the Two Use Levels

The two use levels are heavy and light. Heavy use refers to frequent impacts from wheeled vehicles and/or heavy grazing and browsing by deer, elk, or geese. Light refers to infrequent and light use by vehicles and light to moderate grazing/browsing by deer, elk, or geese. If other factors are held constant; heavier use levels make the revegetation process more expensive and longer to accomplish.

The late-seral community option is not possible under the heavy use option. The late-seral communities are shrub-dominated communities; heavy use will continually reduce shrub coverage and, therefore, reverse the recovery process.

The heavy use option has also been eliminated as a possibility on the riparian, upper elevation, and gravel sites. Erosion control and bank stability are critical goals on the riparian sites. Heavy use is contrary to these goals. Upper elevation sites are far-removed from most mechanical activities of the Hanford Site. Therefore, vehicle use would be expected to be light. If grazing/browsing becomes too heavy on these sites, some of the revegetation objectives might not be possible. There is no reason for heavy vehicle use to occur on the gravel sites, except in limited areas, and heavy concentrations of deer and elk are not expected to occur there.

Conversely, heavy use is expected on the sand and sterilized sites. The introduced and native community options can withstand heavy use <u>after</u> establishment. However, heavy use during the establishment phase of the revegetation will likely result in failure and an increase in costs due to the necessity of repeating the process. Therefore, heavy use by vehicles should be prohibited on all revegetation sites until the target levels are reached. Planning for light use on the sand and sterilized sites would not alter the revegetation procedures. Therefore, light use options are not included in the decision matrix for these sites.

5.3 DECISION MATRIX

To select the proper revegetation scenario, define the objective by selecting the most appropriate option under each of the following three factors. The objective will be defined by a three-part sequence: site-community-time. Once the objective has been defined, use the sequence to select the appropriate revegetation scenario from Table 5.1. The scenarios are listed in Section 5.4, in numerical order.

<u>Site Factor</u>. Five site types are listed. Select the site type most similar to that under consideration for revegetation. Descriptions of the site types are presented in Section 5.2.1.

1. SAND
2. GRAVEL
3. STERILIZED
4. UPPER
5. RIPARIAN

Community Factor. Three community options are listed, from least difficult to achieve (1) to most difficult (3). Select one or more community options for the site under consideration for revegetation. Multiple communities may be appropriate when planning over a period of time. Descriptions are presented in Section 5.2.2.

1. INTRODUCED
2. NATIVE
3. LATE-SERAL

Time Factor. Five time periods are listed. Select one time period in which the objective is to be achieved. Discussions are presented in Section 5.2.3.

1. 2-5 YEARS
2. 5-10 YEARS
3. 10-20 YEARS
4. 20-50 YEARS
5. 50-100 YEARS

Table 5-1. List of 22 Revegetation Scenarios for Hanford Environmental Restoration Contractor (ERC) Projects.

Number	Site Factor	Community Factor	Time Factor	Use Factor
01	Sand	Introduced	2-5	Heavy
02	Sand	Native	2-5	Heavy
03	Sand	Native	5-10	Heavy
04	Sand	Native	10-20	Heavy
05	Sand	Late-seral	20-50	Light
06	Sand	Late-seral	50-100	Light
07	Gravel	Introduced	2-5	Light
08	Gravel	Native	2-5	Light
09	Gravel	Native	5-10	Light
10	Gravel	Late-seral	10-20	Light
11	Sterilized	Introduced	2-5	Heavy
12	Sterilized	Native	2-5	Heavy
13	Sterilized	Native	5-10	Heavy
14	Sterilized	Late-seral	10-20	Light
15	Sterilized	Late-seral	20-50	Light
16	Upper elevation	Native	2-5	Light
17	Upper elevation	Native	5-10	Light
18	Upper elevation	Late-seral	10-20	Light
19	Upper elevation	Late-seral	20-50	Light
20	Riparian	Native	2-5	Light
21	Riparian	Native	5-10	Light
22	Riparian	Late-seral	10-20	Light

5.4 REVEGETATION SCENARIOS

5.4.1 General Comments

The revegetation scenarios presented in Section 5.4.2 are written as specific guidelines and recommendations. However, some flexibility in application will always be necessary, because of specific conditions at a site that were unforseeable at the time this manual was written. The following general comments are presented to give an overview to guide in the applications of these recommendations, and possible modifications to them necessitated by site-specific conditions.

Pre-Planting. Soil fertility and compaction tests should be conducted before final plans for a specific revegetation project are made (Section

4.4.2). Samples should be taken of the material that will function as the initial soil, as it will exist at the beginning of the project. For example, if two materials are to be mixed, the samples should be taken after the mixing takes place, not of the two materials prior to mixing. Samples should be taken at specific depths (e.g., 20 cm) throughout the rooting zone (60 cm for grasses and 120 cm for shrubs or depth to impervious layer, whichever is less). A sufficient number of samples should be taken to adequately sample the variation over the project area. It is not possible to determine beforehand how many samples should be taken. The number will depend upon the heterogeneity of the site (Smith et al. 1994). The greater the variability, the greater the number of samples required. However, approximately 10 samples will probably be adequate for area up to several acres in size.

Each sample should be analyzed for pH, available N, available P, K, and EC (electroconductivity). If the pH is below 6.0, lime should be added to raise it to 6.0. If the pH is above 9.0, sulfur should be added to lower it to 9.0. If the EC is above 4.0, it should be reduced by leaching prior to planting. If plant available N, P, and K are similar to adjacent reference areas based on soil testing, pre-planting fertilization is not necessary.

Samples taken from sterilized sites should also be tested for inhibition of plant germination and growth. If these tests suggest that there is no significant germination or growth inhibitation from the soil sterilants, no topsoil additions are necessary. However, it is very important that these tests be conducted (1) on the soil material after it has been mixed, (2) on the various depths that the roots will be in contact with, (3) for long enough periods of time for any possible accumulative effects to be manifested, and (4) with the species that will be planted on the site.

Irrigation. Irrigation is recommended for most of the scenarios. Eliminating irrigation would reduce the costs of these scenarios. It is probable that a significant number of the scenarios will succeed in some, perhaps most, years without irrigation. However, some will fail without it, at least in some years. The wetter the year, the less necessary irrigation becomes. The drier the year, the more necessary. No one can successfully predict how wet or how dry a year will be beforehand. There is a risk involved in guessing incorrectly. The results of guessing wrong on the dry side (i.e., not irrigating when it is needed) are (1) not meeting the target levels, (2) potentially having to replant, and (3) possible erosion during the period before adequate cover is achieved. The results of guessing wrong on the wet site (i.e., irrigating when it is not necessary) is the expense of the irrigation. However, this expense might be reduced if the target levels are met sooner than expected because of the irrigation. Therefore, the project can be declared successfully completed earlier than planned.

Irrigation eliminates one source of uncertainty in revegetation. Even in average or wet years, the irrigation will allow the plants to establish and grow at a faster rate than without irrigation. In each scenario, irrigation can be discontinued as soon as target levels are met. In most cases, this will be at the end of the first year. And irrigation is not necessary if adequate rainfall is received. This point is made in each of the scenarios.

Irrigation is also a means to give perennials, both shrubs and grasses, competitive advantage over cheatgrass. By irrigating before cheatgrass begins to grow in the fall and after it sets seed in the spring, moisture can be supplied to the perennials and their growth will make invasion by cheatgrass more difficult.

The amount of irrigation recommended is based on supplying optimum conditions to the target species. Less water can be used, but this will result in a lower response to irrigation. A common recommendation is to apply 3.8 cm (1.5 in.) per month for 4 months. In an average year, this would raise the total moisture supply (precipitation + irrigation) to 32 cm (12.7 in.). This amount should provide for successful establishment and growth of the target species in any year.

Over the past 50 years (1946-95), the average March-August precipitation at the Hanford Site has been 6.4 cm (2.50 in.; Hoitink and Burk 1996). In 15 of these 50 years, 30% of the time, March-August precipitation has been less than 80% of average. In 8 of these years, 16% of the time, March-August precipitation has been less than 60% of average [< 3.8 cm (1.50 in.)].

Without irrigation, the scenarios would probably succeed in 3 out of 10 years [above-average (> 120% of average) March-August precipitation], might succeed in 4 out of 10 years [average (80-120% of average) March-August precipitation], and would probably fail in 2 out of 10 years [below-average (< 80% of average) March-August precipitation]. With irrigation, they would probably succeed in all years.

Costs. Each scenario contains a relative cost estimate. These estimates are very general. The actual costs will vary by current prices of site preparation, seed, fertilization, irrigation methods chosen, and labor costs. These costs change on a seasonal, if not monthly, basis, and some will be specific to the Hanford Site. Therefore, it is not possible to be specific relative to them in this document. However, the following general categories apply: (1) very low = < $ 1,000 per acre; (2) low = $ 1,000 to $ 5,000 per acre; (3) moderate = $ 5,000 to $ 10,000 per acre; and (4) high = > $ 10,000 per acre.

5.4.2 Listing of Scenarios

Section 5.4.2 presents the appropriate methodologies for the revegetation scenarios defined in Section 5.3 and listed in Table 5.1. They are presented in numerical order. The seed mixtures for the scenarios are presented in Section 5.5.

5.5 SELECTION OF PLANT MATERIAL

5.5.1 Guidelines for Selection

There are six primary considerations involved in the selection of plant material for a revegetation effort: (1) ecological appropriateness, (2) social appropriateness, (3) availability, (4) compatability, (5) viability, and (6) cost. Each of these six factors can change over time. Therefore, the appropriateness of the selection can also change. For this reason, recommendations should be reviewed periodically to ensure that the suggested mix is still the most appropriate for current conditions.

Ecological Appropriateness. The foremost consideration is whether or not the species, or combination of species, is proper for the ecological conditions and objectives of the revegetation effort. Many of these applications are obvious. Lifeform, climatic, and edaphic limitations must be taken into consideration. Woody plants should not be used on sites subjected to frequent disturbances, species adapted to mesic environments are not likely to grow well in deserts, and species adapted to sandy soils may not establish well on clays. However, other ecological considerations may not be as obvious. Late-seral species may not establish well under early-successional conditions. Some shrubs, such as big sagebrush, are poorly adapted to fire. Some introduced species, such as crested wheatgrass, are very competitive against native species and are difficult to eliminate once they become established during the time periods stated in section 8. Ecological characteristics of the species should always be matched with site conditions and management objectives.

The concept of genetic appropriateness is sometimes confused with ecological appropriateness in revegetation and restoration projects. From a scientific standpoint, for genetic appropriateness to be of concern in revegetation work, there must be enough difference in ecological response within the species to significantly affect the response of the plants to the environmental conditions at the site. If not, then the questions of genetic appropriateness are of social, not ecological, concern. An example may help illustrate the point.

There are four subspecies of big sagebrush (McArthur 1983). The two most widespread are basin big sagebrush (A. tridentata spp. tridentata) and Wyoming big sagebrush (A. tridentata spp. wyomingensis). Basin big sagebrush is better adapted to deep, seasonally-dry, and fertile soils while Wyoming big sagebrush is better adapted to drier and more shallow soils (Barker and McKell 1983). This adaptation of Wyoming populations to xeric sites may be due, in part, to it being genetically adapted to a shorter growing season. Wyoming populations flower and set seed earlier than basin populations (Barker and McKell 1986), and seedlings of Wyoming populations reach maximum growth earlier, and stop growth earlier, in the growing season than basin seedlings (Booth et al. 1990).

Field observations strongly suggest that Wyoming big sagebrush is better able to tolerate low soil moisture levels than basin big sagebrush (Barker and McKell 1983), but greenhouse studies do not support this for seedlings (Barker and McKell 1986). Basin seedlings grow taller and produce more aboveground biomass than Wyoming seedlings (Barker and McKell 1986, Booth et al. 1990). Welch and Jacobson (1988) found rooting depth of seedlings at the end of the growing season to be equal between basin and Wyoming seedlings, but that early-season root growth was more rapid for Wyoming seedlings. They attributed the greater drought tolerance of Wyoming populations to higher root:shoot ratios. Bonham et al. (1991) suggested that basin populations are more adapted to more disturbed and sandy sites than Wyoming populations.

These studies show significant ecological differences between the two populations. Commerical seed may not be labeled as to which subspecies the seed is from. However, differential responses between subspecies may be very important in determining success or failure in a revegetation project.

The nearer the seed source to the revegetation site, the less risk there will be that genetic variability will adversely affect revegetation. If a species is widely distributed, material that grows naturally within 180 km north and 100 km south of the revegetation site will probably be ecologically appropriate for the site (Cooper 1957, Thornburg 1982). If a species is very restricted in its range, or if its distribution is discontinuous over the region, it may be more ecologically important to use material from the nearest population.

<u>Cultural Appropriateness</u>. Cultural appropriateness may be based on ecological criteria, but most often it is not. The question of using native or introduced species in revegetation has an ecological aspect. There are scientific reasons for using one or the other. However, a regulatory decision might be made that stipulates that only native species will be used. Such a decision may have a strong cultural basis to it. Likewise, decisions to require the use of local seed may be more culturally-based than ecologically-based. Tribal, or stakeholder input is important, therefore, cultural issues are incorporated by the Environmental Restoration project.

Guidance on preparing revegetation plans on specific Environmental Restoration Contractor (ERC) projects requires contact with the Natural Resources Group. Input from Native American tribes, the Natural Resource Trustee Council, and stakeholder groups are coordinated with specific revegetation plans before implementation. Specific revegetation objectives will be considered to determine the specific revegetation scenario guidance. Current seed availability will also be determined for each specific seed mixture during this review.

<u>Availability</u>. Often there are problems in the availability of specific plant material. This is especially true with less-common native species and with locally-produced material. It is generally less of a problem with common commercial varieties of native species and with most introduced species. When adequate amounts of the material of choice are not available, the decision has to be made to either wait until adequate quantities are available or to substitute some other species or cultivar. If the decision is made to wait, the site will remain unstabilized for a longer period of time, increasing those associated risks. Generally, it is better to substitute than to wait. However, with proper planning, it should be possible to have adequate quantities available prior to the beginning of the project; thus, substitution is less of a problem.

<u>Compatability</u>. Seed of some species may not be compatable with the equipment available or with the other seeds being used in the mix. Some awned or bristled seed can be broadcast seeded, but not drilled unless the awns or bristles are removed. This removal process increases the cost of the seed. If broadcasting is to be used, there likely will not be a problem. However, if the revegetation plan calls for drilling the seed, then (1) the awned species will have to be left out of the mix, (2) the species will have to be de-awned, thereby increasing costs, or (3) the species will have to be seeded separately, also increasing costs. If the species is a minor component of the mix, or if there is an adequate substitute, the first option probably will be chosen. If the species has significant potential for use in the revegetation plan, however, the second or third option might be selected.

Viability. Purchasing cheap, low-viability seed will not reduce the cost of a revegetation project. It will increase the costs. Seed should always be purchased on a pure live seed (PLS) basis.

Plant material is of little use in a revegetation program if it is not viable. One reason seed is commonly inexpensive is because it is of low viability. In revegetation work, seed cost should not be an item in the budget; the cost of viable seed should be. The success of a revegetation effort is influenced less by how many seeds are planted than by how many seeds germinate. All seeding programs should be on a PLS basis. Similarly, healthy tublings, cuttings, sprigs, or transplants should be used when vegetative material is needed. The cost of transporting and planting dead material is just as high as that for live material. Suppliers of plant material should be selected on the basis of costs per unit of live material, rather than lowest cost per pound or per tubling.

Cost. Cost is an important consideration for any revegetation project, and the costs of plant material vary significantly. These variations are considered when establishing and reviewing planting recommendations for ERC projects.

5.5.2 Seed Mixtures

The 22 revegetation scenarios require 14 seed mixtures, some of which also include vegetative material. These mixtures are listed below, in numerical order.

All rates listed below are moderate drilled rates. Heavy drilled rates are 50% higher. Broadcast or imprint seeded rates are twice the respective drill rate.

Species used in the seed mixes and number seeds per pound are included in Table 5-2 (Thornburg 1982, Curtis 1989, Fulbright et al. 1982, Redente 1982, Vories 1981).

Table 5-2. Species Seed per Kilogram

Species	Number of Seeds per Kilogram
Crested wheatgrass	660,000
Siberian wheatgrass	350,000
Thickspike wheatgrass	330,000
Bluebunch wheatgrass	310,000
Prairie junegrass	4,630,000
Indian ricegrass	350,000
Sheep fescue	1,500,000
Sandberg bluegrass	1,985,000
Big bluegrass	1,950,000
Sand dropseed	12,350,000
Needle and thread	250,000
Mammoth wildrye	120,000
Sand wildrye	840,000
Basin wildrye	330,000
Yellow sweetclover	575,000
Scurf pea	57,000
Gray rabbitbrush	1,445,000
Big sagebrush	5,290,000
Antelope bitterbrush	34,000
Woods rose	110,000

Seed Mixture 01

Scenarios: 01 Sand, introduced, 2-5, heavy

Agropyron cristatum	crested wheatgrass	5.6 kg PLS/ha (5lbs PLS/ac)
Agropyron sibericum	Siberian wheatgrass	5.6 kg PLS/ha (5 lbs PLS/ac)
Elymus giganteus	mammoth wildrye	4.48 kg PLS/ha (4 lbs PLS/ac)
Melilotus officinalis	sweetclover	0.56 kg PLS/ha (0.5 lb PLS/ac)
Psoralea lanceolata	scurf pea	0.56 kg PLS/ha (0.5 lb PLS/ac)
	Total	16.8 kg PLS/ha (15 lbs PLS/ac)

Seed Mixture 02

Scenarios: 02 Sand, native, 2-5, heavy
03 Sand, native, 5-10, heavy
04 Sand, native, 10-20, heavy

Agropyron dasystachyum	thickspike wheatgrass	5.6 kg PLS/ha (5 lb PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Koeleria cristata	prairie junegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Psoralea lanceolata	scurf pea	0.56 kg PLS/ha (0.5 lb PLS/ac) or rhizomes
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
Stipa comata	needle-and-thread	2.24 kg PLS/ha (2 lbs PLS/ac)
	Total	18.2 kg PLS/ha (16.25 lbs PLS/ac)

Seed Mixture 03

Scenarios: 05 Sand, late-seral, 20-50, light
06 Sand, late-seral, 50-100, light

Agropyron dasystachyum	thickspike wheatgrass	1.68 kg PLS/ha (1.5 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Koeleria cristata	prairie junegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	1.12 kg PLS/ha (1 lb PLS/ac)
Psoralea lanceolata	scurf pea	0.56 kg PLS/ha (0.5 lb PLS/ac) or rhizomes
Purshia tridentata	antelope bitterbrush	1.12 kg PLS/ha (1 lb PLS/ac)
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
Stipa comata	needle-and-thread	1.12 kg PLS/ha (1 lb PLS/ac)
Artemisia tridentata	big sagebrush	6-mo tublings
	Total	14.84 kg PLS/ha (13.25 lbs PLS/ac)

Seed Mixture 04

Scenarios: 07 Gravel, introduced, 2-5, light

Agropyron cristatum	crested wheatgrass	5.6 kg PLS/ha (5 lbs PLS/ac)
Agropyron sibericum	Siberian wheatgrass	5.6 kg PLS/ha (5 lbs PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Melilotus officinalis	sweetclover	0.56 kg PLS/ha (0.5 lb PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
	Total	15.12 kg PLS/ha (13.5 lbs PLS/ac)

Seed Mixture 05

Scenarios: 08 Gravel, native, 2-5, light
Scenarios: 09 Gravel, native, 5-10, light

Agropyron dasystachyum	thickspike wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
Stipa comata	needle-and-thread	0.56 kg PLS/ha (0.5 lb PLS/ac)
	Total	12.88 kg PLS/ha (11.5 lbs PLS/ac)

Seed Mixture 06

Scenarios: 10 Gravel, late-seral, 10-20, light

Agropyron dasystachyum	thickspike wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
Artemisia tridentata	big sagebrush	6-mo tublings
	Total	13.72 kg PLS/ha (12.25 lbs PLS/ac)

Seed Mixture 07

Scenarios: 11 Sterilized, introduced, 2-5, heavy

Agropyron cristatum	crested wheatgrass	5.6 kg PLS/ha (5 lbs PLS/ac)
Agropyron sibericum	Siberian wheatgrass	5.6 kg PLS/ha (5 lbs PLS/ac)
Elymus giganteus	mammoth wildrye	3.36 kg PLS/ha (3 lbs PLS/ac)
Melilotus officinalis	sweetclover	0.56 kg PLS/ha (0.5 lb PLS/ac)
	Total	15.12 kg PLS/ha (13.5 lbs PLS/ac)

Seed Mixture 08

Scenarios: 12 Sterilized, native, 2-5, heavy
13 Sterilized, native, 5-10, heavy

Agropyron dasystachyum	thickspike wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Festuca ovina	sheep fescue	2.24 kg PLS/ha (2 lbs PLS/ac)
Koeleria cristata	prairie junegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
Stipa comata	needle-and-thread	1.12 kg PLS/ha (1 lb PLS/ac)
	Total	17.92 kg PLS/ha (16 lbs PLS/ac)

Seed Mixture 09

Scenarios: 14 Sterilized, late-seral, 10-20, light

Agropyron dasystachyum	thickspike wheatgrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Koeleria cristata	prairie junegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lb PLS/ac)
Stipa comata	needle-and-thread	1.12 kg PLS/ha (1 lb PLS/ac)
Artemisia tridentata	big sagebrush	6-mo tublings
	Total	14.28 kg PLS/ha (12.75 lbs PLS/ac)

Seed Mixture 10

Scenarios: 15 Sterilized, late-seral, 20-50, light

Agropyron dasystachyum	thickspike wheatgrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Koeleria cristata	prairie junegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Stipa comata	needle-and-thread	1.12 kg PLS/ha (1 lb PLS/ac)
Artemesian tridentata	big sagebrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
	Total	14.84 kg PLS/ha (13.25 lbs PLS/ac)

Seed Mixture 11

Scenarios: 16 Upper, native, 2-5, light
17 Upper, native, 5-10, light
19 Upper, native, 20-50, light

Agropyron dasystachyum	thickspike wheatgrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	4.48 kg PLS/ha (4 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Festuca ovina	sheep fescue	1.12 kg PLS/ha (1 lb PLS/ac)
Koeleria cristata	prairie junegrass	1.12 kg PLS/ha (1 lb PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	4.48 kg PLS/ha (4 lbs PLS/ac)
Stipa comata	needle-and-thread	0.56 kg PLS/ha (0.5 lb PLS/ac)
Artemesian tridentata (for scenario 19 only)	big sagebrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
	Total	17.92 kg PLS/ha (16 lbs PLS/ac)

Seed Mixture 12

Scenarios: 18 Upper, late-seral, 10-20, light

Agropyron dasystachyum	thickspike wheatgrass	1.12 kg PLS/ha (1 lb PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	4.48 kg PLS/ha (4 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Festuca idahoensis	Idaho fescue	1.12 kg PLS/ha (1 lb PLS/ac)
Koeleria cristata	prairie junegrass	1.68 kg PLS/ha (1.5 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	1.12 kg PLS/ha (1 lb PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Stipa comata	needle-and-thread	0.56 kg PLS/ha (0.5 lb PLS/ac)
Artemisia tridentata	big sagebrush	6-mo tublings
	Total	12.88 kg PLS/ha (11.5 lbs PLS/ac)

Seed Mixture 13

Scenarios: 20 Riparian, native, 2-5, light
21 Riparian, native, 5-20, light

Elymus arenicola	sand wildrye	1.12 kg PLS/ha (1 lb PLS/ac)
Elymus cinereus	basin wildrye	3.36 kg PLS/ha (3 lbs PLS/ac)
Poa juncifolia	alkali bluegrass	4.48 kg PLS/ha (4 lbs PLS/ac)
Rosa woodsii	Woods rose	1.12 kg PLS/ha (1 lb PLS/ac)
	Total	10.08 kg PLS/ha (9 lbs PLS/ac)

Seed Mixture 14

Scenarios: 22 Riparian, late-seral, 10-20, light

Elymus arenicola	sand wildrye	1.12 kg PLS/ha (1 lb PLS/ac)
Elymus cinereus	basin wildrye	3.36 kg PLS/ha (3 lbs PLS/ac)
Poa juncifolia	big bluegrass	4.48 kg PLS/ha (4 lbs PLS/ac)
Rosa woodsii	Woods rose	1.12 kg PLS/ha (1 lb PLS/ac)
Salix sp.	willow	8-in. cuttings
	Total	10.08 kg PLS/ha (9 lbs PLS/ac)

6.0 EVALUATION CRITERIA

6.1 CRITERIA FOR SUCCESS

6.1.1 Short-Term Criteria

The revegetation process will proceed through a series of stages roughly corresponding to stages of secondary succession. These are described in Section 5.4 for each of the 22 revegetation scenarios. The recovery, and therefore the success of the revegetation project, will be evaluated on be basis of (1) the total plant canopy cover, (2) the relative composition of the plant community, and (3) the survival and growth of woody plants, if woody plants are part of the scenario.

Target values are defined for each evaluation variable, each year, and each site. These are the minimum values for the respective variable that indicate success for that year. The vegetation will be sampled at the end of the growing season, according to the methodology presented in Section 6.2.3, and the recorded values will be compared to the target values for that year. If the recorded values meet or exceed the target levels, the revegetation project has been successful for that year and no follow-up treatments are required. If the recorded values are below the target values, follow-up treatment is required that year; the treatment is then listed in the scenario text. This process of sampling and comparing to target values is to continue until the target values for the last year in the scenario are reached. Once this endpoint is reached, the revegetation project can be declared successful.

The first evaluation target variable is total canopy cover, expressed as a percentage (e.g., 25%). The target value is based on the ecological conditions of an average year. If precipitation is below average, this value should be adjusted downward by an amount proportional to the amount that precipitation was below average. The evaluation is to take place at the end of each growing season. The precipitation value compared to average should be the amount received during the 12 months preceding the sampling date.

The next set of evaluation target variables are relative canopy cover by species or group of species. The use of relative cover values eliminates the need to adjust for annual climatic variability.

The final set of evaluation target variables relate to woody species, if they are part of the initial restoration procedure. For the first few years of a scenario, these are usually survival variables. Thereafter, they are total canopy or relative canopy cover variables.

6.1.2 Possible Effects of Climatic Fluctuations

Each revegetation scenario has a time line associated with it (e.g., 5-10 years). The spread in these values is to allow for the effect of ecological variability, primarily precipitation. If the years following planting are above average in precipitation, the scenario should be completed within the lower limit of the spread (e.g., 5 years). Conversely, if the years following planting are below average in precipitation, the scenario will likely require the upper limit for completion (e.g., 10 years). If drought continues throughout the entire period of the scenario, it is unlikely that the objective will be reached in the expected time period unless irrigation is applied for the entire period.

6.2 MEASUREMENT METHODS

6.2.1 Vegetation Sampling Concepts

There is no universal vegetation sampling technique, and no one technique that provides the data to answer all questions. Each technique has its advantages and disadvantages, and adds information that other techniques do not. With unlimited time and money, all techniques could be used to obtain the maximum amount of information. However, with limited resources, it is important to select the appropriate methods (i.e., the methods that will provide the data necessary to answer the required questions at a minimum expenditure of resources).

One question needs to be answered: "Has the particular revegetation scenario been successful?" The vegetation sampling method chosen must provide the data required to answer this question with a minimum expenditure of resources. If fewer resources are required to validate success, more resources should be available to conduct revegetation.

Success is defined in each scenario on the basis of achieving pre-determined levels of plant community development. There are three major aspects to vegetation that can be sampled: composition, structure, and function. Functional restoration is not a requirement of any of the revegetation scenarios; therefore, it is not necessary to sample to verify its redevelopment.

Revegetation success is defined in the scenarios on the basis of structure and composition. The plant communities to be established by the revegetation scenarios are either grasslands or shrublands. Cover is a widely used measurement for composition and structural aspects in grasslands and shrublands.

Cover refers to the percentage of the ground surface, perpendicular vertical projection, that is covered by the plant. Cover data are of two types: basal and canopy. Basal cover refers to the amount of the ground surface covered by the base of the plant at ground surface. Canopy cover refers to the amount of ground surface covered by the vertical projection of the entire canopy of the plant. Basal cover is generally a better measure of long-term dynamics. Canopy cover is generally a better measure of the ecophysiological importance of a species within a community. Basal cover is relatively easy to measure for many species, including some perennial grasses and most trees, but it can be difficult to measure for multi-stemmed shrubs, many forbs, and many grasses.

When comparing among species, canopy cover is generally preferred over basal, because it is a better indicator of ecological importance. For example, most perennial forbs and many semi-shrubs have relatively small basal areas. Yet their relatively small stems support significant amounts of canopy, and the leaves of these canopies produce the biomass that is the primary production of a community and that influences the amount of resources utilized by the plant.

Canopy cover will be used as the primary variable to measure changes in composition and structure in the revegetation projects. The changes will then be compared to expected changes to determine whether or not (1) the revegetation scenario is on schedule, and (2) the endpoint of the project has been achieved. The former is a measure of temporal success, and the latter is a measure of final project success.

Cover can be sampled by three general methods: transects, points, and estimates (Brown 1954, Oosting 1956, Bonham 1989). Transects can be of two types: line or belt. A line transect is simply a line drawn between two points, generally with a measuring tape. A belt transect consists of two parallel lines and the area between them. Belt transects are most often used to sample attributes that require area, such as density of shrubs. Line transects are used to sample cover of all life forms. Belt transects will be used to sample survival and density of shrubs in these revegetation projects, and line transects will be used to sample cover of all life forms.

Once a line transect is established, canopy cover can be easily sampled along it. Simply position yourself directly over a portion of the transect and record the amount of the transect between two finite points that is covered by the canopy of each species. Care should be taken to position yourself directly above the segment you are sampling, and to always record from the same side of transect if you are using a tape. Care should also be exercised in placing the tape so that the tape is as near the ground surface as possible and the vegetation is disturbed as little as possible.

Cover data can also be sampled using the point method. One technique is to use a point-frame, which consists of metal pins arranged along a frame. This technique results in very accurate cover data, but its use is largely limited to relatively low-growing plants. An alternative method is the transect point technique. This is the method that will be used to gather the cover data to test for success in the revegetation scenarios. In this method, a line transect is located and the species occurring at each mark along the transect (e.g., mm or cm) are recorded. The number of "hits" is then summed for the transect for each species. This method results in a sample that is more representative of the area than a single point-frame, since it extends over a larger distance.

The third method of determining cover is by estimation. This is the simplest method, but it is the least accurate. A plot frame is used in this method. The plot is divided into a grid, with the grids subdivided into smaller grids corresponding to standard subdivisions of its area (e.g., 10%, 1%). Once the frame is in place, the percent cover of the target species is estimated to some predetermined accuracy level (e.g., 5%). This method is rapid and easy to use; therefore, a relatively large number of plots can be recorded within a given period of time. Its disadvantage is that it is very dependent upon the estimating ability of the observer.

6.2.2 Sampling Design for the Hanford Site

Each contiguous area treated with the same revegetation scenario at the same time will be treated as a single treatment unit (TU). Each TU will be monitored individually, using a standardized sampling design based on a stratified random placement of line transects. This method will result in a cost-efficient and statistically unbiased sample (Butler and McDonald 1983). The sampling will be conducted at, or near, the end of the growing season each year, until the objectives of the revegetation project are met.

If the TU is sufficiently large that ecological conditions (e.g., soil texture, microtopography, or distance from established vegetation) are likely to differ significantly within its boundries, the TU should be divided into multiple TUs, each one having relatively homogenous conditions within it and each one treated as a separate TU for sampling purposes. Long, linear TUs, such as ditches, should also be subdivided into multiple TUs, because ecological conditions are unlikely to remain homogenous over relatively long distances (e.g., > 1 km).

Standard Sampling Design. A permanent line transect will be placed down the center of the TU along the longest axis of the TU. The line will then be divided into five equal segments. Permanent markers, such as half-in. rebar stakes, will be placed at the beginning and ending points of the transect and at the ending points of the segments.

Each TU will be sampled near the end of each growing season throughout the timeline defined by the scenario. To sample the TU, first randomly locate two points within each of the five segments of the center line. These points are to be randomly relocated each year. Extend a meter tape outward from each of these ten points, perpendicularly in both directions, until the outer boundary of the TU is reached in both directions. Place a temporary stake at the beginning and ending points of the tape. The permanent center line should be approximately in the center of the tape. Either fasten or hold one end of the tape at the beginning stake and the other end at the ending stake, taking care to move the tape along the ground without damaging the vegetation or trapping the upper stems and leaves of the plants under the tape.

At each meter mark along the tape, record the number of 1-cm points that a plant extended over, or that was below, the mark. There are 100 potential "hits," 1 cm per hit. Record cover by species and for all species combined (equal to the total canopy cover). Continue this procedure for each 1-m segment until the end stake is reached. For each species individually, add the total number of "hits" recorded for that species along the transect, then divide that sum by the length of the transect in meters. This quotient is the percent cover for that species along that transect. Compute a similar total canopy cover value for that transect.

If shrub survival is to be measured, form a belt transect along the line transect by measuring 50 cm out from each side of the line transect, along the entire length of the transect. Count the number of live shrubs within each 1 m^2 segment formed by both 50-cm halves along each 1 m of the transect. Add the total number of live shrubs encountered within the belt transect, then divide by the length of the transect to determine live shrub density.

Repeat the line transect and, if appropriate, the belt transect process for all 10 transects in the TU.

6.3 STATISTICAL METHODS

Data will be analyzed by individual TU. Each transect constitutes an observation. Therefore, there are 10 observations per variable per TU.

Compute the mean total canopy cover for the TU by adding the values from the 10 transects and dividing the sum by 10. Compare the mean value to the target value defined in the respective scenario. If the mean meets the target level, the revegetation scenario has been successful for that variable, for that year. If the mean does not meet the target level, follow-up action is required.

Compute the 95% confidence interval of this mean in the following way.

1. Subtract the mean from each of the 10 observations.
2. Square each of the 10 differences.
3. Sum the 10 squares.
4. Divide this sum by 9.
5. Take the square root of the quotient.
6. Divide the square root by 10.
7. Multiply this quotient by 2.26.

The 95% confidence interval of the mean is the mean plus or minus the value computed in Step 7. The 95% confidence interval of the mean should be reported whenever the mean is reported. The smaller the confidence interval is, the more uniform the cover will be over the TU. A large confidence interval indicates patchiness in the vegetation and makes conclusions based on the mean tentative.

Compute relative canopy cover values for each variable required by the scenario (e.g., native perennial grasses). For an individual species, this is done by dividing the cover value for that species along a single transect by the total canopy cover value along that transect, then multiplying this fraction by 100 to convert to percent. For a combination of species (e.g., native perennial grasses), first sum the canopy cover values for those species within the combination, then divide this sum by total canopy cover and multiply by 100.

Compute the appropriate mean relative cover values for the TU by adding the values for the 10 transects and dividing this sum by 10. Compare this mean value to the respective target value from the scenario. If the mean value meets the target level, the revegetation scenario has been successful for that variable for that year. If the mean value does not meet the target level, follow-up action is required. Compute confidence intervals for relative cover means in a similar manner to total cover. If required by the scenario, compute mean shrub survival rate or density for the TU and compare to the target value. Also compute the confidence interval for this mean.

A scenario is successful for the TU for a given year if all measurement variables meet the target levels defined by the scenario. If any variable fails to meet the target level, follow-up action is required. Revegetation of a TU can be declared completed when all target levels defined for the last year of the scenario have been met. Normally, this will occur during the latter part of the scenario timeline. However, it could occur in fewer years than predicted by the scenario, or it could take longer than the predicted time to occur.

6.4 PROCEDURES FOR CHANGES IN RESTORATION PLAN

6.4.1 The Need for a Review Process

This document is produced as a working document. It is expected that changes will need to be made over time, because (1) experience will result in improvements in methodologies and guidelines, (2) future research will lead to new knowledge and perhaps new technology, and (3) goals and objectives may change.

This document contains many specific recommendations. These recommendations are based on current scientific knowledge and the personal experience of the authors. This knowledge and experience is not uniformly available for each aspect of each option. As the recommendations are put into practice, some recommendations will need to be modified in light of on-site experience. At the same time, new data will become available from the scientific literature. This literature should be reviewed, and new findings should be applied to the projects at the Hanford Site. New technology or modifications of present technology may provide practical options in the near future that are not currently available. And, finally, goals and objectives may change. Regulatory guidelines change, as do Government policy and cultural awareness. There will be the opportunity for these changes to be incorporated as they become manifested.

6.4.2 The Review Process

The purpose of the review is to keep this manual up-to-date with current developments. The review will include: (1) an ongoing review of recent scientific literature, (2) new knowledge gained from similar current revegetation projects by BHI and other Hanford Site projects, and (3) initial results from the application of the recommendations of this manual to revegetation projects at the Hanford Site.

The ongoing review of scientific literature will be conducted on an annual basis, either by BHI employees or by a subcontractor. All pertinent literature published within each 12-month period, beginning with 1996, will be reviewed for possible applications to the projects at the Hanford Site. Any significant findings that apply to the scope of this manual will be presented in an annual report. This report will document the scientific study, the applications to the Hanford Site, and the proposed changes to the manual based on the literature, and will provide a justification of these proposed changes.

BHI personnel, and other persons associated with the development and use of this manual, should document any new knowledge that might change any of the recommendations in this manual. Such documentation, which will be prepared for review on an annual basis, should include (1) the specific part of the manual to which the information pertains, (2) the new information, (3) the suggested change to the manual that is based on the information, and (4) justification for the change.

As the recommendations of this manual are applied to projects at the Hanford Site, a significant amount of information will become available relating to the degree of success of each recommendation. This data should be documented and applied to the annual review process. Data will be collected from the application of each scenario, as required by sub-section 4 of each scenario. BHI personnel will then summarize project monitoring reports and recommendations for changes to the manual's procedures will be made with corresponding justification based on observed results.

Project monitoring called for by Section 6.4.1 will be reviewed on an annual basis. Any significant changes in goals or objectives relative to the revegetation/restoration process at Hanford should also be made at this time. Based on this review, changes can be made to the manual. These changes may be to the recommendations, or to the background information contained in the manual. Care must be taken to present the rationale for making the changes and to consider if the changes will adversely affect some other part of the recommendations of the manual.

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8.0 SCENARIOS

SCENARIO 01

SITE:	Sand
COMMUNITY:	Introduced
TIME:	2-5 years
IMPACTS:	Heavy

1. <u>Pre-Planting Procedures</u>:

Physical Seedbed: Harrow lightly to smooth surface.

Chemical Seedbed: None unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).

Topsoil Addition: None

Fertilization: Single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac) surface or subsurface application at time of planting.

Weed Control: Disc before weeds set seed in growing season prior to planting; repeated operations may be necessary (April, June, and September).

If cultivation is not possible, apply low-label rates of glyphosate/2,4-D at a 1:2 ratio to reduce weed seed viability.

2. <u>Propagation Procedures</u>:

Species: Species Mixture 01

Source: Any

Method: Drill, half-in. depth, 0.3 m (12 in.) row spacing; or broadcast and then lightly harrow.

Season: September-November

Mulching: Apply hay or straw at 4.5 Mg/ha (2 T/ac) after planting; crimp mulch into soil surface, or apply 2.5 cm (1 in.) gravel.

3. <u>Post-Planting Procedures</u>:

Irrigation: Apply 0.24 ha-cm (1.5 ac-in.) each in April, May, June, and July until target values are met.

Any method of application can be used, but ground application from a water truck or hand lines is least expensive.

Irrigation is not necessary during those months receiving > 1.9 cm (> 0.75 in.) of rain.

Irrigation can be discontinued once the seeded perennial species reach 30% canopy cover.

Fertilization: Repeat the pre-planting fertilizer application the second growing season unless weeds are > 30% relative cover.

Weed Control: None the first three growing seasons and none thereafter if annual weeds are < 30% relative canopy cover at the end of the third growing season.

If annual weeds are > 50% relative canopy cover at the end of the third growing season, apply low-label rates of 2,4-D and dicamba in early April.

Dynamics: Year 1: Annuals (cheatgrass, Russian thistle, tumble mustard) will dominate, with lesser amounts of perennials.

Year 2: Seeded perennial species should comprise > 25% relative cover.

Year 3: Seeded perennial species should comprise > 50% relative cover.

Year 4: Seeded perennial species should comprise > 75% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total plant cover, by species, near the end of each growing season. If mean values meet target values (Section 4.3), no additional action is necessary. If mean values do not meet target values, go to follow-up.

Target Levels = Minimum of 25% total canopy cover each year, plus relative cover values of

Year 1: Any combination of species
Year 2: Seeded perennial species ≥ 25%
Year 3: Seeded perennial species ≥ 50%
Year 4: Seeded perennial species ≥ 75%

Follow-Up: If no, or very few, seedlings of seeded species are established, the problem was probably poor seed, since supplemental water was applied. Therefore, re-seed the next year using the same seed mixture, but from a different source.

If seedlings are established, but total cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each month (April-July).

If seedlings are established, but relative cover values of seeded species were below target levels, add the additional 0.8 ha-cm (0.5 ac-in.) of water each month (April-July), but no additional fertilizer.

5. Costs:

Moderate.

Seed, irrigation, and annual fertilization are the major costs.

6. Comments:

If precipitation is below average during establishment years (1-5), additional irrigation should be applied (amount equal to the precipitation deficit).

SCENARIO 02

SITE:	Sand
COMMUNITY:	Native
TIME:	2-5 years
IMPACTS:	Heavy

1. Pre-Planting Procedures:

Physical Seedbed:	Harrow lightly to smooth surface.
Chemical Seedbed:	None unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).
Topsoil Addition:	None
Fertilization:	Single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac) surface or subsurface application at time of planting.
Weed Control:	Disc before weeds set seed in growing season prior to planting; repeated operations may be necessary (April, June, and September). If cultivation is not possible, apply low-label rates of glyphosate/2,4-D at a 1:2 ratio to reduce weed seed viability.

2. Propagation procedures:

Species:	Species Mixture 02
Source:	Local < 180 km (< 100 mi), if possible.
Method:	Drill, half-in. depth, 0.3 m (12 in.) row spacing; or broadcast and then lightly harrow.
Season:	September-November
Mulching:	Apply hay or straw at 4.5 Mg/ha (2 T/ac) after planting; crimp mulch into soil surface soil surface, or apply 2.5 cm (1 in.) gravel.

3. Post-Planting Procedures:

Irrigation:	Apply 0.24 ha-cm (1.5 ac-in.) each in April, May, June, and July. Any method of application can be used, but ground application from a water truck or hand lines is least expensive. Irrigation is not necessary during those months receiving > 1.9 cm (> 0.75 in.) of rain. Irrigation can be discontinued once the seeded perennial species reach 30% canopy cover.
Fertilization:	Repeat the pre-planting fertilizer application the second growing season unless weeds are > 30% relative cover.

Weed Control: None the first three growing seasons.

None thereafter if annual weeds are < 50% relative canopy cover at the end of the third growing season.

If annual weeds are > 50% relative canopy cover at the end of the third growing season, apply low-label rates of 2,4-D and dicamba in early April.

Dynamics: Year 1: Annuals (cheatgrass, Russian thistle, tumble mustard) will dominate, with lesser amounts of perennials.

Year 2: Seeded perennial species should comprise > 20% relative cover.

Year 3: Seeded perennial species should comprise > 40% relative cover.

Year 4: Seeded perennial species should comprise > 60% relative cover.

Year 5: Seeded perennial species should comprise > 75% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total plant cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum of 25% total canopy cover each year, plus relative cover values of

Year 1: Any combination of species
Year 2: Seeded perennial species $\geq$ 20%
Year 3: Seeded perennial species $\geq$ 40%
Year 4: Seeded perennial species $\geq$ 60%
Year 5: Seeded perennial species $\geq$ 75%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed the second year using the same seed mixture, but from a different source.

If seedlings of seeded species are established, but total cover values are below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each month (April-July).

If seedlings of seeded species are established, but relative cover values are below target levels, add the additional 0.8 ha-cm (0.5 ac-in.) of water each month (April-July), but do not add additional fertilizer.

5. Costs:

Moderate.

Seed, irrigation, and fertilization are the major costs.

6. Comments:

If precipitation is below average during establishment years (1-5), additional irrigation (in addition to the recommended amount) should be applied. This additional amount should be equal to the amount that precipitation is below normal.

SCENARIO 03

SITE: Sand
COMMUNITY: Native
TIME: 5-10 years
IMPACTS: Heavy

1. Pre-Planting Procedures:

Physical Seedbed: Harrow lightly to smooth surface.

Chemical Seedbed: None unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).

Topsoil Addition: None

Fertilization: Single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac) surface or subsurface application at time of planting.

Weed Control: Disc before weeds set seed in growing season prior to planting; repeated operations may be necessary (April, June, and September).

If cultivation is not possible, apply low-label rates of glyphosate/2,4-D at a 1:2 ratio to reduce weed seed viability.

2. Propagation Procedures:

Species: Species Mixture 02

Source: Local <180 km (<100 mi), if possible.

Method: Drill, half-in. depth, 0.3 m (12 in.) row spacing; or broadcast and then lightly harrow.

Season: September-November

Mulching: Apply hay or straw at 4.5 Mg/ha (2 T/ac) after planting; crimp mulch into soil surface soil surface, or apply 2.5 cm (1 in.) gravel.

3. Post-Planting Procedures:

Irrigation: Apply 0.24 ha-cm (1.5 ac-in.) in April, May, June, and July during the first two growing seasons.

Any method of application can be used, but ground application from a water truck or hand lines is least expensive.

Irrigation is not necessary during those months receiving > 1.9 cm (> 0.75 in.) of rain.

Fertilization: First-year (at planting) only.

Weed Control: None the first six growing seasons.

None thereafter if annual weeds are < 50% relative canopy cover at the end of the sixth growing season.

If annual weeds are > 50% relative canopy cover at the end of the sixth growing season, apply low-label rates of 2,4-D and dicamba in early April until relative canopy cover of weeds at the end of the growing season becomes < 50%.

Dynamics: Years 1-2: Annuals (cheatgrass, Russian thistle, tumble mustard) will dominate, with lesser amounts of perennials.

Year 3: Seeded perennial species should comprise > 25% relative cover.

Year 4: Seeded perennial species should comprise > 40% relative cover.

Year 6: Seeded perennial species should comprise > 50% relative cover.

Year 10: Seeded perennial species should comprise > 75% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total plant cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum of 25% total canopy cover each year, plus relative cover values of

Years 1-2: Any combination of species
Year 3: Seeded perennials ≥ 25%
Years 4-5: Seeded perennials ≥ 40%
Years 6-7: Seeded perennials ≥ 50%
Years 8-9: Seeded perennials ≥ 65%
Year 10: Seeded perennials ≥ 75%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed the second year using the same seed mixture, but from a different source.

If seedlings of seeded species are established, but total cover values are below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each month (April-July).

If seedlings of seeded species are established, but relative cover values are below target levels, add the additional 0.8 ha-cm (0.5 ac-in.) of water each month (April-July), but do not add additional fertilizer.

5. Costs:

Moderate.

Costs of this scenario are less than for Scenario 04, because irrigation is only applied for two years.

6. Comments:

This scenario is very similar to Scenario 02, the major difference being number of years irrigation is applied. Establishment of the perennials will be slower for this scenario than for Scenario 02, because irrigation is only applied for two years. Therefore, site stabilization will be slower than for Scenario 02, with greater possibility of failure the first few years, especially if precipitation is below normal. If precipitation is below average during the establishment years (1-5), additional irrigation (in addition to the recommended amount) should be applied. This additional amount should be equal to the amount that precipitation is below normal.

This scenario is less expensive than Scenario 02, but revegetation and stabilization will occur more slowly. Therefore, the tradeoff becomes one of decreased costs and increased risk.

SCENARIO 04

SITE:	Sand
COMMUNITY:	Native
TIME:	10-20 years
IMPACTS:	Heavy

1. Pre-Planting Procedures:

Physical Seedbed: Harrow lightly to smooth surface.

Chemical Seedbed: None unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).

Topsoil Addition: None

Fertilization: Single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac) surface or subsurface application at time of planting.

Weed Control: Disc before weeds set seed in growing season prior to planting; repeated operations may be necessary (April, June, and September).

If cultivation is not possible, apply low-label rates of glyphosate/2,4-D at a 1:2 ratio to reduce weed seed viability.

2. Propagation Procedures:

Species: Species Mixture 02

Source: Local <180 km (<100 mi), if possible.

Method: Drill, half-in. depth, 0.3 m (12 in.) row spacing; or broadcast and then lightly harrow.

Season: September-November

Mulching: Apply hay or straw at 4.5 Mg/ha (2 T/ac) after planting; crimp mulch into soil surface soil surface, or apply 2.5 cm (1 in.) gravel.

3. Post-Planting Procedures:

Irrigation: Apply 0.24 ha-cm (1.5 ac-in.) each in April, May, June, and July during the first growing season.

Any method of application can be used, but ground application from a water truck or hand lines is least expensive.

Irrigation is not necessary during those months receiving > 1.9 cm (> 0.75 in.) of rain.

Fertilization: First year (at planting) only.

Weed Control: None for the first six growing seasons.

None thereafter if annual weeds are < 50% relative canopy cover at the end of the sixth growing season.

If annual weeds are > 50% relative canopy cover at the end of the sixth growing season, apply low-label rates of 2,4-D and dicamba in early April until relative canopy cover of weeds at the end of the growing season is < 50%.

Dynamics: Years 1-2: Annuals (cheatgrass, Russian thistle, tumble mustard) will dominate, with lesser amounts of perennials.

Year 3: Seeded perennial species should comprise > 20% relative cover.

Year 4: Seeded perennial species should comprise > 35% relative cover.

Year 6: Seeded perennial species should comprise > 50% relative cover.

Year 10: Seeded perennial species should comprise > 80% relative cover; native shrubs should comprise > 10% relative cover.

Year 15: Native shrubs should comprise > 20% relative cover.

Year 20: Native shrubs should comprise > 30% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total plant cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum of 25% total canopy cover each year, plus relative cover values of

Years 1-2: Any combination of species
Year 3: Seeded perennials ≥ 20%
Years 4-5: Seeded perennials ≥ 35%
Years 6-7: Seeded perennials ≥ 50%
Years 8-9: Seeded perennials ≥ 65%
Years 10-20: Seeded perennials ≥ 80%

Follow-Up: If no, or very few, seedlings of seededspecies are established at the end of the first growing season, the problem was probably poor seed. Re-seed the second year using the same seed mixture, but from a different source. Repeat the first-year irrigation regime the second year.

If seedlings of seeded species are established, but total cover values are below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.) of irrigation each month, in addition to any other recommended amount (April-July). Continue this procedure annually until the target levels are reached.

If seedlings of seeded species are established, but relative cover values are below target levels, add the additional 0.8 ha-cm (0.5 ac-in.) of water each month (April-July), but do not add additional fertilizer. Continue this procedure until the target levels are reached.

5. Costs:

Moderate.

Costs of this scenario are less than for Scenario 03, because irrigation is only applied for one year.

6. Comments:

This scenario is similar to Scenarios 02 and 03. In this scenario, irrigation is applied for only one year, whereas it is applied for two years in Scenario 03 and for 2-5 years in Scenario 02. Scenario 04 is the least expensive of the three, but has the highest risk of failure. The tradeoff is then decreased costs against higher risk.

Establishment of the perennials will be slower for this scenario than for Scenario 03; therefore, site stabilization will be slower, especially if precipitation is below normal. If precipitation is below average during the establishment years (1-5), irrigation should be applied. The amount applied should be equal to the amount that the precipitation is below normal.

SCENARIO 05

SITE:	Sand
COMMUNITY:	Late-seral
TIME:	20-50 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed:	Harrow lightly to smooth surface.
Chemical Seedbed:	None unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).
Topsoil Addition:	None
Fertilization:	None
Weed Control:	Disc before weeds set seed in growing season prior to planting; repeated operations may be necessary (April, June, and September).

2. Propagation Procedures:

Species:	Species Mixture 03
Source:	Local <180 km (<100 mi), if possible.
Method:	First drill seed, half-in. depth, 46 cm (18 in.) row spacing; or broadcast and lightly harrow. Then plant shrub tublings on 2.3 m (7.5 ft.) centers 1900 plants/ha (775 plants/acre).
Season:	September-November
Mulching:	Apply hay or straw at 4.5 Mg/ha (2 T/ac) after drilling the seed; crimp mulch into soil surface soil surface, or apply 2.5 cm (1 in.) gravel.

3. Post-Planting Procedures:

Irrigation:	Apply approximately 11.3 L (3 gal.) of water around base of each shrub tubling at 2-wk intervals from March-September of the first growing season. Irrigation is not necessary for any 2-wk interval receiving $\geq$ 0.5 cm ($\geq$ 0.2 in.) of rain.
Fertilization:	None
Weed Control:	None

Dynamics:

Years 1-5: Annuals (cheatgrass, Russian thistle, tumble mustard) will dominate; perennial grasses may comprise < 20% relative cover. Shrubs should comprise 5% relative cover by Year 5.

Years 6-10: Perennial grasses should increase in relative cover from about 20% in Year 6 to about 40% by Year 10. Shrubs should increase to about 10% relative cover by Year 10, with rabbitbrush being most abundant.

Years 11-20: Perennial grasses should increase to about 75% relative cover by Year 20. Shrubs should increase to 20% relative cover by Year 20, with sagebrush and rabbitbrush about equal. Numerous shrubs should be of mature size by Year 20.

Years 21-30: Perennial grasses should decrease to about 50% relative cover by Year 30, and shrubs should increase to 40%. Sagebrush should be the dominant shrub, with most shrubs of mature size.

Years 31-50: Perennial grasses should decrease to about 40% relative cover, and shrubs (mostly sagebrush) should increase to > 50%.

4. Follow-Up Procedures:

Evaluation Criteria:

Measure total plant cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum of 20% total canopy cover in Years 1-20 and a minimum of 25% total canopy cover thereafter, plus relative cover values of

Years 1-5: Any combination of species

Years 6-8: Perennial grasses > 20%, shrubs > 5%

Years 9-12: Perennial grasses > 32%, shrubs > 8%

Years 13-20: Perennial grasses > 50%, shrubs > 12%, big sagebrush > 5%

Years 21-30: Perennial grasses > 50%, shrubs > 20%, big sagebrush > 10%

Years 31-40: Perennial grasses > 40%, shrubs > 40%, big sagebrush > 25%

Years 41-50: Perennial grasses > 30%, shrubs > 45%, big sagebrush > 40%

Follow-Up:

If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed or dry conditions. If dry (below normal precipitation, few seedlings of any species established), either wait until the next year or irrigate. If conditions were not dry, re-seed the next year using the same seed mixture but from a different source and broadcast the seed rather than drill. Care must be taken not to damage the tublings.

If seedlings of seeded species are established, but total cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.16 ha-cm (1 ac-in.), in addition to any other recommended amount, of water each month (April-September). Continue this procedure annually until the target levels are reached. Care must be taken not to damage shrubs.

If seedlings of seeded species are established, but relative cover values were below target levels, add the 0.16 ha-cm (1 ac-in.) of water each month (April-September), but do not add fertilizer. Continue this procedure until the target levels are reached. Care must be taken not to damage shrubs.

A 50% mortality of tublings can be expected. If losses exceed 30% at the end of the first growing season, continue the irrigation regime the second year but at a rate of 18 L (5 gal.) per plant per 2-wk interval. If losses exceed 50% over the first three years, replace half the dead plants with new tublings and water at a rate of 18 L (5 gal.) per plant per 2-wk interval for one year. Continue this procedure until an average of 10 shrubs per 100 m^2 survive for at least three years.

5. Costs:

Moderate.

The major costs in this scenario are purchase and planting costs of the shrub tublings, and the cost of hand watering the shrubs until establishment.

6. Comments:

Without site-wide irrigation, establishment of the perennial grasses will be relatively slow (5-10 years) unless precipitation is above normal during the first few years. Therefore, the site will have soil erosion for the first 3-5 years, until the shrubs become large enough to be effective in stabilization.

Successful establishment of the shrub tublings in the first 2-3 years is crucial. Timely and adequate irrigation for the first year (see Post-Planting Procedures) is critical to accomplish this.

SCENARIO 06

SITE:	Sand
COMMUNITY:	Late-seral
TIME:	50-100 years
IMPACTS:	Light

1. <u>Pre-Planting Procedures</u>:

Physical Seedbed:	Harrow lightly to smooth surface.
Chemical Seedbed:	None unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).
Topsoil Addition:	None
Fertilization:	None
Weed Control:	Disc before weeds set seed in growing season prior to planting; repeated operations may be necessary (April, June, and September).

2. <u>Propagation Procedures</u>:

Species:	Species Mixture 03
Source:	Local <180 km (<100 mi), if possible.
Method:	First drill seeds, half-in. depth; 46 cm (18 in.) row spacings. Then plant sagebrush tublings on 3.05 m (10 ft.) centers 1077 plants/ha (436 plants/ac).
Season:	September-November
Mulching:	Apply hay or straw at 4.5 Mg/ha (2 T/ac) after drilling the seed; crimp mulch into soil surface, or apply 2.5 cm (1 in.) gravel.

3. <u>Post-Planting Procedures</u>:

Irrigation:	Apply approximately 11.3 L (3 gal.) of water around base of each shrub tubling at 2-wk intervals from March-September of the first growing season soil surface, or apply 2.5 cm (1 in.) gravel. Irrigation is not necessary for any 2-wk interval receiving $\geq$ 0.5 cm ($\geq$ 0.2 in.) of rain.
Fertilization:	None
Weed Control:	None

Dynamics:

Years 1-5: Annuals (cheatgrass, Russian thistle, tumble mustard) will dominate; perennial grasses may comprise < 20% relative cover. Shrubs should comprise 1-5% relative cover by Year 5.

Years 6-10: Perennial grasses should increase in relative cover from < 20% in Year 6 to about 25% by Year 10; shrubs should increase to about 5% relative cover by Year 10.

Years 11-25: Perennial grasses should increase to about 50% relative cover by Year 25 and shrubs to about 10%; sagebrush and rabbitbrush should be about equal in abundance, with some mature shrubs.

Years 26-50: Perennial grasses should increase to 60-70% relative cover by Year 50 and shrubs to 25-30%. Sagebrush should be more abundant than rabbitbrush, and there should be numerous sagebrush plants other than those established as tublings.

Years 51-100: Perennial grasses should decrease to about 40% relative cover, and shrubs (mostly sagebrush) should increase to > 50%.

4. Follow-Up Procedures:

Evaluation Criteria:

Measure total plant cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum of 20% total canopy cover in Years 1-25 and a minimum of 25% total canopy cover thereafter, plus relative cover values of

Years 1-5: Any combination of species

Years 6-8: Perennial grasses > 10%

Years 9-15: Perennial grasses > 20%, shrubs > 4%

Years 15-25: Perennial grasses > 33%, shrubs > 6%

Years 25-50: Perennial grasses > 50%, shrubs > 10%, big sagebrush > 5%

Years 50-75: Perennial grasses > 50%, shrubs > 25%, big sagebrush > 20%

Years 75-100: Perennial grasses > 40%, shrubs > 40%, big sagebrush > 35%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed or dry conditions. If dry (below normal precipitation, few seedlings of any species established), either wait until the next year or irrigate. If conditions were not dry, re-seed the next year using the same seed mixture, but from a different source, and broadcast the seed rather than drill. Care must be taken not to damage the tublings.

If seedlings of seeded species are established, but total cover values are below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.16 ha-cm (1 ac-in.), in addition to any other recommended amount, of water each month (April-September). Continue this procedure annually until the target levels are reached. Care must be taken not to damage shrubs.

If seedlings of seeded species are established, but relative cover values are below target levels, add the 0.16 ha-cm (1 ac-in.) of water each month (April-September), but do not add fertilizer. Continue this procedure until the target levels are reached. Care must be taken not to damage shrubs.

A 50% mortality of tublings can be expected. If losses exceed 30% at the end of the first growing season, continue the irrigation regime the second year but at a rate of 18 L (5 gal.) per plant per 2-wk interval. If losses exceed 50% over the first three years, replace half the dead plants with new tublings and water at a rate of 18 L (5 gal.) per plant per 2-wk interval for one year. Continue this procedure until an average of 10 shrubs per 100 m^2 survive for at least three years.

5. Costs:

Moderate.

The major costs in this scenario are purchase and planting costs of the shrub tublings, and the cost of hand watering the shrubs until establishment. There are only half as many shrubs in this scenario as in Scenario 05, so costs are much less. The tradeoff here is lower costs but longer time until establishment of a late-seral shrub community. Risk of failure is no higher than for Scenario 05, only the time for establishment is greater.

6. Comments:

Without site-wide irrigation, establishment of the perennial grasses will be relatively slow (10-25 years) unless precipitation is above normal during the first few years. Therefore, the site will be relatively unstable for the first 3-5 years, until the shrubs become large enough to be effective in stabilization.

Successful establishment of the shrub tublings in the first 2-3 years in crucial. Timely and adequate irrigation in the first growing season is critical to accomplish this, unless precipitation is well above normal.

SCENARIO 07

SITE:	Gravel
COMMUNITY:	Introduced
TIME:	2-5 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed: Cut furrows, 10 cm (4 in.) deep, 0.6 m (24 in.) centers. Furrows are to be cut AFTER topsoil treatment. The purpose is to create microrelief to provide seedlings shelter from wind erosion.

Chemical Seedbed: None

Topsoil Addition: Spread 15 cm (6 in.) loam evenly across the surface. Apply organic matter (hay, straw, wood chips, shredded paper, manure) at rate of 45 Mg/ha (20 T/ac) Mix (after fertilizer is applied) organic matter and loam by discing or plowing.

Fertilization: Single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac); apply with organic matter prior to mixing with the loam.

Weed Control: None

2. Propagation Procedures:

Species: Species Mixture 04

Source: Any

Method: Drill, half-in. depth two rows, 20 cm (8 in.) centers, adjacent to furrow ridge, skip 20 cm (8 in.) (furrow ridge), then repeat pattern.

Season: September-November

Mulching: Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting.

3. Post-Planting Procedures:

Irrigation: Apply 0.8 ha-cm (0.5 ac-in.) every two weeks from April-September.

Irrigation is not necessary during those 2-wk periods receiving >0.5 cm (> 0.2 in.) of rain.

Irrigation is to be applied for a minimum of one year, then continued thereafter until target levels are achieved.

Fertilization: Year 2: Apply (broadcast) 22.4 kg N/ha (20 lbs N/ac) twice (Mar, Jun) unless weeds are > 30% relative cover.

Weed Control: None first year. None thereafter unless relative cover of annual weeds > 50%.

If annual weeds > 50% relative cover at end of a growing season (other than first), apply low-label rates of 2,4-D and dicamba in early April.

Dynamics: Year 1: Annuals may dominate if there was a large seed bank in the loam or organic matter; seeded perennials may comprise < 50% relative cover.

Year 2: Seeded perennial grasses should comprise > 50% relative cover.

Year 3: Seeded perennial grasses should comprise > 75% relative cover.

Year 4: Seeded perennial grasses should comprise > 85% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels =

Year 1: Minimum 10% total cover; seeded perennials > 25% relative cover

Year 2: Minimum 20% total cover; seeded perennials > 50% relative cover

Year 3: Minimum 25% total cover; seeded perennials > 75% relative cover

Year 4: Minimum 25% total cover; seeded perennials > 85% relative cover

Year 5: Minimum 25% total cover; seeded perennials > 90% relative cover

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November using the same seed mixture, but from a different source. Drill seed into the existing surface at the same depth and pattern as the first year.

If seedlings are established, but total cover values were below target levels, double the fertilization and irrigation rates for one year. If seedlings of the seeded species are established, but relative cover values were below target levels, continue irrigation but not fertilization.

5. Costs:

High.

Establishment of an herbaceous cover in less than 20 years on this site will require the addition of topsoil. This is most likely to be expensive. Irrigation is also necessary, and it and the organic matter add significantly to the costs.

6. Comments:

The gravel sites will be among the most difficult areas at Hanford to revegetate because of (1) lack of soil, and (2) harsh environmental conditions resulting from exposure to wind and high surface temperatures. These sites are examples of primary, rather than secondary, succession, and primary succession takes much longer than secondary. In order to reduce the time necessary for establishment of target communities from centuries to decades, significant inputs must be made into the system.

The most critical resource that must be supplied on these sites in order to achieve revegetation is water. A major ecological function of soil is to store water for use by plants. Since these sites have no soil, there is little storage potential. Six inches of topsoil, plus the added organic matter, should be sufficient to store the 2.54 cm (1 in.) additions of water from irrigation. However, if the water is not applied often enough, the seedlings will desiccate. Irrigation is, therefore, critical to the establishment of herbaceous plants on this site.

Once perennial plants reach mature size, they will begin to trap soil particles and other debris moved across the site by wind. This, mixed with organic matter from the plants, will increase the soil depth and development at the site over time, increasing water-holding capacity and fertility, thereby allowing further ecosystem development. Unaided by human manipulations, this soil building and community development process would take over 100 years. If revegetation is to be accomplished on these sites in 5 years, as targeted by Scenario 07, topsoil and water, and to a lesser extent nutrients, will have to be supplied anthropogenically to speed the natural process.

SCENARIO 08

SITE:	Gravel
COMMUNITY:	Native
TIME:	2-5 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed:	Cut furrows, 10 cm (4 in.) deep, 0.6 m (24 in.) centers. Furrows are to be cut AFTER topsoil treatment. The purpose is to create microrelief to provide seedlings shelter from wind erosion.
Chemical Seedbed:	None
Topsoil Addition:	Spread 15 cm (6 in.) loam evenly across the surface. Apply organic matter (hay, straw, wood chips, shredded paper, manure) at rate of 45 Mg/ha (20 T/ac) Mix (after fertilizer is applied) organic matter and loam by discing or plowing.
Fertilization:	Single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac). Apply with organic matter prior to mixing with the loam.
Weed Control:	None

2. Propagation Procedures:

Species:	Species Mixture 05
Source:	Local < 180 km (< 100 mi), if possible.
Method:	Drill, half-in. depth two rows, 20 cm (8 in.) centers, adjacent to furrow ridge, skip 20 cm (8 in.) (furrow ridge), then repeat pattern.
Season:	September-November
Mulching:	Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting.

3. Post-Planting Procedures:

Irrigation:	Apply 0.8 ha-cm (0.5 ac-in.) every two weeks from April-September. Irrigation is not necessary during those 2-wk periods receiving > 0.5 cm (> 0.2 in.) of rain. Irrigation is applied for a minimum of one year, and continued thereafter until target levels are achieved.
Fertilization:	Year 2: Apply (broadcast) 2.54 cm (1 in.) twice (March, June) unless weeds are > 30% relative cover.

Weed Control: None first year. None thereafter unless relative cover of annual weeds > 50%.

If annual weeds > 50% relative cover at end of second or third growing season, apply low-label rates of 2,4-D and dicamba in early April.

Dynamics: Year 1: Annuals may dominate if there was a large seed bank in the loam or organic matter, seeded perennials may comprise < 50% relative cover.

Year 2: Seeded perennial grasses should comprise > 50% relative cover.

Year 3: Seeded perennial grasses should comprise > 75% relative cover.

Year 4: Seeded perennial grasses should comprise > 85% relative cover.

Year 5: Seeded perennial grasses should comprise > 80% relative cover and shrubs > 10% relative cover.

4. <u>Follow-Up Procedures</u>:

Evaluation Criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels =

Year 1: Minimum 10% total cover; seeded perennials > 25% relative cover

Year 2: Minimum 20% total cover; seeded perennials > 40% relative cover

Year 3: Minimum 25% total cover; seeded perennials > 50% relative cover

Year 4: Minimum 25% total cover; native perennials > 60% relative cover

Year 5: Minimum 25% total cover; native perennials ≥ 80% relative cover

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November using the same seed mixture, but from a different source. Drill seed into the existing surface at the same depth and pattern as the first year.

If seedlings are established, but total cover values were below target levels, double the fertilization and irrigation rates for one year. If seedlings of the seeded species are established, but relative cover values were below target levels, continue irrigation but not fertilization.

5. Costs:

High.

Establishment of a perennial, herbaceous cover in less than 20 years on this site will require the addition of topsoil. This is most likely to be expensive. Irrigation is also necessary, and it and the organic matter add significantly to the costs.

6. Comments:

The gravel sites will be among the most difficult areas at Hanford to revegetate because of (1) lack of soil, and (2) harsh environmental conditions resulting from exposure to wind and high surface temperatures. These sites are examples of primary, rather than secondary, succession, and primary succession takes much longer than secondary. In order to reduce the time necessary for establishment of target communities from centuries to decades, significant inputs must be made into the system.

The most critical resource that must be supplied on these sites in order to achieve revegetation is water. A major ecological function of soil is to store water for use by plants. Since these sites have no soil, there is little storage potential. Six inches of topsoil, plus the added organic matter, should be sufficient to store the 2.54 cm (1 in.) additions of water from irrigation. However, if the water is not applied often enough, the seedlings will desiccate. Irrigation is, therefore, critical to the establishment of perennial herbaceous plants on this site.

Once perennial plants reach mature size, they will begin to trap soil particles and other debris moved across the site by wind. This, mixed with organic matter from the plants, will increase the soil depth and development at the site over time, increasing water-holding capacity and fertility, thereby allowing further ecosystem development. Unaided by human manipulations, this soil building and community development process would take over 100 years. If revegetation is to be accomplished on these sites in 5 years, as targeted by Scenario 08, topsoil and water, and to a lesser extent nutrients, will have to be supplied anthropogenically to speed the natural process.

SCENARIO 09

SITE:	Gravel
COMMUNITY:	Native
TIME:	5-10 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed:	Cut furrows, 10 cm (4 in.) deep, 0.6 m (24 in.) centers. The purpose is to create microrelief to provide seedlings shelter from wind erosion.
Chemical Seedbed:	None
Topsoil Addition:	None
Fertilization:	Single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac). Apply in strips at the bottoms of the furrows within one month of planting.
Weed Control:	None

2. Propagation Procedures:

Species:	Species Mixture 06
Source:	Local < 180 km (< 100 mi), if possible.
Method:	Broadcast seeds across the site; plant shrub tublings in bottoms of furrows on 2.3 m (7.5 ft.) centers 1900 plants/ha (775 plants/acre).
Season:	September-November
Mulching:	Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting.

3. Post-Planting Procedures:

Irrigation:	Apply approximately 11.3 L (3 gal.) of water around base of each shrub at 2-wk intervals from March-September of first two years. Irrigation is not necessary during those 2-wk periods receiving > 0.5 cm (> 0.2 in.) of rain.
Fertilization:	None
Weed Control:	None

Dynamics: Year 1: Shrubs should make only limited aboveground growth, death losses should not exceed 25%. Perennial grasses establish in the bottoms of the furrows.

Year 2: Shrub death loss (2-year total) should be < 50%; half of surviving shrubs should be > 0.3 m (1 ft.) tall. Perennial grasses should comprise > 5% total cover.

Year 5: Shrubs should comprise > 10% total cover and density should exceed an average of 10 live plants per 100 m^2. Perennial grasses should comprise > 10% total cover.

Year 10: Minimum of 25% total cover. Shrubs should comprise > 15% total cover. Shrubs and perennial grasses should be establishing outside of the furrow bottoms.

Year 20: Minimum of 25% total cover. Shrubs should comprise > 15% total cover. Perennial grasses should comprise > 10% total cover.

4. Follow-Up Procedures:

Evaluation Criteria: Record the number of live shrubs and measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels =

Year 1: Minimum 75% shrub survival

Year 2: Minimum 50% shrub survival; total cover of perennials within furrows (1-ft wide belt transect centered on line of shrubs) > 10%

Year 3: Minimum 10% total cover; shrubs > 5% total cover

Year 4: Minimum 15% total cover; shrubs > 5% total cover

Year 5: Minimum 20% total cover; shrubs >10% total cover shrub density $\geq$ 10 per 100 m^2

Year 10: Minimum 25% total cover; shrubs >15% total cover perennial grasses > 5% total cover

Year 20: Minimum 25% total cover; shrubs >15% total cover perennial grasses > 10% total cover

Follow-Up: If shrub mortality exceeds 30% at the end of the first growing season, increase the irrigation rate to 11.3 L (3 gal.) per shrub per 2-wk interval. If losses exceed 50% over the first three years, replace half the dead plants with new tublings and continue to irrigate. Continue this procedure until an average of 10 shrubs per 100 m^2 survive for at least three years.

5. Costs:

Moderate.

This is the least expensive scenario for gravel sites, because topsoil and organic matter are not added. Costs of this scenario are primarily determined by the costs of purchasing and planting the tublings, and irrigating.

6. Comments:

The gravel sites will be among the most difficult areas at Hanford to revegetate because of (1) lack of soil, and (2) harsh environmental conditions resulting from exposure to wind and high surface temperatures. These sites are examples of primary, rather than secondary, succession, and primary succession takes much longer than secondary. In order to reduce the time necessary for establishment of target communities from centuries to decades, significant inputs must be made into the system.

The most critical resource that must be supplied on these sites in order to achieve revegetation is water. A major ecological function of soil is to store water for use by plants. Since these sites have no soil, there is little storage potential. This scenario differs from the other gravel site scenarios in that it attempts to establish a perennial community without first adding topsoil. Once perennial plants, especially shrubs, reach mature size, they will begin to trap soil particles and other debris moved across the site by wind. This, mixed with organic matter from the plants, will increase the soil depth and development at the site over time, increasing water-holding capacity and fertility, thereby allowing further ecosystem development.

The design of Scenario 09 is based on the concept that late-seral woody species (i.e., shrubs and trees) have deep taproots and can access moisture from relatively great depths once their root systems have developed sufficiently. It is projected that, by watering the shrubs for two years, they will be able to develop root systems that extent sufficiently deep into the lower levels of the gravel to access moisture that drained through the upper gravel layers. If so, these shrubs should be able to survive thereafter without irrigation. As the shrubs mature, they should serve as focal points for successional islands to form, leading to soil buildup and development of herbaceous perennial plants.

SCENARIO 10

SITE:	Gravel
COMMUNITY:	Late-seral
TIME:	10-20 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed:	Cut furrows, 15 cm (6 in.) deep, 1 m (36 in.) centers. Furrows are to be cut AFTER topsoil treatment. The purpose is to create microrelief to provide seedlings shelter from wind erosion (Fairchild and Brotherson 1980).
Chemical Seedbed:	None
Topsoil Addition:	Spread 20 cm (8 in.) loam evenly across the surface. Apply organic matter (hay, straw, wood chips, shredded paper, manure) at rate of 45 Mg/ha (20 T/ac) Mix (after fertilizer is applied) organic matter and loam by discing or plowing.
Fertilization:	Single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac). Apply with organic matter prior to mixing with the loam.
Weed Control:	None

2. Propagation Procedures:

Species:	Species Mixture 06
Source:	Local < 180 km (< 100 mi), if possible.
Method:	First drill seeds at half-in. depth in five rows with 15 cm (6 in.) centers, adjacent to the furrow ridge; skip 15 cm (6 in.) (furrow ridge), then repeat pattern. Then plant shrub tublings in bottoms of furrows on 2.3 m (7.5 ft.) intervals 1900 plants/ha (775 plants/ac).
Season:	September-November
Mulching:	Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting.

3. Post-Planting Procedures:

Irrigation:	Apply 0.8 ha-cm (0.5 ac-in.) every two weeks from April-September during the first year. Irrigation is not necessary during those 2-wk periods receiving > 0.5 cm (> 0.2 in.) of rain.
Fertilization:	None
Weed Control:	None

Dynamics:

Years 1-2: Annuals may dominate if there was a large seed bank in the loam or organic matter. Native perennials may comprise < 50% relative cover.

Years 3-5: Perennials should become dominant. Perennial grasses should comprise > 50% relative cover by Year 5, and shrubs > 10% by Year 3 and > 20% by Year 5.

Years 6-10: Perennial grasses should comprise > 50% relative cover; shrubs should comprise > 40% by Year 10.

Years 11-15: Perennial grasses should begin to decrease, comprising about 40% relative cover by Year 15. Shrubs should increase to > 50% by Year 15. Many of the shrubs should approach mature size by Year 15.

Year 20: Perennial grasses should comprise 30-40% relative cover and shrubs 60-65%; most shrubs should be mature.

4. Follow-Up Procedures:

Evaluation Criteria:

Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels =

Years 1-2: Minimum 10% total cover; native perennials > 30% relative cover

Years 3-5: Minimum 15% total cover; perennial grasses > 40% relative cover; shrubs > 10% relative cover

Years 6-8: Minimum 20% total cover; perennial grasses > 40% relative cover; shrubs > 20% relative cover

Years 9-11: Minimum 25% total cover; perennial grasses > 40% relative cover; big sagebrush > 20% relative cover

Years 12-15: Minimum 25% total cover; perennial grasses > 40% relative cover; big sagebrush > 30% relative cover

Years 16-19: Minimum 25% total cover; perennial grasses > 30% relative cover; big sagebrush > 40% relative cover

Year 20: Minimum 25% total cover; native perennials > 85% relative cover; big sagebrush > 50% relative cover

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November using the same seed mixture, but from a different source. Broadcast the seed in order not to damage the shrubs.

If seedlings are established, but total cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and continue the first-year irrigation regime. Continue this procedure annually until the target levels are reached. If annuals increase to > 30% of relative cover, discontinue fertilization, but continue to irrigate until target levels are achieved. Care must be taken not to damage shrubs.

A 75% mortality of tublings can be expected. If losses exceed 30% at the end of the first growing season, continue the irrigation regime the second year plus an additional 11.3 L (3 gal.) applied around each shrub per 2-wk interval. If losses exceed 50% over the first three years, replace half the dead plants with new tublings and continue the irrigation, including the 10 gal. application per shrub. Continue this procedure until an average of 10 shrubs per 100 m^2 survive for at least three years.

5. Costs:

High.

Establishment of the perennial, herbaceous cover will require the addition of topsoil. This will most likely be expensive. Irrigation will also be necessary and adds significantly to the costs. Purchase and planting of the shrub tublings will be relatively expensive, but is necessary to meet the target of establishing a late-seral community on the gravel site in 20 years.

6. Comments:

Scenario 10 is probably the most challenging of the 22 scenarios to accomplish. The gravel sites will be among the most difficult areas at Hanford to revegetate because of (1) lack of soil, and (2) harsh environmental conditions resulting from exposure to wind and high surface temperatures. These sites are examples of primary, rather than secondary, succession, and primary succession takes much longer than secondary. In addition, this scenario requires a late-seral community to be established. Under natural conditions, this would take 100-200 years. The time line for Scenario 10 is 20 years. In order to reduce the time necessary for establishment of target communities from centuries to decades, significant inputs into the system must be made.

The most critical resource that must be supplied on these sites in order to achieve revegetation is water. A major ecological function of soil is to store water for use by plants. Since these sites have no soil, there is little storage potential, especially for shallow- to moderate-rooted grasses. Eight inches of topsoil, plus the added organic matter, should be sufficient to store the 2.54 cm (1 in.) additions of water from irrigation. However, if the water is not applied often enough, the seedlings will desiccate. Irrigation is therefore critical to the establishment of perennial herbaceous plants on this site. Without irrigation, establishment can only occur during infrequent wet years.

Once perennial plants reach mature size, they will begin to trap soil particles and other debris moved across the site by wind. This, mixed with organic matter from the plants, will increase the soil depth and development at the site over time, increasing water-holding capacity and fertility, thereby allowing further ecosystem development. Unaided by human manipulations, this soil building and community development process would take over 100 years. If establishment of a late-seral community is to be accomplished on these sites in 20 years, topsoil and water will have to be supplied anthropogenically to speed the natural process.

The design of Scenario 10 is based on the concept that, in arid systems such as Hanford, the establishment phase is a very important stage in the development of late-seral species under conditions of primary succession. Once established, shrubs should be able to survive on the gravel site because of their deep root systems. Likewise, mature perennial grasses should be able to survive on sites with 20 cm (8 in.) of soil.

SCENARIO 11

SITE:	Sterilized
COMMUNITY:	Introduced
TIME:	2-5 years
IMPACTS:	Heavy

1. <u>Pre-Planting Procedures</u>:

Physical Seedbed: None

Chemical Seedbed: None, unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).

Topsoil Addition: Conduct a germination and growth test on existing soil.

If the soil does not inhibit plant germination or growth, no topsoil addition is necessary.

If the soil does inhibit plant germination and growth, spread 15 cm (6 in.) of topsoil material evenly across the surface. Apply organic matter (hay, straw, wood chips, shredded paper, manure) at a rate of 45 Mg/ha (20 T/ac) Mix organic matter and topsoil material by discing.

Fertilization: None

Weed Control: Apply low-level label rates of glyphosate/ 2,4-D at a 1:2 ratio to reduce weed seed viability.

Mulching: None

2. <u>Propagation Procedures</u>:

Species: Species Mixture 07

Source: Any

Method: Drill, half-in. depth, 0.3 m (12 in.) row spacing.

Season: September-November

Mulching: Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting and crimp mulch into soil surface soil surface, or apply 2.5 cm (1 in.) gravel.

3. <u>Post-Planting Procedures</u>:

Irrigation: Apply 0.24 ha-cm (1.5 ac-in.) each in April, May, June, and July.

Any method of application can be used, but ground application from a water truck or hand lines is least expensive.

Irrigation is not necessary during those months receiving > 1.25 cm (> 0.5 in.) of rain.

Irrigation should be continued until target levels are reached.

Fertilization: None

Weed Control: None the first growing season.

None thereafter if annual weeds are < 50% relative canopy cover at the end of the preceding growing season.

If annual weeds are > 50% relative canopy cover at the end of the preceding growing season, apply low-label rates of 2,4-D and dicamba in early April.

Spot spray any Centaurea plants that invade onto the site with Tordon at low label rates.

Dynamics: Year 1: Annuals (cheatgrass, Russian thistle, tumble mustard) may dominate if there was a large seed bank in the topsoil material.

Year 2: Seeded perennials should comprise > 30% relative cover.

Year 3: Seeded perennials should comprise > 50% relative cover.

Year 4: Seeded perennials should comprise > 70% relative cover.

Year 5: Seeded perennials should comprise > 85% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total plant canopy cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum of 25% total canopy cover each year, plus relative cover values of

Year 1: Any combination of species
Year 2: Seeded perennial species > 25%
Year 3: Seeded perennial species > 50%
Year 4: Seeded perennial species > 70%
Year 5: Seeded perennial species > 80%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November with the same seed mixture, but from a different source.

If seedlings of seeded species established but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amounts, of irrigation each month (April-July). If relative cover values of seeded species were under target levels, add the additional irrigation, but not the fertilizer.

5. Costs:

High.

The application of topsoil is the highest-cost item in this scenario. Seed and fertilization costs are low, and irrigation costs are only moderate.

6. Comments:

These sites pose two major potential ecological problems, both of which are related to possible residual herbicides. The topsoil treatment should solve both problems.

First, if residual herbicide levels are significantly high, they will retard plant growth and slow or stop successful revegetation. The placement of a 15 cm (6 in.) layer of uncontaminated topsoil should provide the plants with an adequate growth medium. As roots penetrate the 15 cm (6 in.), they may encounter toxic conditions, but these effects should be minor in the layer immediately below the topsoil. The presence of toxic material at deeper layers may inhibit the growth of deeper-rooted species such as shrubs.

Second, there must be enough uncontaminated soil to store sufficient moisture to support the target plant community. Six inches, plus the added organic matter, should hold a minimum of 5 cm (2 in.) of soil moisture. This storage capacity should be adequate during the growing season in the arid climate at Hanford, because few rains will be in excess of this amount and the plant community should deplete this amount before the next rains occur. However, the site will not be able to store much moisture in the upper profile from snow melt. A significant portion of the moisture from snowmelt will probably enter into the subsoil (> 15 cm [6 in.]). Plants should be able to access some of this moisture in the layer immediately below the topsoil, but any moisture moving into a contaminated zone may be unavailable to the plant community. Therefore, these sites may remain relatively dry sites until residual herbicides eventually break down or they are moved downward in the profile by water movement.

SCENARIO 12

SITE:	Sterilized
COMMUNITY:	Native
TIME:	2-5 years
IMPACTS:	Heavy

1. <u>Pre-Planting Procedures</u>:

Physical Seedbed: None

Chemical Seedbed: None, unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).

Topsoil Addition: Conduct a germination and growth test on existing soil.

If the soil does not inhibit plant germination or growth, no topsoil addition is necessary.

If the soil does inhibit plant germination or growth, spread 15 cm (6 in.) of topsoil material evenly across the surface. Apply organic matter (hay, straw, wood chips, shredded paper, manure) at a rate of 45 Mg/ha (20 T/ac) Mix organic matter and topsoil material by discing.

Fertilization: None

Weed Control: Apply low-label rates of glyphosate/2,4-D at a 1:2 ratio to reduce weed seed viability.

Mulching: None

2. <u>Propagation Procedures</u>:

Species: Species Mixture 08

Source: Local < 180 km (< 100 mi), if possible.

Method: Drill, half-in., 0.3 m (12 in.) row spacing.

Season: September-November

Mulching: Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting and crimp mulch into surface.

3. <u>Post-Planting Procedures</u>:

Irrigation: Apply 0.24 ha-cm (1.5 ac-in.) each in April, May, June, and July for minimum of 2 years.

Any method of application can be used, but ground application from a water truck or hand lines is least expensive.

Irrigation is not necessary during those months receiving > 1.25 cm (> 0.5 in.) of rain.

Irrigation should be continued until the target levels are reached.

Fertilization: None

Weed Control: None the first growing season.

None thereafter if annual weeds are < 50% relative canopy cover at the end of the preceding growing season.

If annual weeds are > 50% relative canopy cover at the end of the preceding growing season, apply low-label rates of 2,4-D and dicamba in early April.

Spot spray any Centaurea plants that invade onto the site with picloram in early April at low label rates.

Dynamics: Year 1: Annuals (cheatgrass, Russian thistle, tumble mustard) may dominate if there was a large seed bank in the topsoil material.

Year 2: Native perennials should comprise > 30% relative cover.

Year 3: Native perennials should comprise > 50% relative cover.

Year 4: Native perennials should comprise > 70% relative cover.

Year 5: Native perennials should comprise > 85% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total plant canopy cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target values, go to follow-up.

Target Levels = Minimum of 25% total canopy cover each year, plus relative cover values of

Year 1: Any combination of species
Year 2: Native perennial species > 25%
Year 3: Native perennial species > 50%
Year 4: Native perennial species > 70%
Year 5: Native perennial species > 80%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November with the same seed mixture, but from a different source. If seedlings of seeded species established, but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each month (April-July). If relative cover values of seeded species were under target levels, add the additional irrigation, but not the fertilizer.

5. Costs:

High.

The application of topsoil is the highest-cost item in this scenario. Fertilization costs are low, and seed and irrigation costs are only moderate.

6. Comments:

These sites pose two major potential ecological problems, both of which are related to possible residual herbicides. The topsoil treatment should solve both problems.

First, if residual herbicide levels are significantly high, they will retard plant growth and slow or stop successful revegetation. The placement of a 15 cm (6 in.) layer of uncontaminated topsoil should provide the plants with an adequate growth medium. As roots penetrate the 15 cm (6 in.), they may encounter toxic conditions, but these effects should be minor in the layer immediately below the topsoil. The presence of toxic material at deeper layers may inhibit the growth of deeper-rooted species such as shrubs.

Second, there must be enough uncontaminated soil to store sufficient moisture to support the target plant community. Six inches, plus the added organic matter, should hold a minimum of 2 in. of soil moisture. This storage capacity should be adequate during the growing season in the arid climate at Hanford, because few rains will be in excess of this amount and the plant community should deplete this amount before the next rains occur.However, the site will not be able to store much moisture in the upper profile from snow melt. A significant portion of the moisture from snowmelt will probably enter into the subsoil (< 15 cm (6 in.)). Plants should be able to access some of this moisture in the layer immediately below the topsoil, but any moisture moving into a contaminated zone may be unavailable to the plant community. Therefore, these sites may remain relatively dry sites until residual herbicides eventually break down or they are moved downward in the profile by water movement.

SCENARIO 13

SITE:	Sterilized
COMMUNITY:	Native
TIME:	5-10 years
IMPACTS:	Heavy

1. <u>Pre-Planting Procedures</u>:

Physical Seedbed:	None
Chemical Seedbed:	None unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).
Topsoil Addition:	Conduct a germination and growth test on existing soil. If the soil does not inhibit plant germination or growth, no topsoil addition is necessary. If the soil does inhibit plant germination or growth, spread 15 cm (6 in.) of topsoil material evenly across the surface. Apply organic matter (hay, straw, wood chips, shredded paper, manure) at a rate of 45 Mg/ha (20 T/ac) Mix organic matter and topsoil material by discing.
Fertilization:	None
Weed Control:	Apply low-label rates of glyphosate/2,4-D at a 1:2 ratio to reduce weed seed viability.

2. <u>Propagation Procedures</u>:

Species:	Species Mixture 08
Source:	Local < 180 km (< 100 mi), if possible.
Method:	Drill, half-in., 0.3 m (12 in.) row spacing.
Season:	September-November
Mulching:	Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting and crimp mulch into surface.

3. <u>Post-Planting Procedures</u>:

Irrigation:	Apply 0.24 ha-cm (1.5 ac-in.) each in April, May, June, and July for a minimum of 1 year. Any method of application can be used, but ground application from a water truck or hand lines is least expensive. Irrigation is not necessary during those months receiving > 1.25 cm (> 0.5 in.) of rain. Irrigation should be continued until the target levels are reached.

Fertilization: None

Weed Control: None the first growing season.

None thereafter if annual weeds are < 50% relative canopy cover at the end of the preceding growing season.

If annual weeds are > 50% relative canopy cover at the end of the preceding growing season, apply low-label rates of 2,4-D and dicamba in early April.

Spot spray any Centaurea plants that invade onto the site with picloram in early April at low label rates.

Dynamics: Year 1: Annuals (cheatgrass, Russian thistle, tumble mustard) may dominate if there is a large seed bank in the topsoil material.

Year 2: Native perennials should comprise > 25% relative cover.

Year 4: Native perennials should comprise > 50% relative cover.

Year 6: Native perennials should comprise > 65% relative cover; shrubs should comprise about 5% relative cover.

Year 8: Native perennials should comprise > 80% relative cover; shrubs should comprise > 10% relative cover.

Year 10: Native perennials should comprise ≥ 90% relative cover; shrubs should comprise > 10% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total plant canopy cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum of 25% total canopy cover each year, plus relative cover values of

Year 1: Any combination of species
Year 2: Native perennials > 25%
Year 3: Native perennials > 40%
Year 4: Native perennials > 50%
Year 5: Native perennials > 60%
Year 6: Native perennials > 65%
Year 7: Native perennials > 75%
Year 8: Native perennials > 80%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November with the same seed mixture, but from a different source.

If seedlings of seeded species are established, but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each month (April-July). If relative cover values of seeded species were under target levels, add the additional irrigation, but not the fertilizer.

5. Costs:

High.

The application of topsoil is the highest-cost item in this scenario. Fertilization costs are low, and seed and irrigation costs are only moderate. This scenario is very similar to Scenario 12. The only difference between the two is that irrigation may not continue as long in Scenario 13 (minimum of 1 year) as in Scenario 12 (minimum of 2 years).

6. Comments:

These sites pose two major potential ecological problems, both of which are related to possible residual herbicides. The topsoil treatment should solve both problems.

First, if residual herbicide levels are significantly high, they will retard plant growth and slow or stop successful revegetation. The placement of a 15 cm (6 in.) layer of uncontaminated topsoil should provide the plants with an adequate growth medium. As roots penetrate the 15 cm (6 in.), they may encounter toxic conditions, but the effects should be minor in the layer immediately below the topsoil. The presence of toxic material at deeper layers may inhibit the growth of deeper-rooted species such as shrubs.

Second, there must be enough uncontaminated soil to store sufficient moisture to support the target plant community. Six inches, plus the added organic matter, should hold a minimum of 2 in. of soil moisture. This storage capacity should be adequate during the growing season in the arid climate at Hanford, because few rains will be in excess of this amount and the plant community should deplete this amount before the next rains occur. However, the site will not be able to store much moisture in the upper profile from snow melt. A significant portion of the moisture from snowmelt will probably enter into the subsoil (> 15 cm [>6 in.]). Plants should be able to access some of this moisture in the layer immediately below the topsoil, but any moisture moving into a contaminated zone may be unavailable to the plant community. Therefore, these sites may remain relatively dry sites until residual herbicides eventually break down or they are moved downward in the profile by water movement.

SCENARIO 14

SITE:	Sterilized
COMMUNITY:	Late-seral
TIME:	10-20 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed:	None
Chemical Seedbed:	None unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).
Topsoil Addition:	Spread 0.5 m (18 in.) of topsoil material evenly across the surface. Apply organic matter (hay, straw, wood chips, shredded paper, manure) at a rate of 22.4 Mg/ha (10 T/ac). Incorporate organic matter into topsoil material by discing.
Fertilization:	None
Weed Control:	After topsoil treatments have been completed, but before planting, disc whenever cover of weeds becomes > 20%.

2. Propagation Procedures:

Species:	Species Mixture 09
Source:	Local < 180 km (< 100 mi), if possible.
Method:	First drill seeds to half-in. depth in 0.3 m (12 in.) rows, then plant shrub tublings on 3.05 m (10 ft.) centers 1077 plants/ha (436 plants/acre).
Season:	September-November
Mulching:	Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface after drilling (< 3 days), crimp mulch into surface.

3. Post-Planting Procedures:

Irrigation:	Apply 0.8 ha-cm (0.5 ac-in.) every two weeks from April-September of the first year. Irrigation is not necessary during those 2-wk periods receiving > 0.5 cm (> 0.2 in.) of rain.
Fertilization:	None
Weed Control:	None, except spot spray any Centaurea plants that invade onto the site with picloram in early April at low label rates.

Dynamics:

Years 1-2: Annuals may dominate if there was a significant seed bank in the topsoil material; perennials may comprise < 50% relative cover.

Years 3-5: Perennials should become dominant. Perennial grasses should comprise > 50% relative cover by Year 5 and shrubs > 10% by Year 3 and > 20% by Year 5.

Years 6-10: Perennial grasses should comprise > 60% relative cover; shrubs should comprise > 30% relative cover by Year 10.

Years 10-15: Perennial grasses should comprise 50-60% relative cover. Shrubs should comprise > 40% relative cover. Some shrubs should be mature size.

Years 15-20: Perennial grasses and shrubs should both comprise about 50% relative cover; most shrubs should be mature.

4. <u>Follow-Up Procedures</u>:

Evaluation Criteria:

Measure total cover, by species, and record the number of live shrubs near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum 25% total canopy cover each year, plus

Year 1: Minimum 75% shrub survival

Year 2: Minimum 50% shrub survival; relative canopy cover of native perennials > 30%

Year 3: Relative canopy cover of shrubs > 10%; relative canopy cover of native grasses > 35%

Year 4: Relative canopy cover of shrubs > 15%; relative canopy cover of native grasses > 40%

Year 5: Relative canopy cover of shrubs > 20%; relative canopy cover of native grasses > 50%

Year 10: Relative canopy cover of shrubs > 30%; relative canopy cover of native grasses > 60%

Year 15: Relative canopy cover of shrubs > 40%; relative canopy cover of native grasses > 45%

Year 20: Relative canopy cover of shrubs $\geq$ 45%; relative canopy cover of native grasses $\geq$ 45%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November with the same seed mixture, but from a different source. Broadcast rather than drill. Care must be taken not to damage shrubs.

If seedlings of seeded species are established, but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2-wk (March-September). Care must be taken not to damage shrubs.

If shrub mortality exceeds 30% at the end of the first growing season, increase irrigation rate by 0.8 ha-cm (0.5 ac-in.) per 2 wk (March-September). If losses exceed 50% over the first three years, replace half the dead plants with new tublings and continue to irrigate. Continue this procedure until canopy cover targets for shrubs are reached.

5. Costs:

High.

The application of 0.5 m (18 in.) of topsoil and the costs of purchasing and planting the shrub tublings make this scenario expensive. Irrigation adds significantly to the costs. However, without the deeper topsoil, it is doubtful that a significant shrub component can be established on these sites, because of the deeper root systems of the shrubs. Without irrigation and the use of tublings, it is doubtful that the shrub component can be established within the target time line (20 years).

6. Comments:

The presence of contaminated subsoil will make establishment of a late-seral community difficult on these sites. The 0.5 m (18 in.) topsoil treatment should provide an adequate matrix on which to develop a shallow-soil shrubland community, but there will continue to be the potential of moisture loss from translocation to deeper layers. Water can enter the deeper layers following snowmelt, but the roots cannot (at least not until residual herbicides break down or are translocated to even deeper layers).

The required topsoil thickness is greater for this scenario than for scenarios targeting a grass community on these sites. This is because the late-seral target community contains significant amounts of shrubs, and because shrubs are deeper rooted than grasses.

SCENARIO 15

SITE:	Sterilized
COMMUNITY:	Late-seral
TIME:	20-50 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed:	None
Chemical Seedbed:	None unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).
Topsoil Addition:	Spread 46 cm (18 in.) of topsoil material evenly across the surface. Apply organic matter (hay, straw, wood chips, shredded paper, manure) at a rate of 45 Mg/ha (20 T/ac). Incorporate organic matter into topsoil material by raking.
Fertilization:	None
Weed Control:	After topsoil treatments have been completed, but before planting, disc whenever cover of weeds becomes > 20%.

2. Propagation Procedures:

Species:	Species Mixture 10
Source:	Local < 180 km (< 100 mi), if possible.
Method:	Drill, half-in. depth, 0.3 m (12 in.) spacing.
Season:	September-November
Mulching:	Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting and crimp mulch into surface.

3. Post-Planting Procedures:

Irrigation:	Apply 0.8 ha-cm (0.5 ac-in.) every two weeks from April-September of the first year. Irrigation is not necessary during those 2-wk periods receiving > 0.5 cm (> 0.2 in.) of rain.
Fertilization:	None
Weed Control:	None, except spot spray any Centaurea plants that invade onto the site with picloram in early April at low labes rates.

Dynamics:

Years 1-2: Annuals may dominate if there was a significant seed bank in the topsoil material. Perennials may comprise < 50% relative cover.

Years 3-5: Perennials should become dominant. Perennial grasses should comprise > 50% relative cover by Year 5.

Years 6-10: Perennial grasses should comprise > 60% relative cover. Shrubs should comprise > 5% relative cover by Year 10.

Years 11-20: Perennial grasses should comprise > 80% relative cover. Shrubs should comprise > 10% relative cover by Year 20, with rabbitbrush more abundant than sagebrush.

Years 21-30: Perennial grasses should comprise > 70% relative cover. Shrubs should comprise > 20% relative cover by Year 30, with rabbitbrush and big sagebrush about equal.

Years 31-50: Perennial grasses should decrease to about 40% relative cover, shrubs should increase to > 50% relative cover, and big sagebrush should largely replace rabbitbrush by Year 50.

4. Follow-Up Procedures:

Evaluation Criteria:

Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum 25% total canopy cover each year, plus relative canopy cover values of

Years 1-2: Any combination of species
Year 3: Native perennials > 25%
Year 4: Native perennials > 35%
Years 5-6: Native perennials > 50%
Years 7-9: Native perennials > 60%
Years 10-13: Native perennials > 70%; shrubs > 5%
Years 14-19: Native perennials > 75%; shrubs > 5%
Years 20-30: Native perennials > 80%; shrubs > 10%
Years 31-40: Native perennials > 85%; sagebrush > 20%
Years 41-49: Native perennials > 85%; sagebrush > 30%
Year 50: Native perennials > 85%; sagebrush > 45%

Follow-Up:

If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November with the same seed mixture, but from a different source.

If seedlings of seeded species are established, but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2-wk (April-September). If relative cover values of seeded species were under target levels, add the additional irrigation, but not the fertilizer.

5. Costs:

High.

The application of 0.5 m (18 in.) of topsoil makes this scenario expensive. However, without the deeper topsoil, it is doubtful that a significant shrub component can be established on these sites, because of the deeper root systems of the shrubs.

This scenario is less expensive that Scenario 18, because this scenario does not use shrub tublings, relying instead on the shrubs to establish from seed. This method takeslonger (50 years, compared to 20 years with tublings), but it costs less.

6. Comments:

The presence of contaminated subsoil will make establishment of a late-seral community difficult on these sites. The 0.5 m (18 in.) topsoil treatment should provide an adequate matrix on which to develop a shallow-soil shrubland community, but there will continue to be the potential for moisture loss from translocation to deeper layers. Water can enter the deeper layers following snowmelt, but the roots cannot (at least not until residual herbicides break down or are translocated to even deeper layers) survive in the deeper layers.

The required topsoil thickness is greater for this scenario than for scenarios targeting grass communities on these sites. This is because the late-seral target community contains significant amounts of shrubs and shrubs, are deeper-rooted than grasses.

SCENARIO 16

SITE:	Upper elevation
COMMUNITY:	Native
TIME:	2-5 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed:	None
Chemical Seedbed:	None
Topsoil Addition:	None
Fertilization:	None
Weed Control:	Disc before weeds set seed in growing season prior to planting. Repeated operations may be necessary (April, June, and September). If cultivation is not possible, apply low-label rates of glyphosate/2,4-D at a 1:2 ratio to reduce weed seed viability.

2. Propagation Procedures:

Species:	Species Mixture 11
Source:	Local < 180 km (< 100 mi), if possible.
Method:	Drill, half-in. depth, 0.3 m (12 in.) rows; or broadcast, followed by light harrowing.
Season:	September-November
Mulching:	Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting and crimp mulch into surface.

3. Post-Planting Procedures:

Irrigation:	Apply 0.8 ha-cm (0.5 ac-in.) every 2 wk (April-July). Any method of application can be used, but ground application from a water truck or hand lines is least expensive. Irrigation is not necessary during those 2-wk periods receiving > 0.5 cm (> 0.2 in.) of rain. Irrigation can be discontinued once native perennials reach 30% total canopy cover.
Fertilization:	None, unless follow-up is required.

Weed Control: None the first two growing seasons.

None thereafter if annual weeds are < 50% relative canopy cover at the end of the second growing season.

If annual weeds are > 50% relative canopy cover at the end of the second growing season, apply low-label rates of 2,4-D and dicamba in early April.

Dynamics: Year 1: Annuals (cheatgrass, Russian thistle, tumble mustard) may dominate; native perennials should comprise > 25% relative cover.

Year 2: Native perennials should comprise > 40% relative cover.

Year 3: Native perennials should comprise > 60% relative cover.

Year 4: Native perennials should comprise > 75% relative cover.

Year 5: Native perennials should comprise ≥ 85% relative cover.

4. <u>Follow-Up Procedures</u>:

Evaluation Criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum 30% total canopy cover in Years 1-2 and minimum of 40% thereafter, plus relative canopy cover values of

Year 1: Native perennial species > 25%
Year 2: Native perennial species > 40%
Year 3: Native perennial species > 60%
Year 4: Native perennial species > 70%
Year 5: Native perennial species > 80%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November with the same seed mixture, but from a different source.

If seedlings of seeded species are established, but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2 wk (April-September). If relative cover values of seeded species were under target levels, add the additional irrigation, but not the fertilizer.

5. <u>Costs</u>:

Low to moderate.

6. <u>Comments</u>:

Irrigation should not be necessary for more than two years, and may not be necessary for more than one. However, there will be the risk of cheatgrass invasion until there is significant establishment of perennials.

SCENARIO 17

SITE:	Upper elevation
COMMUNITY:	Native
TIME:	5-10 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed:	None
Chemical Seedbed:	None
Topsoil Addition:	None
Fertilization:	None
Weed Control:	Disc before weeds set seed in growing season prior to planting. Repeated operations may be necessary (April, June, and September). If cultivation is not possible, apply low-label rates of glyphosate/2,4-D at a 1:2 ratio to reduce weed seed viability.

2. Propagation Procedures:

Species:	Species Mixture 11
Source:	Local < 180 km (< 100 mi), if possible.
Method	Drill, half-in. depth, 0.3 m (12 in.) rows; or broadcast, followed by light harrowing.
Season:	September-November
Mulching:	Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting and crimp mulch into surface.

3. Post-Planting Procedures:

Irrigation:	Apply 0.8 ha-cm (0.5 ac-in.) every 2 weeks (April-July) of the first growing season. Any method of application can be used, but ground application from a water truck or hand lines is least expensive. Irrigation is not necessary during any 2-wk period receiving > 0.5 cm (> 0.2 in.) of rain.
Fertilization:	None, unless follow-up is required.

Weed Control: None the first two growing seasons.

None thereafter if annual weeds are < 50%relative canopy cover at the end of the second growing season.

If annual weeds are > 50% relative canopy cover at the end of the second growing season, apply low-label rates of 2,4-D and dicamba in early April.

Dynamics: Year 1: Annuals (cheatgrass, Russian thistle, tumble mustard) may dominate; native perennials should comprise > 25% relative cover.

Year 2: Native perennials should comprise > 35% relative cover.

Year 4: Native perennials should comprise > 50% relative cover.

Year 6: Native perennials should comprise > 60% relative cover.

Year 8: Native perennials should comprise > 75% relative cover.

Year 10: Native perennials should comprise ≥ 85% relative cover.

4. <u>Follow-Up Procedures</u>:

Evaluation Criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum 30% total canopy cover in Years 1-4 and minimum of 40% thereafter, plus relative canopy cover values of

Year 1: Native perennial species > 25%
Year 2: Native perennial species > 35%
Year 3: Native perennial species > 45%
Year 4: Native perennial species > 50%
Year 5: Native perennial species > 55%
Year 6: Native perennial species > 60%
Year 7: Native perennial species > 70%
Year 8: Native perennial species > 75%
Year 9: Native perennial species > 80%
Year 10: Native perennial species ≥ 85%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November with the same seed mixture, but from a different source.

If seedlings of seeded species are established, but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2 wk (April-September). If relative cover values of seeded species were under target levels, add the additional irrigation, but not the fertilizer.

5. Costs:

Low to moderate.

Costs should be lower than for Scenario 16 because irrigation irrigation should be necessary only 1 year.

6. Comments:

This scenario is very similar to Scenario 16. The primary differences are that this scenario has slower establishment, lower costs, and greater risk of cheatgrass invasion.

SCENARIO 18

SITE:	Upper elevation
COMMUNITY:	Late-seral
TIME:	10-20 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed:	None
Chemical Seedbed:	None
Topsoil Addition:	None
Fertilization:	None
Weed Control:	Disc before weeds set seed in growing season prior to planting. Repeated operations may be necessary (April, June, and September).

2. Propagation Procedures:

Species:	Species Mixture 12
Source:	Local < 180 km (< 100 mi), if possible.
Method:	First drill seeds to half-in. depth with 0.3 m (12 in.) spacing. Then plant shrub tublings on 2.3 m (7.5 ft.) centers; 1900 plants/ha (775 plants/acre). Add 45 g (0.1 lb.) of 16-16-16 fertilizer in bottom of each tubling hole prior to placing the tubling in the hole.
Season:	September-November
Mulching:	Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after drilling and crimp mulch into surface.

3. Post-Planting Procedures:

Irrigation:	Apply 0.8 ha-cm (0.5 ac-in.) every 2 wk (April-September) for minimum of 2 years. Any method of application can be used, but ground application from a water truck or hand lines is least expensive. Care must be taken not to damage shrubs. Irrigation is not necessary during any 2-wk period receiving > 0.5 cm (> 0.2 in.) of rain.
Fertilization:	None, unless follow-up is required.
Weed Control:	None

Dynamics: Year 1: Annuals (cheatgrass, Russian thistle, tumble mustard) may dominate; native perennials should comprise > 25% relative cover.

Year 2: Native perennials should comprise > 35% relative cover.

Year 4: Native perennials should comprise > 50% relative cover; shrubs should comprise > 10% relative cover.

Year 6: Native perennials should comprise > 60% relative cover; shrubs should comprise > 20% relative cover.

Year 8: Native perennials should comprise > 75% relative cover; shrubs should comprise > 30% relative cover.

Year 10: Native perennials should comprise ≥ 90% relative cover; shrubs should comprise > 40% relative cover.

Year 15: Native perennials should comprise ≥ 90% relative cover; big sagebrush should comprise > 35% relative cover.

Year 20: Native perennials should comprise ≥ 90% relative cover; big sagebrush should comprise > 50% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total cover, by species, and record number of live shrubs near the end of each growingseason. If mean values meet target levels (Section 4.3), noadditional action is necessary. If mean values do not meettarget levels, go to follow-up.

Target Levels = Minimum 30% total canopy cover in Years 1-2 and minimum of 40% thereafter, plus

Year 1: Minimum 75% shrub survival; relative cover of native perennials > 25%

Year 2: Minimum 50% shrub survival; relative cover of native perennials > 35%

Year 3: Relative cover of native perennials > 40%; relative cover of shrubs > 5%

Year 4: Relative cover of native perennials > 50%; relative cover of shrubs > 10%

Year 6: Relative cover of native perennials > 60%; relative cover of shrubs > 20%

Year 8: Relative cover of native perennials > 75%; relative cover of shrubs > 30%

Year 10: Relative cover of native perennials > 85%; relative cover of shrubs > 40%

Year 15: Relative cover of native perennials > 85%; relative cover of big sagebrush > 30%

Year 20: Relative cover of native perennials > 85%; relative cover of big sagebrush > 50%

Follow-Up: If no, or very few, seedlings of seededspeciesare established at the end of the first growingseason, the problem was probably poor seed. Re-seed in September-November with the same seed mixture, but from a different source. Broadcast rather than drill. Care must be taken not to damage shrubs.

If seedlings of seeded species are established, but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2 wks (April-September). Care must be taken not to damage the shrubs.

If shrub mortality exceeds 30% at the end of the first growing season, increase irrigation rate by 0.8 ha-cm (0.5 ac-in.) per 2 wk (April-September). If losses exceed 50% over the first three years, replace half the dead plants with new tublings and continue to irrigate. Continue this procedure until canopy cover targets for shrubs are reached.

5. Costs:

Moderate.

The major costs in this scenario are for the purchase and planting of the tublings and irrigation.

6. Comments:

Two years of irrigation should be sufficient to achieve the target levels. Perennial grasses should dominate for the first 10 years, with big sagebrush becoming dominant by Year 15. If precipitation is above average, or irrigation is applied longer, big sagebrush could become dominant by Year 10.

SCENARIO 19

SITE: Upper elevation
COMMUNITY: Late-seral
TIME: 20-50 years
IMPACTS: Light

1. Pre-Planting Procedures:

Physical Seedbed: None

Chemical Seedbed: None

Topsoil Addition: None

Fertilization: None

Weed Control: Disc before weeds set seed in growing season prior to planting. Repeated operations may be necessary (April, June, and September).

2. Propagation Procedures:

Species: Species Mixture 11

Source: Local < 180 km (< 100 mi), if possible.

Method: Drill, half-in. depth, 0.3 m (12 in.) spacing; or broadcast, followed by light harrowing.

Season: September-November

Mulching: Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting and crimp mulch into surface.

3. Post-Planting Procedures:

Irrigation: Apply 0.8 ha-cm (0.5 ac-in.) every 2 wk (April-September) for a minimum of 1 year.

Any method of application can be used, but ground application from a water truck or hand lines is least expensive.

Irrigation is not necessary during any 2-wk period receiving > 0.5 cm (> 0.2 in.) of rain.

Fertilization: None, unless follow-up is required.

Weed Control: None

Dynamics: Years 1-2: Annuals (cheatgrass, Russian thistle, tumble mustard) may dominate; native perennials should comprise > 25% relative cover.

Years 3-5: Native perennials should comprise >35% relative cover.

Years 6-10: Native perennials should comprise > 45% relative cover; shrubs should comprise > 5% relative cover.

Years 11-20: Native perennials should comprise > 60% relative cover; shrubs should comprise > 10% relative cover.

Years 21-30: Native perennials should comprise > 75% relative cover; shrubs should comprise > 20% relative cover.

Years 31-40: Native perennials should comprise > 85% relative cover; big sagebrush should comprise > 30% relative cover.

Years 41-49: Native perennials should comprise > 85% relative cover; big sagebrush should comprise > 40% relative cover.

Year 50: Native perennials should comprise > 85% relative cover; big sagebrush should comprise > 50% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum 30% total canopy cover in Years 1-3 and minimum of 40% thereafter, plus a relative canopy cover of

Years 1-2: Native perennials > 25%
Years 3-5: Native perennials > 35%; shrubs > 5%
Years 6-10: Native perennials > 45%; shrubs > 5%
Years 11-15: Native perennials > 50%; shrubs > 10%
Years 16-20: Native perennials > 60%; shrubs > 15%
Years 21-30: Native perennials > 70%; big sagebrush > 15%
Years 31-40: Native perennials > 80%; big sagebrush > 30%
Years 41-49: Native perennials > 85%; big sagebrush > 40%
Year 50: Native perennials > 85%; big sagebrush > 50%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November with the same seed mixture, but from a different source. If there are significant numbers of shrub seedlings, broadcast rather than drill.

If seedlings of seeded species are established, but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2 wk (April-September). If relative cover values of seeded species were under target levels, add the additional irrigation, but not the fertilizer.

5. Costs:

Moderate.

Costs of this scenario are significantly less than for Scenario 18, because no tublings are used in this scenario.

6. Comments:

The primary difference between this scenario and Scenario 18 is that, in Scenario 18, tublings are used. In this scenario, shrub establishment is from seed only. This makes late-seral community establishment slower, but less expensive, in this scenario. The longer irrigation is applied, the sooner a late-seral shrubland will become established. This scenario will probably also have a greater cheatgrass component for a longer period of time than will Scenario 18.

SCENARIO 20

SITE:	Riparian
COMMUNITY:	Native
TIME:	2-5 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed:	Smooth surface to eliminate ditches and erosion rills.
Chemical Seedbed:	None
Topsoil Addition:	None
Fertilization:	Single application of 16-16-16 fertilizer at 22.4 kg/ha (20 lb/ac).
Weed Control:	None

2. Propagation Procedures:

Species:	Species Mixture 13
Source:	Local < 180 km (< 100 mi), if possible.
Method:	Broadcast, followed by light harrowing or raking.
Season:	September-November
Mulching:	Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface and crimp mulch into surface, or apply 2.54 cm (1 in.) of net mulching to surface; apply mulching within 3 days of planting.

3. Post-Planting Procedures:

Irrigation:	Apply 0.8 ha-cm (0.5 ac-in.) every 2 wk (April-September). Drip or truck application can be used, but ground application from a water truck or hand lines is least expensive. If truck irrigation is used, care must be taken not to cause water erosion. Irrigation is not necessary during any 2-wk period receiving > 0.5 cm (> 0.2 in.) of rain. Irrigation can be discontinued as soon as target values are reached.
Fertilization:	None, unless follow-up is required.
Weed Control:	None

Dynamics: Year 1: Annuals may be abundant in spots; perennial grasses should comprise > 60% relative cover.

Year 2: Perennial grasses should comprise > 90% relative cover; some woody species should begin to establish.

Year 3: Perennial grasses should comprise > 90% relative cover; woody species should be common on lower slopes.

Year 4: Perennial grasses should comprise > 80% relative cover and shrubs > 10% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum of 50% total canopy cover in Year 1, 75% in Year 2, and 90% thereafter, and relative canopy cover of

Year 1: Perennials > 60%
Years 2-4: Perennials > 90%
Year 3: Perennials > 90%; woody species > 10%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November with the same seed mixture, but from a different source.

If seedlings of seeded species are established, but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2 wk (April-September). If relative cover values of seeded species were under target levels, add the additional irrigation, but not the fertilizer.

5. Costs:

Low to moderate.

The primary costs of this scenario are seedbed preparation, seed purchase, fertilizer, mulching, and irrigation. None of these are high-cost items.

6. Comments:

The potential for rapid revegetation is high on these sites. They are mesic sites with relatively light disturbances. However, erosion could be a problem if establishment of perennials is slow. Care should be taken to make sure that the surface is covered at all times by either plants or mulch.

SCENARIO 21

SITE:	Riparian
COMMUNITY:	Native
TIME:	5-20 years
IMPACTS:	Light

1. Pre-Planting Procedures:

Physical Seedbed:	Smooth surface to eliminate ditches and erosion rills.
Chemical Seedbed:	None
Topsoil Addition:	None
Fertilization:	Single application of 16-16-16 fertilizer at 22.4 kg/ha (20 lb/ac).
Weed Control:	None

2. Propagation Procedures:

Species:	Species Mixture 13
Source:	Local < 180 km (< 100 mi), if possible.
Method:	Broadcast, followed by light harrowing or raking.
Season:	September-November
Mulching:	Apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface and crimp mulch into surface, or apply 2.54 cm (1 in.) of net mulching; apply mulch within 3 days of planting.

3. Post-Planting Procedures:

Irrigation:	None
Fertilization:	None, unless follow-up is required.
Weed Control:	None
Dynamics:	Year 1: Annuals may dominate; perennial grasses should comprise > 30% relative cover.
	Year 2: Perennial grasses should comprise > 50% relative cover.
	Year 3: Perennial grasses should comprise > 75% relative cover; some woody species should be present.
	Year 4: Perennial grasses should comprise> 85% relative cover; woody species should comprise about 5% relative cover.
	Year 5: Perennial grasses should comprise > 85% relative cover; woody species should comprise >10% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels = Minimum 50% total canopy cover in Year 1, 65% in Year 2, 80% in Year 3, and 90% thereafter, plus a relative canopy cover of

Year 1: Perennials > 25%
Year 2: Perennials > 50%
Year 3: Perennials > 75%
Year 4: Perennials > 90%
Year 5: Perennials > 90%; shrubs > 5%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed, unless it was a dry year (< 70% of average precipitation). If it was a dry year, wait until the next year. If it was an average or above-average year, re-seed in September-December with the same seed mixture, but from a different seed source.

If seedlings of seeded species are established, but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and irrigate with 0.8 ha-cm (0.5 ac-in.) each 2 wk (April-September). If relative cover values of seeded species were under target levels, add the irrigation, but not the fertilizer.

5. Costs:

Low.

This scenario only requires seedbed preparation, seed purchase and broadcasting, and fertilizer application.

6. Comments:

This scenario is a low-cost version of Scenario 20. In average or above-average precipitation years, it will probably result in the same community establishing on the site as would Scenario 20, but 1-2 years later and at much less cost. The two major risks with Scenario 21 are (1) the site will remain unstable longer, and therefore more subject to erosion, and (2) invasion by cheatgrass and other undesirable species will be more likely, and these species will probably remain in the community much longer.

In average or above-average precipitation years, a perennial community should establish on the site under this scenario within 5 years. Under dry conditions, it might take 10-15 years.

SCENARIO 22

SITE: Riparian
COMMUNITY: Late-seral
TIME: 10-20 years
IMPACTS: Light

1. Pre-Planting Procedures:

Physical Seedbed: Smooth surface to eliminate ditches and erosion rills.

Chemical Seedbed: None

Topsoil Addition: None

Fertilization: Single application of 16-16-16 fertilizer at 22.4 kg/ha (20 lb/ac).

Weed Control: None

2. Propagation Procedures:

Species: Species Mixture 14

Source: Local < 180 km (< 100 mi), if possible.

Method: Broadcast seed; plant willow cuttings (20 cm [8 in.] long, 10 cm [4 in.] into ground) by hand, on 12-ft centers (1210 cuttings/acre).

Season: September-November

Mulching: Apply 4.5 Mg/ha (2 T/ac) of hay or straw on surface and crimp mulch into surface, or apply 2.54 cm (1 in.) of net mulching; apply mulch within 3 days of planting seed.

3. Post-Planting Procedures:

Irrigation: Apply 0.8 ha-cm (0.5 ac-in.) overall, and an additional 7.5 L (2 gal.) around the base of each willow cutting every 2 wk (March-September) for minimum of 1 year.

Drip or truck application can be used, but ground application from a water truck or hand lines is least expensive.

If truck irrigation is used, care must be taken not to cause water erosion.

Irrigation is not necessary during any 2-wk period receiving > 0.5 cm (> 0.2 in.) of rain.

Irrigation can be discontinued as soon as target values are reached.

Fertilization: None, unless follow-up is required.

Weed Control: None

Dynamics: Year 1: Annuals may be abundant in spots. Perennial grasses should comprise > 60% relative cover. Willows should double in height.

Year 2: Perennial grasses should comprise > 90% relative cover. Most willows should be > 0.3 m (1 ft.) tall.

Year 3: Perennial grasses should cover the entire site. Willows should be > 2 ft tall.

Year 5: Perennial grasses should cover the entire site. Willows should be > 5 ft tall. Other woody species should be invading into the site.

Year 10: Perennial grasses should dominate on the upper slopes, and the lower slopes should support a willow thicket. There should be significant amounts (> 10% of surface) in other woody species.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total cover, by species, and the number of live willow shoots near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target Levels =

Year 1: Total canopy cover > 50%; perennial grass relative canopy cover > 60%; 75% willow survival

Year 2: Total canopy cover > 65%; perennial grass relative canopy cover > 90%; willow survival > 70%, mean willow height > 0.3 m (12 in.)

Year 3: Perennial grass total cover > 80%; willow total cover > 5%; willow mean height > 0.6 m (24 in.)

Year 4: Perennial grass total cover > 80%; willow total cover > 10%; willow mean height > 40 in.

Year 5: Perennial grass total cover > 80%; willow total cover > 15%; willow mean height > 60 in.

Year 10: Perennial grass total cover > 50%; willow total cover > 40%; total cover of other woody species > 5%

Follow-Up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in September-November with the same seed mixture, but from a different source.

If seedlings of seeded species are established, but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2 wk (April-September). If relative cover values of seeded species or willow values were under target levels, add the additional irrigation, but not the fertilizer.

5. Costs:

Moderate.

Seedbed preparation, seed, seeding, fertilizer application, and irrigation costs are moderate. Preparation and hand planting of the willow cuttings will increase the costs somewhat.

6. Comments:

This scenario is similar to Scenario 21, except with the addition of the willow cuttings. Once the willow cuttings root, they should for thickets on the wetter sites within 5-10 years. The relative amount of woody species (willow and others) will depend on microtopography of the individual site.

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Environmental Restoration Contractor Revegetation Manual

-Application Guide-

Environmental Excellence

HANFORD

CONTENTS

TABLES

1.0 EXECUTIVE SUMMARY

The purpose of this Application Guide is to provide guidance and general guidelines for the revegetation of remediated waste sites and other disturbed areas on the Hanford Site. It is the companion document to the more complete Revegetation Manual for the Environmental Restoration Contractor. The manual should be read by all personnel using this application guide prior to use.

Disturbances have occurred to some of the ecological communities of the Hanford Site. Many of these disturbances are the result of operations of the Hanford facility, including CERCLA waste sites on small portions of the Hanford Site. However, there were extensive disturbances to the native vegetation prior to operations of the facility, resulting from cultivation, grazing, fire, and introduction of exotics. Revegetation planning must take into account these earlier, as well as later, disturbances.

There are three primary goals in land rehabilitation: revegetation, reclamation, and restoration. Revegetation and reclamation are practical and achievable goals in most cases. This guide concentrates on these goals and how to achieve them. Restoration is much more difficult. Restoration implies that the Site be returned to its pre-disturbance condition. In an absolute sense, this is not possible.

Late-successional ecosystems are very complex systems involving linkages among plant, animal, microbial, soil, and atmospheric subsystems that take biologically long periods of time to develop. Under natural conditions, this process of ecological recovery in the climate of the Hanford Site might take on the order of 200 years to complete. Although we can not return to pre-disturbance conditions, we can restore a site to conditions similar to pre-disturbance conditions in much shorter periods of time, and these procedures are presented in this manual. Section 2.0 discusses these goals of revegetation, reclamation, and restoration, and the objectives associated with them.

Revegetation, reclamation, and restoration involve many ecological processes. Understanding these processes and using them to help accomplish our goals greatly reduces the time, effort, and money required to achieve the objectives. Ignoring these ecological principles and conducting projects contrary to the natural processes will greatly increase the probability of failure. A successful revegetation program must be built on a sound ecological basis.

The specific recommendations for revegetation projects at the Hanford Site are presented in Section 3.0. The first step is to define the objective. This is accomplished by selecting, from a decision matrix menu (Section 3.3), the appropriate combination of sites (5 selections), desired community type (3 selections), time line (5 selections), and use or impact level (2 selections). Based on the selection made in this decision matrix, one of 22 specific revegetation scenarios is recommended (Section 3.4). For each scenario, pre-planting, propagation, and post-propagation procedures are presented, along with expected vegetation dynamics, evaluation procedures, and discussions of relative costs and ecological considerations. Guidelines for selection of plant material are presented in Section 3.5, along with 14 recommended seed mixtures.

A fundamental consideration of any revegetation project is subsequent evaluation. Did it succeed or did it fail? Evaluation criteria to be used to quantitatively answer this question are presented in each of the 22 recommended revegetation scenarios and a general discussion is presented in Section 4.1. Measurement concepts and specific designs and methods for evaluating the scenarios are presented in Section 4.2.

This document is produced as a working document, one that will change over time as new information becomes available and as goals and objectives change. It is based on current scientific knowledge and the personal experience of the authors. A continuing review process is essential for its continued usefulness. The final section of the guide presents a procedure for review and update.

2.0 DEVELOPMENT OF RESTORATION GOALS AND STRATEGIES

2.1 GOALS

There are three primary goals in land rehabilitation: revegetation, reclamation, and restoration. The goals are not exclusive, but they are different and have important differences for Hanford Site needs that should be recognized from the beginning. A successful rehabilitation project must clearly state which goal applies. This goal then provides the guidance and limits to the project.

The purpose of revegetation is to establish some type of vegetative cover to the Site. Various types of vegetation or levels of cover may be specified, but the purpose is to get plants growing on the Site. The first objective in most rehabilitation projects is to stabilize the site. Site stabilization is the primary objective in most revegetation projects.

Revegetation projects may be relatively simple or they may be very complex. The endpoints of a simple revegetation project may be (1) to establish any type of plant community on the site and (2) to assure that some type of plant community succession continues on the site. A more complex revegetation project might require that a specific type of plant community (e.g., big sagebrush shrubland) be established on the site and that it continues to exist on the site after management ends.

Reclamation implies more than just revegetation. It implies that a site has been significantly disturbed and that the site must be returned to ecological conditions similar to surrounding sites that were not subjected to the disturbance. Reclamation projects include revegetation of the Site, but they also include amelioration of the effects of the disturbance. Whereas revegetation accepts the conditions left by the disturbance and proceeds from that point to establish vegetation on the Site, reclamation first attempts to ameliorate the effect of the disturbance, then proceeds to establish vegetation.

Restoration is the most difficult of the three goals. The word restoration implies that the site be returned to its pre-disturbance conditions. Most often, this is not possible in an absolute sense. To achieve complete restoration, the entire ecosystem must be reconstructed. This, in most cases, is beyond our current ability. However, partial restoration, or restoration of certain components of the ecosystem, is often possible and many times practical.

2.2 OBJECTIVES AND STRATEGIES

Once the project goal has been defined, objectives can be defined to attain the goal, and strategies can be developed to accomplish the objectives. Revegetation is an acceptable and achievable goal for many rehabilitation projects. If site revegetation is the goal, objectives are generally defined on the basis of (1) what type of plants are acceptable, (2) how much cover is acceptable, and (3) how long the process is to take. Revegetation objectives can be defined and evaluated solely on the plant community: what type, how much, and how long. Strategies can then be developed to accomplish the objectives (Section 3.0).

Both plant and abiotic objectives are included in reclamation projects. Abiotic objectives address how well the effects of the disturbance have been rectified and what is necessary for the establishment of the target plant community. Examples include altering pH, moving the rooting zone away from contamination by adding topsoil, and recontouring the surface to remove artificial obstructions to surface water flow. The plant objectives may then be similar to revegetation objectives (what plant community, how much, how long?).

There is only one objective to a pure restoration project: restoration of the complete pre-disturbance ecosystem. The first step of this process is to define the pre-disturbance plant community. This definition must include composition, structure, and functional aspects. These values should be based on field data from nearby reference sites.

Once the pre-disturbance plant community is defined, a soil profile must be established similar to the reference site soil profile. This must include similar physical, chemical, and biological components. The more similar the restored profile is to the reference site profile, the more likely it will be that the pre-disturbance plant community can be established on the site and that it will be self-perpetuating. Conversely, the less similar the restored profile is to the reference profile, the less likely the pre-disturbance community can be restored to the site or that it will perpetuate itself after establishment. The restoration of the soil profile includes the re-establishment of surface topography similar to pre-disturbance conditions.

Once the soil profile and surface topography have been restored, the plant community can be established. The target composition is generally easier to establish than recreating the soil structure and surface topography. Structural restoration (e.g., height of plants, depth of rooting) requires more time, because the plants must grow to maturity both above and belowground. Structural restoration may take several years in grasslands, several decades in shrublands, and several centuries in forests. Functional restoration is the last of the objectives to be accomplished. If possible at all, functional restoration may require 50-100 years in grasslands, 100-200 years in shrublands, and 200-500 years in forests.

3.0 DEVELOPMENT OF RESTORATION PLAN

3.1 INTRODUCTION TO THE SELECTION PROCESS

Five types of sites have been identified as possible restoration/revegetation sites. At each site, a combination of three factors determines the revegetation option to be used to achieve the desired objective. These factors are (1) type of plant community that is desired, (2) the time period in which the objective is to achieved, and (3) the intensity of use the site will be exposed to during the revegetation process. The specific objective of a revegetation project can therefore be defined by combining the choices of site, community, time, and use.

In consultation with personnel from Bechtel Hanford, Inc., three potential communities, five time periods, and two use levels were defined (Section 5.3). When combined with the five site types, this results in 150 potential objective scenarios (5 sites x 3 communities x 5 times x 2 use levels). However, most of these scenarios are either not ecologically possible or not cost effective from a management standpoint. For example, one of the site types is a gravel site, where all topsoil has been removed. Only the gravel substrate remains. Natural revegetation on this site would involve primary, not secondary, succession. The pre-disturbance community was a big sagebrush shrubland. One of the community types is late-seral and one of the time periods is 2-5 years. It is not ecologically possible to restore a late-seral shrubland on this type of a site in 2-5 years. Plants can be established within that time period, but to redevelop a complex plant-soil-animal interactive system that is a late-seral community takes much longer, even if topsoil was returned to the site.

The set of 150 potential objective scenarios (site-community-time-use combinations) were reduced to 22 ecologically and management significant scenarios (Table 3-1, Section 3.3). A specific revegetation plan is presented for each of the 22 scenarios and a decision matrix approach is used to provide the user with rapid access to the most appropriate revegetation methodology to meet the defined objective.

3.2 DEFINING THE OBJECTIVE

The revegetation objective is defined by selecting one of the possible values for each of the four factors: site, community, time, and use (impact) level. Descriptions of the four factors are presented in this section. The decision matrix is presented in Section 3.3 and the individual revegetation scenarios are presented in Section 3.4.

3.2.1 Definitions of the Five Site Types

Sand Sites. These sites are located in the 200, 300, and 600 Areas with Quincy sands, Hezel sands, or Burbank loamy sands. These sites may be mixed with small amounts (< 10%) of small gravel (< 2 mm). Native vegetation was big sagebrush shrubland, with significant amounts of perennial grasses. These sites are bare of vegetative cover after an environmental cleanup action, and wind erosion is significant.

Gravel Sites. These sites are located in the 100, 200, 300, and 600 Areas. At these sites, all topsoil has been removed leaving only the Pasco gravel formation parent material. Some have a thin subsoil consisting of sand mixed with the gravel and stones.

Sterilized Sites. These are primarily 100 Area sites, although there are small sterilized sites within the 200 and 300 Areas. The sterilized sites consist of Ephrata stony loams, Ephrata sandy loams, Quincy sands, and Burbank sandy loams above waste sites. They have been kept clear of vegetation by the application of herbicides. Prior to the mid-1980's, the herbicides were long-lived herbicides such as Ureabore. Since then, they have been treated with pre-emergent products such as diuron/bromacil, tebuthiuron, and oryzalin. Revegetation on these sites will begin after the hazardous and radioactive contaminated soils are exhumed. At that time, the nonradioactive, herbicide-treated soil will be used as a subsoil, covered with adjacent surface soil mixed with Pasco gravel or stony loam soils.

Fine Soil Sites. These sites are located in the 600 Areas on northeast-facing slopes of Rattlesnake mountain and south-facing slopes of the Saddle Mountain area. Soils include Warden, Ritzville, and Lickskillet silt loams. These sites are generally more mesic than most other Hanford sites, and they have received less extensive soil disturbance than the previously mentioned sites.

Riparian Sites. These areas are located along the banks of the Columbia River that are influenced by shallow groundwater or intermittent flooding in 100, 300, and 600 Areas. The primary disturbances on these sites are physical disturbances related to construction, site excavation along the river, and old reactor discharge lines. These sites vary in microtopography from steep, short banks to long, gradual sloping areas. The lower elevations are infrequently saturated. It is crucial to maintain or restore stability to these sites and to minimize erosion and subsequent soil loss into the Columbia River.

3.2.2 Definitions of the Four Community Types

Introduced. This objective is to establish a perennial plant community, composed of introduced (i.e., not native to the area) species. In most cases, these species will be perennial grasses. Introduced grasses are often less expensive to establish than native grasses, and are usually easier to establish agronomically. In addition, introduced grasses often make superior growth, compared to natives, under disturbed or heavy-use conditions because they have been genetically selected to perform well under the disturbed conditions associated with cultivation. This community type option would result in the establishment of a perennial grass community that would stabilize the site for at least 20 years. After that time, some native species would likely establish on the site, resulting in a mixed introduced-native community of perennial grasses and shrubs. Although this introduced option results in a community compositionally different from the pre-disturbance native communities, it stabilizes the site and is structurally similar to some of the native communities in the area (i.e., a grassland).

The introduced community type is not a useful option for the riparian sites. Native species can be established on this mesic site as easily as introduced species. Therefore, there is no advantage to using introduced species. In addition, planting non-native species along a plant invasion corridor, such as a river bank, would lead to regulatory violations in the future if the seeded species was later deemed to be noxious.

Native. The native option is appropriate on all sites. This objective is to establish a perennial plant community, composed of native species, primarily grasses. It is similar to the introduced option, except that native perennial species are used instead of introduced species. This increases the costs somewhat because (1) seed of native species is more expensive than seed of introduced species, (2) at present, the Hanford Site Natural Resource Trustee Council for CERCLA actions is requesting locally derived, native seed, and (3) most native species are more difficult to establish than many introduced species. The advantage of the native species establishment over introduced species is twofold. First, native species are generally better adapted to long-term ecological conditions at a site than are introduced species. Ecological conditions can vary greatly on decade and century time scales, especially in arid and semiarid regions, and native species can tolerate most of these fluctuations. In contrast, introduced species may be well-adapted to initial conditions, especially following disturbance, but may not be well-adapted to the long-term fluctuations. Secondly, there is considerable social and regulatory pressure to use locally-derived native species, rather than introduced species, and this pressure from stakeholder groups is likely to increase in the future.

The native species used in this option are mostly perennial grasses because these establish more quickly than shrubs. However, some shrub and forb seed are included in the mixtures.
The community initially established will be a grassland. Over time however, other native species, primarily shrubs, will invade the site and

slowly shift the site from a grassland to a shrubland.

Late-seral. This objective is to establish a late-seral native community on the site. This is the most difficult and expensive of the three options to accomplish. Late-seral communities must have late successional characteristics related to composition, structure, and function of the plant community. Provided adequate soil conditions exist, target plant composition can generally be achieved by planting the proper mix of species. However, late-seral structure is also important and this takes time for the plants to grow to maturity (10-20 years for some shrubs). Costs are higher for this option than for the other options because some of the late-seral species can not, or only very slowly, establish under disturbed conditions. Some critical late-seral conditions must be re-established before the plant community can be re-established. One primary example is soil. A number of late-seral species may require a significant layer of topsoil to be present or significant redevelopment of parts of the soil microbial system before the plants can adequately function on the site.

It is probable that, over time, the other options will develop late-seral communities, if the sites are not re-disturbed. However, this process may take 100-200 years. In addition, the late-seral communities that may result from this secondary succession may be significantly different than the desired late-seral community, especially in the case of the introduced option. The purpose of the late-seral option is to establish the appropriate late-seral community on the site in a relatively short period of time.

The late-seral option is appropriate on all sites.

3.2.3 Definitions of the Five Time Periods

The five time periods are (1) 2-5 years, (2) 5-10 years, (3) 10-20 years, (4) 20-50 years, and (5) 50-100 years. A range of values is given in each case. The lower value is the estimated time the revegetation objective could be reached under ideal conditions (e.g., above average precipitation, excellent germination, little herbivory or pathogenic attack). The upper value is the estimated time under adverse, but not necessarily worst-case, conditions. Under normal conditions, something slightly less than the lower value should be expected.

These time lines define the period in which it is desired to achieve the stated revegetation objective. For example, the community option chosen for a sand site might be a native community. This objective might be planned for accomplishment in 2-5 years or in 5-10 years. The revegetation procedures (scenario) would be different for the two time periods. It will take more resources to achieve the same objective in a shorter period of time.

The shorter the time period selected for a given revegetation option, the more extensive the procedure and the higher the costs. Conversely, if time is not as important, the same revegetation option can generally be achieved at a lower cost if the time period is longer. In the latter case, the natural process of secondary succession can be used to help the revegetation process. Whenever management objectives can be matched with natural ecological processes, there will be a cost savings.

Only the 2-5 year time option is available for the introduced community option for much the same reason. Introduced species, and their related establishment procedures, are well-adapted to post-disturbance conditions and can be successfully applied in short periods of time. A major advantage of the introduced species over the native option is that the introduced species can be established more quickly than the native. If time periods greater than 5 years are used, the introduced option looses much of its advantage.

The native option is limited to the 2-5 and 5-10 year periods, except for the sand site where it can also have a 10-20 year period. Like the introduced option, the native option establishes a grassland. These grass species can be established within 10 years on most sites. Longer establishment times generally do not provide any management advantage.

Late-seral communities require more time to develop than early- or mid-seral communities, even with extensive anthropogenic inputs. No 2-5 or 5-10 year time options are available for the late-seral community option because the woody late-seral plants require at least 10 years to reach maturity, even under good conditions. Revegetation to late-seral conditions should be most rapid on the mesic riparian sites. Here, the moist conditions should allow the willow and late-seral grasses to reach maturity within 10-15 years. Therefore only the 10-20 year time option is available for this community option in this community type.

The gravel site will remain an extremely xeric site for a considerable period of time. Extensive inputs will be required to establish a late-seral community on this site and this level of effort should allow a shrubland to be established within 10-20 years. Further successional development will be slow and can occur through natural means as rapidly as with human inputs. Therefore, time options past 20 years are not included for this site.

Late-seral conditions should be attainable within 50 years on the upper elevation and sterilized sites. Extending this time period to 100 years does not significantly decrease the revegetation costs but it would significantly increase risks associated with erosion and weed control. Therefore, only 10-20 and 20-50 year time options are presented for these two site types.

Late-seral species may be initially difficult to establish on the sand sites, but once succession has adequately stabilized the site complex and productive late-seral communities are possible. Establishment of a late-seral community on these sites might be possible in 10-20 years, but it would take very high inputs of resources. Establishment of the same community in 20-50 years is much more feasible. Therefore, the 10-20 year time option has not been included for this site.

3.2.4 Definitions of the Two Use Levels

The two use levels are heavy and light. Heavy use refers to frequent impacts from wheeled vehicles and/or heavy grazing and browsing by deer, elk, or geese. Light refers to infrequent and light use by vehicles and light-to-moderate grazing/browsing by deer, elk, or geese. All other factors constant, the heavier the use level, the longer the revegetation process will take or the more expensive it will be to accomplish.

The late-seral community option is not possible under the heavy use option. The late-seral communities are shrub-dominated communities and heavy use will continually reduce shrub coverage and therefore reverse the recovery process.

The heavy use option has also been eliminated as a possibility on the riparian, upper elevation, and gravel sites. Erosion control and bank stability are critical goals on the riparian sites. Heavy use is contrary to these goals. Upper elevation sites are far-removed from most mechanical activities of the Hanford Site. Therefore, vehicle use would be expected to be light. If grazing/browsing becomes too heavy on these sites, some of the revegetation objectives might not be possible. There is no reason for heavy vehicle use to occur, except in limited areas, on the gravel sites, or heavy concentrations of deer and elk are not expected to occur there.

Conversely, heavy use is expected on the sand and sterilized sites. The introduced and native community options can withstand heavy use after establishment. However, heavy use during the establishment phase of the revegetation will likely result in failure and therefore the process will have to be repeated with the associated increase in costs. Heavy use by vehicles should be prohibited on all revegetation sites until the target levels are reached. Planning for light use on the sand and sterilized sites would not alter the revegetation procedures. Therefore, light use options are not included in the decision matrix for these sites.

3.3 DECISION MATRIX

To select the proper revegetation scenario, define the objective by selecting the most appropriate option under each of the following three factors. The objective will be defined by a three-part sequence (Site-Community-Time). Once the objective has been defined, use the sequence to select the appropriate revegetation scenario from Table 3-1. The scenarios are listed in Section 3.4, in numerical order.

Site Factor. Five site types are listed. Select the site most similar to the site under consideration for revegetation. Descriptions of the site types are presented in Section 3.2.1.

1. SAND
2. GRAVEL
3. STERILIZED
4. UPPER
5. RIPARIAN

Community Factor. Three community options are listed, from least difficult to achieve (1) to most difficult (3). Select one or more community options for the site under consideration for revegetation. Multiple communities may be appropriate when planning over a period of time. Descriptions are presented in Section 3.2.2.

1. INTRODUCED
2. NATIVE
3. LATE-SERAL

Time Factor. Five time periods are listed. Select one time period in which the objective is to be achieved. Discussions are presented in Section 3.2.3.

1. 2-5 YEARS
2. 5-10 YEARS
3. 10-20 YEARS
4. 20-50 YEARS
5. 50-100 YEARS

Table 3-1. List of 22 Revegetation Scenarios for Hanford Environmental Restoration Contractor (ERC) Projects.

Number	Site Factor	Community Factor	Time Factor	Use Factor
01	Sand	Introduced	2-5	Heavy
02	Sand	Native	2-5	Heavy
03	Sand	Native	5-10	Heavy
04	Sand	Native	10-20	Heavy
05	Sand	Late-seral	20-50	Light
06	Sand	Late-seral	50-100	Light
07	Gravel	Introduced	2-5	Light
08	Gravel	Native	2-5	Light
09	Gravel	Native	5-10	Light
10	Gravel	Late-seral	10-20	Light
11	Sterilized	Introduced	2-5	Heavy
12	Sterilized	Native	2-5	Heavy
13	Sterilized	Native	5-10	Heavy
14	Sterilized	Late-seral	10-20	Light
15	Sterilized	Late-seral	20-50	Light
16	Upper elevation	Native	2-5	Light
17	Upper elevation	Native	5-10	Light
18	Upper elevation	Late-seral	10-20	Light
19	Upper elevation	Late-seral	20-50	Light
20	Riparian	Native	2-5	Light
21	Riparian	Native	5-10	Light
22	Riparian	Late-seral	10-20	Light

3.4 REVEGETATION SCENARIOS

3.4.1 General Comments

The revegetation scenarios presented in Section 3.4.2 are written as specific guidelines and recommendations. However, some flexibility in application will always be necessary because of specific conditions at a site that were unforseeable at the time this manual was written. The following general comments are presented to give an overview to guide in the applications of these recommendations and possible modifications to them necessitated by site-specific conditions.

Pre-planting. Soil fertility and compaction tests should be conducted prior to making final plans for a specific revegetation project (Manual Section 4.4.2). Samples should be taken of the material that will function as the initial soil, as it will exist at the beginning of the project. For example, if two materials are to be mixed, the samples should be taken after the mixing takes place, not of the two materials prior to mixing. Samples should be taken at specific depths (e.g., 20 cm) throughout the rooting zone (60 cm for grasses and 120 cm for shrubs or depth to impervious layer, whichever is less). A sufficient number of samples should be taken to adequately sample the variation over the project area. It is not possible to determine beforehand how many this will be. It will depend upon the heterogeneity of the site. The greater the variability, the greater the number of samples required. However, approximately 10 will probably be adequate for an area up to several acres in size.

Each sample should be analyzed for pH, available N, available P, K, and EC (electroconductivity). If pH is below 6.0, lime should be added to raise it to 6.0. If pH is above 9.0, sulfur should be added to lower it to 9.0. If EC is above 4.0, it should be reduced by leaching prior to planting. If plant available N, P, and K are similar to adjacent areas, based on soil testing, pre-planting fertilization is not necessary.

Samples taken from sterilized sites should also be tested for inhibition of plant germination and growth. If these tests suggest that there is no significant germination or growth inhibitation from the soil sterilants, no topsoil additions are necessary. However, it is very important that these tests be conducted (1) on the soil material after it has been mixed, (2) on the various depths that the roots will be in contact with, (3) for long enough periods of time for any possible accumulative effects to be manifested, and (4) with the species that will be planted on the site.

Irrigation. Irrigation is recommended for most of the scenarios. Eliminating irrigation would reduce the costs of these scenarios. It is probable that a significant number of the scenarios will succeed in some, perhaps most, years without irrigation. However, some will fail without it, at least in some years. The wetter the year, the less necessary irrigation becomes. The drier the year, the more necessary. No one can successfully predict how wet or how dry a year will be beforehand. There is a risk involved in guessing wrong. The results of guessing wrong on the dry side (i.e., not irrigating when it is needed) are (1) not meeting the target levels, (2) potentially having to replant, and (3) possible erosion during the period before adequate cover is achieved. The results of guessing wrong on the wet site (i.e., irrigating when it is not necessary) is the expense of the irrigation. However, this expense might be reduced if the target levels are met sooner than expected because of the irrigation and therefore the project can be declared successfully completed earlier than planned.

Irrigation eliminates one source of uncertainty in revegetation. Even in average or wet years, the irrigation will allow the plants to establish and grow at a faster rate than without irrigation. In each scenario, irrigation can be discontinued as soon as target levels are met. In most cases, this will be at the end of the first year. And irrigation is not necessary if adequate rainfall is received. This point is made in each of the scenarios.

Irrigation is also a means to give perennials, both shrubs and grasses, competitive advantage over cheatgrass. By irrigating before cheatgrass begins to grow in the fall and after it sets seed in the spring, moisture can be supplied to the perennials and their growth will make invasion by cheatgrass more difficult.

The amount of irrigation recommended is based on supplying optimum conditions to the target species. Less water can be used, but this will result in a lower response to irrigation.
A common recommendation is to apply 3.8 cm (1.5 in.) per month for 4 months. In an average year, this would raise the total moisture supply (precipitation + irrigation) to 32 cm (12.7 in.). This amount should provide for successful establishment and growth of the target species in any year.

Over the past 50 years (1946 through 95), the average Mar-Aug precipitation at the Hanford Site has been 6.4 cm (2.50 in.). In 15 of these 50 years, 30% of the time, Mar-Aug precipitation has been less than 80% of average. In 8 of these years, 16% of the time, Mar-Aug precipitation has been less than 60% of average (< 3.8 cm [1.50 in.]). Without irrigation, the scenarios would probably succeed in 3 out of 10 years (above-average [> 120% of average] Mar-Aug precipitation), might succeed in 4 out of 10 years (average [80-120% of average] Mar-Aug precipitation), and would probably fail in 2 out of 10 years (below-average [< 80% of average] Mar-Aug precipitation). With irrigation, they would probably succeed in all years.

Costs. Each scenario contains a relative cost estimate. These estimates are very general. The actual costs will vary by current prices of site preparation, seed, fertilization, irrigation methods chosen, and labor costs. These costs change, on a seasonal if not monthly basis, and some will be specific to the Hanford Site. Therefore, it is not possible to be specific relative to them in this document. However, the following general categories will probably apply:
(1) very low = < $1,000 per acre;
(2) low = $1,000 to $5,000 per acre;
(3) moderate = $5,000 to $10,000 per acre, and
(4) high = > $10,000 per acre.

3.4.2 Listing of Scenarios

Section 3.4.2 presents the appropriate methodologies for the revegetation scenarios defined in Section 3.3 and listed in Table 3-1. They are presented in numerical order. The seed mixtures for the scenarios are presented in Section 3.5.

3.5 SELECTION OF PLANT MATERIAL

3.5.1 Guidelines for Selection

There are six primary considerations involved in the selection of plant material for a revegetation effort: (1) ecological appropriateness, (2) social appropriateness, (3) availability, (4) compatibility, (5) viability, and (6) cost. Each of these six factors can change over time. Therefore, the appropriateness of the selection can also change. For this reason, recommendations should be reviewed periodically to insure that the suggested mix is still the most appropriate for current conditions.

Ecological Appropriateness. The foremost consideration is whether or not the species, or combination of species, is proper for the ecological conditions and objectives of the revegetation effort. Many of these applications are obvious. Life form, climatic, and edaphic limitations must be taken into consideration. Woody plants should not be used on sites subjected to frequent disturbances, species adapted to mesic environments are not likely to grow well in deserts, and species adapted to sandy soils may not establish well on clays. However, other ecological considerations may not be as obvious. Late-seral species may not establish well under early-successional conditions. Some shrubs, such as big sagebrush, are poorly adapted to fire. Some introduced species, such as crested wheat grass, are very competitive against native species and are difficult to eliminate once they become established during the time periods used in the revegetation scenarios. Ecological characteristics of the species should always be matched with site conditions and management objectives.

The concept of genetic appropriateness is sometimes confused with ecological appropriateness in revegetation and restoration projects. From a scientific standpoint, for genetic appropriateness to be of concern in revegetation work, there must be enough difference in ecological response within the species to significantly affect the response of the plants to the environmental conditions at the site. If not, then the questions of genetic appropriateness are of social, not ecological, concern.

Significant ecological differences may exist between populations of the same species. Commercial seed may not be labeled as to which subspecies the seed is from. However, differential responses between subspecies may be very important in determining success or failure in a revegetation project. The nearer the seed source to the revegetation site, the less risk there will be that genetic variability will adversely affect revegetation. If a species is widely distributed, material that grows naturally within 100 miles of the revegetation site will probably be ecologically appropriate for the site. If a species is very restricted in its range, or if its distribution is discontinuous over the region, it may be more ecologically important to use material from the nearest population.

Social Appropriateness. Social appropriateness may be based on ecological criteria, but most often it is not. The question of using native or introduced species in revegetation has an ecological aspect. There are scientific reasons for using one or the other. However, a regulatory decision might be made that stipulates that only native species will be used. Such a decision may have a strong social basis to it. Likewise, decisions to require the use of local seed may be more social-based than ecologically-based. If stakeholder or regulator input is important, social issues must also be considered.

Guidance on preparing revegetation plans on specific ERC projects requires contact with the Natural Resources Group. Input from stakeholders, the Natural Resource Trustee Council, and Native American groups will be coordinated with specific revegetation plants before the specifics are implemented. Specific revegetation objectives will be considered to determine the specific revegetation scenario guidance. Current seed availability will also be determined for each specific seed mixture during this review.

Availability. Often there are problems in the availability of specific plant material. This is especially true with less-common native species and with locally-produced material. It is generally less of a problem with common commercial varieties of native species and with most introduced species. When adequate amounts of the material of choice are not available, the decision has to be made to either wait until adequate quantities are available or to substitute some other species or cultivar. If the decision is made to wait, the site will remain unstabilized for a longer period of time, increasing those associated risks. Generally, it is better to substitute than to wait. However, with proper planning it should be possible to have adequate quantities available prior to the beginning of the project and substitution is less of a problem.

Compatibility. Seed of some species may not be compatible with the equipment available or with the other seeds being used in the mix. Some awned or bristled seed can be broadcast seeded but not drilled, unless the awns or bristles are removed. This removal process increases the cost of the seed. If broadcasting is to be used, there probably would not be a problem. However if the revegetation plan called for drilling the seed, (1) the awned species would have to be left out of the mix, (2) the species would have to be de-awned, thereby increasing costs, or (3) the species would have to be seeded separately, thereby also increasing costs. If the species was a minor component of the mix or if there was an adequate substitute, the first option probably would be chosen. But the species might have significant potential for use in the revegetation plan. If so, the second or third option might be selected.

Viability. Purchasing cheap, low-viability seed will not reduce the cost of a revegetation project. It will increase the costs. Seed should always be purchased on a pure live seed (PLS) basis.

Plant material is of little use in a revegetation program if it is not viable. One reason seed is commonly inexpensive is because it is of low viability. In revegetation work, seed cost should not be an item in the budget, cost of viable seed should be. The success of a revegetation effort is less influenced by how many seed are planted than by how many seed germinate. All seeding programs should be on a pure live seed (PLS) basis. Similarly, healthy tublings, cuttings, sprigs, or transplants should be used when vegetative material is needed. There is just as high a cost in transporting and planting dead material as there is with live material. Suppliers of plant material should be selected on the basis of costs per unit of live material rather than lowest cost per pound or per tubling.

Cost. Costs are important items in any revegetation project and costs of plant material vary significantly. These variations should be considered when establishing and reviewing planting recommendations.

3.5.2 Seed Mixtures

The 22 revegetation scenarios require 14 seed mixtures, some of which also include vegetative material. These mixtures are listed below, in numerical order.

All rates listed below are moderate rates, drilled. For heavy drilled rates, increase by 50%. For broadcast or imprint seeded, use twice the respective drill rate.

Seed Mixture 01

Scenarios: 01 Sand, introduced, 2-5, heavy

Agropyron cristatum	crested wheatgrass	5.6 kg PLS/ha (5lbs PLS/ac)
Agropyron sibericum	Siberian wheatgrass	5.6 kg PLS/ha (5 lbs PLS/ac)
Elymus giganteus	mammoth wildrye	4.48 kg PLS/ha (4 lbs PLS/ac)
Melilotus officinalis	sweetclover	0.56 kg PLS/ha (0.5 lb PLS/ac)
Psoralea lanceolata	scurf pea	0.56 kg PLS/ha (0.5 lb PLS/ac)
	Total	16.8 kg PLS/ha (15 lbs PLS/ac)

Seed Mixture 02

Scenarios:
02 Sand, native, 2-5, heavy
03 Sand, native, 5-10, heavy
04 Sand, native, 10-20, heavy

Agropyron dasystachyum	thickspike wheatgrass	5.6 kg PLS/ha (5 lb PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Koeleria cristata	prairie junegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Psoralea lanceolata	scurf pea	0.56 kg PLS/ha (0.5 lb PLS/ac) or rhizomes
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
Stipa comata	needle-and-thread	2.24 kg PLS/ha (2 lbs PLS/ac)
	Total	18.2 kg PLS/ha (16.25 lbs PLS/ac)

Seed Mixture 03

Scenarios:
05 Sand, late-seral, 20-50, light
06 Sand, late-seral, 50-100, light

Agropyron dasystachyum	thickspike wheatgrass	1.68 kg PLS/ha (1.5 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Koeleria cristata	prairie junegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	1.12 kg PLS/ha (1 lb PLS/ac)
Psoralea lanceolata	scurf pea	0.56 kg PLS/ha (0.5 lb PLS/ac) or rhizomes
Purshia tridentata	antelope bitterbrush	1.12 kg PLS/ha (1 lb PLS/ac)
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
Stipa comata	needle-and-thread	1.12 kg PLS/ha (1 lb PLS/ac)
Artemisia tridentata	big sagebrush	6-mo tublings
	Total	14.84 kg PLS/ha (13.25 lbs PLS/ac)

Seed Mixture 04

Scenarios: 07 Gravel, introduced, 2-5, light

Agropyron cristatum	crested wheatgrass	5.6 kg PLS/ha (5 lbs PLS/ac)
Agropyron sibericum	Siberian wheatgrass	5.6 kg PLS/ha (5 lbs PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Melilotus officinalis	sweetclover	0.56 kg PLS/ha (0.5 lb PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
	Total	15.12 kg PLS/ha (13.5 lbs PLS/ac)

Seed Mixture 05

Scenarios: 08 Gravel, native, 2-5, light
Scenarios: 09 Gravel, native, 5-10, light

Agropyron dasystachyum	thickspike wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
Stipa comata	needle-and-thread	0.56 kg PLS/ha (0.5 lb PLS/ac)
	Total	12.88 kg PLS/ha (11.5 lbs PLS/ac)

Seed Mixture 06

Scenarios: 10 Gravel, late-seral, 10-20, light

Agropyron dasystachyum	thickspike wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
Artemisia tridentata	big sagebrush	6-mo tublings
	Total	13.72 kg PLS/ha (12.25 lbs PLS/ac)

Seed Mixture 07

Scenarios: 11 Sterilized, introduced, 2-5, heavy

Agropyron cristatum	crested wheatgrass	5.6 kg PLS/ha (5 lbs PLS/ac)
Agropyron sibericum	Siberian wheatgrass	5.6 kg PLS/ha (5 lbs PLS/ac)
Elymus giganteus	mammoth wildrye	3.36 kg PLS/ha (3 lbs PLS/ac)
Melilotus officinalis	sweetclover	0.56 kg PLS/ha (0.5 lb PLS/ac)
	Total	15.12 kg PLS/ha (13.5 lbs PLS/ac)

Seed Mixture 08

Scenarios: 12 Sterilized, native, 2-5, heavy
13 Sterilized, native, 5-10, heavy

Agropyron dasystachyum	thickspike wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Festuca ovina	sheep fescue	2.24 kg PLS/ha (2 lbs PLS/ac)
Koeleria cristata	prairie junegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Sporobolus cryptandrus	sand dropseed	0.56 kg PLS/ha (0.5 lb PLS/ac)
Stipa comata	needle-and-thread	1.12 kg PLS/ha (1 lb PLS/ac)
	Total	17.92 kg PLS/ha (16.0 lbs PLS/ac)

Seed Mixture 09

Scenarios: 14 Sterilized, late-seral, 10-20, light

Agropyron dasystachyum	thickspike wheatgrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Koeleria cristata	prairie junegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lb PLS/ac)
Stipa comata	needle-and-thread	1.12 kg PLS/ha (1 lb PLS/ac)
Artemisia tridentata	big sagebrush	6-mo tublings
	Total	14.28 kg PLS/ha (12.75 lbs PLS/ac)

Seed Mixture 10

Scenarios: 15 Sterilized, late-seral, 20-50, light

Agropyron dasystachyum	thickspike wheatgrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	3.36 kg PLS/ha (3 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Koeleria cristata	prairie junegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Stipa comata	needle-and-thread	1.12 kg PLS/ha (1 lb PLS/ac)
Artemesian tridentata	big sagebrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
	Total	15.68 kg PLS/ha (14 lbs PLS/ac)

Seed Mixture 11

Scenarios: 16 Upper, native, 2-5, light
17 Upper, native, 5-10, light
19 Upper, native, 20-50, light

Agropyron dasystachyum	thickspike wheatgrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	4.48 kg PLS/ha (4 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.56 kg PLS/ha (0.5 lb PLS/ac)
Festuca ovina	sheep fescue	1.12 kg PLS/ha (1 lb PLS/ac)
Koeleria cristata	prairie junegrass	1.12 kg PLS/ha (1 lb PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Poa sandbergii	Sandberg bluegrass	4.48 kg PLS/ha (4 lbs PLS/ac)
Stipa comata	needle-and-thread	0.56 kg PLS/ha (0.5 lb PLS/ac)
Artemesian tridentata (for scenario 19 only)	big sagebrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
	Total	17.92 kg PLS/ha (16.0 lbs PLS/ac)

Seed Mixture 12

Scenarios: 18 Upper, late-seral, 10-20, light

Agropyron dasystachyum	thickspike wheatgrass	1.12 kg PLS/ha (1 lb PLS/ac)
Agropyron spicatum	bluebunch wheatgrass	4.48 kg PLS/ha (4 lbs PLS/ac)
Artemisia tridentata	big sagebrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Chrysothamnus nauseosus	gray rabbitbrush	0.28 kg PLS/ha (0.25 lb PLS/ac)
Festuca idahoensis	Idaho fescue	1.12 kg PLS/ha (1 lb PLS/ac)
Koeleria cristata	prairie junegrass	1.68 kg PLS/ha (1.5 lbs PLS/ac)
Oryzopsis hymenoides	Indian ricegrass	1.12 kg PLS/ha (1 lb PLS/ac)
Poa sandbergii	Sandberg bluegrass	2.24 kg PLS/ha (2 lbs PLS/ac)
Stipa comata	needle-and-thread	0.56 kg PLS/ha (0.5 lb PLS/ac)
Artemisia tridentata	big sagebrush	6-mo tublings
	Total	12.88 kg PLS/ha (11.5 lbs PLS/ac)

Seed Mixture 13

Scenarios: 20 Riparian, native, 2-5, light
21 Riparian, native, 5-20, light

Elymus arenicola	sand wildrye	1.12 kg PLS/ha (1 lb PLS/ac)
Elymus cinereus	basin wildrye	3.36 kg PLS/ha (3 lbs PLS/ac)
Poa juncifolia	alkali bluegrass	4.48 kg PLS/ha (4 lbs PLS/ac)
Rosa woodsii	Woods rose	1.12 kg PLS/ha (1 lb PLS/ac)
	Total	10.08 kg PLS/ha (9 lbs PLS/ac)

Seed Mixture 14

Scenarios: 22 Riparian, late-seral, 10-20, light

Elymus arenicola	sand wildrye	1.12 kg PLS/ha (1 lb PLS/ac)
Elymus cinereus	basin wildrye	3.36 kg PLS/ha (3 lbs PLS/ac)
Poa juncifolia	big bluegrass	4.48 kg PLS/ha (4 lbs PLS/ac)
Rosa woodsii	Woods rose	1.12 kg PLS/ha (1 lb PLS/ac)
Salix sp.	willow	8-in. cuttings
	Total	10.08 kg PLS/ha (9 lbs PLS/ac)

4.0 EVALUATION CRITERIA

4.1 CRITERIA FOR SUCCESS

4.1.1 Short-term Criteria

The revegetation process will proceed through a series of stages roughly corresponding to stages of secondary succession. These are described in Section 3.4 for each of the 22 revegetation scenarios. Recovery, and therefore success of the revegetation project, will be evaluated on be basis of (1) total plant canopy cover, (2) relative composition of the plant community, and (3) survival and growth of woody plants, if woody plants are part of the scenario.

Target values are defined for each evaluation variable, for each year, for each site. These are the minimum values for the respective variable that indicate success for that year. The vegetation will be sampled at the end of the growing season, according to the methodology presented in Section 4.2.3, and the recorded values compared to the target values for that year. If the recorded values meet or exceed the target levels, the revegetation project has been successful for that year and no follow-up treatments are required. If the recorded values are below the target values, follow-up treatment is required that year and this treatment is listed in the scenario text. This process of sampling and comparing to target values is to continue until the target values for the last year in the scenario are reached. Once this endpoint is reached, the revegetation project can be declared successful.

The first evaluation target variable is total canopy cover, expressed as a percentage (e.g., 25%). The target value is based on ecological conditions of an average year. If precipitation is below average, this value should be adjusted downward by an amount proportional to the amount that precipitation was below average. The evaluation is to take place at the end of each growing season. The precipitation value compared to average should be the amount received during the 12 months preceding the sampling date.

The next set of evaluation target variables are relative canopy cover by species or group of species. The use of relative cover values eliminates the need to adjust for annual climatic variability.

The final set of evaluation target variables relate to woody species, if they are part of the initial restoration procedure. For the first few years of a scenario, these are usually survival variables. Thereafter, they are total canopy or relative canopy cover variables.

4.1.2 Possible Effects of Climatic Fluctuations

Each revegetation scenario has a time line associated with it (e.g., 5-10 years). The spread in these values is to allow for the effect of ecological variability, primarily precipitation. If the years following planting are above average in precipitation, the scenario should be completed within the lower limit of the spread (e.g., 5 years). Conversely, if the years following planting are below average in precipitation, the scenario will likely require the upper limit for completion (e.g., 10 years). If drought continues throughout the entire period of the scenario, it is unlikely that the objective will be reached in the expected time period unless irrigation is applied for the entire period.

4.2 MEASUREMENT METHODS

4.2.1 Vegetation Sampling Concepts

There is no universal vegetation sampling technique. There is no one technique that provides the data to answer all questions. Each technique has its advantages and disadvantages, and adds information that other techniques do not. With unlimited time and money, all techniques could be used to obtain the maximum amount of information. However, with limited resources it is important to select the appropriate methods, i.e., the methods that will provide the data necessary to answer the required questions at a minimum expenditure of resources.

The question that needs to be answered is "Has the particular revegetation scenario been successful?." The vegetation sampling method chosen must provide the data required to answer this question and to do so with a minimum expenditure of resources. If fewer resources are required to validate success, more resources should be available to conduct revegetation. Success is defined in each scenario on the basis of achieving pre-determined levels of plant community development. There are three major aspects to vegetation that can be sampled: composition, structure, and function. Functional restoration is not a requirement of any of the revegetation scenarios, therefore it is not necessary to sample to verify its redevelopment.

Revegetation success is defined in the scenarios on the basis of structure and composition. The plant communities to be established by the revegetation scenarios are either grasslands or shrublands. Cover is a widely used measurement for composition and structural aspects in grasslands and shrublands.

Cover refers to the percent of the ground surface, perpendicular vertical projection, covered by the plant. Cover data are of two types, basal and canopy. Basal cover refers to the amount of the ground surface covered by the base of the plant at ground surface. Canopy cover refers to the amount of ground surface covered by the vertical projection of the entire canopy of the plant. Basal cover is generally a better measure of long-term dynamics. Canopy cover is generally a better measure of the ecophysiological importance of a species within a community. Basal cover is relatively easy to measure for many species, including some perennial grasses and most trees, but it can be difficult to measure for multi-stemmed shrubs, many forbs, and many grasses.

When comparing among species, canopy cover is generally preferred over basal because it is a better indicator of ecological importance. For example, most perennial forbs and many semi-shrubs have relatively small basal areas. And yet their relatively small stems support significant amounts of canopy, and it is the leaves of these canopies that produce the biomass that is the primary production of a community and that influences the amount of resources utilized by the plant.

Canopy cover will be used as the primary variable to measure changes in composition and structure in the revegetation projects. The changes will then be compared to expected changes to determine whether or not (1) the revegetation scenario is on schedule and (2) if the endpoint of the project has been achieved. The former is a measure of temporal success and the latter is a measure of final project success.

Cover can be sampled by three general methods: transects, points, and estimates. Transects can be of two types, line or belt. A line transect is simply a line drawn between two points, generally with a measuring tape. A belt transect consists of two parallel lines and the area between them. Belt transects are most often used to sample attributes that require area, such as density of shrubs. Line transects are used to sample cover of all lifeforms. Belt transects will be used to sample survival and density of shrubs in these revegetation projects and line transects will be used to sample cover of all lifeforms.

Once a line transect is established, canopy cover can be easily sampled along it. Simply position yourself directly over a portion of the transect and record the amount of the transect between two finite points that is covered by the canopy of each species. Care should be taken to position yourself directly above the segment you are sampling and always record from the same side of transect if you are using a tape. Care should also be exercised in placing the tape so that the tape is as near the ground surface as possible and that the vegetation is disturbed as little as possible.

Cover data can also be sampled using the point method. One technique is to use a point-frame, consisting of metal pins arranged along a frame. This technique results in very accurate cover data, but its use is largely limited to relatively low-growing plants. An alternative method is the transect point technique. This is the method that will be used to gather the cover data to test for success in the revegetation scenarios. In this method, a line transect is located and the species occurring at each mark along the transect (e.g., mm or cm) are recorded. Number of "hits" is then summed for the transect for each species. This method results in a sample that is more representative of the area than a single point-frame since it extends over a larger distance.

The third method of determining cover is by estimation. This is the simplest method but it is the least accurate. A plot frame is used in this method and the plot is divided into a grid, with the grids subdivided into smaller grids corresponding to standard subdivisions of its area (e.g., 10%, 1%). Once the frame is in place, the percent cover of the target species is estimated to some predetermined accuracy level (e.g., 5%). This method is rapid and easy to use, therefore a relatively large number of plots can be recorded within a given period of time. Its disadvantage is that it is very dependent upon the estimating ability of the observer.

4.2.2 Sampling Design for the Hanford Site

Each contiguous area treated with the same revegetation scenario at the same time will be treated as a single treatment unit (TU). Each TU will be monitored individually, using a standardized sampling design based on a stratified random placement of line transects. This method will result in a cost-efficient and statistically unbiased sample. The sampling will be conducted at, or near, the end of the growing season each year until the objectives of the revegetation project are met.

If the TU is sufficiently large that ecological conditions (e.g., soil texture, microtopography, distance from established vegetation) are likely to differ significantly within its boundaries, the TU should be divided into multiple TUs, each one having relatively homogenous conditions within it and each one treated as a separate TU for sampling purposes. Long, linear TUs, such as ditches, should also be subdivided into multiple TUs because ecological conditions are unlikely to remain homogenous over relatively long distances (e.g., > 1 km).

Standard Sampling Design. A permanent line transect will be placed down the center of the TU along the longest axis of the TU. The line will then be divided into five equal segments. Permanent markers, such as half-in. rebar stakes, will be placed at the beginning and ending points of the transect and at the ending points of the segments.

Each TU will be sampled near the end of each growing season throughout the time line defined by the scenario. To sample the TU, first randomly locate two points within each of the five segments of the center line. These points are to be randomly relocated each year. Extend a meter tape outward from each of these ten points, perpendicularly in both directions until the outer boundary of the TU is reached in both directions. Place a temporary stake at the beginning and ending points of the tape (the permanent center line should be approximately in the center of the tape). Either fasten or hold one end of the tape at the beginning stake and the other end at the ending stake, taking care to move the tape along the ground without damaging the vegetation or trapping the upper stems and leaves of the plants under the tape.

At each meter mark along the tape, record the number of 1-cm points that a plant extended over, or that was below, the mark. There are 100 potential "hits", one cm per hit. Record cover by species and for all species combined (= total canopy cover). Continue this procedure for each one-meter segment until the end stake is reached. For each species individually, add the total number of "hits" recorded for that species along the transect and divide that sum by the length of the transect, in meters. This quotient is the percent cover for that species along that transect. Compute a similar total canopy cover value for that transect.

If shrub survival is to be measured, form a belt transect along the line transect by measuring 50 cm out from each side of the line transect, along the entire length of the transect. Count the number of live shrubs within each 1 m^2 segment formed by both 50-cm halves along each 1 m of the transect. Add the total number of live shrubs encountered within the belt transect and divide by the length of the transect to determine live shrub density.

Repeat the line transect and, if appropriate, the belt transect process for all 10 transects in the TU.

4.3 STATISTICAL METHODS

Data will be analyzed by individual TU. Each transect constitutes an observation. Therefore there are 10 observations per variable per TU.

Compute the mean total canopy cover for the TU by adding the values from the 10 transects and dividing the sum by 10. Compare the mean value to the target value defined in the respective scenario. If the mean meets the target level, the revegetation scenario has been successful for that variable, for that year. If the mean does not meet the target level, follow-up action is required.

Compute the 95% confidence interval of this mean in the following way.

1. Subtract the mean from each of the 10 observations.
2. Square each of the 10 differences.
3. Sum the 10 squares.
4. Divide this sum by 9.
5. Take the square root of the quotient.
6. Divide the square root by 10.
7. Multiply this quotient by 2.26.

The 95% confidence interval of the mean is the mean $\pm$ the value computed in Step 7. The 95% confidence interval of the mean should be reported whenever the mean is reported. The smaller the confidence interval, the more uniform the cover over the TU. A large confidence interval indicates patchiness in the vegetation and makes conclusions based on the mean more tentative.

Compute relative canopy cover values for each variable required by the scenario (e.g., native perennial grasses). For an individual species, this is done by dividing the cover value for that species along a single transect by the total canopy cover value along that transect and multiplying this fraction by 100 to convert to percent. For a combination of species (e.g., native perennial grasses), first sum the canopy cover values for those species within the combination and then divide this sum by total canopy cover and multiply by 100.

Compute the appropriate mean relative cover values for the TU by adding the values for the 10 transects and dividing this sum by 10. Compare this mean value to the respective target value from the scenario. If the mean value meets the target level, the revegetation scenario has been successful for that variable for that year. If the mean value does not meet the target level, follow-up action is required. Compute confidence intervals for relative cover means in a similar manner to total cover.

If required by the scenario, compute mean shrub survival rate or density for the TU and compare to the target value. Also compute the confidence interval for this mean.

A scenario is successful for the TU for a given year if all measurement variables meet the target levels defined by the scenario. If any variable fails to meet the target level, follow-up action is required. Revegetation of a TU can be declared completed when all target levels defined for the last year of the scenario have been met. Normally, this will occur during the latter part of the scenario time line. However, it could occur in fewer years than predicted by the scenario, or it could take longer than the predicted time to occur.

4.4 PROCEDURES FOR CHANGES IN RESTORATION PLAN

4.4.1 The Need for a Review Process

This document is produced as a working document. It is expected that changes will need to be made over time because: (1) experience will result in improvements in methodologies and guidelines, (2) future research will lead to new knowledge and perhaps new technology, and (3) goals and objectives may change.

This document contains many specific recommendations. These recommendations are based on current scientific knowledge and the personal experience of the authors. This knowledge and experience is not uniformly available for each aspect of each option. As the recommendations are put into practice, a significant learning process will occur. Some recommendations will need to be modified in light of this on-site experience. At the same time, new data will become available from the scientific literature. This literature should be reviewed and new findings applied to the projects at the Hanford Site. New technology or modifications of present technology may provide practical options in the near future that are not currently available. And finally, goals and objectives may change. Regulatory guidelines change. Government policy changes. Social views change. This document can not remain rigid. There must be the opportunity for these changes to be incorporated as they become manifested.

4.4.2 The Review Process

The purpose of the review is to keep the manual up-to-date with current developments. This will include: (1) an ongoing review of recent scientific literature, (2) new knowledge gained from similar current revegetation/restoration projects by Bechtel and associated personnel, and (3) initial results from the application of the recommendations of this manual to revegetation projects at Hanford.

The ongoing review of scientific literature will be conducted on an annual basis, either by Bechtel employees or by a subcontractor. All pertinent literature published within each 12-month period, beginning with 1996, will be reviewed for possible applications to the projects at the Hanford Site. Any significant findings that apply to the scope of this manual will be presented in an annual report. This report will document the scientific study, the applications to the Hanford Site, and the proposed changes to the manual based on the literature, and will provide a justification of these proposed changes.

Any new knowledge, pertinent to the subjects addressed in this manual, gained by Bechtel personnel or other persons associated with the development or use of this manual, that might change any of the recommendations of this manual should be documented and prepared for review on an annual basis. The documentation will include (1) the specific part of the manual the information pertains to, (2) the new information, (3) the suggested change to the manual based on the information, and (4) justification for the change.

As the recommendations of this manual are applied to projects at the Hanford Site, a significant amount of information will become available relating to the degree of success of each recommendation. This data should be documented and applied to the annual review process. Data will be collected from the application of each scenario, as required by Sub-Section 4 of each scenario. An annual report will be written for each application documenting the results of the application and making suggestions for any possible changes for the next year. These reports will then be summarized by Bechtel personnel and, based on these results, any recommendations for changes to the procedures recommended by the manual will be made, with the corresponding justification based on observed results.

The reports called for by Section 4.4.1 will be reviewed on an annual basis. Any significant changes in goals or objectives relative to the revegetation/restoration process at Hanford should also be made at this time. Based on this review, changes can be made to the manual. These changes may be to the recommendations or to the background information contained in the manual. Care must be taken to present the rationale for making the changes and to consider if the changes will adversely affect some other part of the recommendations of the manual.

Before any changes are made, the recommended changes, along with their rationale, should be reviewed by a qualified outside expert. Once agreement is reached with the outside expert, the changes to the manual can be made.

5.0 SCENARIOS

SCENARIO 01

SITE:	Sand
COMMUNITY:	Introduced
TIME:	2-5 years
IMPACTS:	Heavy

1. Pre-Planting Procedures:

Physical Seedbed:	Harrow lightly to smooth surface.
Chemical Seedbed:	None unless pH is below 6.0 or above 9.0. If necessary, add lime to raise or sulfur to lower pH (in amounts based on soil tests).
Topsoil Addition:	None
Fertilization:	Single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac) surface or subsurface application at time of planting.
Weed Control:	Disc before weeds set seed in growing season prior to planting; repeated operations may be necessary (April, June, and September). If cultivation is not possible, apply low-label rates of glyphosate/2,4-D at a 1:2 ratio to reduce weed seed viability.

2. Propagation Procedures:

Species:	Species Mixture 01
Source:	Any
Method:	Drill, half-in. depth, 0.3 m (12 in.) row spacing; or broadcast and then lightly harrow.
Season:	September-November
Mulching:	Apply hay or straw at 4.5 Mg/ha (2 T/ac) after planting; crimp mulch into soil surface, or apply 2.5 cm (1 in.) gravel.

3. Post-Planting Procedures:

Irrigation:	Apply 0.24 ha-cm (1.5 ac-in.) each in April, May, June, and July until target values are met. Any method of application can be used, but ground application from a water truck or hand lines is least expensive.

Irrigation is not necessary during those months receiving > 1.9 cm (> 0.75 in.) of rain.

Irrigation can be discontinued once the seeded perennial species reach 30% canopy cover.

Fertilization: Repeat the pre-planting fertilizer application the second growing season unless weeds are > 30% relative cover.

Weed Control: None the first three growing seasons and none thereafter if annual weeds are < 30% relative canopy cover at the end of the third growing season.

If annual weeds are > 50% relative canopy cover at the end of the third growing season, apply low-label rates of 2,4-D and dicamba in early April.

Dynamics: Year 1: Annuals (cheatgrass, Russian thistle, tumble mustard) will dominate, with lesser amounts of perennials.

Year 2: Seeded perennial species should comprise > 25% relative cover.

Year 3: Seeded perennial species should comprise > 50% relative cover.

Year 4: Seeded perennial species should comprise > 75% relative cover.

4. Follow-Up Procedures:

Evaluation Criteria: Measure total plant cover, by species, near the end of each growing season. If mean values meet target values (Section 4.3), no additional action is necessary. If mean values do not meet target values, go to follow-up.

Target Levels = Minimum of 25% total canopy cover each year, plus relative cover values of

Year 1: Any combination of species
Year 2: Seeded perennial species ≥ 25%
Year 3: Seeded perennial species ≥ 50%
Year 4: Seeded perennial species ≥ 75%

Follow-Up: If no, or very few, seedlings of seeded species are established, the problem was probably poor seed, since supplemental water was applied. Therefore, re-seed the next year using the same seed mixture, but from a different source.

If seedlings are established, but total cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each month (April-July).

If seedlings are established, but relative cover values of seeded species were below target levels, add the additional 0.8 ha-cm (0.5 ac-in.) of water each month (April-July), but no additional fertilizer.

5. Costs:

Moderate.

Seed, irrigation, and annual fertilization are the major costs.

6. Comments:

If precipitation is below average during establishment years (1-5), additional irrigation should be applied (amount equal to the precipitation deficit).

SCENARIO 02

SITE: Sand
COMMUNITY: Native
TIME: 2-5 years
IMPACTS: Heavy

1. Pre-planting procedures:

   Same as Scenario 01

2. Propagation procedures:

   Same as Scenario 01

3. Post-planting procedures:

   Same as Scenario 01

4. Follow-up procedures:

   Same as Scenario 01 with the following exception:

   Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed germination. Re-seed the second year using the same seed mixture, but from a different source.

   If seedlings of seeded species established but total cover values are below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each month (Apr-Jul).

   If seedlings of seeded species established but relative cover values are below target levels, add the additional 0.8 ha-cm (0.5 ac-in.) of water each month (Apr-Jul), but do not add additional fertilizer.

5. Costs:

   Low.

   Seed, irrigation, and fertilization are the major costs.

6. Comments:

   If precipitation is below average during establishment years (1-5), additional irrigation (in addition to the recommended amount) should be applied. This additional amount should be equal to the amount that precipitation is below normal.

SCENARIO 03

SITE:	Sand
COMMUNITY:	Native
TIME:	5-10 years
IMPACTS:	Heavy

1. <u>Pre-planting procedures:</u>

Physical seedbed:	harrow lightly to smooth surface
Chemical seedbed:	none unless pH is below 6.0 or above 9.0; if necessary, add lime to raise or sulfur to lower pH; amounts based on soil tests
Topsoil addition:	none
Fertilization:	single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac) surface or subsurface application at time of planting
Weed control:	disc before weeds set seed in growing season prior to planting; repeated operations may be necessary (Apr, Jun, Sep)
	if cultivation is not possible, apply low- label rates of glyphosate/2,4-D at a 1:2 ratio to reduce weed seed viability

2. <u>Propagation procedures:</u>

Species:	Species Mixture 02
Source:	local < 180 km (< 100 mi) if possible
Method:	drill, half-in. depth, 0.3 m (12 in.) row spacing; or broadcast and then lightly harrow
Season:	Sep-Nov
Mulching:	apply hay or straw at 4.5 Mg/ha (2 T/ac) after planting; crimp mulch into soil surface, or apply 2.5 cm (1 in.) gravel.

3. <u>Post-planting procedures:</u>

Irrigation:	apply 0.24 ha-cm (1.5 ac-in.) in Apr, May, Jun, Jul during first two growing seasons
	any method of application can be used, but ground application from a water truck or hand lines is least expensive
	irrigation is not necessary during those months receiving > 1.9 cm (> 0.75 in.) of rain
Fertilization:	first-year (at planting) only

Weed control: none the first six growing seasons

none thereafter if annuals weeds are < 50% relative canopy cover at the end of the sixth growing season

if annual weeds are > 50% relative canopy cover at the end of the sixth growing season, apply low-label rates of 2,4-D and dicamba in early April until relative canopy cover of weeds at the end of the growing season becomes < 50%

Dynamics:

	Years 1-2	annuals (cheatgrass, Russian thistle, tumble mustard) will dominate, with lesser amounts of perennials
	Year 3	seeded perennial species should comprise > 25% relative cover
	Year 4	seeded perennial species should comprise > 40% relative cover
	Year 6	seeded perennial species should comprise > 50% relative cover
	Year 10	seeded perennial species should comprise > 75% relative cover

4. Follow-up procedures:

Evaluation criteria: Measure total plant cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels = minimum of 25% total canopy cover each year, and relative cover levels of

Years 1-2 any combination of species
Year 3 seeded perennials ≥ 25%
Years 4-5 seeded perennials ≥ 40%
Years 6-7 seeded perennials ≥ 50%
Years 8-9 seeded perennials ≥ 65%
Year 10 seeded perennials ≥ 75%

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed germination. Re-seed the second year using the same seed mixture, but from a different source.

If seedlings of seeded species established but total cover levels are below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each month (Apr-Jul).

If seedlings of seeded species established but relative cover levels are below target levels, add the additional 0.8 ha-cm (0.5 ac-in.) of water each month (Apr-Jul), but do not add additional fertilizer.

5. <u>Costs:</u>

Moderate.

Costs of this scenario are increased due to irrigation.

6. <u>Comments:</u>

This scenario is very similar to Scenario 02, the major difference being number of years irrigation is applied. Establishment of the perennials will be slower for this scenario than for Scenario 02 because irrigation is only applied for two years. Therefore site stabilization will be slower than for Scenario 02, with greater possibility of failure the first few years, especially if precipitation is below normal. If precipitation is below average during the establishment years (1-5) additional irrigation (in addition to the recommended amount) should be applied. This additional amount should be equal to the amount that precipitation is below normal.

This scenario is less expensive than Scenario 02, but revegetation and stabilization will occur more slowly. Therefore the tradeoff becomes one of decreased costs and increased risk.

SCENARIO 04

SITE: Sand
COMMUNITY: Native
TIME: 10-20 years
IMPACTS: Heavy

1. Pre-planting procedures:

   Same as Scenario 03

2. Propagation procedures:

   Same as Scenario 03

3. Post-planting procedures:

   Same as Scenario 03

4. Follow-up procedures:

   Evaluation criteria: Measure total plant cover, by species, near the end of each growing season. If mean levels meet target levels (Section 4.3), no additional action is necessary. If mean levels do not meet target levels, go to follow-up.

   Target levels = minimum of 25% total canopy cover each year, and relative cover levels of

   Years 1-2 any combination of species
   Year 3 seeded perennials $\geq$ 20%
   Years 4-5 seeded perennials $\geq$ 35%
   Years 6-7 seeded perennials $\geq$ 50%
   Years 8-9 seeded perennials $\geq$ 65%
   Years 10-20 seeded perennials $\geq$ 80%

   Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed germination. Re-seed the second year using the same seed mixture, but from a different source. Repeat the first-year irrigation regime the second year.

   If seedlings of seeded species established but total cover values are below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.) of irrigation each month, in addition to any other recommended amount, (Apr-Jul). Continue this procedure annually until the target levels are reached.

   If seedlings of seeded species established but relative cover values are below target levels, add the additional 0.8 ha-cm (0.5 ac-in.) of water each month (Apr-Jul), but do not add additional fertilizer. Continue this procedure until the target levels are reached.

5. Costs:

Moderate.

Costs of this scenario are less than for Scenario 03 because irrigation is only applied for one year.

6. Comments:

This scenario is similar to Scenarios 02 and 03. In this scenario, irrigation is applied for only one year, whereas it is applied for two years in Scenario 03 and for 2-5 years in Scenario 02.

Establishment of the perennials will be slower for this scenario than for Scenario 03, therefore site stabilization will be slower, especially if precipitation is below normal. If precipitation is below average during the establishment years (1-5), irrigation should be applied. The amount applied should be equal to the amount that the precipitation is below normal.

SCENARIO 05

SITE:	Sand
COMMUNITY:	Late-seral
TIME:	20-50 years
IMPACTS:	Light

1. Pre-planting procedures:

Physical seedbed:	harrow lightly to smooth surface
Chemical seedbed:	none unless pH is below 6.0 or above 9.0; if necessary, add lime to raise or sulfur to lower pH; amounts based on soil tests
Topsoil addition:	none
Fertilization:	none
Weed control:	disc before weeds set seed in growing season prior to planting; repeated operations may be necessary (Apr, Jun, Sep)

2. Propagation procedures:

Species:	Species Mixture 03
Source:	local < 180 km (< 100 mi) if possible
Method:	first drill seed, half-in. depth, 46 cm (18 in.) row spacing; or broadcast and lightly harrow
	then plant shrub tublings on 2.3 m (7.5 ft.) centers 1900 plants/ha (775 plants/acre)
Season:	Sep-Nov
Mulching:	apply hay or straw at 4.5 Mg/ha (2 T/ac) after drilling the seed; crimp mulch into soil surface, or apply 2.5 cm (1 in.) gravel.

3. Post-planting procedures:

Irrigation:	apply approximately 11.3 L (3 gal.) of water around base of each shrub tubling at 2-wk intervals from Mar-Sep of the first growing season	
	irrigation is not necessary for any 2-wk interval receiving $\geq$0.5 cm ($\geq$ 0.2 in.) of rain	
Fertilization:	none	
Weed control:	none	
Dynamics:	Years 1-5	annuals (cheatgrass, Russian thistle, tumble mustard) will dominate; perennial grasses may comprise < 20%

	relative cover; shrubs should comprise 5% relative cover by Year 5
Years 6-10	perennial grasses should increase in relative cover from about 20% in Year 6 to about 40% by Year 10; shrubs should increase to about 10% relative cover by Year 10, with rabbitbrush being most abundant
Years 11-20	perennial grasses should increase to about 75% relative cover by Year 20; shrubs should increase to 20% relative cover by Year 20, with sagebrush and rabbitbrush about equal; numerous shrubs should be of mature size by Year 20
Years 21-30	perennial grasses should decrease to about 50% relative cover by Year 30, and shrubs should increase to 40%; sagebrush should be the dominant shrub, with most shrubs of mature size Years 31-50 perennial grasses should decrease to about 40% relative cover and shrubs (mostly sagebrush) should increase to > 50%

4. <u>Follow-up procedures:</u>

Evaluation criteria: Measure total plant cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels = minimum of 20% total canopy cover in Years 1-20 and a minimum of 25% total canopy cover thereafter, and relative cover values of

Years 1-5	any combination of species
Years 6-8	perennial grasses > 20%, shrubs > 5%
Years 9-12	perennial grasses > 32%, shrubs > 8%
Years 13-20	perennial grasses > 50%, shrubs > 12%, big sagebrush > 5%
Years 21-30	perennial grasses > 50%, shrubs > 20%, big sagebrush > 10%
Years 31-40	perennial grasses > 40%, shrubs > 40%, big sagebrush > 25%
Years 41-50	perennial grasses > 30%, shrubs > 45%, big sagebrush > 40%

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed or dry conditions. If dry (below normal precipitation, few seedlings of any species established), either wait until the next year or irrigate. If conditions were not dry, reseed the next year using the same seed mixture but from a different source and broadcast the seed rather than drill. Care must be taken not to damage the tublings.

If seedlings of seeded species established but total cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.16 ha-cm (1 ac-in.), in addition to any other recommended amount, of water each month (Apr-Sep). Continue this procedure annually until the target levels are reached. Care must be taken not to damage shrubs.

If seedlings of seeded species established but relative cover values were below target levels, add the 0.16 ha-cm (1 ac-in.) of water each month (Apr-Sep), but do not add fertilizer. Continue this procedure until the target levels are reached. Care must be taken not to damage shrubs.

A 50% mortality of tublings can be expected. If losses exceed 30% at the end of the first growing season, continue the irrigation regime the second year but at a rate of 18 L (5 gal.) per plant per 2-wk interval. If losses exceed 50% over the first three years, replace half the dead plants with new tublings and water at a rate of 18 L (5 gal.) per plant per 2-wk interval for one year. Continue this procedure until an average of 10 shrubs per 100 m^2 survive for at least three years.

5. Costs:

Moderate

The major costs in this scenario are purchase and planting costs of the shrub tublings and hand watering the shrubs until establishment.

6. Comments:

Without site-wide irrigation, establishment of the perennial grasses will be relatively slow (5-10 years) unless precipitation is above normal during the first few years. Therefore the site will have soil erosion for the first 3-5 years until the shrubs become large enough to be effective in stabilization.

Successful establishment of the shrub tublings in the first 2-3 years is crucial. Timely and adequate irrigation for the first year (see Post-Planting Procedures) is critical to accomplish this.

SCENARIO 06

SITE:	Sand
COMMUNITY:	Late-seral
TIME:	50-100 years
IMPACTS:	Light

1. Pre-planting procedures:

   Same as Scenario 05

2. Propagation procedures:

   Same as Scenario 05

3. Post-planting procedures:

   Same as Scenario 05

4. Follow-up procedures:

Evaluation criteria: Measure total plant cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels = minimum of 20% total canopy cover in Years 1-25 and a minimum of 25% total canopy cover thereafter, and relative cover values of

Years 1-5	any combination of species
Years 6-8	perennial grasses > 10%
Years 9-15	perennial grasses > 20%, shrubs > 4%
Years 15-25	perennial grasses > 33%, shrubs > 6%
Years 25-50	perennial grasses > 50%, shrubs > 10%, big sagebrush > 5%
Years 50-75	perennial grasses > 50%, shrubs > 25%, big sagebrush > 20%
Years 75-100	perennial grasses > 40%, shrubs > 40%, big sagebrush > 35%

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed or dry conditions. If dry (below normal precipitation, few seedlings of any species established), either wait until the next year or irrigate. If conditions are not dry, reseed the next year using the same seed mixture but from a different source and broadcast the seed rather than drill. Care must be taken not to damage the tublings. If seedlings of seeded species established but total cover values are below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.16 ha-cm (1 ac-in.), in addition to any other recommended amount, of water each month (Apr-Sep). Continue this procedure annually until the target levels are reached. Care must be taken not to damage shrubs.

If seedlings of seeded species established but relative cover values are below target levels, add the 0.16 ha-cm (1 ac-in.) of water each month (Apr-Sep), but do not add fertilizer. Continue this procedure until the target levels are reached. Care must be taken not to damage shrubs. A 50% mortality of tublings can be expected. If losses exceed 30% at the end of the first growing season, continue the irrigation regime the second year but at a rate of 18 L (5 gal.) per plant per 2-wk interval. If losses exceed 50% over the first three years, replace half the dead plants with new tublings and water at a rate of 18 L (5 gal.) per plant per 2-wk interval for one year. Continue this procedure until an average of 10 shrubs per 100 m^2 survive for at least three years.

5. Costs:

Moderate

The major costs in this scenario are purchase and planting costs of the shrub tublings and hand watering the shrubs until establishment. There are only half as many shrubs in this scenario as in Scenario 05, so costs are much less. The tradeoff here is lower costs but longer time until establishment of a late-seral shrub community. Risk of failure is no higher than for Scenario 05, only the time for establishment is greater.

6. Comments:

Without site-wide irrigation, establishment of the perennial grasses will be relatively slow (10-25 years) unless precipitation is above normal during the first few years. Therefore the site will be relatively unstable for the first 3-5 years until the shrubs become large enough to be effective in stabilization.

Successful establishment of the shrub tublings in the first 2-3 years in crucial. Timely and adequate irrigation in the first growing season is critical to accomplish this, unless precipitation is well- above normal.

SCENARIO 07

SITE:	Gravel
COMMUNITY:	Introduced
TIME:	2-5 years
IMPACTS:	Light

1. <u>Pre-planting procedures:</u>

Physical seedbed:	cut furrows, 10 cm (4 in.) deep, 0.6 m (24 in.) centers furrows to be cut AFTER topsoil treatment purpose is to create micro relief to provide seedlings shelter from wind erosion
Chemical seedbed:	none
Topsoil addition:	spread 15 cm (6 in.) loam evenly across the surface apply organic matter (hay, straw, wood chips, shredded paper, manure) at rate of 45 Mg (20 T/ac) mix (after fertilizer is applied) organic matter and loam by discing or plowing
Fertilization:	single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac) apply with organic matter prior to mixing with the loam
Weed control:	none

2. <u>Propagation procedures:</u>

Species:	Species Mixture 04
Source:	any
Method:	drill, half-in. depth two rows, 20 cm (8 in.) centers, adjacent to furrow ridge, skip 20 cm (8 in.) (furrow ridge), then repeat pattern
Season:	Sep-Nov
Mulching:	apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting

3. <u>Post-planting procedures:</u>

Irrigation:	apply 0.8 ha-cm (0.5 ac-in.) every two weeks, Apr-Sep
	irrigation not necessary during those 2-wk periods receiving > 0.5 cm (> 0.2 in.) of rain
	irrigation applied minimum of one year; continued thereafter until target levels are achieved
Fertilization:	Year 2 apply (broadcast) 22.4 kg N/ha (20 lb N/ac) twice (Mar, Jun) unless weeds are > 30% relative cover

Weed control: none first year; none thereafter unless relative cover of annual weeds > 50%

if annual weeds > 50% relative cover at end of a growing season (other than first), apply low-label rates of 2,4-D and dicamba in early April

Dynamics:
- Year 1 annuals may dominate if there was a large seed bank in the loam or organic matter, seeded perennials may comprise < 50% relative cover
- Year 2 seeded perennial grasses should comprise > 50% relative cover
- Year 3 seeded perennial grasses should comprise > 75% relative cover
- Year 4 seeded perennial grasses should comprise > 85% relative cover

4. Follow-up procedures:

Evaluation criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels =

- Year 1 minimum 10% total cover; seeded perennials > 25% relative cover
- Year 2 minimum 20% total cover; seeded perennials > 50% relative cover
- Year 3 minimum 25% total cover; seeded perennials > 75% relative cover
- Year 4 minimum 25% total cover; seeded perennials > 85% relative cover
- Year 5 minimum 25% total cover; seeded perennials > 90% relative cover

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Reseed in Sep-Nov using the same seed mixture, but from a different source. Drill seed into the existing surface at the same depth and pattern as the first year.

If seedlings established but total cover values were below target levels, double the fertilization and irrigation rates for one year. If seedlings of the seeded species established but relative cover values were below target levels, continue irrigation but not fertilization.

5. Costs:

High

Establishment of a perennial, herbaceous cover in less than 20 years on this site will require the addition of topsoil. This is most likely to be expensive. Irrigation is also necessary and it and the organic matter add significantly to the costs.

6. Comments:

The gravel sites will be among the most difficult areas at Hanford to revegetate because of (1) lack of soil and (2) harsh environmental conditions resulting from exposure to wind and high surface temperatures. These sites are examples of primary, rather than secondary, succession and primary succession takes much longer than secondary. In order to reduce the time necessary for establishment of target communities from centuries to decades, significant inputs must be made into the system.

The most critical resource that must be supplied on these sites in order to achieve revegetation is water. A major ecological function of soil is to store water for use by plants. Since these sites have no soil, there is little storage potential. Six inches of topsoil, plus the added organic matter, should be sufficient to store the 2.54 cm (1 in.) additions of water from irrigation. However, if the water is not applied often enough, the seedlings will desiccate. Irrigation is therefore critical to the establishment of herbaceous plants on this site.

Once perennial plants reach mature size, they will begin to trap soil particles and other debris moved across the site by wind. This, mixed with organic matter from the plants, will increase the soil depth and development at the site over time, increasing water-holding capacity and fertility, thereby allowing further ecosystem development. Unaided by human manipulations, this soil building and community development process would take over 100 years. If revegetation is to be accomplished on these sites in 5 years, as targeted by Scenario 07, topsoil and water, and to a lesser extent nutrients, will have to be supplied anthropogenically to speed the natural process.

SCENARIO 08

SITE: Gravel
COMMUNITY: Native
TIME: 2-5 years
IMPACTS: Light

1. Pre-planting procedures:

   Same as Scenario 07

2. Propagation procedures:

   Same as Scenario 07

3. Post-planting procedures:

   Same as Scenario 07 with the following exception:

   Dynamics:
   - Year 1 annuals may dominate if there was a large seed bank in the loam or organic matter, seeded perennials may comprise < 50% relative cover
   - Year 2 seeded perennial grasses should comprise > 50% relative cover
   - Year 3 seeded perennial grasses should comprise > 75% relative cover
   - Year 4 seeded perennial grasses should comprise > 85% relative cover
   - Year 5 seeded perennial grasses should comprise > 80% relative cover and shrubs > 10% relative cover

4. Follow-up procedures:

   Evaluation criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

   Target levels =

   - Year 1 minimum 10% total cover; seeded perennials > 25% relative cover
   - Year 2 minimum 20% total cover; seeded perennials > 40% relative cover
   - Year 3 minimum 25% total cover; seeded perennials > 50% relative cover
   - Year 4 minimum 25% total cover; native perennials > 60% relative cover
   - Year 5 minimum 25% total cover; native perennials ≥ 80% relative cover

   Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Reseed in Sep-Nov using the same seed mixture, but from a different source. Drill seed into the existing surface at the same depth and pattern as the first year.

If seedlings established but total cover values were below target levels, double the fertilization and irrigation rates for one year. If seedlings of the seeded species established but relative cover values were below target levels, continue irrigation but not fertilization.

5. <u>Costs:</u>

Same as Scenario 07

6. <u>Comments:</u>

Same as Scenario 07

SCENARIO 09

SITE:	Gravel
COMMUNITY:	Native
TIME:	5-10 years
IMPACTS:	Light

1. Pre-planting procedures:

Physical seedbed:	cut furrows, 10 cm (4 in.) deep, 0.6 m (24 in.) centers purpose is to create micro relief to provide seedlings shelter from wind erosion
Chemical seedbed:	none
Topsoil addition:	none
Fertilization:	single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac) apply in strips at the bottoms of the furrows within one month of planting
Weed control:	none

2. Propagation procedures:

Species:	Species Mixture 06
Source:	local < 180 km (< 100 mi) if possible
Method:	broadcast seeds across the site; plant shrub tublings in bottoms of furrows on 2.3 m (7.5 ft.) centers 1900 plants/ha (775 plants/acre)
Season:	Sep-Nov
Mulching:	apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting

3. Post-planting procedures:

Irrigation:	apply approximately 11.3 L (3 gal.) of water around base of each shrub at 2-wk intervals from Mar-Sep of first two years irrigation not necessary during those 2-wk periods receiving > 0.5 cm (> 0.2 in.) of rain
Fertilization:	none
Weed control:	none

Dynamics:	Year 1	shrubs should make only limited aboveground growth, death losses should not exceed 25%; perennial grasses establish in the bottoms of the furrows
	Year 2	shrub death loss (2-year total) should be < 50%; half of surviving shrubs should be > 0.3 m (1 ft.) tall; perennial grasses should comprise > 5% total cover
	Year 5	shrubs should comprise > 10% total cover and density should exceed an average of 10 live plants per 100 m^2; perennial grasses should comprise > 10% total cover
	Year 10	minimum of 25% total cover; shrubs should comprise > 15% total cover; shrubs and perennial grasses should be establishing outside of the furrow bottoms
	Year 20	minimum of 25% total cover; shrubs should comprise > 15% total cover; perennial grasses should comprise > 10% total cover

4. Follow-up procedures:

Evaluation criteria: Record number of live shrubs and measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels =

Year 1	*minimum 75% shrub survival*
Year 2	minimum 50% shrub survival; total cover of perennials within furrows (>0.3 m [1 ft] wide belt transect centered on line of shrubs) > 10%
Year 3	minimum 10% total cover; shrubs > 5% total cover
Year 4	minimum 15% total cover; shrubs > 5% total cover
Year 5	minimum 20% total cover; shrubs >10% total cover shrub density $\geq$ 10 per 100 m^2
Year 10	minimum 25% total cover; shrubs >15% total cover perennial grasses > 5% total cover
Year 20	minimum 25% total cover; shrubs >15% total cover perennial grasses > 10% total cover

Follow-up: If shrub mortality exceed 30% at the end of the first growing season, increase the irrigation rate to 11.3 L (3 gal.) per shrub per 2-wk interval. If losses exceed 50% over the first three years, replace half the dead plants with new tublings and continue to irrigate. Continue this procedure until an average of 10 shrubs per 100 m^2 survive for at least three years.

5. Costs:

Moderate

This is the least expensive scenario for gravel sites because topsoil and organic matter are not added. Costs of this scenario are primarily determined by the costs of purchasing and planting the tublings and irrigating.

6. Comments:

The gravel sites will be among the most difficult areas at Hanford to revegetate because of (1) lack of soil and (2) harsh environmental conditions resulting from exposure to wind and high surface temperatures. These sites are examples of primary, rather than secondary, succession and primary succession takes much longer than secondary. In order to reduce the time necessary for establishment of target communities from centuries to decades, significant inputs must be made into the system.

The most critical resource that must be supplied on these sites in order to achieve revegetation is water. A major ecological function of soil is to store water for use by plants. Since these sites have no soil, there is little storage potential. This scenario differs from the other gravel site scenarios in that it attempts to establish a perennial community without first adding topsoil. Once perennial plants, especially shrubs, reach mature size, they will begin to trap soil particles and other debris moved across the site by wind. This, mixed with organic matter from the plants, will increase the soil depth and development at the site over time, increasing water-holding capacity and fertility, thereby allowing further ecosystem development.

The design of Scenario 09 is based on the concept that late-seral woody species (shrubs and trees) have deep taproots and can access moisture from relatively great depths once their root systems have developed sufficiently. It is projected that by watering the shrubs for two years, they will be able to develop root systems that extent sufficiently deep into the lower levels of the gravel to access moisture that drained through the upper gravel layers. If so, these shrubs should be able to survive thereafter without irrigation. As the shrubs mature, they should serve as focal points for successional islands to form, leading to soil buildup and development of herbaceous perennial plants.

SCENARIO 10

SITE:	Gravel
COMMUNITY:	Late-seral
TIME:	10-20 years
IMPACTS:	Light

1. Pre-planting procedures:

Physical seedbed: cut furrows, 15 cm (6 in.) deep, 1 m (38 in.) centers furrows to be cut AFTER topsoil treatment purpose is to create micro relief to provide seedlings shelter from wind erosion

Chemical seedbed: none

Topsoil addition: spread 20 cm (8 in.) loam evenly across the surface apply organic matter (hay, straw, wood chips, shredded paper, manure) at rate of 45 Mg (20 T/ac) mix (after fertilizer is applied) organic matter and loam by discing or plowing

Fertilization: single application of 16-16-16 fertilizer at 134 kg/ha (120 lbs/ac) apply with organic matter prior to mixing with the loam

Weed control: none

2. Propagation procedures:

Species: Species Mixture 06

Source: local < 180 km (< 100 mi) if possible

Method: first drill seeds half-in. depth; five rows, 15 cm (6 in.) centers, adjacent to furrow ridge, skip 15 cm (6 in.) (furrow ridge), then repeat pattern then plant shrub tublings in bottoms of furrows on 2.3 m (7.5 ft.) intervals 1900 plants/ha (775 plants/ac)

Season: Sep-Nov

Mulching: apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting

3. Post-planting procedures:

Irrigation: apply 0.8 ha-cm (0.5 ac-in.) every two weeks, Apr-Sep, for one year

irrigation not necessary during those 2-wk periods receiving > 0.5 cm (> 0.2 in.) of rain

Fertilization: none

Weed control: none

Dynamics:	Years 1-2	annuals may dominate if there was a large seed bank in the loam or organic matter, native perennials may comprise < 50% relative cover
	Years 3-5	perennials should become dominant; perennial grasses should comprise > 50% relative cover by Year 5 and shrubs > 10% by Year 3 and > 20% by Year 5
	Years 6-10	perennial grasses should comprise > 50% relative cover; shrubs should comprise > 40% by Year 10
	Years 11-15	perennial grasses should begin to decrease, comprising about 40% relative cover by Year 15; shrubs should increase to > 50% by Year 15; many of the shrubs should approach mature size by Year 15
	Year 20	perennial grasses should comprise 30-40% relative cover and shrubs 60-65%; most shrubs should be mature

4. Follow-up procedures:

Evaluation criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels =

Years 1-2	minimum 10% total cover; native perennials > 30% relative cover
Years 3-5	minimum 15% total cover; perennial grasses > 40% relative cover; shrubs > 10% relative cover
Years 6-8	minimum 20% total cover; perennial grasses > 40% relative cover; shrubs > 20% relative cover
Years 9-11	minimum 25% total cover; perennial grasses > 40% relative cover; big sagebrush > 20% relative cover
Years 12-15	minimum 25% total cover; perennial grasses > 40% relative cover; big sagebrush > 30% relative cover
Years 16-19	minimum 25% total cover; perennial grasses > 30% relative cover; big sagebrush > 40% relative cover
Year 20	minimum 25% total cover; native perennials > 85% relative cover; big sagebrush > 50% relative cover

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Reseed in Sep-Nov using the same seed mixture, but from a different source. Broadcast the seed in order not to damage the shrubs.

If seedlings established but total cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and continue the first-year irrigation regime. Continue this procedure annually until the target levels are reached. If annuals increase to > 30% of relative cover, discontinue fertilization but continue to irrigate until target levels are achieved. Care must be taken not to damage shrubs.

A 75% mortality of tublings can be expected. If losses exceed 30% at the end of the first growing season, continue the irrigation regime the second year plus an additional 11.3 L (3 gal.) applied around each shrub per 2-wk interval. If losses exceed 50% over the first three years, replace half the dead plants with new tublings and continue the irrigation, including the 10 gal. application per shrub. Continue this procedure until an average of 10 shrubs per 100 m^2 survive for at least three years.

5. Costs:

High

Establishment of the perennial, herbaceous cover will require the addition of topsoil. This will most likely be expensive. Irrigation will also be necessary and adds significantly to the costs. Purchase and planting of the shrub tublings will be relatively expensive, but is necessary to meet the target of establishing a late-seral community on the gravel site in 20 years.

6. Comments:

Scenario 10 is probably the most challenging of the 22 scenarios to accomplish. The gravel sites will be among the most difficult areas at Hanford to revegetate because of (1) lack of soil and (2) harsh environmental conditions resulting from exposure to wind and high surface temperatures. These sites are examples of primary, rather than secondary, succession and primary succession takes much longer than secondary. In addition, this scenario requires a late-seral community to be established. Under natural conditions, this would take 100-200 years. The time line for Scenario 10 is 20 years. In order to reduce the time necessary for establishment of target communities from centuries to decades, significant inputs into the system must be made.

The most critical resource that must be supplied on these sites in order to achieve revegetation is water. A major ecological function of soil is to store water for use by plants. Since these sites have no soil, there is little storage potential, especially for shallow- to moderate-rooted grasses. Eight inches of topsoil, plus the added organic matter, should be sufficient to store the 2.54 cm (1 in.) additions of water from irrigation. However, if the water is not applied often enough, the seedlings will desiccate. Irrigation is therefore critical to the establishment of perennial herbaceous plants on this site. Without irrigation, establishment can only occur during infrequent wet years.

Once perennial plants reach mature size, they will begin to trap soil particles and other debris moved across the site by wind. This, mixed with organic matter from the plants, will increase the soil depth and development at the site over time, increasing water-holding capacity and fertility, thereby allowing further ecosystem development. Unaided by human manipulations, this soil building and community development process would take over 100 years. If establishment of a late-seral community is to be accomplished on these sites in 20 years, topsoil and water will have to be supplied anthropogenically to speed the natural process.

The design of Scenario 10 is based on the concept that, in arid systems such as Hanford, the establishment phase is a very important stage in the development of late-seral species under conditions of primary succession. Once established, shrubs should be able to survive on the gravel site because of their deep root systems. Likewise, mature perennial grasses should be able to survive on sites with 20 cm (8 in.) of soil.

SCENARIO 11

SITE:	Sterilized
COMMUNITY:	Introduced
TIME:	2-5 years
IMPACTS:	Heavy

1. Pre-planting procedures:

Physical seedbed: none

Chemical seedbed: none, unless pH is below 6.0 or above 9.0; if necessary, add lime to raise or sulfur to lower pH; amounts based on soil tests

Topsoil addition: conduct a germination and growth test on existing soil

if the soil does not inhibit plant germination or growth, no topsoil addition is necessary

if the soil does inhibit plant germination and growth, spread 15 cm (6 in.) of topsoil material evenly across the surface; apply organic matter (hay, straw, wood chips, shredded paper, manure) at a rate of 45 Mg (20 T/ac); mix organic matter and topsoil material by discing

Fertilization: none

Weed control: apply low-level label rates of glyphosate/ 2,4-D at a 1:2 ratio to reduce weed seed viability

Mulching: none

2. Propagation procedures:

Species: Species Mixture 07

Source: any

Method: drill, half-in. depth, 0.3 m (12 in.) row spacing

Season: Sep-Nov

Mulching: apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting and crimp mulch into soil surface, or apply 2.5 cm (1 in.) gravel.

3. Post-planting procedures:

Irrigation: apply 0.24 ha-cm (1.5 ac-in.) each in Apr, May, Jun, Jul

any method of application can be used, but ground application from a water truck or hand lines is least expensive irrigation is not necessary during those months receiving > 1.25 cm (> 0.5 in.) of rain

irrigation should be continued until target levels are reached

Fertilization: none

Weed control: none the first growing season

none thereafter if annual weeds are < 50% relative canopy cover at the end of the preceding growing season

if annual weeds are > 50% relative canopy cover at the end of the preceding growing season, apply low-label rates of 2,4-D and dicamba in early April

spot spray any Centaurea plants that invade onto the site with Tordon at low label rates.

Dynamics:

Year 1	annuals (cheatgrass, Russian thistle, tumble mustard) may dominate if there was a large seed bank in the topsoil material
Year 2	seeded perennials should comprise > 30% relative cover
Year 3	seeded perennials should comprise > 50% relative cover
Year 4	seeded perennials should comprise > 70% relative cover
Year 5	seeded perennials should comprise > 85% relative cover

4. Follow-up procedures:

Evaluation criteria: Measure total plant canopy cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels = minimum of 25% total canopy cover each year and relative cover values of

Year 1	any combination of species
Year 2	seeded perennial species > 25%
Year 3	seeded perennial species > 50%
Year 4	seeded perennial species > 70%
Year 5	seeded perennial species > 80%

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in Sep-Nov with the same seed mixture, but from a different source.

If seedlings of seeded species established but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amounts, of irrigation each month (Apr-Jul). If relative cover values of seeded species were under target levels, add the additional irrigation but not the fertilizer.

5. Costs:

High

The application of topsoil is the highest cost item in this scenario. Seed and fertilization costs are low and irrigation costs are only moderate.

6. Comments:

These sites pose two major potential ecological problems, both related to possible residual herbicides. The topsoil treatment should solve both problems.

First, if residual herbicide levels are significantly high, they will retard plant growth and slow or stop successful revegetation. The placement of a 15 cm (6 in.) layer of uncontaminated topsoil should provide the plants with an adequate growth medium. As roots penetrate the 15 cm (6 in.), they may encounter toxic conditions but these effects should be minor in the layer immediately below the topsoil. The presence of toxic material at deeper layers may inhibit the growth of deeper-rooted species such as shrubs.

Second, there must be enough uncontaminated soil to store sufficient moisture to support the target plant community. Six inches, plus the added organic matter, should hold a minimum of 5 CM (2 in.) of soil moisture. This storage capacity should be adequate during the growing season in the arid climate at Hanford because few rains will be in excess of this amount and the plant community should deplete this amount before the next rains occur. However, the site will not be able to store much moisture in the upper profile from snowmelt. A significant portion of the moisture from snowmelt will probably enter into the subsoil (> 15 cm [6 in.]). Plants should be able to access some of this moisture in the layer immediately below the topsoil, but any moisture moving into a contaminated zone may be unavailable to the plant community. Therefore these sites may remain relatively dry sites until residual herbicides eventually breakdown or they are moved downward in the profile by water movement.

SCENARIO 12

SITE: Sterilized
COMMUNITY: Native
TIME: 2-5 years
IMPACTS: Heavy

1. Pre-planting procedures:

   Same as Scenario 11

2. Propagation procedures:

   Same as Scenario 11 with the following exception:

   Species: Species Mixture 08

3. Post-planting procedures:

   Same as Scenario 11

4. Follow-up procedures:

   Same as Scenario 11

5. Costs:

   Same as Scenario 11

6. Comments:

   Same as Scenario 11

SCENARIO 13

SITE: Sterilized
COMMUNITY: Native
TIME: 5-10 years
IMPACTS: Heavy

1. Pre-planting procedures:

   Same as Scenario 11

2. Propagation procedures:

   Same as Scenario 11

3. Post-planting procedures:

   Same as Scenario 11

4. Follow-up procedures:

Evaluation criteria: Measure total plant canopy cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels = minimum of 25% total canopy cover each year and relative cover values of

Year 1 any combination of species
Year 2 native perennials > 25%
Year 3 native perennials > 40%
Year 4 native perennials > 50%
Year 5 native perennials > 60%
Year 6 native perennials > 65%
Year 7 native perennials > 75%
Year 8 native perennials > 80%

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in Sep-Nov with the same seed mixture, but from a different source.

If seedlings of seeded species established but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each month (Apr-Jul). If relative cover values of seeded species were under target levels, add the additional irrigation but not the fertilizer.

5. Costs:

High

The application of topsoil is the highest cost item in this scenario. Fertilization costs are low and seed and irrigation costs are only moderate.

6. Comments:

Same as Scenario 11

SCENARIO 14

SITE:	Sterilized
COMMUNITY:	Late-seral
TIME:	10-20 years
IMPACTS:	Light

1. Pre-planting procedures:

Physical seedbed:	none
Chemical seedbed:	none unless pH is below 6.0 or above 9.0; if necessary, add lime to raise or sulfur to lower pH; amounts based on soil tests
Topsoil addition:	spread 46 cm (18 in.) of topsoil material evenly across the surface; apply organic matter (hay, straw, wood chips, shredded paper, manure) at a rate of 22.5 Mg/ha (10 T/ac); incorporate organic matter into topsoil material by discing
Fertilization:	none
Weed control:	after topsoil treatments have been completed but before planting, disc whenever cover of weeds becomes > 20%

2. Propagation procedures:

Species:	Species Mixture 09
Source:	local < 180 km (< 100 mi) if possible
Method:	first drill seeds half-in. depth; 0.3 m (12 in.) rows then plant shrub tublings on 3.05 m (10 ft.) centers 1077 plants/ha (436 plants/ac)
Season:	Sep-Nov
Mulching:	apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface after drilling (< 3 days), crimp mulch into surface

3. Post-planting procedures:

Irrigation:	apply 0.8 ha-cm (0.5 ac-in.) every two weeks, Apr-Sep, first year	
	irrigation not necessary during those 2-wk periods receiving > 0.5 cm (> 0.2 in.) of rain	
Fertilization:	none	
Weed control:	Same as Scenario 11	
Dynamics:	Years 1-2	annuals may dominate if there was a significant seed bank in the topsoil material; perennials may comprise < 50% relative cover

Years 3-5	perennials should become dominant; perennial grasses should comprise > 50% relative cover by Year 5 and shrubs > 10% by Year 3 and > 20% by Year 5
Years 6-10	perennial grasses should comprise > 60% relative cover; shrubs should comprise > 30% relative cover by Year 10
Years 10-15	perennial grasses should comprise 50-60% relative cover; shrubs should comprise > 40% relative cover; some shrubs should be mature size
Years 15-20	perennial grasses and shrubs should both comprise about 50% relative cover; most shrubs should be mature

4. Follow-up procedures:

Evaluation criteria: Measure total cover, by species, and record number of live shrubs near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels = minimum 25% total canopy cover each year +

Year 1	minimum 75% shrub survival
Year 2	minimum 50% shrub survival; relative canopy cover of native perennials > 30%
Year 3	relative canopy cover of shrubs > 10%; relative canopy cover of native grasses > 35%
Year 4	relative canopy cover of shrubs > 15%; relative canopy cover of native grasses > 40%
Year 5	relative canopy cover of shrubs > 20%; relative canopy cover of native grasses > 50%
Year 10	relative canopy cover of shrubs > 30%; relative canopy cover of native grasses > 60%
Year 15	relative canopy cover of shrubs > 40%; relative canopy cover of native grasses > 45%
Year 20	relative canopy cover of shrubs ≥ 45%; relative canopy cover of native grasses ≥ 45%

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in Sep-Nov with the same seed mixture, but from a different source. Broadcast rather than drill. Care must be taken not to damage shrubs.

If seedlings of seeded species established but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2-wk (Mar-Sep). Care must be taken not to damage shrubs.

If shrub mortality exceeds 30% at the end of the first growing season, increase irrigation rate by 0.8 ha-cm (0.5 ac-in.) per 2 wk (Mar-Sep). If losses exceed 50% over the first three years, replace half the dead plants with new tublings and continue to irrigate. Continue this procedure until canopy cover targets for shrubs are reached.

5. Costs:

High

The application of 46 cm (18 in.) of topsoil and the costs of purchasing and planting the shrub tublings make this scenario expensive. Irrigation adds significantly to the costs. However, without the deeper topsoil, it is doubtful that a significant shrub component can be established on these sites because of the deeper root systems of the shrubs. Without irrigation and use of tublings, it is doubtful that the shrub component can be established within the target time line (20 years).

6. Comments:

The presence of contaminated subsoil will make establishment of a late-seral community difficult on these sites. The 46 cm (18 in.) topsoil treatment should provide an adequate matrix on which to develop a shallow-soil shrubland community, but there will continue to be the potential of moisture loss from translocation to deeper layers. Water can enter the deeper layers following snowmelt, but the roots can not, at least not until residual herbicides breakdown or are translocated to even deeper layers.

The required topsoil thickness is greater for this scenario than for scenarios targeting a grass community on these sites. This is because the late-seral target community contains significant amounts of shrubs and shrubs are deeper rooted than grasses.

SCENARIO 15

SITE:	Sterilized
COMMUNITY:	Late-seral
TIME:	20-50 years
IMPACTS:	Light

1. Pre-planting procedures:

   Same as Scenario 14

2. Propagation procedures:

Species:	Species Mixture 10
Source:	local < 180 km (< 100 mi) if possible
Method:	drill, half-in. depth, 0.3 m (12 in.) spacing
Season:	Sep-Nov
Mulching:	apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting and crimp mulch into surface

3. Post-planting procedures:

   Same as Scenario 14

4. Follow-up procedures:

Evaluation criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels = minimum 25% total canopy cover each year and relative canopy cover values of

Years 1-2	any combination of species
Year 3	native perennials > 25%
Year 4	native perennials > 35%
Years 5-6	native perennials > 50%
Years 7-9	native perennials > 60%
Years 10-13	native perennials > 70%; shrubs > 5%
Years 14-19	native perennials > 75%; shrubs > 5%
Years 20-30	native perennials > 80%; shrubs > 10%
Years 31-40	native perennials > 85%; sagebrush > 20%
Years 41-49	native perennials > 85%; sagebrush > 30%
Year 50	native perennials > 85%; sagebrush > 45%

Follow-up: Same as Scenario 14

5. Costs:

Same as Scenario 14

6. Comments:

Same as Scenario 14

SCENARIO 16

SITE: Upper elevation
COMMUNITY: Native
TIME: 2-5 years
IMPACTS: Light

1. Pre-planting procedures:

Physical seedbed: none

Chemical seedbed: none

Topsoil addition: none

Fertilization: none

Weed control: disc before weeds set seed in growing season prior to planting; repeated operations may be necessary (Apr, Jun, Sep) if cultivation is not possible, apply low-label rates of glyphosate/2,4-D at a 1:2 ratio to reduce weed seed viability

2. Propagation procedures:

Species: Species Mixture 11

Source: local < 180 km (< 100 mi), if possible

Method: drill, half-in. depth, 0.3 m (12 in.) rows; or broadcast, followed by light harrowing

Season: Sep-Nov

Mulching: apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after planting and crimp mulch into surface

3. Post-planting procedures:

Irrigation: apply 0.8 ha-cm (0.5 ac-in.) every 2 wk (Apr-Jul)

any method of application can be used, but ground application from a water truck or hand lines is least expensive

irrigation is not necessary during those 2-wk periods receiving > 0.5 cm (> 0.2 in.) of rain

irrigation can be discontinued once native perennials reach 30% total canopy cover

Fertilization: none, unless follow-up is required

Weed control: none the first two growing seasons none thereafter if annual weeds are < 50% relative canopy cover at the end of the second growing season

if annual weeds are > 50% relative canopy cover at the end of the second growing season, apply low-label rates of 2,4-D and dicamba in early April

Dynamics:

Year 1	annuals (cheatgrass, Russian thistle, tumble mustard) may dominate; native perennials should comprise > 25% relative cover
Year 2	native perennials should comprise > 40% relative cover
Year 3	native perennials should comprise > 60% relative cover
Year 4	native perennials should comprise > 75% relative cover
Year 5	native perennials should comprise ≥ 85% relative cover

4. Follow-up procedures:

Evaluation criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels = minimum 30% total canopy cover in Years 1-2 and minimum of 40% thereafter, and relative canopy cover values of

Year 1	native perennial species > 25%
Year 2	native perennial species > 40%
Year 3	native perennial species > 60%
Year 4	native perennial species > 70%
Year 5	native perennial species > 80%

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in Sep-Nov with the same seed mixture, but from a different source.

If seedlings of seeded species established but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2 wk (Apr-Sep). If relative cover values of seeded species were under target levels, add the additional irrigation, but not the fertilizer.

5. Costs: Low to moderate

6. Comments:

Irrigation should not be necessary for more than two years, and may not be necessary more than one. However, there will be the risk of cheatgrass invasion until there is significant establishment of perennials.

SCENARIO 17

SITE: Upper elevation
COMMUNITY: Native
TIME: 5-10 years
IMPACTS: Light

1. <u>Pre-planting procedures:</u>

   Same as Scenario 16

2. <u>Propagation procedures:</u>

   Same as Scenario 16

3. <u>Post-planting procedures:</u>

   Same as Scenario 16

4. <u>Follow-up procedures:</u>

   Evaluation criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

   Target levels = minimum 30% total canopy cover in Years 1-4 and minimum of 40% thereafter, and relative canopy cover values of

Year 1	native perennial species > 25%
Year 2	native perennial species > 35%
Year 3	native perennial species > 45%
Year 4	native perennial species > 50%
Year 5	native perennial species > 55%
Year 6	native perennial species > 60%
Year 7	native perennial species > 70%
Year 8	native perennial species > 75%
Year 9	native perennial species > 80%
Year 10	native perennial species ≥ 85%

   Follow-up: Same as Scenario 16

5. <u>Costs:</u>

   Low to moderate

   Costs should be lower than for Scenario 16 because irrigation should be necessary only 1 year.

6. Comments:

Same as Scenario 16

SCENARIO 18

SITE:	Upper elevation
COMMUNITY:	Native
TIME:	10-20 years
IMPACTS:	Light

1. Pre-planting procedures:

   Same as Scenario 16

2. Propagation procedures:

Species:	Species Mixture 12
Source:	local < 180 km (< 100 mi), if possible
Method:	first drill seeds, half-in. depth, 0.3 m (12 in.) spacing then plant shrub tublings on 2.3 m (7.5 ft.) centers 1900 plants/ha (775 plants/acre) add 45 g (0.1 lb) of 16-16-16 fertilizer in bottom of each tubling hole PRIOR to placing the tubling in the hole
Season:	Sep-Nov
Mulching:	apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface immediately (< 3 days) after drilling and crimp mulch into surface

3. Post-planting procedures:

   Same as Scenario 16 with the following exception:

Dynamics:	Year 1	annuals (cheatgrass, Russian thistle, tumble mustard) may dominate; native perennials should comprise > 25% relative cover
	Year 2	native perennials should comprise > 35% relative cover
	Year 4	native perennials should comprise > 50% relative cover; shrubs should comprise > 10% relative cover
	Year 6	native perennials should comprise > 60% relative cover; shrubs should comprise > 20% relative cover
	Year 8	native perennials should comprise > 75% relative cover; shrubs should comprise > 30% relative cover
	Year 10	native perennials should comprise ≥ 90% relative cover; shrubs should comprise > 40% relative cover
	Year 15	native perennials should comprise ≥ 90% relative cover; big sagebrush should comprise > 35% relative cover
	Year 20	native perennials should comprise ≥ 90% relative cover; big sagebrush should comprise > 50% relative cover

4. Follow-up procedures:

Evaluation criteria: Measure total cover, by species, and record number of live shrubs near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels = minimum 30% total canopy cover in Years 1-2 and minimum of 40% thereafter, and

Year 1	minimum 75% shrub survival; relative cover of native perennials > 25%
Year 2	minimum 50% shrub survival; relative cover of native perennials > 35%
Year 3	relative cover of native perennials > 40%; relative cover of shrubs > 5%
Year 4	relative cover of native perennials > 50%; relative cover of shrubs > 10%
Year 6	relative cover of native perennials > 60%; relative cover of shrubs > 20%
Year 8	relative cover of native perennials > 75%; relative cover of shrubs > 30%
Year 10	relative cover of native perennials > 85%; relative cover of shrubs > 40%
Year 15	relative cover of native perennials > 85%; relative cover of big sagebrush > 30%
Year 20	relative cover of native perennials > 85%; relative cover of big sagebrush > 50%

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in Sep-Nov with the same seed mixture, but from a different source. Broadcast rather than drill. Care must be taken not to damage shrubs.

If seedlings of seeded species established but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2 weeks (Apr-Sep). Care must be taken not to damage the shrubs.

If shrub mortality exceeds 30% at the end of the first growing season, increase irrigation rate by 0.8 ha-cm (0.5 ac-in.) per 2 wk (Apr-Sep). If losses exceed 50% over the first three years, replace half the dead plants with new tublings and continue to irrigate. Continue this procedure until canopy cover targets for shrubs are reached.

5. Costs:

Moderate

The major costs in this scenario are for the purchase and planting of the tublings and irrigation.

6. <u>Comments:</u>

Two years of irrigation should be sufficient to achieve the target levels. Perennial grasses should dominate for the first 10 years, with big sagebrush becoming dominant by Year 15. If precipitation is above average, or irrigation is applied longer, big sagebrush could become dominant by Year 10.

SCENARIO 19

SITE:	Upper elevation
COMMUNITY:	Late-seral
TIME:	20-50 years
IMPACTS:	Light

1. Pre-planting procedures:

   Same as Scenario 16

2. Propagation procedures:

   Same as Scenario 16

3. Post-planting procedures:

   Same as Scenario 16 with the following exception:

   Dynamics: Same as Scenario 18

4. Follow-up procedures:

   Evaluation criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

   Target levels = minimum 30% total canopy cover in Years 1-3 and minimum of 40% thereafter, and relative canopy cover of

Years 1-2	native perennials > 25%
Years 3-5	native perennials > 35%; shrubs > 5%
Years 6-10	native perennials > 45%; shrubs > 5%
Years 11-15	native perennials > 50%; shrubs > 10%
Years 16-20	native perennials > 60%; shrubs > 15%
Years 21-30	native perennials > 70%; big sagebrush > 15%
Years 31-40	native perennials > 80%; big sagebrush > 30%
Years 41-49	native perennials > 85%; big sagebrush > 40%
Year 50	native perennials > 85%; big sagebrush > 50%

   Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in Sep-Nov with the same seed mixture, but from a different source. If there are significant numbers of shrub seedlings, broadcast rather than drill.

   If seedlings of seeded species established but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2 wk (Apr-Sep). If relative cover values of seeded species were under target levels, add the additional irrigation but not the fertilizer.

5. Costs:

Moderate

Costs of this scenario are significantly less than for Scenario 18 because no tublings are used in this scenario.

6. Comments:

The primary difference between this scenario and Scenario 18 is that in Scenario 18 tublings are used. In this scenario, shrub establishment is from seed only. This makes late-seral community establishment slower, but less expensive, in this scenario than in Scenario 18. The longer irrigation is applied, the sooner a late-seral shrubland will become established. This scenario will probably also have a greater cheatgrass component for a longer period of time than will Scenario 18.

SCENARIO 20

SITE: Riparian
COMMUNITY: Native
TIME: 2-5 years
IMPACTS: Light

1. Pre-planting procedures:

Physical seedbed: smooth surface to eliminate ditches and erosion rills

Chemical seedbed: none

Topsoil addition: none

Fertilization: single application of 16-16-16 fertilizer at 134 kg/ha (120 lb/ac).

Weed control: none

2. Propagation procedures:

Species: Species Mixture 13

Source: local < 180 km (< 100 mi), if possible

Method: broadcast, followed by light harrowing or raking

Season: Sep-Nov

Mulching: apply 4.5 Mg/ha (2 T/ac) of hay or straw to surface and crimp mulch into surface, or apply 2.54 cm (1 in.) of net mulching to surface; apply mulching within 3 days of planting

3. Post-planting procedures:

Irrigation: apply 0.8 ha-cm (0.5 ac-in.) every 2 wk (Apr-Sep)

drip or truck application can be used, but ground application from a water truck or hand lines is least expensive

if truck irrigation is used, care must be taken not to cause water erosion

irrigation is not necessary during any 2-wk period receiving > 0.5 cm (> 0.2 in.) of rain

irrigation can be discontinued as soon as target values are reached

Fertilization: none, unless follow-up is required

Weed control: none

Dynamics:

Year 1	annuals may be abundant in spots; perennial grasses should comprise > 60% relative cover
Year 2	perennial grasses should comprise > 90% relative cover; some woody species should begin to establish
Year 3	perennial grasses should comprise > 90% relative cover; woody species should be common on lower slopes
Year 4	perennial grasses should comprise > 80% relative cover and shrubs > 10% relative cover

4. Follow-up procedures:

Evaluation criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels = minimum of 50% total canopy cover in Year 1, 75% in Year 2, and 90% thereafter, and relative canopy cover of

Year 1	=	perennials > 60%
Years 2-4	=	perennials > 90%
Year 3	=	perennials > 90%; woody species > 10%

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in Sep-Nov with the same seed mixture, but from a different source.

If seedlings of seeded species established but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2 wk (Apr-Sep). If relative cover values of seeded species were under target levels, add the additional irrigation but not the fertilizer.

5. Costs: Low to moderate

The primary costs of this scenario are seedbed preparation, seed purchase, fertilizer, mulching, and irrigation. None of these are high-cost items.

6. Comments:

The potential for rapid revegetation is high on these sites. They are mesic sites with relatively light disturbances. However, erosion could be a problem if establishment of perennials is slow. Care should be taken to make sure the surface is covered at all times by either plants or mulch.

SCENARIO 21

SITE: Riparian
COMMUNITY: Native
TIME: 5-20 years
IMPACTS: Light

1. Pre-planting procedures:

Same as Scenario 20

2. Propagation procedures:

Same as Scenario 20

3. Post-planting procedures:

Irrigation: none

Fertilization: none, unless follow-up is required

Weed control: none

Dynamics:
Year 1 annuals may dominate; perennial grasses should comprise > 30% relative cover
Year 2 perennial grasses should comprise > 50% relative cover
Year 3 perennial grasses should comprise > 75% relative cover; some woody species should be present
Year 4 perennial grasses should comprise > 85% relative cover; woody species should comprise about 5% relative cover
Year 5 perennial grasses should comprise > 85% relative cover; woody species should comprise >10% relative cover

4. Follow-up procedures:

Evaluation criteria: Measure total cover, by species, near the end of each growing season. If mean values meet target levels (Section 4.3), no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels = minimum 50% total canopy cover in Year 1, 65% in Year 2, 80% in Year 3, and 90% thereafter, and relative canopy cover of

Year 1 perennials > 25%
Year 2 perennials > 50%
Year 3 perennials > 75%
Year 4 perennials > 90%
Year 5 perennials > 90%; shrubs > 5%

Follow-up: Same as Scenario 20

5. Costs:

Same as Scenario 20

6. Comments:

This scenario is a low-cost version of Scenario 20. In average or above-average precipitation years, it will probably result in the same community establishing on the site as would Scenario 20, but 1-2 years later and at much less cost. The two major risks with Scenario 21 are (1) the site will remain unstable longer, and therefore more subject to erosion, and (2) invasion by cheatgrass and other undesirable species will be more likely and these species would probably remain in the community much longer.

In average or above-average precipitation years, a perennial community should establish on the site under this scenario within 5 years. Under dry conditions, it might take 10-15 years.

SCENARIO 22

SITE:	Riparian
COMMUNITY:	Late-seral
TIME:	10-20 years
IMPACTS:	Light

1. <u>Pre-planting procedures:</u>

   Same as Scenario 20

2. <u>Propagation procedures:</u>

   Same as Scenario 20 with the following exception:

   Species: Species Mixture 14

3. <u>Post-planting procedures:</u>

   Irrigation: apply 0.8 ha-cm (0.5 ac-in.) overall, and an additional 7.5 L (2 gal.) around the base of each willow cutting every 2 wk (Mar-Sep) for minimum of 1 year

   drip or truck application can be used, but ground application from a water truck or hand lines is least expensive

   if truck irrigation is used, care must be taken not to cause water erosion

   irrigation is not necessary during any 2-wk period receiving > 0.5 cm (> 0.2 in.) of rain

   irrigation can be discontinued as soon as target values are reached

   Fertilization: none, unless follow-up is required

   Weed control: none

Dynamics:		
	Year 1	annuals may be abundant in spots; perennial grasses should comprise > 60% relative cover; willows should double in height
	Year 2	perennial grasses should comprise > 90% relative cover; most willows should be > 0.3 m (1 ft.) tall
	Year 3	perennial grasses should cover the entire site; willows should be > 2 ft tall
	Year 5	perennial grasses should cover the entire site; willows should be > 5 ft tall; other woody species should be invading into the site
	Year 10	perennial grasses should dominate on the upper slopes and the lower slopes should support a willow thicket; there should be significant amounts (> 10% of surface) in other woody species

4. Follow-up procedures:

Evaluation criteria: Measure total cover, by species, and number of live willow shoots near the end of each growing season. If mean values meet target levels (Section 4.3) no additional action is necessary. If mean values do not meet target levels, go to follow-up.

Target levels =

Year 1	total canopy cover > 50%; perennial grass relative canopy cover > 60%; 75% willow survival
Year 2	total canopy cover > 65%; perennial grass relative canopy cover > 90%; willow survival > 70%, mean willow height > 0.3 m (12 in.)
Year 3	perennial grass total cover > 80%; willow total cover > 5%; willow mean height > 0.6 m (24 in.)
Year 4	perennial grass total cover > 80%; willow total cover > 10%; willow mean height > 40 in.
Year 5	perennial grass total cover > 80%; willow total cover > 15%; willow mean height > 60 in.
Year 10	perennial grass total cover > 50%; willow total cover > 40%; total cover of other woody species > 5%

Follow-up: If no, or very few, seedlings of seeded species are established at the end of the first growing season, the problem was probably poor seed. Re-seed in Sep-Nov with the same seed mixture, but from a different source.

If seedlings of seeded species established but cover values were below target levels, fertilize with N twice annually at 22.4 kg/ha (20 lb/ac) per application and add an additional 0.8 ha-cm (0.5 ac-in.), in addition to any other recommended amount, of irrigation each 2 wk (Apr-Sep). If relative cover values of seeded species or willow values were under target levels, add the additional irrigation but not the fertilizer.

5. Costs:

Moderate

Seedbed preparation, seed, seeding, fertilizer application, and irrigation costs are moderate. Preparation and hand planting of the willow cuttings will increase the costs somewhat.

6. Comments:

This scenario is similar to Scenario 21, except with the addition of the willow cuttings. Once the willow cuttings root, they should for thickets on the wetter sites within 5-10 years. The relative amount of woody species (willow and others) will depend on microtopography of the individual site.