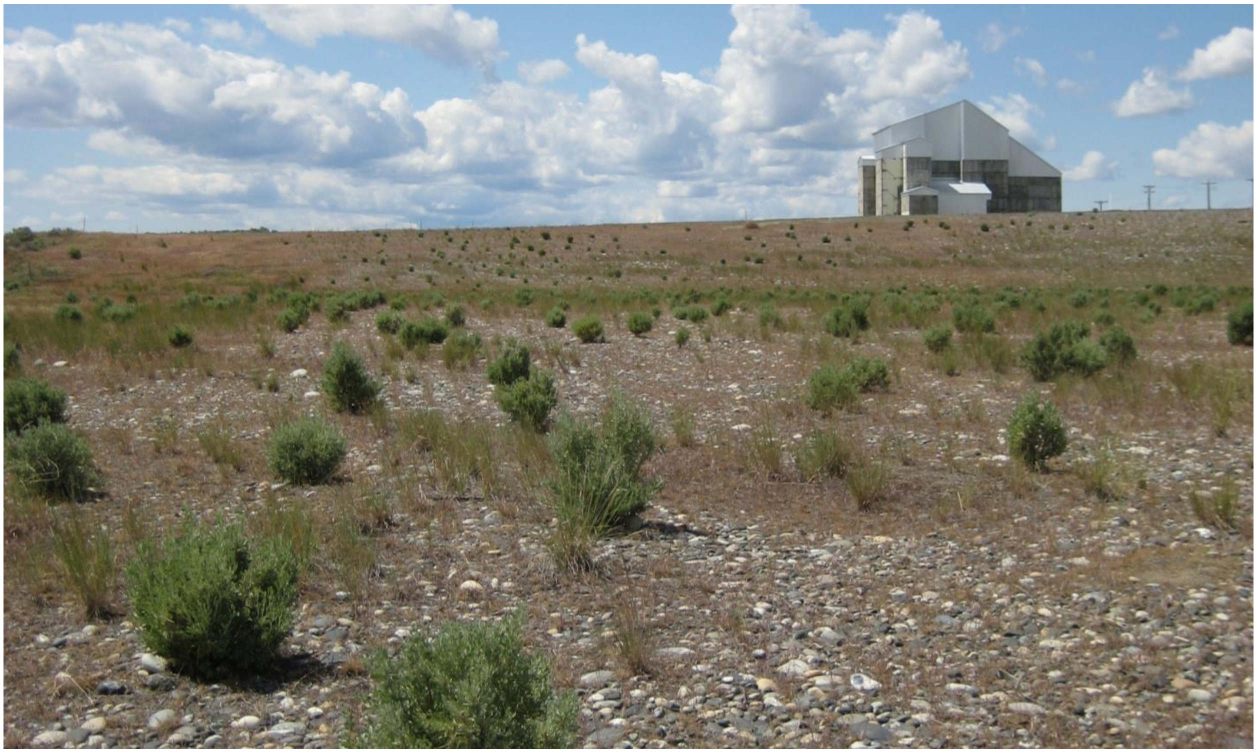
DOE/RL-2011-116
Revision 2

Hanford Site Revegetation Manual



Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

U.S. Department of Energy Richland Operations Office
P.O. Box 550
Richland, Washington 99352

Approved for Public Release
Further Dissemination Unlimited

This page intentionally left blank.

DOE/RL-2011-116
Revision 2

Hanford Site Revegetation Manual

Date Published
September 2020

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

U.S. DEPARTMENT OF ENERGY | Richland Operations Office
P.O. Box 550
Richland, Washington 99352

Summary

Revegetation, stabilization, and ecological restoration activities are performed by the various Hanford Site contractors to support the U.S. Department of Energy Richland Operations Office (DOE-RL) long-term stewardship goals, achieve habitat mitigation, and meet cleanup and revegetation requirements mandated in the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) of 1980. Because multiple Hanford Site contractors are responsible for conducting various types of revegetation actions, a consistent strategy and approach to revegetation and restoration are needed to improve planning and scheduling of revegetation activities, identify cost savings, avoid duplication, and provide an overall benefit from a landscape perspective.

The *Hanford Site Revegetation Manual* describes the DOE-RL strategy and applies to all actions that occur on the Hanford Site, unless specifically directed otherwise by DOE-RL. It is the DOE-RL policy, that the project or contractor that creates the disturbance is responsible for planning and performing the revegetation action consistent with this manual. This manual is not retroactively applicable to completed projects; however, the manual is applicable to actions or disturbances that are in progress upon publication of this manual.

This manual provides DOE-RL and its contractor's clear and consistent direction regarding revegetation, restoration, and stabilization actions to meet the following goals:

- Develop and apply consistent revegetation and restoration criteria to meet and support the DOE long-term stewardship goals, contribute to wildlife habitat, enhance ecological function on Hanford Site lands, and for consistency with historic tribal use of the Hanford site vegetation resources.
- Develop revegetation criteria and implement revegetation actions that satisfy final CERCLA restoration goals and are consistent with the Hanford Natural Resource Trustee Council objectives to meet natural resource damage assessment requirements.
- Ensure that planning and scheduling of revegetation and restoration actions are performed in a cost-efficient and responsible manner, and are coordinated to allow for long-range planning required for long-lead items (seed and live plants).
- Ensure that revegetation actions are appropriate and achieve environmental compliance.
- Reduce duplication of restoration actions and avoid, when possible, situations in which restored areas or mitigation sites may be negatively affected by future cleanup actions.

This manual describes three different types of revegetation actions and implementation strategies, each with a different objective for the endpoint or future condition, as noted below:

- Planting to restore native vegetation and habitats on barren or heavily disturbed areas (excavated and remediated waste sites).
- Planting to either improve or modify existing communities after natural disturbance, or to provide enhanced habitat for selected wildlife species, including pollinators.
- Planting to provide interim stabilization of bare soils and substrates, until further remediation or cleanup action is initiated.

Interim stabilization refers to planting or stabilizing the soil surface in areas that will be subject to future disturbance. For short-term stabilization (less than one year), the ground surface may be stabilized using fixatives or short-lived vegetation covers until final revegetation and restoration actions can be planned and implemented, or until the land area is utilized for other purposes. Long-term stabilization (several years) requires, at a minimum, planting perennial grasses until the site can be fully remediated or developed for another purpose. The use of native species is recommended for long-term stabilization.

Revegetation actions to restore native plant communities are necessary when activities such as waste site cleanup actions and decommissioning have been conducted and the affected lands are left bare or with little native vegetation cover intact. Any type of action that involves clearing the surface of

vegetation may ultimately require revegetation to restore native plant communities. In these cases, restoring a functional plant community dominated by locally derived native species is the goal of the revegetation action.

Plant community enhancements or improvements are intended to increase the habitat quality and value (plant and animal diversity, tribal utility, etc.) of a specific site. The objectives may be to increase habitat for selected wildlife species or group of species, accelerate the recovery of ecosystems after natural disturbances, or improve communities that have been degraded through human disturbances or invasion by exotic plant species. The use of locally derived native species is required for plant community enhancement and improvement projects.

Chapter 2 provides guidance designed to help project managers integrate the planning and implementation of revegetation actions into their overall Hanford Site operations and cleanup action project planning. Chapter 2 provides information on project timelines and schedules for plant or seed procurement, timing of field actions, documentation, and long-term project responsibilities, such as monitoring and maintenance. In addition, the importance of the various project team members is discussed, especially the revegetation specialist, and the need for early and regular interaction between the project manager and the revegetation specialist. A detailed checklist for planning revegetation actions is provided, along with a quick reference outline of the site-specific revegetation plan contents.

Chapter 3 provides guidelines or generic specifications for use in various combinations of soil types and revegetation objectives along with guidelines for pollinator-focused restorations. Because each project site presents a unique combination of ecological settings and limiting factors, the generic guidelines are not to be used as standalone specifications for contracting purposes. Instead, the generic guidelines are intended as a starting point for several common situations. The guidelines or generic specifications include:

- Recommended grass species mixes and seeding rates
- Recommended shrub and forb species for each ecological setting including suggested planting rates or densities
- Considerations for planting techniques, site and soil preparation
- Considerations for site maintenance
- Monitoring guidelines, including success criteria for each situation.

Chapter 4 provides additional information on site conditions and limitations that need to be assessed in preparation of a site-specific revegetation plan. The details include an overview of the Hanford Site physical and ecological settings, climate, topography, soils, and vegetation types and their effect on site-specific planning. In addition, the methods to address these limitations are also discussed.

Chapter 5 provides a detailed discussion of revegetation planning applicable to different scenarios, a discussion of the factors that affect the selection and establishment of plants, and an overview of available planting methods and seeding rates.

Revegetation site monitoring and management are discussed in Chapter 6, which includes an overview of measurement methods for plant species abundance, diversity, and growth. In addition, a recommended monitoring procedure utilizing a nested plot design is described. Information on management of a revegetation site including provision for protection from human intrusion or disturbance and from biological factors (weed invasion or herbivory). Management also includes regular monitoring of the site, comparison of the site with predefined success criteria, and if those criteria are not met, implementation of corrective actions.

Key DOE Guidance Regarding Revegetation

- Unless otherwise specifically directed by DOE-RL, the *Hanford Site Revegetation Manual* applies to all revegetation actions that occur on the Hanford Site.
- The project or contractor that creates the disturbance is responsible for planning and performing revegetation consistent with this manual. Disturbance includes any actions that result in the loss of vegetation where an alternative land-use has not been instituted.
- All revegetation actions on the Hanford Site will use locally-derived, native species unless specifically authorized by DOE-RL Environmental Safety and Quality (ESQ) staff. Certain commercial cultivars of native species are allowed for interim stabilization.
- All projects must have a project specific revegetation plan that is consistent with the guidelines contained in the Hanford Site Revegetation Manual and approved by DOE-RL ESQ staff.
- All revegetation actions intended to restore or improve native plant communities must be conducted in accordance with the guidance described in the *Hanford Site Biological Resource Management Plan* (BRMaP) , and the *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP-EIS*), (DOE/EIS 0222-F).
- Project Managers shall include revegetation and restoration considerations at all phases of project planning, and enlist the help of a revegetation specialist as early in project planning as possible.
- Projects will budget for appropriate revegetation actions, monitoring of revegetated sites, and corrective actions if needed.

This manual is intended for project managers and DOE staff overseeing remediation and restoration projects; however, the manual contains information that will helpful to revegetation specialists. Chapters 2, 3 and 6 are intended to be useful to both the project manager and the revegetation specialist in that they describe many of the procedural steps that need to be considered and they provide relatively succinct guidance for various scenarios that will be commonly encountered on the Hanford Site. Chapters 4 and 5 are likely to be of interest primarily to revegetation specialists. An abridged User's Guide of this manual is available (DOE/RL-2011-115) that provides focused instructions to project managers and DOE oversight personnel. The User's Guide contains the same guidance, specifications, and instructions as found in this manual.

Because of the likely time lag in the ability to obtain suitable quantities of native seed, there will be a phased implementation of the guidelines described in this manual. Beginning on the publication date of this manual, DOE-RL Environmental Safety and Quality (ESQ) staff will review site-specific revegetation plans for all projects, and all projects will be expected to comply with this guidance to the extent practical. All guidelines concerning native grasses and native shrubs will be required of all projects starting one year from the date of publication. All guidelines concerning native forbs will be required starting two years from the publication date of this manual.

This page intentionally left blank.

Acronyms and Abbreviations

ac	acre
ATV	all-terrain vehicle
BLM	Bureau of Land Management
BRMaP	Biological Resources Management Plan
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	centimeter
CTIP	Coordinated Technology Implementation Program
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESQ	Environmental Safety and Quality
FHA	Federal Highway Administration
HCP-EIS	Hanford Comprehensive Land-Use Plan Environmental Impact Statement
lb	pound
m	meters
NEPA	National Environmental Policy Act
NRCS	Natural Resources Conservation Service
PLS	pure live seed
lb PLS/ac	pounds of pure live seed per acre
RL	Richland Operations Office
SER	Society for Ecological Restoration
USDA	U.S. Department of Agriculture
USC	United States Code
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service

Glossary

anticlinal ridge	an upward geological fold where the oldest rocks are at the center
broadcast	A method of seeding where the seeds are flung or spread on the soil surface
bulk density	the weight of a dry soil sample divided by the volume of that sample; the total volume includes particle volume and pore (or empty space) volume
community	a group of species occupying a particular area, usually interacting with each other and their environment
compaction	the result of heavy machinery or other weight (e.g., livestock) pressing on the soil and reducing soil pores and therefore reducing the soil's ability to hold water and air
cryptogamic crust	a soil surface crust formed of algae, lichens, and/or mosses
cuttings	branches, roots or leaves that are separated from a plant and used to create new plants
desired future conditions	specific, measurable goals for each revegetation unit, usually defined in terms of the percentage of vegetative cover, ground cover, species composition, and so on
drill	A seed planting implement, normally pulled by tractor, that opens a furrow, places seeds in the bottom of the furrow, then covers the seed with soil.
ecological restoration	measures taken to return a degraded ecosystem function to a less degraded condition
edaphic plant community	controlled by some property of the soil having an effect on species composition and plant growth
evapotranspiration	loss of water by evaporation from the soil and transpiration for plants
forb	a broad-leaf, herbaceous plant
herbaceous	plant having no wood in the stem
hydro mulch	material composed of fine wood or paper applied through hydroseeding equipment to the soil surface for surface stabilization
hydroseeding	the hydraulic application of seed through hydroseeding equipment: seeds are placed in a slurry that may also include hydromulch, tackifiers, and soil amendments, and sprayed thinly over the soil surface
imprinter	an implement, usually towed behind tractor, consisting of a large rolling cylinder with knobs or teeth to push broadcast seed into the soil surface
interim stabilization	Revegetation or surface stabilization that is performed to provide erosion control and/or contaminant transport control in areas that will be re-disturbed later, not a final or permanent action.

introduced species	plants that are not native or locally adapted to the area
invasive species	any non-native species that occupies a revegetation site and may limit revegetation success; categories of invasive species (weeds) include invasive, noxious, competing, introduced, and exotic
litter	the layer of fresh and partially decomposed plant material that covers the soil surface, generally under or near the plant
locally adapted native plants	plants collected near the project site (or sites with ecological attributes similar to the project site) and best suited to local conditions; generally requiring less maintenance and persisting longer than non-local species
mulch	protective material placed on the soil surface; mulch materials may include straw, native grass, erosion control fabric
mycorrhizae	symbiosis between the roots of a seed plant and the mycelium of certain beneficial fungi that act as an extension of the root system; thought to increase water and mineral uptake by the plant among other benefits
native plants	plants that are locally adapted and genetically appropriate; they are indigenous species that have evolved and occur naturally in a particular region, ecosystem, and habitat
pollinator	an agent (typically insect) that transfers pollen from one flower to another facilitating plant reproduction
restoration	the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed, usually by undertaking efforts to aid the recovery of the plant species assemblage that was historically present in that area
revegetation specialist	resource person tasked with overseeing the initiation, planning, implementation, and monitoring phases of the revegetation project; usually has a background in the natural sciences such as botany
riparian	occurring along the edges of water
sediment	sand, clay, silt, and organic material eroded and deposited by water and wind
seed mix	a combination of species used in a seeding project that meet the environmental requirements of the site and project objectives
seed source	the identity of a batch of seed which includes seed collection location, number of parents, date collected, and ownership
seral plant community	an intermediate stage in ecological succession
slope aspect	the direction a slope is facing; measured by facing the fall line (the direction a ball would roll) and taking a compass bearing downslope

slope gradient	the angle of a slope, i.e., the rise (vertical distance) divided by the run (horizontal distance)
soil	a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment. Under USDA classification, mineral soils are the particle size fraction < 2.0 mm.
soil structure	the arrangement of soil pores (or voids) determined by how individual soil granules aggregate together; soil structure is responsible for water movement, water storage, air flow, and root penetration
soil texture	the relative proportion of sand, silt, and clay particles in a soil; controls how soils store water, release nutrients, erodibility, and type of sediments that will result
subsoil	the soil horizon between topsoil and parent material; the subsoil is generally lighter in color than the topsoil and contains less organic matter and nutrients
succession	ecological succession is the process of change in the species structure of a community over time
swale	a ground depression, usually wetter than adjacent, higher ground
symbiosis	a relation between two different species of organisms from which each gains benefits
tillage	any mechanical action applied to the soil for the purposes of improving soil productivity, reestablishing plants, and controlling soil erosion; used to shatter compacted soils, incorporate soil amendments, and/or to roughen soil surfaces

Sources: CTIP 2007; SER 2004.

Contents

Appendices

Figures

Tables

This page intentionally left blank.

1.0 Introduction

Revegetation and ecological restoration are important components of several Hanford Site activities, especially as the DOE moves toward final restoration and stabilization of remediated waste sites and continues restoration of disturbed lands. Over time, Hanford Site contractors have performed numerous revegetation and restoration activities in support of DOE's long-term stewardship goals, habitat mitigation, and *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) revegetation requirements. Because multiple Hanford Site contractors are responsible for conducting various types of revegetation actions, a consistent strategy and approach to revegetation and restoration are needed to improve planning and scheduling of revegetation, identify cost savings, avoid duplication, and provide an overall benefit from a landscape perspective. Unless otherwise specifically directed by DOE-RL, this manual applies to all revegetation actions that occur on the Hanford Site Central Hanford (Figure 1.1); and the project or contractor that creates the disturbance will be responsible for planning and performing the revegetation action.

To satisfy these requirements, DOE-RL has developed the *Hanford Site Revegetation Manual* to provide consistent direction for revegetation and restoration actions designed and implemented by the Hanford Site contractors. The manual describes the overall revegetation strategy for the Hanford Site and provides general specifications for the design, timing, scheduling, plant and seed selection, and implementation of various types of revegetation actions, and the background information needed by restoration ecologists to modify these specifications as needed to account for site-specific conditions.

This manual provides DOE and its contractors with clear and consistent direction regarding revegetation, restoration, and stabilization actions to meet the following goals:

- Develop and apply consistent revegetation/restoration criteria to meet and support DOE's long-term stewardship goals, contribute to wildlife habitat, enhance ecological function that are consistent with historic tribal use of the Hanford Site vegetation resources.
- Develop revegetation criteria and implement revegetation actions that satisfy final CERCLA restoration goals and are consistent with the Hanford Site Natural Resource Trustee Council objectives that meet natural resource damage assessment requirements.
- Ensure that planning and scheduling of revegetation and restoration actions are performed in a cost-efficient and responsible manner, and are coordinated to allow for long-range planning for long-lead items (seeds and live plants).
- Ensure that revegetation actions are appropriate and achieve environmental compliance.
- Reduce duplication of restoration actions and avoid, where possible, situations where restored areas or mitigation sites may be negatively affected by future cleanup actions.

The guidelines and policies described in this manual were developed based on the current scientific literature, Hanford Site and Columbia Basin revegetation and mitigation planting experience (CTUIR et al. 2009), and previous Hanford Site guidance (BHI-00971). Restoration and revegetation specialists from the Hanford Site prime contractors, Natural Resource Trustees, and the tribes provided input for this manual. This manual considered guidance, comments, and recommendations developed by the Hanford Site Natural Resource Trustee Council (NRTC) and its Restoration Technical Working Group. The *Hanford Site Revegetation Manual* is a living document that will be periodically updated as necessary to incorporate scientific discoveries, advances in technology, lessons learned, and to integrate with and complement the NRTC resource restoration processes and goals.

This manual is useful for project managers and DOE staff overseeing remediation and restoration projects in addition to revegetation specialists. Chapters 2, 3, and 6 are useful to both the project manager and revegetation specialist. These chapters describe many of the procedural steps, with succinct guidelines for commonly encountered Hanford Site scenarios. Chapters 4 and 5 apply primarily to revegetation specialists.

An abridged version of this manual is also available and provides more focused instructions for project managers and DOE oversight personnel (*Hanford Site Revegetation Manual User's Guide*, DOE/RL-2011-115). The User's Guide contains the same guidance, specifications, and instructions as found in this manual.

1.1 Revegetation, Restoration, and Rehabilitation on the Hanford Site

Revegetation means to plant something or reestablish plant cover by means of seeding or transplanting on a site disturbed by natural or human-caused actions. Revegetation may be as simple as providing ground cover to prevent erosion or as complex as recreating lost habitat. In this manual, revegetation is a general term that encompasses Hanford Site-specific actions using native plant materials to stabilize soils and restore or enhance native plant communities.

For the Hanford Site, restoration is defined as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed, usually by undertaking efforts to aid the recovery of the plant species assemblage, historically present in that area (SER 2004).

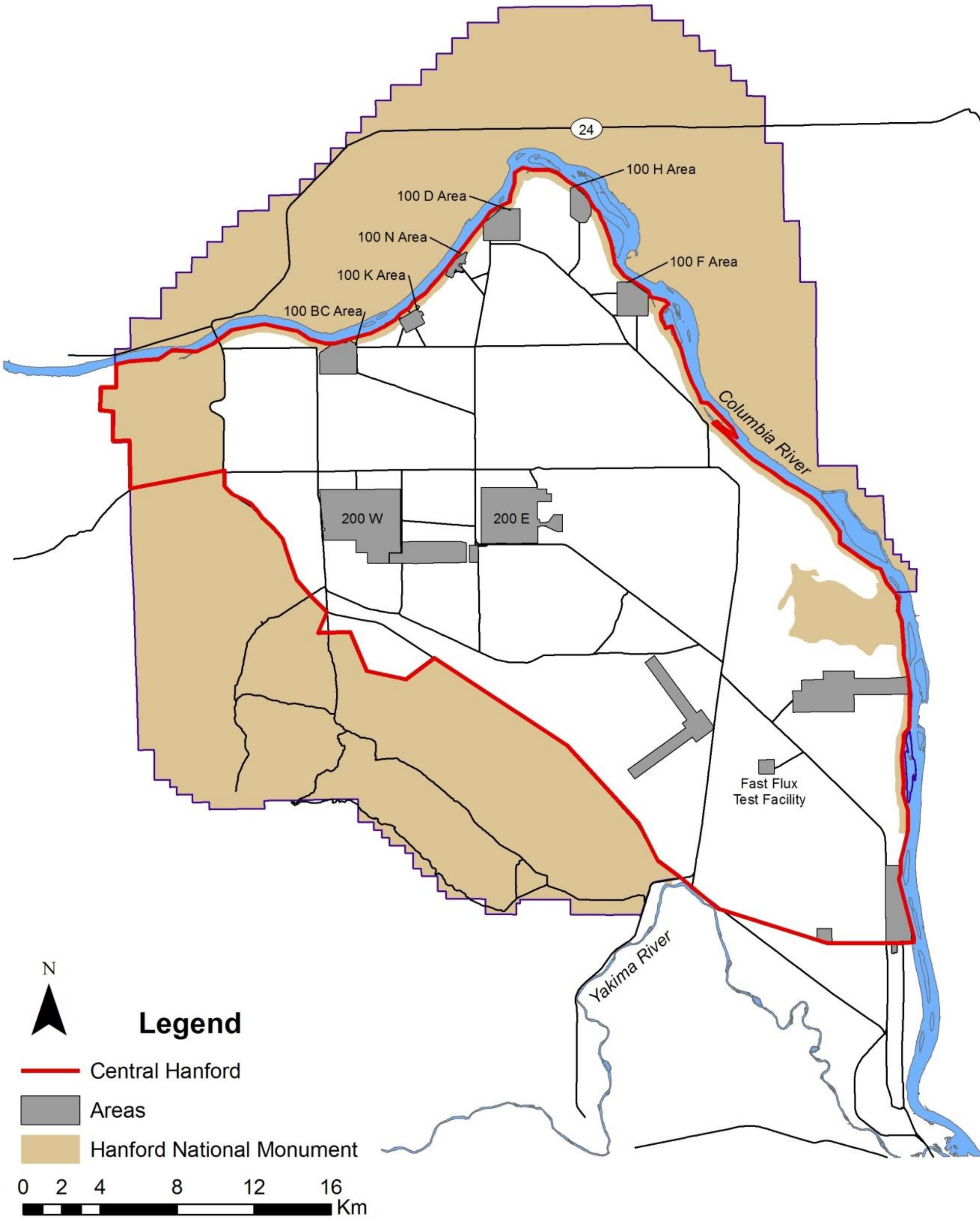
Rehabilitation or plant community enhancement includes actions focused on reparation of ecosystem processes and services after natural or human-caused disturbances. Mitigation plantings enhance existing habitats to compensate for environmental damage or loss of habitat elsewhere on the Hanford Site. The general types of revegetation actions undertaken on the Hanford Site are described in the following sections.

1.2 General Types of Revegetation Actions

Hanford Site contractors generally undertake three different types of revegetation actions. Each type of action has a different objective for the endpoint or desired future condition, and may require different implementation strategies to achieve the endpoint, as noted below:

- Planting to restore native vegetation and habitats on barren or heavily disturbed areas such as excavated and remediated waste sites.
- Planting to enhance, improve, or modify existing communities following a natural disturbance, provide an enhanced habitat for selected wildlife species or group of species (e.g., pollinators).
- Provide interim stabilization of bare soils and substrates until further remediation or cleanup actions are initiated.

Figure 1.1. Hanford Site Revegetation Plan locations for Central Hanford



1.2.1 Restore Native Plant Communities

The establishment of native plant communities to re-initiate natural processes of succession is a cornerstone of most ecological restoration work (Dorner 2002). Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2004). Native plants are a foundation of ecological function, affecting soil conservation, wildlife habitat, plant communities, potential for invasive species, and water and air quality.

Revegetation actions to restore native plant communities are necessary when site activities, such as waste site cleanup actions and building decommissioning, have been conducted and the affected lands are left bare of vegetation cover. Any type of action that involves clearing the surface, herbicide spraying, or burning may require revegetation to restore native plant communities. Examples of these activities where the establishment of native communities are necessary include:

- Revegetation as a final step in waste site closure
- Restoration and planting of the soil component of Hanford Site protective barriers (an engineered, multilayer barrier over a waste site designed to minimize water infiltration—usually with a fine silt layer on top of course sands or gravels)
- Establishment of native plant communities at the conclusion of building demolition and decommissioning actions or following removal of Hanford Site debris or infrastructure.

1.2.2 Enhance and Improve Habitat or Native Plant Communities

Plant community improvements are intended to increase the habitat quality and value of a specific site. The objectives may be to increase habitat for selected wildlife species or group of species, accelerate the recovery of ecosystems after natural disturbances, or improve communities that have been degraded through human disturbances or invasion by exotic plant species such as cheatgrass (*Bromus tectorum*) and Russian thistle (*Salsola tragus*). The site often has some native habitat components required by the target wildlife species or groups of species, or is specifically targeted towards a group of species like in pollinator-focused revegetation sites. These types of revegetation actions may be prescribed for several reasons. The most common habitat improvement actions are those conducted as part of compensatory mitigation for loss of habitat elsewhere on the Hanford Site. Improvement actions may also be needed after severe wildfire or prescribed burns to re-establish fire-sensitive components of native plant communities.

Improvement actions of this type are intended to be permanent; therefore, these areas are considered high-value biological resources in Hanford Site resource management planning. Species used for habitat amendment should be native to the Hanford Site and preferably be of locally derived genetic stock. Depending on the starting condition of the area under consideration for improvement, the improvements may be made to the understory (grass and forb/herb components), to the shrub component of the plant community, or to both. Although difficult now, technological innovations may allow for improvement of the cryptogamic crust as well. Avoid the use of non-native species for habitat improvement. Non-native plant species can significantly alter native plant community structure and composition, especially if the non-native species are capable of reproducing and expanding into the adjacent native communities. Proper planning, through implementation of this manual, will ensure that sufficient quantities of native seed is available; thus, eliminating the need to use of non-native species in most or all situations.

1.2.3 Interim Stabilization

Interim stabilization refers to planting or stabilizing the soil surface in areas that will be subject to future disturbance. In these cases, the ground surface may be stabilized using fixatives or vegetation covers, until final revegetation and restoration actions can be implemented, or until the land area is utilized for other planned purposes. Examples of appropriate interim stabilization actions include stabilization of bare soils on waste sites for which final remediation and restoration actions will occur in the future, areas where industrial development is planned, or areas disturbed by construction projects that conclude outside the appropriate time for revegetation with native species. The primary purpose of many stabilization plantings or treatments on the Hanford Site is to prevent contaminant uptake and migration from inactive waste sites and to minimize erosion from waste sites or areas slated for future industrial development. Interim revegetation also is appropriate for areas where soils are stockpiled for future use in remediation and restoration actions. By definition, plantings or treatments for interim stabilization of soils are intended to be temporary in that the sites will be disturbed again through DOE actions. Revegetation plans for interim stabilization projects that follow these guidelines do not require review by DOE-RL ESQ staff.

1.2.3.1 Short-Term Interim Stabilization

Short-term interim stabilization actions are appropriate to protect exposed soil surfaces for periods of up to several months. For example, if a construction project clears or blades existing vegetation and leaves soils bare between project activities (or to accommodate schedule delays), the bare soils remaining would need to be stabilized to avoid negative impacts from wind and water erosion until the area can be revegetated using native species. Short-term interim stabilization actions may include planting temporary ground covers or applying soil fixatives to minimize erosion and blowing dust.

1.2.3.2 Long-Term Interim Stabilization

Long-term interim stabilization is appropriate when a site requires stabilization for an indefinite period (normally years). In these situations, it is assumed that the site will eventually be re-disturbed for either final remediation or other site development (e.g., inactive waste sites: cribs, burial grounds, backfilled ponds, or trenches). Plant species appropriate for long-term interim stabilization include perennial bunchgrasses that are locally derived or non-invasive cultivars of species native to the Hanford Site that are adapted to grow in this environment. Introduced species such as crested wheatgrass (*Agropyron cristatum)* should not be used except under special circumstances where other options are not feasible, and the introduced species are the only viable option to produce a relatively fast establishing, long-lasted vegetation cover. Use of non-native species for revegetation will require review and approval by DOE-RL ESQ staff. In general, native or non-native shrubs are not appropriate for interim stabilization where deeper-rooted plants are undesirable or the site will be re-disturbed within a relatively short time.

1.3 Application

DOE-RL direction stipulates that all lands not needed for continued access or use within the Hanford Site that are disturbed by site cleanup, maintenance, development, or infrastructure installation or modification will be revegetated in accordance with this manual. Disturbances that require revegetation include physical disturbances resulting from actions such as, but not limited to, digging, grading, remediation actions, off-road vehicle travel, etc.; or other actions that may remove or damage native vegetation (e.g., impacts of herbicide applications or controlled burns not accounted for within the controlling *National Environmental Policy Act* (NEPA) documents and/or project specific ecological reviews). In addition, all revegetation actions undertaken to restore or improve native plant communities on the Hanford Site must be conducted in accordance with the guidance described in the *Hanford Site Biological Resource Management Plan* (DOE/RL 96-32) the HCP-EIS (DOE/EIS-0222-F, 2008) and considered in context with current biological resource information including DOE priorities for resource management.

The use of native plant species in revegetation and restoration actions is an integral and necessary component of DOE's management of ecological resources on the Hanford Site. DOE guidance regarding revegetation requires the use of locally derived native plant species in most revegetation actions on the Hanford Site (DOE/RL 96-32). *Native plants*, as defined in this manual, are locally adapted, genetically appropriate native plant materials (Withrow-Robinson and Johnson 2006). These plants are best adapted to grow well in local conditions and generally require less maintenance and persist longer than non-local species. When properly established, they form plant communities with the potential to be self-sustaining and self-perpetuating over time, requiring little or no input from humans to persist. DOE's guidance to use native plants in Hanford Site revegetation aligns with other federal agency land management policies and guidance. For example, the U.S. Forest Service (USFS) and U.S. Department of the Interior (DOI) both mandate the use of native plants as the first choice in revegetation efforts (DOI 2002, and USFS 2008). In addition, the Presidential Memorandum on Beneficial Landscaping (Clinton 1994) directs federal agencies to use regionally native plants for landscaping and to minimize adverse impacts to natural habitats. The *Federal Land Policy and Management Act* of 1976 (43 USC §1700 et seq.), Section 102, also directs management of public lands in a manner that will protect the quality of the ecological values; where appropriate, preserve and protect their natural condition; provide food and habitat for fish and wildlife and domestic animals; and provide for outdoor recreation and human occupancy and use; the use of native species meets the intent of this Act. The Presidential Memorandum to the Secretary of Energy (Clinton 2000) that accompanied the Proclamation establishing the Hanford Reach National Monument (65 FR 37253-37257) directs DOE to manage Hanford land under its jurisdiction to protect the values protected within the National Monument, preserve the option of adding Central Hanford lands to the monument in the future; the use of native species meets the intent of this memorandum. Use of native species also complies with recommendations within the 2008-2012 *National Invasive Species Management Plan* (National Invasive Species Council 2008). In addition to being better suited ecologically, locally derived native species are likely to be more culturally relevant than non-native species, thus meeting local tribal goals.

In addition to restoring with native plants, emphasis has been placed in land-owning federal departments to restore with pollinator-friendly species. The 2014 presidential memorandum "Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators" called for immediate action to be taken by land-owning federal departments to prevent further pollinator population declines (79 FR 35903-35907). The memorandum resulted in the *Pollinator Research Action Plan*, which had the goal of restoring or enhancing 2.8 million hectares (7 million acres) of pollinator habitat on federally owned land (Pollinator Health Task Force 2015). Pollinator-friendly native species on the Hanford Site were identified in the Hanford Site Pollinator Study (HNF-62689), which provides the basis for pollinator-friendly restoration and enhancements described in Section 3.2.8.

This manual applies to revegetation of areas affected by Hanford Site operations and cleanup and is not intended to provide direction for landscaping actions around buildings and facilities; however, the manual may be applied for landscaping actions. The U.S. Fish and Wildlife Service (USFWS) manages the Fitzner/Eberhardt Arid Lands Ecology Reserve and the portions of the Hanford Site lying to the north and east of the Columbia River. Revegetation and restoration action and practices in those areas will follow the guidance in the *Final Hanford Reach National Monument Comprehensive Conservation Plan and Environmental Impact Statement* and supporting documents (USFWS 2008). This manual is intended to be compatible with USFWS resource management objectives and may be useful for USFWS and other agencies that conduct revegetation and restoration within the lower Columbia Basin.

Because of the likely time lag in the ability to obtain suitable quantities of native seed, there will be a phased implementation of the manual guidelines. Beginning on the manual publication date, DOE-RL ESQ staff will review site-specific revegetation plans for all projects, and all projects will be expected to comply with this manual to the extent practical. All guidelines concerning native grasses and native shrubs will be required of all projects starting one year from this manual publication date. All guidelines concerning native forbs will be required starting two years from this manual publication date.

1.4 Report Contents

Portions of this manual (Chapters 2, 3, and 6), are useful for revegetation specialists; however, these chapters are intended to inform project managers in charge of cleanup or project development and provide guidance for appropriate planning and consideration of revegetation or restoration needs early during project planning and throughout project implementation. Other portions of this manual, especially Chapters 4 and 5 provide useful information for site-specific revegetation planning and implementation, and provide an overview of available options and revegetation techniques. These chapters will be of primarily interest to revegetation specialists. The abridged version of this manual (User's Guide), is directed primarily at project managers and DOE oversight staff.

Chapter 2 outlines a series of steps to guide project managers through the revegetation and restoration planning process, describe briefly how to develop a site-specific revegetation plan for a project, and provide suggestions for integrating revegetation implementation with overall project planning. Chapter 3 summarizes the overall revegetation strategy for the Hanford Site, including determination of the type of revegetation action needed, selection of appropriate plant species, and the basis for those selections centered on the goals of revegetation. Chapter 4 discusses the ecological setting and factors to consider in a revegetation preparatory site assessment. Revegetation planning and implementation are discussed in Chapter 5, including the selection and handling of plant materials and techniques to address environmental conditions and site-specific factors and limitations, as well as special considerations for specific types of revegetation actions. Revegetation or restoration site management, maintenance, and monitoring are discussed in Chapter 6. Sources cited in the text are provided in Chapter 7. Supplemental information is provided in two appendices. Appendix A presents phenological information on plants native to the Hanford Site, and Appendix B contains a list of additional resources for revegetation planning and implementation.

This page intentionally left blank.

2.0 Project Manager Guidance

This chapter is designed to help project managers integrate the planning and implementation of revegetation actions into their overall Hanford Site operations and cleanup action project plans. Establishing native vegetation is widely recognized as an essential and cost-effective step to improve the environment, maintain safe working conditions, and meet stakeholder expectations for environmental stewardship at the Hanford Site. By incorporating an integrated approach to revegetation into the project vision at an early stage, the project is more likely to be successful, meet environmental requirements, stakeholder expectations, and ultimately reduce costs. A properly planned and integrated approach to revegetation greatly reduces the likelihood of replanting a site because the site failed to meet the pre-defined success criteria.

Revegetation planning is an integral part of overall project planning. An essential component of the project manager's role involves understanding the scope and timing of the revegetation efforts with respect to the overall project scope. To ensure successful integration of revegetation issues within the project, managers need to understand how the revegetation process works, including:

- specifications for seeding and planting
- schedule for revegetation, including timing for activities such as seed collection, seed increase, and plant propagation as needed
- funding required to complete revegetation tasks
- review and approval of revegetation plan by DOE-RL ESQ staff
- criteria for plant establishment
- monitoring and maintenance of the revegetated site
- restoration is only complete once pre-defined success criteria are met or exceeded.

As described in the introduction, three general types of revegetation actions are commonly conducted on the Hanford Site: 1) planting or soil treatment to provide interim stabilization at a site, 2) planting or seeding to re-create or re-establish a native plant community in a barren or non-vegetated area such as a remediated waste site, or 3) planting or seeding of selected species to enhance conditions in existing plant communities. Although the endpoint for each of these actions differs, the sequence of activities and some of the considerations for timing and planning are very similar.

2.1 Project Team and Responsibilities

The protection and establishment of healthy communities of native plants is an important part of the scope of final cleanup and decommissioning projects. Managers will need to assemble a multi-disciplinary project team to address revegetation and restoration early in the planning process. Revegetation and ecological restoration actions require team members who understand the complex environmental conditions at the Hanford Site, including soils, precipitation, temperatures, and topographic position, and how these conditions interact to affect plant establishment and growth. These factors, as well as other ecological, cultural, and political considerations, determine the desired future conditions for any particular revegetation site as well as the limitations faced during the revegetation process.

The project manager's role is to provide leadership and direction to the project, to ensure budgets, schedules are met, and that all materials, equipment, and personnel are available when needed. The project manager also is responsible for ensuring that all permits and documentation are in place when needed and deciding how to address unanticipated events or unusual circumstances. Permits and documentation will include, at a minimum, a NEPA evaluation, which includes cultural and biological resource reviews. The revegetation action and footprint, including physically separated actions such as mitigation plantings, should be included in the scope of the cultural and biological review requests for the project as a whole. Revegetation actions that are independent of a cleanup, demolition, or construction project will require their own NEPA, cultural, and ecological reviews. Other permits (such as an excavation permit) or requirements (such as air monitoring) may also need to be addressed. Depending on the size of the project, the project manager may designate responsibility for some or all of these areas to others.

To design effective revegetation and restoration actions, project managers should engage a qualified revegetation or restoration specialist as part of the project team as early as possible and during all subsequent aspects of revegetation projects, especially those intended to restore native plant communities or enhance and improve native habitats on the Hanford Site. The revegetation or restoration specialist's role is to work closely with the project manager as part of the project team. The revegetation specialist will determine the type of revegetation action that is needed, identify the desired future conditions, determine physical limitations that will be faced at the site, and determine how those limitations may be addressed. The revegetation specialist will develop the approved seed mix for the action using Hanford Site specifications (Chapter 3), determine the planting methods and soil treatments, and identify the equipment needed. The project manager, working with the revegetation specialist, will be responsible for developing the site-specific revegetation plan and the detailed contract specifications required to implement that plan. Specifications will cover areas such as seed mix and amounts, seed quality, mulch and/or soil amendments (type, amount, and quality), site preparation requirements, qualifications of revegetation workers, and other items required by DOE or company policies and procedures. The project manager will be responsible for assuring that quality control of all aspects of the revegetation process is implemented in accordance with DOE and company procedures.

Early coordination between the project manager and the revegetation specialist allows the project to be planned with restoration needs in mind, for instance, arranging for materials, equipment, and qualified staff to be available at the appropriate planting season. Plant material needs can be estimated to help ensure that the plant materials are procured and available when needed. The revegetation specialist should review project plans to determine how anticipated actions may affect or limit the revegetation options. Continued coordination during the project will allow the revegetation specialist to modify plans, as needed as the project site changes and will allow for input by the revegetation specialist on schedules and physical attributes such as grading and contouring.

Other specialists also may contribute, either as members of the project team or as consultants to the revegetation specialist. Areas of expertise that may be drawn upon include soil science, wildlife biology, botany, plant ecology, hydrology, landscape architecture, and cultural resources, among others.

DOE-RL ESQ staff who oversees biological resource management on the Hanford Site are responsible for reviewing and approving the revegetation plan for the specific project.

2.2 Management and Integration

In general, the project manager's task is to ensure that the end product of each project meets DOE expectations to be completed efficiently, effectively, and to high standards of excellence within budget and on schedule. Project managers are responsible for coordinating revegetation actions with other project activities in a collaborative and integrated manner. This effort requires bringing together team members from different disciplines and organizations. Coordination needs to begin before any disturbance to soil or vegetation takes place and if possible, coordination should begin 1 to 3 years ahead of the action to provide ample lead-time for securing sufficient quantities of native seed and/or native seedlings. To optimize results, a revegetation/restoration specialist should be involved as early as possible after a project is initiated to integrate issues of native plant revegetation (including protection of existing soils and vegetation) into the larger design and construction processes of the overall project. Considering revegetation in isolation from, or as an appendix to, the larger project is an approach that often results in failure.

Table 2.1 is adapted from the Federal Highway Administration's *A Manager's Guide to Roadside Revegetation with Native Plants* (Steinfeld et al., 2007a) and provides insight regarding issues that Hanford Site project managers should consider when integrating revegetation with other project activities.

2.3 Scope and Timing of Revegetation

This section outlines the sequence of events and information for project managers to consider in planning and implementing effective revegetation actions on the Hanford Site. The revegetation processes consists of four stages: 1) initiation, 2) planning, 3) implementation, and 4) monitoring and management (Table 2.2).

Stage 1 – Initiation involves determining project requirements and defining key relationships and communication avenues among project team members. Steps should be taken to coordinate revegetation efforts with planning and construction activities, including identification of funding and scheduling issues. In addition, initiation involves creating bridges among project managers, engineers, cultural resource specialists, and revegetation specialists regarding terminology and technical concepts to improve communication.

Stage 2 – Planning is the process of defining project objectives, assessing the site, overcoming limitations, strategizing revegetation procedures, and integrating the revegetation activities with the project. This stage culminates in the creation of a Revegetation Plan. Specific planning tasks include determining the equipment and supplies needed, determining the species to be planted, and calculating the amount of seed or transplants required

Project planning must carefully account for several critical constraints, including the timing and appropriate season for planting activities and the timing of seed collection and plant propagation. Because the Hanford Site lies within the driest region of the Columbia Basin in Washington, consideration of the timing of seeding and planting actions with respect to season and weather is critical to success of the revegetation or restoration action.

Some types of interim stabilization actions or revegetation implementation may include irrigation as a treatment and, thus, timing of seeding and planting may be less critical. However, these activities still will require consideration of weather and season to optimize the success of planting and seeding. In addition, weather and seasonality are critical issues to consider when planning and executing the collection of locally derived native plant seeds. Some plants flower and seed during the spring and early summer months, whereas other native species flower and set seed in the late summer and early fall. These activities usually need to be planned and considered with respect to overall project activities far in advance of actual seeding and planting on the ground at the completion of construction/demolition actions (Figure 2.1).

Stage 3 – Implementation occurs when the Revegetation Plan is executed in the field. This stage includes coordinating contracts and managing budgets and schedules. All necessary environmental reviews and approvals must be acquired. Implementation involves carrying out site treatments, mitigation measures, and revegetation tactics. Implementation includes tasks to stabilize soils, overcome limiting factors, improve site conditions, and establish communities of native plants.

Stage 4 – Monitoring and Management involves assessing the effectiveness of the revegetation project, correcting any shortcomings if goals were not met, and adding to the knowledge base for revegetation techniques and methods. Maintenance actions, such as invasive weed control, replanting, and protection of the site from trespass, may be required during the first several years of plant growth to ensure successful revegetation of the site. These responsibilities will continue well after other aspects of the project have been completed.

The end goal for most projects on the Hanford Site includes establishment of native plant communities and habitats that are self-sustaining and functional over the long term. No 'one-size-fits-all' plant mix or planting methodology exists that can be applied to accomplish this goal in all circumstances. As described in Chapter 3, some generalities can be drawn based on soil type, slope, and other factors; therefore, similar revegetation projects in the same physical area may be able to duplicate previous revegetation plans. However, the interdisciplinary team should realize that project-specific revegetation strategies may need to address the unique ecological factors at play in each project and at each individual site on the Hanford Site. Site-specific strategies may vary to suit different conditions; however, an approved list of native species that have been demonstrated to be useful in revegetation actions is included in this manual as well directions for developing an appropriate species mixture depending on site conditions.

The following sections describe the process and components necessary to develop site-specific and ecologically appropriate revegetation plans for lands within Central Hanford. These sections provide principles and a systematic process for revegetation practitioners to take into the field to generate and implement a locally appropriate, context-sensitive site-specific revegetation plan.

Table 2.1. Examples of Integrating Project Management with Revegetation Actions

(adapted from Steinfeld et al. 2007a)

Management Focus	Integrating Revegetation
Project Scope: What and Why	• Incorporate the establishment of healthy native plant communities as part of the project's goals—native plants are important to meet the Hanford Site's resource management goals. • Ensure all members of the team are aware of native plants and ecological concerns as integral to project, not an afterthought. • Set goals for long-term ecological health and self-perpetuating native plant communities, not just fast-growing cover or stabilization unless the action is intended to be interim and temporary.
Statement of Work: Who and How	• Assemble team to include revegetation specialist *before* disturbances are planned. • Understand revegetation process and approach to support work. • Consider revegetation plan as an integral part of project plans, not an appendix.
Milestones: When	• Understand timelines for revegetation processes so they may be successfully integrated with other processes. • Ensure revegetation and project activities will be complementary, not conflicting. • Be aware that revegetation tasks may begin 1 to 3 years before site construction and decommissioning and continue after project is complete.
Communication	• Ensure key opportunities for collaboration are utilized. • Encourage cooperation between engineering and natural sciences—optimal results often come from collaboration. • Involve revegetation specialist when disturbances to soil and vegetation are being planned or revised. • Allow special contract requirements to support context-sensitive revegetation needs.
Funding	• Plan funding as needed for revegetation schedule • Know that revegetation tasks begin 1 to 3 years before construction and continue well after construction or cleanup portion of the project is complete. Monitoring can extend for at least five years after project completion, and funding will be required to support that monitoring and corrective action, if needed
Quality Assurance	• Ensure measurable revegetation goals are set and met. • Use context-sensitive goals, matched to unique site.

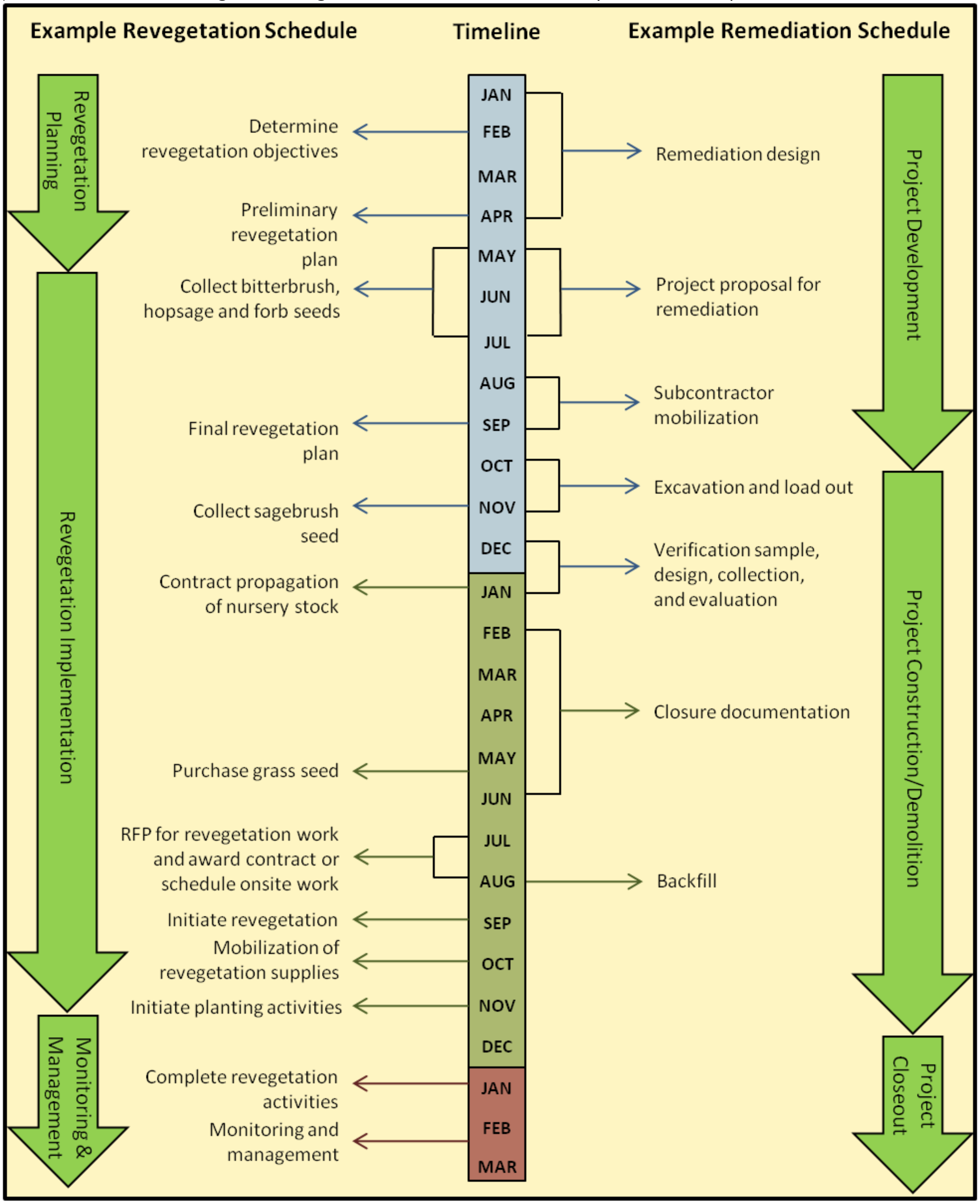
Table 2.2. Examples of Project Life Cycle Events integrated with Revegetation Planning and Implementation

(adapted from Steinfeld et al. 2007b)

Revegetation Phase	Goal	Revegetation Project Tasks	Project Phase
Stage 1 - Initiation	Understand Cooperators and Decision Process	• Identify cooperators • Define cooperator processes, establish a schedule to include timelines, and milestones • Define objectives: What is the project trying to accomplish? • Understand key concepts and terminology	Initial Planning and Programming
Stage 2 - Revegetation Planning	Orient to the Project	• Determine revegetation objectives • Define revegetation units • Define the desired future conditions for the site	Project Development
	Assess Site	• Identify limiting factors • Consider mitigating measures for limiting factors • Assess site resources	
	Analyze Vegetation Requirements	• Determine which species and groups of species will be used on the project. Develop species mixture based on specifications in Chapter 3. • Identify the target plant requirements • Determine number/amount of plant materials needed	
	Integrate Information and Develop Strategy	• Determine appropriate plant establishment methods (e.g., drill seeding, hydroseeding, broadcast seeding, and transplants) depending on seed availability and site characteristics. Consult with revegetation or restoration specialists. • Determine whether site treatment is necessary and develop plan for treatment application (e.g., mulching, crimping native grass straw, re-contouring or topsoil additions) • Assemble preliminary revegetation plan	
Stage 3 - Revegetation Implementation	Implement Strategies and Establish Vegetation	• Review plans with project staff and obtain DOE-RL ESQ staff approval of preliminary revegetation plan • Complete NEPA analysis and conduct required biological and cultural resource reviews • Develop contracts for plant materials and special contract requirements (seed collection, seed increase, plant propagation) • Review revegetation treatment details and timelines • Review recontouring and final site preparation • Design and specify monitoring methods • Complete Final Revegetation Plan • Recontour and prepare site for planting • Implement planting/seeding/treatments	Project Construction/ Demolition
Stage 4 - Monitoring and Management	Evaluate Status and Implement Corrective Strategies as Necessary	• Implement monitoring and determine whether desired future conditions are met • Evaluate data and apply any corrective measures • Report on monitoring information and share lessons learned	Project Closeout

Figure 2.1. Waste-Site Remediation Project Sample Schedule for Planning and Implementing Revegetation

(Note that site monitoring and management will continue for several years after completion of the rest of the



project)

2.4 Checklist for Planning Revegetation Actions

The following provides a checklist to aid in revegetation project planning and management and provides the steps to work through, the decision points at each step, and the factors to consider or evaluate to support the decision. References to other chapters and sections of this document are provided where appropriate.

1. **Determine Revegetation Purpose and Goal**
   - Identify the desired endpoint (Section 1.2)
     - *Permanent restoration* – appropriate for most waste site remediation actions, facility closures, protective barrier covers, etc. May include very-small-scale restoration
     - *Habitat enhancement* – use for actions including mitigation via habitat improvement, pollinator-focused restoration, post-fire restoration, etc.
     - *Short-term interim stabilization* (generally months; i.e., construction areas, stockpiles. If shorter time frame, use physical/chemical stabilization rather than revegetation
     - *Long-term interim stabilization* (applicable if the site will clearly be re-disturbed at a later date, within 1 to 5 years; i.e., partially closed waste sites) if next known disturbance greater than 5 years out, follow the permanent restoration procedures
2. **Conduct Site Assessment and Analysis**
   - Determine final soil type and source for the project (i.e., native or backfill) (Section 4.1.2)
   - Determine the relative topography of the project site at completion (Section 4.2.4)
   - Determine whether the site is homogeneous with respect to soils and topographic relief and identify homogeneous units for revegetation if necessary
   - Identify the appropriate reference plant community for the revegetation site if restoration is the endpoint (Section 4.1.3)
3. **Select the Appropriate Revegetation Specification (Chapter 3)**
   - Identify appropriate guidelines based on revegetation goal and soil type (Table 3.2)
   - Identify the recommended species mix and planting rate for different planting methods (Sections 3.2 and 5.1)
   - Identify the recommended site preparation and maintenance actions (Sections 3.2 and 5.1)
   - Identify the methods to be used for monitoring and criteria determining success of the project (Sections 3.2 and 6.1)
4. **Modify Guidelines Based on Site-Specific Conditions and Limitations**
   - Evaluate factors that may need to be considered in identifying the final seed mix:
     - Elevation – probably most important for silt loam sites, as these encompass the greatest range in elevation; less important for sands and sandy loam sites.
     - Aspect – can favor increasing some species in the mix and decreasing others.
     - Special climate considerations – may influence timing of site preparation and planting actions, may affect species proportions in the seed mix.
     - Surrounding plant community – may alter the species mix, especially in choice of shrubs and forbs.
   - Evaluate factors that that affect the selection of planting method:
     - Determine site area (acres)
     - Topography (Section 4.2.4)
   - Evaluate factors that affect site preparation and maintenance:
     - Soil structure/compaction (Section 4.2.1)
     - Weeds on site or in surrounding areas (Section 4.2.5)
     - Soil fertility (Section 4.2.2)
     - Site access limitations or restrictions
     - Topsoil storage options (Section 4.2.3)
     - Herbivory control (Section 4.2.6)
5. **Develop Site-Specific Revegetation Plan and Implement the Action**
   - Develop project and revegetation timeline (Section 2.3)
   - Determine quantity of seed/plants needed
   - Develop plant material procurement strategy (Section 5.6)
     - On-site collection
     - Contract for seed increase (project- or program-based)
     - Commercial acquisition
     - Contract for nursery production (project- or program-based)
   - Develop detailed specifications for the revegetation subcontractor or site forces based on general guidelines as modified by special considerations (Section2.5)
   - Identify revegetation subcontractor or identify appropriate site-forces unit.
   - Develop monitoring and maintenance plan based on guidelines and special considerations (Section 6.1)
   - Develop long-term management plan for the site to protect against further disturbance
   - Establish graded contractual penalties if contractor or subcontractor fails to meet specific contractual requirements (e.g., establishes non-native plants instead of native plants; has an abundance of weed seed in the native seed mixture, uses non-local seed and/or plants, etc.)

2.5 Site-Specific Revegetation Plans

Site-specific revegetation or mitigation plans are necessary for all soil and vegetation disturbing actions on the Hanford Site as described in the *Hanford Site Biological Resources Management Plan* (DOE/RL-96-32) and as mandated by CERCLA Records of Decision and applicable NEPA documents. A site-specific plan can provide coverage for multiple sites that are grouped by programmatic, temporal, or geographic criteria, provided the plan accounts for differences among sites and the specific revegetation needs and limitations of the individual sites included in the plan.

At a minimum, site-specific revegetation plans should include the following components:

Roles and Responsibilities: Provide introductory information describing the overall revegetation project, the parties responsible for conducting the revegetation action, and any cooperators who may participate in the different phases of the revegetation action.

Site Description: Provide a description of the physical location(s) (including coordinates), size, and the ecological and physical characteristics (slope, aspect, etc.) of the area(s) to be revegetated. Include information on the type of soils and the historic plant community if available. Define and describe the potential revegetation units for the area. Revegetation units are areas within the project site that have similar physical/ecological characteristics where similar revegetation strategies and treatments will be applied. Homogeneous areas will have one or a few units; areas that are more heterogeneous may have more units. Provide a map showing each revegetation unit.

Site Analysis: Describe results of analysis of the physical and ecological site attributes/conditions that need to be considered in revegetating the area, including the identification of limiting factors and any mitigating measures that will be applied. It is appropriate to consider and include the factors critical for plant establishment, such as soils and climate as well as any obstacles to revegetation at the site.

Statement of Goals for the Specific Action: Describe the intended goals for the type of revegetation action (e.g., stabilization, restoration, pollinator-focused restoration, habitat enhancement, or mitigation) being conducted. Short-term, immediate revegetation objectives on most projects include erosion control and water quality protection through mulch and vegetative cover. Long-term revegetation objectives generally include the exclusion of invasive weeds, development of wildlife habitat, and establishment of healthy native plant communities through soil restoration. Specific, measurable objectives for plant establishment and site condition, usually called *desired future conditions*, should also be set by the revegetation specialist early in the planning phase. It is appropriate here to describe the desired future conditions in terms of criteria for the plant density, cover, and species composition to be established on each revegetation unit.

Site Revegetation Strategy: Describe the revegetation strategy, including the plant materials/stock types and application methods for each revegetation unit. Revegetation protocols are dictated by the context and site conditions and the seed mixture specifications for the Hanford Site as provided in Chapter 3. The strategy will also site contouring, soil preparation, physical protection, and control of weeds and pests. The revegetation strategy identifies:

- The contouring and physical/topographic layout of the site
- Soil preparation requirements (compaction, mulching, fertilizer, etc.)
- The species to be seeded or planted
- The amounts of plant materials required
- The planting methods and timing
- Timing and acquisition methods for seed collection as needed
- Plant material propagation as needed
- Seed cleaning requirements
- Treatments that will be applied to modify the revegetation unit based on the results of the site analysis (e.g., treatments to control noxious weeds, control erosion, soil amendments to accelerate soil development or increase soil nutrients).

Budgets and Timelines: Describe the budget and schedule necessary to plan and implement the revegetation strategies. Include time and costs for monitoring and management of the revegetated site in out-years.

Monitoring and Management: Describe how and when monitoring will be conducted, how the data will be evaluated, and what criteria will be used to assess the success of the revegetation effort. Include contingency planning and description of potential corrective actions if revegetation and plant establishment do not meet the objectives and desired future conditions. Generally, interim stabilization will require less monitoring than other revegetation actions. Describe the institutional controls and physical systems (if any) that will help protect the site from further disturbance.

As shown in Figure 2.1, a preliminary revegetation plan is drafted early in the project planning process. This plan is reviewed with the project manager, project engineers, and other team members to ensure that the revegetation strategy is compatible with project objectives and engineering limitations. Depending on the type of revegetation action, the project manager may need to consult with the DOE-RL ESQ staff during development of the revegetation strategy to ensure that the revegetation objectives are aligned with site-wide goals for the protection and enhancement of ecological resources.

The draft revegetation plans for projects in which the objectives and methods are intended to restore native plant communities or to improve native habitats shall be reviewed by DOE-RL ESQ staff before implementation to ensure that planned actions meet the overall management guidelines described in the *Hanford Site Biological Resources Management Plan* (BRMaP) (DOE/RL-96-32).

3.0 Revegetation Strategies for Central Hanford Lands

Revegetation actions at the Hanford Site generally fall into three categories: interim stabilization, revegetation to restore or recreate native plant communities, and revegetation to improve existing conditions, including mitigation plantings. With the exception of interim stabilization actions, effective revegetation of disturbed areas on the Hanford Site aims to initiate or accelerate processes of natural succession or plant community development following disturbances. Restoring plant communities to a predisturbance state on highly disturbed areas usually is not a feasible short-term goal, but aspects of the ecosystem function can be improved with appropriate revegetation practices so that the predisturbance state may be approximated in the long term.

The general strategy for each of the three categories of revegetation at Hanford is similar:

- Define the desired future condition and develop the revegetation objectives.
- Assess the site.
- Identify the key limiting characteristics of the site to be revegetated.
- Develop and implement the treatments that most likely will result in the desired future conditions.
- Monitor the revegetation site against predefined success criteria and manage the site to protect it from disturbance, degradation, or invasion.

Determining the desired future conditions and revegetation objectives for the land areas being revegetated on the Hanford Site is a critical component of the strategy. The goal of revegetation is not merely to establish plants but to create functioning, sustainable plant communities. When native species colonize and become established on a disturbance, this initiates processes of succession including soil genesis and nutrient cycling. The revegetation strategy can determine the trajectory of succession and the time required for ecosystem recovery, and the initial treatments can significantly influence the long-term plant community development.

Defining the desired future conditions also affects selection of the appropriate species mix and seeding or planting rates for each type of revegetation action. The desired future condition may be simple for actions such as short-term interim stabilization actions in which the primary purpose is to prevent soil erosion and transport. In such a case, the main revegetation objective might be the establishment of a stand of plants of at least 30-cm height that provide 60 percent canopy cover over the site. If the desired future condition is to recreate or restore habitat, the description of the revegetation objectives will be more complex, based on the number and type of species that are appropriate for the area being restored, as well as the criteria for initial establishment and long-term success. For example, successfully restoring pollinator habitat may include establishing successful floral cover and having pollinators present. The minimization of invasive and noxious weed establishment would be a universal objective for Hanford Site revegetation projects. The expected future land use of the site is also very important in determining the desired future conditions. Areas designated for resource conservation or preservation in the *Hanford Site Comprehensive Land Use Plan* (DOE/EIS-0222-F, 2008) should have a desired future condition that is consistent with native shrub steppe plant communities. The desired future condition at sites that are within areas dedicated to industrial uses, research and development, or waste management, may more closely resemble an interim cover, depending on the known future uses, and the length of time anticipated until those alternative land uses are implemented.

3.1 Actions Defined by Endpoints and Objectives

Each type of revegetation action has a different objective or set of objectives to achieve the endpoint or desired future condition and each likely will require different implementation strategies to achieve those endpoints. The specific direction and protocols that should be followed for each type of revegetation action depend on multiple site-specific factors, including:

- Past land use and current condition of the area to be revegetated
- Future land use for the site, consistent with the Hanford Site comprehensive land use plan (DOE/EIS-0222-F, 2008).
- Desired revegetation or restoration endpoint
- Purpose of the revegetation/restoration action
- Length of time required to establish a functional vegetation cover
- Availability of appropriate types of plants for successful revegetation, given the physical and biological conditions of the local environment

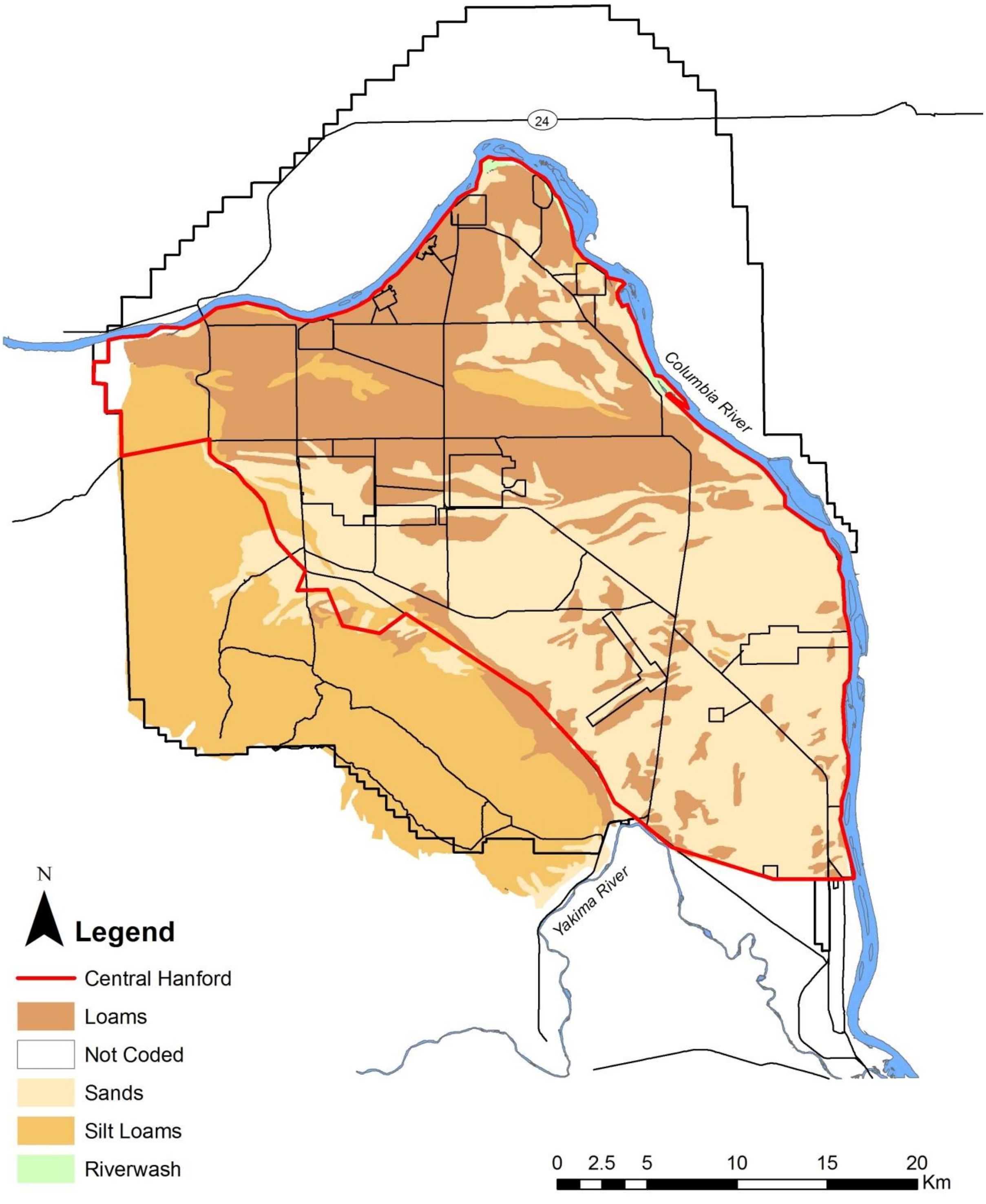
Several factors are generally identified by the type of revegetation action being planned (Table 3.1) and through the process of site assessment and analysis (Chapter 4). Determining the appropriate types and species of plants and the necessary treatments to mitigate site-specific obstacles to revegetation depends on the location of the revegetation site and the physical and ecological attributes of the area to be planted.

The distribution and occurrence of native plant species is generally a function of the environmental characteristics to which each species is best adapted or can tolerate. Two major factors controlling the availability of water and nutrients for plants and, thus, the distribution of species, are local climate and the soils at the site. Both soils and microclimate can be influenced in turn by the topographic relief at the site being revegetated. Topography influences how soil particles are moved and deposited by wind and water, and differences in slope or aspect, even at very small scales, can have profound influence on the plant community via effects on the available soil moisture. These factors are critical to consider in determining the probability of success of establishment of selected species. Because soils are a driving factor controlling the potential native plant community on the Hanford Site, soil texture classes are used as the primary selection criteria for developing the general planting guidelines provided in Section 3.2 as well as the identification of an appropriate species list for each type of revegetation action. For revegetation, soils are considered to consist of the particle size fraction less than 2.0 mm. The term *particle size* is used to characterize the grain-size composition of the mineral portion of a whole soil, while the term *texture* is used in describing its fine-earth fraction (Soil Survey Staff 1994). The generalized soil textural categories shown in Figure 3.1 were derived from more comprehensive soil map data available for the Hanford Site (BNWL-243, shown in Chapter 4) and are used to develop lists of species believed to be appropriate to each general textural type. These generalized soil textural types were used because the soils map data available for Central Hanford is dated and does not provide the scale or level of mapping detail to determine accurately the site potential and representative native plant community solely based on individual soil classes. However, there are plans to update the Hanford Site Soil Survey, which will provide significantly more detailed information on soil distribution, land-use interpretation based upon soil characteristics, soil fertility, and potential for revegetation.

Table 3.1. Examples of Types of Revegetation Actions with Different Endpoints and Objectives

Revegetation Action	Past Land Use	Current Condition	Future Land Use	Purpose	Desired Endpoint	Length of Time to Establish
Interim stabilization	Burial ground or waste site	Bare soils or gravels		Stabilize soils, inhibit erosion, and prevent contaminant uptake	Shallow-rooted plant cover	Short (months)
Interim stabilization	Industrial area	Bare soils or gravels	Industrial development	Stabilize soils until site can be utilized in accordance with HCP-EIS (DOE/EIS-0222-F, 2008)	Native perennial grass cover	Moderate (years)
Interim stabilization	Construction area	Bare soils	Wildlife habitat	Stabilize soils with soil fixative until revegetation/restoration can be planned and implemented	Weed-resistant, stabilized soil surface	Short (months)
Restoration of native community	Remediated waste site in upland areas	Graded backfill or bare soil	Preservation or conservation	Restore functional shrub-steppe plant community	Shrub-steppe	Long (decades)
Restoration of native community	Decommissioned groundwater well, pad, and access road	Bare soils or gravels	Preservation or conservation	Restore functional shrub-steppe plant community	Shrub-steppe	Long (decades)
Restoration of pollinator habitat	Temporarily disturbed pipeline	Bare soils or gravels	Preservation or conservation	Restore functional shrub-steppe plant community with emphasis on pollinator-friendly plants	Shrub-steppe	Long (decades)
Habitat improvement: mitigation	Buffer areas	Steppe	Preservation or conservation	Increase habitat value for selected wildlife species by planting shrubs	Higher-quality shrub-steppe	Moderate (years)
Habitat improvement: reseeding native species after fire	Buffer areas	Non-native grassland	Preservation or conservation	Control non-native plant species and increase habitat value by planting native grass species	Higher-quality shrub-steppe	Moderate (years)
Habitat improvement: pollinator habitat	Burned area	Shrub-steppe	Preservation or conservation	Increase habitat value for pollinators by planting pollinator-friendly plants	Higher-quality shrub-steppe	Moderate (years)

Figure 3.1.Hanford Site Generalized Soil Types



3.2 Restoration Based on Soil Types and Desired Future Conditions

The following subsections provide guidelines for a variety of common restoration, habitat enhancement, and interim stabilization scenarios on the Hanford Site. These sections are provided to support project planning, provide acceptable species for various settings, and to provide insight to potential problems and limitations that may be encountered under each scenario. These guidelines are not intended to function as standalone specifications for contracting purposes, and they must be tailored to each individual setting and restoration, enhancement, or revegetation action. The user of these generic guidelines should be familiar with the more detailed discussions of site conditions, assessment considerations, and limitations on restoration that are provided in Chapters 4 and 5 of this manual. Eight subsections provide generic guidelines for these combinations of revegetation objectives and soil types (Table 3.2).

Table 3.2. Generic Revegetation Guideline Matrix

Revegetation Objective	Soil Type	Subsection
Restoration or plant community enhancement	Sand	3.2.1
	Sandy loam/loamy sands	3.2.2
	Silt loams	3.2.3
	Cobble/mixed backfill	3.2.4
Restoration	Lithosols	3.2.5
Restoration or enhancement	Riparian/wetlands	3.2.6
Interim stabilization	All	3.2.7
Pollinator-focused restoration or enhancement	Sand, loams, cobble	3.2.8

3.2.1 Sandy Soil Restoration or Enhancement

These generic guidelines are designed for sites with sandy soils, as shown in Figure 3.1, with the goal of site restoration or habitat enhancement. Sandy soils on the Hanford Site vary from coarse dune sands that support distinctive dune vegetation to Quincy and Hezel sands that support more typical shrub-steppe vegetation. Sandy soils are the most common soils in the southern half of Central Hanford.

3.2.1.1 Species and Planting Recommendations

Tables 3.3 and 3.4 provide acceptable plant species for use in sandy soils; however, an ecologist or revegetation specialist should be consulted regarding species selection for a specific revegetation or restoration project.

If not all species are available, then adjust the seeding rates of other species to compensate. Indian ricegrass, needle-and-thread grass, and thickspike wheatgrass are typically the most important to include. In some cases, Sandberg's bluegrass (*Poa secunda*) may be included at seeding rates of up to 2 lb/ac (drill) or 3 lb/ac (broadcast). In dune sand, increase the thickspike wheatgrass and add sand wildrye at a seeding rate up to 1 lb/ac if available. All seed should be locally derived or source-identified from a nearby location with similar climatic and soil conditions (preferably within 50 miles). If the supply of forbs is limited, the available material can be planted in clumps to form islands of diversity that can serve as a seed source that can expand through the rest of the revegetation area over time.

Table 3.3. Sandy Soil Sites Recommended Grass Species Mix and Seeding Rates for Plant Community Restoration or Enhancement

Common Name	Species	Drill Seed (lb PLS/ac)[a]	Broadcast (lb PLS/ac)	Hydroseed (lb PLS/ac)
Indian ricegrass	*Achnatherum hymenoides*	3	4.5	6
Needle-and-thread	*Hesperostipa comata*	3	4.5	6
Thickspike wheatgrass	*Elymus lanceolatus*	3	4.5	6
Prairie Junegrass	*Koeleria cristata*	0.25	0.375	0.5
Sand dropseed	*Sporobolus cryptandrus*	0.25	0.375	0.5

(a) lb PLS/ac = pounds of pure live seed per acre.

Table 3.4. Sandy Soil Sites Recommended Shrubs, Legumes, and Forbs for Plant Community Restoration or Enhancement

Common Name	Species	Comments
Shrubs		
Antelope bitterbrush	*Purshia tridentata*	Drill, broadcast, or hydroseed between 0.25 to 0.5 lb/ac/species up to a total of 0.5 lb/ac, or transplant seedlings up to 400 plants/ac/species up to a total of 600 plants/ac. Big sagebrush may be appropriate at up to 400 plants/ac.
Snow buckwheat	*Eriogonum nivium*	
Legumes		
Crouching milkvetch	*Astragalus succumbens*	Preferable to use scurf pea, prairie clover, and at least one milkvetch; drill, broadcast, or hydroseed at least 0.1 lb/ac total, or transplant seedlings at a total of 200/ac.
Stalked-pod milkvetch	*Astragalus sclerocarpus*	
Buckwheat milkvetch	*Astragalus caricinus*	
Dune scurf-pea	*Psoralea lanceolata*	
Western prairie clover	*Petalostemon ornatum*	
Forbs		
Hoary false-yarrow	*Chaenactis douglasii*	Select at least four species; and drill, broadcast, or hydroseed at a minimum rate of 0.1 lb/ac, or transplant seedlings for a total minimum of 400 plants/ac. A combination of seeding and transplant may be used.
Hoary aster	*Machaeranthera canescens*	
Threadleaf scorpionweed	*Phacelia linearis*	
Whiteleaf scorpionweed	*Phacelia hastata*	
Mariposa lily	*Calochorus macrocarpus*	
Yellowbell	*Frittellaria pudica*	
Pale eveningprimrose	*Oenothera pallida*	Forb species mix should match the surrounding vegetation and should include both early and mid-late successional species.
Sand beardtongue	*Penstemon accuminatus*	
Turpentine springparsley	*Pterexia terebinthina*	
Columbia cutleaf	*Hymenopappus filifolius*	
Franklin's sandwort	*Arenaria franklinii var. franklinii*	

3.2.1.1.1 Selection of Planting Method

Use drill or broadcast and imprint for normal sites. Small sites maybe broadcast from an all-terrain vehicle with chain or harrow. At very small sites, hand-apply seed, and rake. Steep sites (more than 10–15 percent slope) should be hydroseeded if access is possible. Some remote or very large areas may be aerially seeded.

3.2.1.2 Timing and Season for Planting

Unless supplemental irrigation is planned, seeding and transplanting should take place no earlier than October and no later than February; the preferred window is from mid-November to early February. The planting window can be extended at small sites by regular irrigation (water truck or some other means).

3.2.1.3 Habitat Enhancement Considerations

If the purpose of the action is habitat enhancement and the site has a relatively intact native grass overstory, bitterbrush transplants should be planted at a rate of approximately 400 to 500 plants/ac, augmented with 100 to 200 plants/ac/species of at least four forb species, if total existing forb cover is less than five percent.

3.2.1.4 Recommended Site Preparation Actions

3.2.1.4.1 Site Recontouring

If the site has been heavily disturbed, the site may be recontoured to blend aesthetically with the surrounding topography. However, site grading and contouring should be performed to have minimal or no effect on surrounding areas otherwise not disturbed by the remediation and restoration action.

3.2.1.4.2 Soil Preparation

- If possible, stockpile clean fine-grained soil prior to site remediation. Soils directly overlying remediation zones may not be suitable for stockpiling. However, adjacent soils within support and staging areas should be stockpiled. Spread the stockpiled material over the site after final grading or contouring, and prior to seeding.
- If surface is compacted, loosen using a plow, ripper, or disk.
- After seeding, clean certified weed-free straw (preferably native grass) should be applied at a rate of 1 to 3 ton/ac followed by crimping.

3.2.1.4.3 Fertilization

In most cases, fertilizer applications are not recommended, since the straw will provide organic matter.

3.2.1.4.4 Weed Control

- If the site is freshly graded or recontoured, weed control is probably not needed.
- If noxious weeds or significant populations of Russian thistle or other weeds are present on the site, consult Hanford Site Biological Controls regarding spraying or weed control options.
- If the site is dominated by cheatgrass or other invasive species and sufficient time is available, work with the Hanford Site Biological Controls to spray the site with a glyphosate or other suitable herbicide in the spring before the cheatgrass seed sets and again in the fall after cheatgrass germination.

3.2.1.5 Site Maintenance

3.2.1.5.1 Weed Control

If desirable native forbs or shrubs are not present, then control invasive broadleaf weeds with a selective herbicide. If desirable forbs and/or shrubs are present, the herbicide application method or timing may need to be adjusted. Consult with Hanford Site Biological Controls to develop weed control strategy and schedule.

3.2.1.5.2 Herbivory Control

Young plants of some species of forbs and shrubs, such as spiny hopsage and antelope bitterbrush, are often targeted by herbivores. If herbivory is anticipated to be a significant problem, then use of herbivore protection, such as fencing or protective sleeves, should be considered. Protective sleeves shall be collected after no more than two years, and protective sleeves that become dislodged shall be picked up or replaced during routine site inspections. Some forb species are also likely to be targeted. Transplants should be monitored for the first season post-planting, and protective actions initiated if needed.

3.2.1.6 Site Monitoring and Success Criteria

Site monitoring should be conducted annually for at least five years after planting. If vegetation development after five years does not meet the minimum specifications provided in Table 3.5, additional actions, such as transplanting more shrubs or forbs, interseeding grasses, or repeating any or all of the original planting actions as appropriate, will be performed. Monitoring should indicate a steady progression toward the desired future conditions; however, the annual monitoring results may indicate the need for corrective action. The values provided for the first or second monitoring years are suggested benchmarks for comparison with early monitoring results that may help predict the likelihood of successful plant establishment. Alternatively, the measured values may be compared with similarly collected data from a nearby reference community.

Table 3.5. Sandy Soil Site Success Criteria for Restoration or Community Enhancement

Component	First or Second Year	Fifth Year	Desired Future Condition
Shrubs (transplanted)	75 percent survival	60 percent survival or 600 plants/ha (240/ac)	10–15 percent cover
Shrubs (seeded)	500 plants/ha (200/ac)	600 plants/ha (240/ac)	10–15 percent cover
Perennial grasses	10–20 plants/m^2 (1–2/ft^2)	10 percent cover	10–25 percent cover
Forbs/legumes (transplanted)	75 percent survival	60 percent survival	2–5 percent cover
Forbs/legumes (seeded)	2–5 plants/m^2 (0.2–0.5/ft^2)	2 plants/m^2 (0.2 /ft^2)	2–5 percent cover

Chapter 6 provides generic monitoring procedures that should be the basis for the site-specific monitoring plan. The number, shape, and size of monitoring plots may need to be adjusted based on the configuration of the restoration or enhancement site.

3.2.2 Sandy Loam or Loamy Sand Site Restoration Actions

These guidelines are designed for use at sites with sandy-loam or loamy-sand soils, shown as 'loams' in Figure 3.1, with the goal of site restoration or habitat enhancement. Loam soils are especially common in the northern half of Central Hanford. The natural vegetation on these soils is sagebrush steppe hopsage, which is an important shrub component in some areas.

3.2.2.1 Species and Planting Recommendations

Tables 3.6 and 3.7 provide lists of acceptable species for use in loam soils; an ecologist or revegetation specialist should be consulted regarding the species selection for specific revegetation or restoration projects. If not all species are available or appropriate for the specific site based on surrounding communities, then adjust the seeding rates of the other species to compensate. All seed should be locally derived or source-identified from a nearby location with similar climatic and soil conditions (preferably within 50 miles). If the supply of forbs is limited, the available material can be planted in clumps to form islands of diversity that can serve as a seed source that can expand through the rest of the revegetation area over time.

Table 3.6. Sandy Loam or Loamy Sand Sites Recommended Grass Species Mix and Seeding Rates for Plant Community Restoration or Enhancement

Species	Common Name	Drill Seed (lb PLS/ac)[a]	Broadcast (lb PLS/ac)	Hydroseed (lb PLS/ac)
Grasses				
Sandberg's bluegrass	*Poa secunda*	2.5	3.75	5
Indian ricegrass	*Achnatherum hymenoides*	2	3	4
Needle-and-thread grass	*Hesperostipa comata*	2	3	4
Prairie Junegrass	*Koeleria cristata*	0.25	0.375	0.5
Bottlebrush squirreltail	*Elymus elymoides*	1.25	1.825	2.5

(a) lb PLS/ac = pounds of pure live seed per acre

3.2.2.1.1 Selection of Planting Method

Use drill or broadcast and imprint for normal sites. Small sites maybe broadcast from an all-terrain vehicle with chain or harrow. At very small sites, hand-apply seed, and rake. Steep sites (more than 10–15 percent slope) should be hydroseeded if access is possible. Some remote or very large areas may be aerially seeded.

3.2.2.1.2 Timing and Season for Planting

Unless supplemental irrigation is planned, seeding and transplanting should take place no earlier than October and no later than February; the preferred window is from mid-November to early February. The planting window can be extended at small sites by regular irrigation (water truck or some other means).

3.2.2.1.3 Habitat Enhancement Considerations

If the purpose of the action is habitat enhancement and the site has a relatively intact native grass overstory; sagebrush transplants should be planted at approximately 400 plants/ac and 200 plants/ac of hopsage and/or green rabbitbrush, augmented with 100 to 200 plants/ac/species of at least four forb species if total existing forb cover is less than five percent.

3.2.2.2 Recommended Site Preparation Actions

3.2.2.2.1 Site Recontouring

If the site has been heavily disturbed, the site may be recontoured to blend aesthetically with the surrounding topography. However, site grading and contouring should be performed to have minimal or no effect on surrounding areas otherwise not disturbed by the remediation and restoration action.

Table 3.7. Sandy Loam or Loamy Sand Sites Recommended Shrub, Legume, and Forb Species for Plant Community Restoration or Enhancement

Common Name	Species	Comments
Shrubs		
Big sagebrush	*Artemisia tridentata*	Use sagebrush and a minimum of one other species; drill, broadcast, or hydroseed between 0.25 and 0.5 lb/ac/species up to a total of 1 lb/ac., or transplant seedlings up to 400 plants/ac/species up to a total of 600 plants/ac.
Spiny hopsage	*Grayia spinosa*	
Gray rabbitbrush	*Ericameria nauseosa*	
Green rabbitbrush	*Chrysothamnus viscidiflorus*	
Legumes		
Stalked-pod milkvetch	*Astragalus succumbens*	Use a minimum of one species of milkvetch; and plant seed at a minimum of 0.1 lb/ac or transplant seedlings at a minimum of 200 plants/ac.
Crouching milkvetch	*Astragalus sclerocarpus*	
Buckwheat milkvetch	*Astragalus caricinus*	
Forbs		
Carey's balsamroot	*Balsamorhiza careyana*	Select at least four species; and drill, broadcast, or hydroseed at a minimum rate of 0.1 lb/ac, or transplant seedlings at 100 to 200 plants/ac/species, for a total minimum of 600 plants/ac. A combination of seeding and transplant may be used. Forb species mix should match the surrounding vegetation and should include both early and mid-late successional species.
Munro's globemallow	*Sphaeralcea munroana*	
Long-leaf phlox	*Phlox longifolia*	
Threadleaf fleabane	*Erigeron filifolius*	
Hoary false-yarrow	*Chaenactis douglasii*	
Slender hawksbeard	*Crepis atribarba*	
Hoary aster	*Machaeranthera canescens*	
Threadleaf scorpionweed	*Phacelia linearis*	
Mariposa lily	*Calochorus macrocarpus*	
Yellowbell	*Frittellaria pudica*	
Pale eveningprimrose	*Oenothera pallida*	
Sand beardtongue	*Penstemon accuminatus*	
Yarrow	*Achillea millefolium*	
Cusion fleabane	*Erigeron poliospermus*	
Shaggy fleabane	*Erigeron pumilus*	
Upland larkspur	*Delphinium nuttallianum*	
Turpentine springparsley	*Pterexia terebinthina*	

3.2.2.2.2 Soil Preparation

- If possible, stockpile clean fine-grained soil prior to site remediation. Soils directly overlying remediation zones may not be suitable for stockpiling. However, adjacent soils within support and staging areas should be stockpiled. Spread the stockpiled material over the site after final grading or contouring, and prior to seeding.
- If surface is compacted, loosen using a plow, ripper, or disk.
- After seeding, clean certified weed-free straw (preferably native grass) should be applied at a rate of 1 to 3 ton/ac followed by crimping.

3.2.2.2.3 Fertilization

In most cases, fertilizer applications are not recommended, since the straw will provide organic matter.

3.2.2.2.4 Weed Control

- If the site is freshly graded or recontoured, weed control is probably not needed.

- If noxious weeds or significant populations of Russian thistle or other weeds are present on the site, consult Hanford Site Biological Controls regarding spraying or weed control options.
- If the site is dominated by cheatgrass or other invasive species and sufficient time is available, work with Site Biological Controls group to spray the site with a glyphosate or other suitable herbicide in spring before cheatgrass seed set and again after cheatgrass germination in the fall.

3.2.2.3 Site Maintenance

3.2.2.3.1 Weed Control

If desirable native forbs or shrubs are not present, then control invasive broadleaf weeds with a selective herbicide. If desirable forbs and/or shrubs are present, the herbicide application method or timing may need to be adjusted. Consult with Hanford Site Biological Controls to develop weed control strategy and schedule.

3.2.2.3.2 Herbivory Control

Young plants of some species of forbs and shrubs, such as spiny hopsage and antelope bitterbrush, are often targeted by herbivores. If herbivory is anticipated to be a significant problem, then use of herbivore protection, such as fencing or protective sleeves, should be considered. Protective sleeves shall be collected after no more than two years, and protective sleeves that become dislodged shall be picked up or replaced during routine site inspections. Some forb species are also likely to be targeted. Transplants should be monitored for the first season post-planting, and protective actions initiated if needed.

3.2.2.4 Site Monitoring and Success Criteria

Site monitoring should be conducted annually for at least five years after planting. If vegetation development after five years does not meet the minimum specifications provided in Table 3.8, additional actions, such as transplanting more shrubs or forbs, interseeding grasses, or repeating any or all of the original planting actions as appropriate, will be performed. Monitoring should indicate a steady progression toward the desired future conditions; however, the annual monitoring results may indicate the need for corrective action. The values provided for the first or second monitoring years are suggested benchmarks for comparison with early monitoring results that may help predict the likelihood of successful plant establishment. Alternatively, the measured values may be compared with similarly collected data from a nearby reference community.

Chapter 6 provides generic monitoring procedures that should be the basis for the site-specific monitoring plan. The number, shape, and size of monitoring plots may need to be adjusted based on the configuration of the stabilization site.

Table 3.8. Sandy Loam or Loamy Sand Sites Success Criteria for Restoration or Community Enhancement

Component	First or Second Year	Fifth Year	Desired Future Condition
Shrubs (transplanted)	75 percent survival	60 percent survival or 600 plants/ha (240/ac)	10–15 percent cover
Shrubs (seeded)	500 plants/ha (200/ac)	600 plants/ha (240/ac)	10–15 percent cover
Perennial grasses	10–20 plants/m^2 (1–2/ft^2)	10 percent cover	15–25 percent cover
Forbs/legumes (transplanted)	75 percent survival	60 percent survival	2–5 percent cover
Forbs/legumes (seeded)	2–5 plants/m^2 (0.2–0.5/ft^2)	2 plants/m^2 (0.2 /ft^2)	2–5 percent cover

3.2.3 Silt Loam Soil Restoration or Enhancement

These guidelines are designed for use in sites with silt loam soils, as shown in Figure 3.1, with the goal of site restoration or habitat enhancement. Silt loam soils are the most common type of soil on the Arid Lands Ecology Reserve, McGee Ranch, Umtanum Ridge, Gable Mountain, and portions of Gable Butte. However, long-term protective barriers may also have silt soil surface layers. Plant communities on most native silt loam sites are dominated by big sagebrush and bluebunch wheatgrass, although there are many variants (PNNL-13688).

3.2.3.1 Species and Planting Recommendations

Tables 3.9 and 3.10 provide lists of acceptable species for use in silt loam soils; an ecologist or revegetation specialist should be consulted regarding the species selection for specific revegetation or restoration projects. If not all species are available or appropriate based on surrounding plant community, then adjust the seeding rates of other species to compensate. In most native areas, bluebunch wheatgrass and Sandberg's bluegrass are the most important species to include. For lowland protective barriers, consider dropping Idaho fescue, Thurber's needlegrass, and Cusick's bluegrass and adding needle-and-thread grass (*Hesperostipa comata*) at rates of up to 3 lb/ac (drill) or 4.5 lb/ac (broadcast). All seed should be locally derived or source-identified from a nearby location with similar climatic and soil conditions (preferably within 50 miles). If the supply of forbs is limited, the available material can be planted in clumps to form islands of diversity that can serve as a seed source that can expand through the rest of the revegetation area over time.

Table 3.9. Silt Loam Soil Sites Grass Species Mix and Seeding Rates for Restoration or Enhancement

Species	Common Name	Drill Seed (lb PLS/ac)(a)	Broadcast (lb PLS/ac)	Hydroseed (lb PLS/ac)
Bluebunch wheatgrass	*Pseudoroegneria spicata*	5	7.5	10
Sandberg's bluegrass	*Poa secunda*	2	3	4
Idaho fescue	*Festuca idahoensis*	0.5	0.75	1
Thurber's needlegrass	*Achnatherum thurberianum*	1	1.5	2
Cusick's bluegrass	*Poa cusickii*	0.5	0.75	1

(a) lb PLS/ac = pounds of pure live seed per acre.

Table 3.10. Silt Loam Soil Sites Recommended Shrub, Legume, and Forb Species for Restoration or Enhancement

Common Name	Species	Comments
Shrubs		
Big sagebrush	*Artemisia tridentata*	Select one or more species to match the surrounding vegetation; and drill, broadcast, or hydroseed between 0.25-0.5 lb/ac, or transplant 500 plants/ac.
Threetip sage	*Artemisia tripartita*	
Winterfat	*Krascheninnikovia lanata*	
Legumes		
Lupine	*Lupinus sp.*	Drill, broadcast, or hydroseed at a minimum of 0.1 lb/ac. Use locally collected or derived lupine seed; or transplant seedlings at 100 plants/ac.
Forbs		
Cusick's sunflower	*Helianthus cusickii*	Select at least four species; and drill, broadcast, or hydroseed between 0.1 to 0.25 lb/ac, or transplant seedlings at 100 to 200 plants/ac/species, for a total minimum of 600 plants/ac. A combination of seeding and transplant may be used. Forb species mix should match the surrounding vegetation and should include both early and mid-late successional species. Other species may be appropriate based on surrounding plant community
Carey's balsamroot	*Balsamorhiza careyana*	
Piper's daisy	*Erigeron piperianus*	
Western gromwell	*Lithospermum ruderale*	
Munro's globemallow	*Sphaeralcea munroana*	
Slender hawksbeard	*Crepis atribarba*	

3.2.3.1.1 Selection of Planting Method

Use drill or broadcast and imprint for normal sites. Small sites maybe broadcast from an all-terrain vehicle with chain or harrow. At very small sites, hand-apply seed, and rake. Steep sites (more than 10–15 percent slope) should be hydroseeded if access is possible. Some remote or very large areas may be aerially seeded.

3.2.3.1.2 Timing and Season for Planting

Unless supplemental irrigation is planned, seeding and transplanting should take place no earlier than October and no later than February; the preferred window is from mid-November to early February. The planting window can be extended at small sites by regular irrigation (water truck or some other means).

3.2.3.1.3 Habitat Enhancement Considerations

If the purpose of the action is habitat enhancement and the site has a relatively intact native grass overstory, shrub transplants should be planted at approximately 500 plants/ac, augmented with 100 to 200 plants/ac/species of at least four forb species if total existing forb cover is less than five percent.

3.2.3.2 Site Preparation Actions

3.2.3.2.1 Site Recontouring

If the site has been heavily disturbed, the site may be recontoured to blend aesthetically with the surrounding topography. However, site grading and contouring should be performed to have minimal or no effect on surrounding areas otherwise not disturbed by the remediation and restoration action.

3.2.3.2.2 Soil Preparation

- If possible, stockpile clean fine-grained soil prior to site remediation. Soils directly overlying remediation zones may not be suitable for stockpiling. However, adjacent soils within support and staging areas should be stockpiled. Spread the stockpiled material over the site after final grading or contouring, and prior to seeding.
- If surface is compacted, loosen using a plow, ripper, or disk.
- After seeding, clean certified weed-free straw (preferably native grass) should be applied at a rate of 1 to 3 ton/ac followed by crimping.

3.2.3.2.3 Fertilization

In most cases, fertilizer applications are not recommended, since the straw will provide organic matter.

3.2.3.2.4 Weed Control

- If the site is freshly graded or recontoured, weed control is probably not needed.
- If noxious weeds or significant populations of Russian thistle or other weeds are present on the site, consult Hanford Site Biological Controls regarding spraying or weed control options.
- If the site is dominated by cheatgrass or other invasive species and sufficient time is available, work with Site Biological Control group to spray the site with a glyphosate or other suitable herbicide in spring before cheatgrass seed set and again after cheatgrass germination in the fall.

3.2.3.3 Site Maintenance

3.2.3.3.1 Weed Control

If native desirable forbs or shrubs are not present, then control invasive broadleaf weeds with a selective herbicide. If desirable forbs and/or shrubs are present, the herbicide application method or timing may need to be adjusted. Consult with Hanford Site Biological Controls to develop weed control strategy and schedule.

3.2.3.3.2 Herbivory Control

Young plants of some species of forbs and shrubs, such as spiny hopsage and antelope bitterbrush, are often targeted by herbivores. If herbivory is anticipated to be a significant problem, then use of herbivore protection, such as fencing or protective sleeves, should be considered. Protective sleeves shall be collected after no more than two years, and protective sleeves that become dislodged shall be picked up or replaced during routine site inspections. Some forb species are also likely to be targeted. Transplants should be monitored for the first season post-planting, and protective actions initiated if needed.

3.2.3.4 Site Monitoring and Success Criteria

Site monitoring should be conducted annually for at least five years after planting. If vegetation development after five years does not meet the minimum specifications provided in Table 3.11, additional actions, such as transplanting more shrubs or forbs, interseeding grasses, or repeating any or all of the original planting actions, as appropriate, will be performed. Monitoring should indicate a steady progression toward the desired future conditions; however, the annual monitoring results may indicate the need for corrective action. The values provided for the first or second monitoring years are suggested benchmarks for comparison with early monitoring results that may help predict the likelihood of successful plant establishment. Alternatively, the measured values may be compared with similarly collected data from a nearby reference community.

Chapter 6 provides generic monitoring procedures that should be the basis for the site-specific monitoring plan. The number, shape, and size of monitoring plots may need to be adjusted based on the configuration of the restoration or enhancement site.

Table 3.11. Silt Loam Soil Sites Success Criteria for Restoration or Community Enhancement

Component	First or Second Year	Fifth Year	Desired Future Condition
Shrubs (transplanted)	75 percent survival	60 percent survival or 600 plants/ha (240/ac)	10–15 percent cover
Shrubs (seeded)	500 plants/ha (200/ac)	600 plants/ha (240/ac)	10–15 percent cover
Perennial grasses	10–20 plants/m^2 (1–2/ft^2)	10 percent cover	35–50 percent cover
Forbs/legumes (transplanted)	75 percent survival	60 percent survival	2–5 percent cover
Forbs/legumes (seeded)	2–5 plants/m^2 (0.2–0.5/ft^2)	2 plants/m^2 (0.2 /ft^2)	2–5 percent cover

3.2.4 Mixed or Cobble Backfill Restoration

These guidelines are designed for restoration sites that have been backfilled with pit-run or mixed-cobble backfill. In general, the soil substrate at these sites does not closely resemble any native soil/vegetation systems on the Hanford Site, although some 50 to 60 year old, naturally revegetated disturbed areas may be analogs.

3.2.4.1 Species and Planting Recommendations

Tables 3.12 and 3.13 provide acceptable species for use in backfill or cobble substrates; an ecologist or revegetation specialist should be consulted regarding species selection for specific revegetation or restoration projects. If not all species are available, then adjust the seeding rates of the other species to compensate. Other species such as thickspike wheatgrass, needle-and-thread grass, Indian ricegrass, or even bluebunch wheatgrass may be appropriate and useful substitutes in some cases. All seed should be locally derived or source-identified from a nearby location with similar climatic and soil conditions (preferably within 50 miles). If the supply of forbs is limited, the available material can be planted in clumps to form islands of diversity that can serve as a seed source that can expand through the rest of the revegetation area over time.

3.2.4.1.1 Selection of Planting Method

In backfill with considerable cobble content drill seeding will be difficult or impractical. Use broadcast or hydroseed on cobble covered sites. Small sites may be broadcast from all-terrain vehicle with dragged chain. At very small sites, hand-apply seed, and rake. Steep sites (more than 1-15 percent slope) should be hydroseeded.

Table 3.12. Mixed or Cobble Backfill Substrate Restoration Sites Recommended Grass Species Mix and Seeding Rates

Species	Common Name	Drill Seed (lb PLS/ac)[a]	Broadcast (lb PLS/ac)	Hydroseed (lb PLS/ac)
Sandberg's bluegrass	Poa secunda	4–8	5–10	7–12
Sand dropseed	Sporobolus cryptandrus	0.25	0.5	0.75
Bottlebrush squirreltail	Elymus elymoides	2–4	3–5	4–6

(a) lb PLS/ac = pounds of pure live seed per acre.

Table 3.13. Mixed or Cobble Backfill Substrate Restoration Sites Recommended Shrub, Legume, and Forb Species

Common Name	Species	Comments
Shrubs		
Big sagebrush	*Artemisia tridentata*	Use sagebrush and a minimum of two other species, and drill, broadcast, or hydroseed between 0.1 to 0.25 lb/ac/species for a total of 0.5 lb/ac, or transplant seedlings at 400 plants/ac big sagebrush, and 100 plants/ac each with a minimum of two, of the other species. A combination of seeding and transplant can be used.
Spiny hopsage	*Grayia spinosa*	
Antelope bitterbrush	*Purshia tridentata*	
Gray rabbitbrush	*Ericameria nauseosa*	
Green rabbitbrush	*Chrysothamnus viscidiflorus*	
Legumes		
buckwheat milkvetch	*Astragalus caricinus*	Select one or more species, drill, broadcast, or hydroseed at a total rate of 0.1 lb/ac, or transplant seedlings at a total minimum of 100 plants/ac.
Stalked-pod milkvetch	*Astragalus sclerocarpus*	
Crouching milkvetch	*Astragalus succumbens*	
Forbs		
Munro's globemallow	*Sphaeralcea munroana*	Select at least four species, and broadcast between 0.1 lb/ac to 0.25 lb/ac, or transplant seedlings at 100 plants/ac/species, for a total minimum of 400 plants/ac. A combination of seeding and transplant may be used. Forb species mix should match the surrounding vegetation and should include both early and mid-late successional species.
Carey's balsamroot	*Balsamorhiza careyana*	
Cusion fleabane	*Erigeron poliospermus*	
Shaggy fleabane	*Erigeron pumilus*	
Piper's daisy	*Erigeron piperianus*	
Hoary aster	*Machaeranthera canescens*	
Pale eveningprimrose	*Oenothera pallida*	
Yarrow	*Achillea millefolium*	
Slender hawksbeard	*Crepis atribarba*	
Turpentine springparsley	*Pterexia terebinthina*	

3.2.4.1.2 Timing and Season for Planting

Unless supplemental irrigation is planned, seeding and transplanting should take place no earlier than October and no later than February; the preferred window is from mid-November to early February. The planting window can be extended at small sites by regular irrigation (water truck or some other means).

3.2.4.1.3 Habitat Enhancement Considerations

Cobble or backfill sites are not likely candidates for habitat enhancement.

3.2.4.2 Recommended Site Preparation Actions

3.2.4.2.1 Site Recontouring

Upon completion of the waste site remediation or facility demolition, the site should be recontoured to blend aesthetically with the surrounding topography. Care should be taken to avoid impacts to surrounding areas.

3.2.4.2.2 Soil Preparation

- If possible, stockpile fine-grained soil prior to site remediation. Soils directly overlying remediation zones may not be suitable for stockpiling. However, adjacent soils within support and staging areas should be stockpiled. Spread stockpiled material over site after final grading or contouring and prior to seeding. If backfill is imported from a borrow site, mix the stockpiled fine-grained soil with the upper one foot of backfill material.
- Backfill should be selected, if possible, to have similar properties as the area surrounding the remediation or decommissioning site. If the backfill material has very little sand or other finer material, blend with sand or silt from a separate borrow source for the upper one foot of fill, if feasible. This should not be pursued if it would create additional revegetation problems elsewhere.
- If surface is compacted, loosen using a plow, ripper, or disk.
- After seeding, clean certified weed-free straw (preferably native grass) should be applied at a rate of 1 to 3 ton/ac followed by crimping.

3.2.4.2.3 Fertilization

If the substrate consists of very coarse backfill with very little organic matter, small amounts of slow-release fertilizer may be applied not to exceed a rate of 20 lb N/ac.

3.2.4.2.4 Weed Control

- Weed control on a freshly backfilled site is probably not needed but may be needed if the site has been idle for one or more years or if the original revegetation actions was unsuccessful.
- If noxious weeds or significant populations of Russian thistle or other weeds are present on the site, consult Hanford Site Biological Controls regarding spraying or weed control options.
- If the site is dominated by cheatgrass or other invasive species and sufficient time is available, work with Site Biological Controls group to spray the site with a glyphosate or other suitable herbicide in spring before cheatgrass seed set and again after cheatgrass germination in the fall.

3.2.4.3 Site Maintenance

3.2.4.3.1 Weed Control

If native desirable forbs or shrubs are not present, then control invasive broad leafweeds with a selective herbicide. If desirable forbs, and/or shrubs are present, the herbicide application method or timing may need to be adjusted, such as hand application to undesirable species. Consult with Hanford Site Biological Controls to develop weed control strategy and schedule.

3.2.4.3.2 Herbivory Control

Young plants of some species of forbs and shrubs, such as spiny hopsage and antelope bitterbrush, are often targeted by herbivores. If herbivory is anticipated to be a significant problem, then use of herbivore protection, such as fencing or protective sleeves, should be considered. Protective sleeves shall be collected after no more than two years, and protective sleeves that become dislodged shall be picked up or replaced during routine site inspections. Some forb species are also likely to be targeted. Transplants should be monitored for the first season post-planting, and protective actions initiated if needed.

3.2.4.4 Site Monitoring and Success Criteria

Site monitoring should be conducted annually for at least five years after planting. If vegetation development after five years does not meet the minimum specifications provided in Table 3.14, additional actions, such as planting more transplant shrubs or forbs, interseeding grasses, or repeating any or all of the original planting actions as appropriate, will be performed. Monitoring should indicate a steady progression toward the desired future conditions; however, the annual monitoring results may indicate the need for corrective action.

The values provided for the first or second monitoring years are suggested benchmarks for comparison with early monitoring results that may help predict the likelihood of successful plant establishment. Alternatively, the measured values may be compared with similarly collected data from a nearby reference community.

Chapter 6 provides generic monitoring procedures that should be the basis for the site-specific monitoring plan. The number, shape, and size of monitoring plots may need to be adjusted based on the configuration of the restoration site.

Table 3.14. Mixed Cobble and Backfill Soil Revegetation Success Criteria

Component	First or Second Year	Fifth Year	Desired Future Condition
Shrubs (transplanted)	75 percent survival	60 percent survival or 600 plants/ha (240/ac)	10–15 percent cover
Shrubs (seeded)	500 plants/ha (200/ac)	600 plants/ha (240/ac)	10–15 percent cover
Perennial grasses	10–20 plants/m^2 (1–2/ft^2)	10 percent cover	10–25 percent cover
Forbs/legumes (transplanted)	75 percent survival	60 percent survival	2–5 percent cover
Forbs/legumes (seeded)	2–5 plants/m^2 (0.2–0.5/ft^2)	2 plants/m^2 (0.2 /ft^2)	2–5 percent cover

3.2.5 Lithosol Sites Restoration

These guidelines are designed for restoration of sites with thin, very rocky soils, i.e., lithosols. Most lithosols on the Hanford Site are located on top of the major mountains and ridges, have more extreme climatic conditions than elsewhere on the site, and generally support relatively sparse, low-growing plant communities.

3.2.5.1 Species and Planting Recommendations

Table 3.15 provides acceptable species for use at lithosol sites; an ecologist or revegetation specialist should be consulted regarding species selection for specific revegetation or restoration projects. If the supply of forbs is limited, the available material can be planted in clumps to form islands of diversity that can serve as a seed source, to expand through the rest of the revegetation area over time.

3.2.5.1.1 Grasses

Seeding rates are higher for lithosol sites than for other substrate types. In some areas, Idaho fescue may be an appropriate addition to the seed mix.

3.2.5.1.2 Shrubs

Plant seed of two or more species listed in Table 3.15 at recommended rates; species choice depends on the surrounding plant community. Because of the coarse rocky substrate, transplanting shrubs is problematic and will not always be possible. If conditions allow, transplant some or all of the selected shrub species at a minimum rate of 600 plants/ac/species.

Forbs

Select at least four species from Table 3.15; must have a total minimum of 0.25 lb/ac broadcast. Because of the rocky nature of the substrate, transplanting may be difficult or may not be possible. If conditions allow, transplant some or all of the selected species at a rate of 200 plants/ac. Forb species mix should reflect surrounding community.

Table 3.15. Lithosol Sites Recommended Species Mix and Seeding Rates

Common Name	Species	Comments
Grasses		
Sandberg's bluegrass	*Poa secunda*	6 to 10 lb PLS/ac broadcast or hydroseed
Bluebunch wheatgrass	*Pseudoroegneria spicata*	6 to 10 lb PLS/ac broadcast or hydroseed
Shrubs		
Rock buckwheat	*Eriogonum sphaerocephalum*	Select at least two species that match the surrounding vegetation, and broadcast or hydroseed seed at a total rate of 0.5 to 1.0 lb/ac. If conditions allow, transplant some or all of the selected shrub species at a minimum rate of 200 plants/ac/species for a total minimum of 600 plants/ac.
Thyme buckwheat	*Eriogonum thymoides*	
Green rabbitbrush	*Chrysothamnus viscidiflorus*	
Purple sage	*Salvia dorrii*	
Stiff sagebrush	*Artemisia rigida*	
Forbs		
Gray's desert parsley	*Lomatium grayi*	Select at least four species that match the surrounding vegetation, and broadcast at a total rate of 0.25 lb/ac. Higher rates increase the potential for success. If conditions allow, transplant some or all of the selected species at a rate of 200 plants/ac.
Big-seed desert parsley	*Lomatium macrocarpum*	
Low hawksbeard	*Crepis modocensis*	
Cusion fleabane	*Erigeron poliospermus*	
White scorpionweed	*Phacelia hastata*	
Daggerpod	*Phoenicaulis cheiranthoides*	
Rosy balsamroot	*Balsamorhiza rosea*	
Bitterroot	*Lewisia rediviva*	

3.2.5.1.3 Selection of Planting Method

Drill seeding or imprinting are not likely to be effective in lithosols. Broadcast methods should be used; hydroseeding (without a hydromulch) offers the advantage of washing seeds into safe sites where they are protected from wind, predation, and have better soil contact. Steep sites (more than 10-15 percent slope) should be hydroseeded. Hydromulch can be applied after hydroseeding to provide erosion protection.

3.2.5.1.4 Timing and Season for Planting

Unless supplemental irrigation is planned, seeding and transplanting should take place no earlier than October and no later than February; the preferred window is from mid-November to early February. The planting window can be extended at small sites by regular irrigation (water truck or some other means).

3.2.5.1.5 Habitat Enhancement Considerations

Lithsol sites generally are not likely candidates for habitat enhancement. However, some sites could be hydroseeded to increase grass, shrub, or forb cover and/or species diversity.

3.2.5.2 Recommended Site Preparation Actions

3.2.5.2.1 Site Recontouring

Upon completion of the waste site remediation or facility demolition, the site should be recontoured to blend aesthetically with the surrounding topography.

Care should be taken to avoid impacts to surrounding areas.

3.2.5.2.2 Soil Preparation

- The final surface should resemble the natural lithosols surrounding the revegetation site. Therefore, the final surface should be very rocky; appropriately, sized basalt can be imported if needed.
- If possible, small amounts of stockpiled fine-grained soil can be mixed with upper layers of rocky backfill or applied with hydromulch equipment.
- After seeding, apply clean certified weed-free straw at a rate of 1 to 3 ton/ac followed by a tackifier, or apply hydromulch.

3.2.5.2.3 Fertilization

If the substrate consists of very coarse backfill with very little organic matter, apply small amounts of slow-release fertilizer at a rate not to exceed 20 lb N/ac.

3.2.5.2.4 Weed Control

- Weed control on a freshly backfilled site is probably not needed but may be needed if the site has been idle for one or more years or if the original revegetation actions was unsuccessful.
- If noxious weeds or significant populations of Russian thistle or other weeds are present on the site, consult Hanford Site Biological Controls regarding spraying or weed control options.
- If the site is dominated by cheatgrass or other invasive species and sufficient time is available, work with Site Biological Controls group to spray the site with a glyphosate or other suitable herbicide in spring before cheatgrass seed set and again after cheatgrass germination in the fall.

3.2.5.3 Site Maintenance

3.2.5.3.1 Weed Control

If native desirable forbs or shrubs are not present, then control invasive broadleaf weeds with a selective herbicide. If desirable forbs, and/or shrubs are present, the herbicide application method or timing may need to be adjusted, such as hand application to undesirable species. Consult with Hanford Site Biological Controls to develop weed control strategy and schedule.

3.2.5.3.2 Herbivory Control

Herbivory control is difficult in the extreme (i.e., very windy) environments found at lithosol sites.

3.2.5.4 Site Monitoring and Success Criteria

Site monitoring should be conducted annually for at least five years after planting. If vegetation development after five years does not meet the minimum specifications provided in Table 3.16, additional actions, such as transplanting more shrubs or forbs, interseeding grasses, or repeating any or all of the original planting actions as appropriate, will be performed. Monitoring should indicate a steady progression toward the desired future conditions; however, the annual monitoring results may indicate the need for corrective action. The values provided for the first or second monitoring years are suggested benchmarks for comparison with early monitoring results that may help predict the likelihood of successful plant establishment. Alternatively, the measured values may be compared with similarly collected data from a nearby reference community.

Chapter 6 provides generic monitoring procedures that should be the basis for the site-specific monitoring plan. The number, shape, and size of monitoring plots may need to be adjusted based on the configuration of the restoration site.

Table 3.16. Lithosols Revegetation Success Criteria

Component	First or Second Year	Fifth Year	Desired Future Condition
Shrubs (transplanted)	75 percent survival	50 percent survival or 600 plants/ha (240/ac)	10–15 percent cover
Shrubs (seeded)	500 plants/ha (200/ac)	600 plants/ha (240/ac)	10–15 percent cover
Perennial grasses	10–20 plants/m^2 (1–2/ft^2)	10 percent cover	25–40 percent cover
Forbs/legumes (transplanted)	75 percent survival	50 percent survival	15–30 percent cover
Forbs/legumes (seeded)	2–5 plants/m^2 (0.2–0.5/ft^2)	10 percent cover	15–30 percent cover

3.2.6 Wetlands or Riparian Site Species Restoration

Generic guidelines for the restoration or enhancement of wetland or riparian sites are not provided here for several reasons:

- The actions requiring such restoration are likely to be relatively few in number but highly variable in site conditions and restoration needs
- Many sites along the Columbia River are relatively steep and quickly change from upland through riparian to wetland situations in a matter of meters, requiring more careful consideration of topography, soils, vegetation, and limiting conditions than can be provided in generic guidelines
- Many sites along the Columbia River will likely be under additional permitting and agency review because of salmon, steelhead, or bull trout critical habitat considerations or *Clean Water Act* Section 404 permits
- Restoration work at non-Columbia River wetland or riparian sites on the Hanford Site would be highly variable, with site-specific conditions and needs

A list of native plant species for use in the restoration or enhancement of wetland or riparian sites on the Hanford Site is provided in Table 3.17. The mix of species, planting rates, types of plant material, planting methods, spatial distribution, site preparation, erosion protection, and other considerations must be developed on a site-specific basis and will require input from a revegetation specialist or restoration ecologist.

3.2.7 Long-Term Interim Stabilization

These guidelines are designed for the long-term stabilization sites that that will be either re-disturbed or replanted later. Interim stabilization sites may have sand, sandy-loam, silt loam, or backfill substrates.

3.2.7.1 Species and Planting Recommendations

Table 3.18 provides a list of acceptable species for use in interim stabilization in different soil types; an ecologist or revegetation specialist should be consulted regarding species selection for a specific revegetation or restoration project.

Table 3.17. Wetland or Riparian Site Recommended Species for Restoration or Enhancement

Common Name	Species	Common Name	Species
Trees and Shrubs		**Grasses, Sedges, and Rushes**	
Peach-leaf willow	*Salix amygdaloides*	Sedges	*Carex* sp.
Coyote willow	*Salix exigua*	Spikerushs	*Eleocharis* sp.
Black cottonwood	*Populus trichocarpa*	Bulrushs	*Schoenoplectus (Scirpus)* sp.
Wood's rose	*Rosa woodsii*	Rushs	*Juncus* sp.
Golden currant	*Ribes aureum*	Thickspike wheatgrass	*Elymus lanceolatus*
Red-osier dogwood	*Cornus stolonifera*	Fowl bluegrass	*Poa palustris*
Chokecherry	*Prunus virginiana*	Canada bluegrass	*Poa compressa*
Blue elderberry	*Sambucus cerulea*	Ticklegrass	*Agrostis scabra*
		Red three-awn	*Aristida longiseta*
		Sand dropseed	*Sporobolus cryptandrus*
Forbs			
Common dogbane	*Apocynum cannabinum*	Western goldenrod	*Euthamia occidentalis*
Pacific sagebrush	*Artemisia campestris*	Sneezeweed	*Helenium autumnale*
Prairie sagebrush	*Artemisia ludoviciana* (includes *A. lindleyana*)	Columbia River gumweed	*Grindelia columbiana*
Western meadow aster	*Symphyotrichum (Aster) campestre*	Yellowcress sp.	*Rorippa* sp.
Western marsh aster	*Symphyotrichum (Aster) hesperium*	Chives	*Allium schoenoprasum*
Hairy golden aster	*Heterotheca villosa*	Water speedwell	*Veronica anagallis-aquatica*
Common tickseed	*Coreopsis tinctoria var atkinsoniana*	Blue verbena	*Verbena hastata*
Blanket flower	*Gaillardia aristata*		

Table 3.18. Long-Term Interim Stabilization Recommended Species Mix and Seeding Rates

Common Name	Species	Drill Seed (lb PLS/ac)	Broadcast (lb PLS/ac)	Hydroseed (lb PLS/ac)
Backfill Sites				
Sandberg's bluegrass	*Poa secunda*	4	6	8
Indian ricegrass	*Achnatherum hymenoides*	3	4.5	6
Gray rabbitbrush	*Ericameria nauseosa*	0.25	0.35	0.5
Sandy Loam Sites				
Sandberg's bluegrass	*Poa secunda*	4	6	8
Indian ricegrass	*Achnatherum hymenoides*	3	4.5	6
Gray rabbitbrush	*Ericameria nauseosa*	0.25	0.35	0.5
Sandy Sites				
Indian ricegrass	*Achnatherum hymenoides*	6	9	12
Thickspike wheatgrass	*Elymus lanceolatus*	6	9	12
Green rabbitbrush	*Chrysothamnus viscidiflorus*	0.25	0.35	0.5
Silt Loam Sites				
Sandberg's bluegrass	*Poa secunda*	3	4.5	6
Bluebunch wheatgrass	*Pseudoroegneria spicata*	6	9	12

3.2.7.1.1 Grasses

In most cases, bottlebrush squirreltail can also be added at up to 2.5 lbs/ac. If it is known that the site will be idle for more than five years, locally derived or source-identified seed from a nearby location with similar climatic and soil conditions should be used (preferably within 50 miles). If the site is to be stabilized for a short time and it is certain that the vegetation will be removed later, the following commercial cultivars of native species may be used:

- Sandberg's bluegrass – Sherman's big blue or Canbar
- Indian ricegrass – NezPar
- Thickspike wheatgrass – Bannock, Schwendimar, or Critana, depending on soil conditions
- Bluebunch wheatgrass – use locally derived seed. (Note: although sold as *bluebunch wheatgrass*, the SECAR cultivar should not be used at Hanford because it derived from a different species—*Elymus wawawaiensis*—that is not found on the Hanford Site).

3.2.7.1.2 Shrubs

Rabbitbrush may be added if site will be dormant for more than five years; however, shrubs are not appropriate on interim stabilized waste sites. Plant seed at recommended rates or transplant 200 plants/ac.

3.2.7.1.3 Selection of Planting Method

Drill seeding will be difficult or impractical in backfill with considerable cobble content. Use broadcast or hydroseed on cobble-covered sites. Small sites may be broadcast from an all-terrain vehicle with dragged chain. At very small sites, hand-apply seed, and rake. Steep sites (more than 10–15 percent slope) should be hydroseeded if access is possible.

3.2.7.1.4 Timing and Season for Planting

Unless supplemental irrigation is planned, seeding and transplanting should take place no earlier than October and no later than February; the preferred window is from mid-November to early February. The planting window can be extended at small sites by regular irrigation (water truck or some other means).

3.2.7.1.5 Habitat Enhancement Considerations

Interim stabilization is not performed for habitat enhancement.

3.2.7.2 Recommended Site Preparation Procedures

3.2.7.2.1 Site Recontouring

Upon completion of the waste site remediation or facility demolition, the site should be recontoured to blend aesthetically with the surrounding topography. Care should be taken to avoid impacts to surrounding areas.

3.2.7.2.2 Soil Preparation

- If possible, stockpile clean fine-grained soil prior to site remediation. Soils directly overlying remediation zones may not be suitable for stockpiling. However, adjacent soils within support and staging areas should be stockpiled. Spread the stockpiled material over the site after final grading, or contouring and prior to seeding.
- If the primary backfill material has very little sand or other finer material, consider blending with sand or silt from a separate source for the upper one foot of fill. This is not advised if it would create additional revegetation concerns elsewhere.
- If surface is compacted, loosen using a plow, ripper, or disk.
- After seeding, clean certified weed-free straw (preferably native grass) should be applied at a rate of 1 to 3 ton/ac followed by crimping.

3.2.7.2.3 Fertilization

If the substrate consists of very coarse backfill with very little organic matter, apply small amounts of slow-release fertilizer at a rate not to exceed 20 lb N/ac.

3.2.7.2.4 Weed Control

Weed control on a freshly backfilled site is probably not needed but may be needed if the site has been idle for one or more years or if the original revegetation actions was unsuccessful.

If noxious weeds or significant populations of Russian thistle or other weeds are present on the site, consult Hanford Site Biological Controls regarding spraying or weed control options.

If the site is dominated by cheatgrass or other invasive species and sufficient time is available, work with Biological Controls group to spray the site with a glyphosate or other suitable herbicide in spring before cheatgrass seed set and again after cheatgrass germination in the fall.

3.2.7.3 Site Maintenance

3.2.7.3.1 Weed Control

If native forbs or shrubs are not present, then control invasive broadleaf weeds with a selective herbicide. If desirable forbs, and/or shrubs are present, herbicide application method or timing may need to be adjusted (i.e., hand application for undesirable species). Consult with Hanford Site Biological Controls to develop weed control strategy and schedule.

3.2.7.3.2 Herbivory Control

Herbivory control is not likely to be needed at interim stabilization sites. In some cases, fencing may be used to exclude large herbivores.

3.2.7.4 Site Monitoring and Success Criteria

Site monitoring should be conducted annually for at least five years after planting. If vegetation development after five years does not meet the minimum specifications provided in Table 3.19, additional actions such as transplanting more shrubs or forbs, interseeding grasses, or repeating any or all of the original planting actions as appropriate will be performed. Monitoring should indicate a steady progression toward the desired future conditions; however, the annual monitoring results may indicate the need for corrective action. The values provided for the first or second monitoring years are suggested benchmarks for comparison with early monitoring results that may help predict the likelihood of successful plant establishment.

Chapter 6 provides generic monitoring procedures that should be the basis for the site-specific monitoring plan. The number, shape, and size of monitoring plots may need to be adjusted based on the configuration of the stabilization site.

Table 3.19. Interim Stabilization Action Success Criteria

Component	First or Second Year	Fifth Year	Desired Future Condition
Shrubs (transplanted)	75 percent survival	60 percent survival or 600/ha (240/ac)	10–15 percent cover
Shrubs (seeded)	500 plants/ha (200/ac)	600 plants/ha (240/ac)	10–15 percent cover
Perennial grasses	10 plants/m^2 (1/ft^2)	10 percent cover	10–25 percent cover

3.2.8 Pollinator-Focused Restoration or Enhancement

These guidelines provide recommendations for use of native species in habitat revegetation or habitat enhancements focused on restoring pollinator habitat. The recommendations are based on results and best management practices from the *Hanford Site Pollinator Study* (HNF-62689), which identified common pollinators and pollinator-supporting native plants on the Hanford Site. By attracting pollinators, pollinator-friendly species benefit both the health of revegetation areas and the surrounding environments.

Pollinator-friendly native species can be used exclusively or as components of typical restoration projects, depending on the goals of the project. Even when a restoration project does not have the explicit goal of restoring pollinator habitat, it can benefit from the inclusion of pollinator-friendly plants. Choosing plants that attract pollinators can increase pollination in the restoration area that can increase seed set and viability of the native plants, eventually increasing native cover. Many bees native to the Hanford Site are small-bodied bees with relatively limited ranges, making local habitat restoration or enhancement important after a disturbance.

3.2.8.1 Species and Planting Recommendations

Table 3.20 provides acceptable plant species to be used in a pollinator-friendly restoration on the Hanford Site. Forbs and flowering shrubs provide the majority of food resources to pollinators and are included in Table 3.20. Native grasses are an important component of any shrub-steppe restoration; for native grass species recommendations refer to the revegetation guidelines for the appropriate soil type. For more information regarding how the species on Table 3.20 were selected, see the *Hanford Site Pollinator Study* (HNF-62689).

3.2.8.1.1 Forbs

When choosing pollinator-friendly forb species, selecting a mix of species with bloom times throughout the active season for pollinators (March-October) is essential to supporting all pollinators throughout their lifecycle. In the Columbia Basin, many forbs bloom in April and May and pollinator food resources become scarce from June to August. Planting forbs that bloom through the summer is important to supply food resources to pollinators when food is otherwise limited. Table 3.20 lists approximate bloom times.

Along with variation in bloom time, selecting species with variation in bloom size is important to both attract and support a wide variety of native pollinators. Relative bloom sizes are listed in Table 3.20. Bloom sizes were determined based on relative size of the inflorescence compared to other shrub-steppe plants, not necessarily the flower size. Few species with 'small' blooms are listed in Table 3.20, as they are less commercially available due to difficulty collecting seed.

Forb selection should also consider the presence of specialist bees within the restoration area and in nearby environments. One group of specialist bees abundant at Hanford are *Diadasia* bees, which are usually specialists on globemallow plants. Increased research is still needed to identify specialist bees and their relationships with plants in the Columbia Basin. A relatively simple way to support specialist bees in their habitats is to include forbs from the surrounding area in the seed mix. This increases the chances that specialist bees in the local habitat will be supported by forbs in the seed mix.

3.2.8.1.2 Shrubs

Like forbs, native shrubs provide important food resources to pollinators. Shrubs also provide above-ground nesting bees with twigs and branches that can be used as nesting habitat. There are four relatively common, insect pollinated shrubs (listed in Table 3.20) found on the Hanford Site that can be used to provide floral resources and nesting habitat for pollinators in restoration seed mixes. Additionally, three of the four shrubs bloom in the late summer to early fall, providing important food resources for bees that overwinter. Wind pollinated shrubs (e.g, sagebrush) remain an important component of a pollinator focused restoration, as they provide habitat structure and nesting habitat for bees.

3.2.8.1.3 Grasses

Though grasses do not provide food resources to pollinators, they do provide important habitat structure. Perennial bunchgrasses used in restoration projects help prevent cheatgrass from dominating the understory of a revegetation site and can result in more patches of bare soil, which provide essential habitat for ground nesting bees. Preventing cheatgrass from dominating the understory also provides more open space for native forbs to germinate, potentially increasing native cover and floral resources for pollinators.

3.2.8.1.4 Soil Type

Included in Table 3.20 is the appropriate soil type(s) for each pollinator-friendly species. All soil types support pollinator species and sandy soils on the Hanford Site and may be especially important in supporting large populations of native pollinators. Different soil types likely support different guilds of pollinators due to both the floral communities and differing preferences of ground nesting bees. Pollinator restoration can only be successful if native plants are able to establish and reproduce; selecting species appropriate for the soil type is necessary for a pollinator-focused restoration to be successful.

3.2.8.1.5 Selection of Planting Methods

Due to the sensitive nature of ground-nesting bees, ground disturbance should be limited to the extent possible when allowed by the project. Use drill or broadcast and imprint for normal sites. Small sites may be broadcast from an all-terrain vehicle with chain or harrow. At very small sites, hand-apply seed, and rake. Steep sites (more than 10 to 15% slope) should be hydroseeded if access is possible. Some remote or very large areas may be aerially seeded.

3.2.8.1.6 Timing and Season for Planting

Unless supplemental irrigation is planned, seeding and transplanting should take place no earlier than October and no later than February; the preferred window is from mid-November to early February. The planting window can be extended at small sites by regular irrigation (water truck or some other means).

3.2.8.1.7 Habitat Enhancement Considerations

In some cases, habitat suitable for pollinator habitat enhancement may be selected as a form of mitigation. Special care must be taken when enhancing pollinator habitat that has been previously undisturbed. Significant ground disturbance can kill ground nesting bees, and removal of shrubs or woody plants can kill above-ground nesting bees. When possible, enhancing pollinator habitat by adding shrubs, forbs, and grasses should be done by planting plugs or hand seeding. This will limit ground-disturbing activities while still providing benefit to pollinators. The rate of plug planting or seeding will vary depending on the current habitat conditions.

In addition to planting, pollinator habitat can be enhanced by adding nesting resources like bee nest boxes or by maintaining patches of bare ground. Refer to the *Hanford Site Pollinator Study* for more information regarding nesting habitat enhancement.

3.2.8.2 Recommended Site Preparation Actions

3.2.8.2.1 Site Recontouring

If the site has been heavily disturbed, the site may be recontoured to blend aesthetically with the surrounding topography. However, site grading and contouring should be performed to have minimal or no effect on surrounding areas otherwise undisturbed by the remediation and restoration action. Areas that have not been heavily disturbed and are believed to provide habitat for ground-nesting bees should not be recontoured, as it can disturb bee nests.

3.2.8.2.2 Soil Preparation

- If possible, stockpile clean fine-grained soil prior to site remediation. Soil should be the same soil type as the surrounding habitat to provide continuous habitat for ground-nesting bees. Soils directly overlying remediation zones may not be suitable for stockpiling. However, adjacent soils within support and staging areas should be stockpiled. Spread the stockpiled material over the site after final grading or contouring and prior to seeding.
- If surface is compacted, loosen using a plow, ripper, or disk.
- After seeding, clean certified weed-free straw (preferably native grass) should be applied at a rate of 1 to 3 ton/ac followed by crimping.

3.2.8.2.3 Fertilization

In most cases, fertilizer applications are not recommended, since the straw will provide organic matter.

3.2.8.2.4 Weed Control

- If the site is freshly graded or recontoured, weed control is probably not needed.
- If noxious weeds or significant populations of Russian thistle or other weeds are present on the site, consult Hanford Site Biological Controls regarding spraying or weed control options.

Table 3.20. Shrubs and Forbs for use in Pollinator-Focused Restoration and Enhancement

Common Name	Species	Bloom Times[a, b]			Bloom Size	Soil Type[c]	Comments
Shrubs		**Spring**	**Summer**	**Fall**			
Big sagebrush	*Artemisia tridentata*	N/A	N/A	N/A	N/A	Loam, cobble	Follow seeding rates and use shrubs for the appropriate soil type. Transplant snow buckwheat at 100 plants/ac or seed at 0.25 lb/ac for all soil types.
Green rabbitbrush	*Chrysothamnus viscidiflorus*		o	X	Medium	Loam, cobble	
Gray rabbitbrush	*Ericameria nauseosa*		o	X	Medium	Loam, cobble	
Snow buckwheat	*Eriogonum niveum*		o	X	Small	Sand, loam, cobble	
Antelope bitterbrush	*Purshia tridentata*	X	o		Medium	Sand, cobble	
Forbs		**Spring**	**Summer**	**Fall**			
Stalked-pod milkvetch	*Astragalus sclerocarpus*	X			Medium	Sand, loam, cobble	Forb species should be appropriate for the soil type, match the surrounding vegetation, and include a variety of bloom times. Select at least four species and broadcast seed at a rate of 0.1 lb/ac to 0.25 lb/ac per species or transplant seedlings at a rate of 100 plants/ac/species. A combination of seeding and transplanting may be used.
Carey's balsamroot	*Balsamorhiza careyana*	X			Large	Sand, loam, cobble	
Douglas' dustymaiden	*Chaenactis douglasii*		X		Medium	Sand, loam, cobble	
Prairie clover	*Dalea ornata*	X	X		Medium	Sand, cobble	
Upland larkspur	*Delphinium nuttallianum*	X			Medium	Sand	
Hoary aster	*Machaeranthera canescens*		o	X	Medium	Sand, loam, cobble	
Pale-evening primrose	*Oenothera pallida*	X	o	o	Large	Sand, loam, cobble	
Sand beardtongue	*Penstemon acuminatus*	X	o		Medium	Sand, loam	
Threadleaf phacelia	*Phacelia linearis*	X	o		Medium	Sand, loam	
Munro's globemallow	*Sphaeralcea munroana*	o	X		Medium	Loam, cobble	

[a] Where 'X' denotes the season the species is typically in full/peak bloom and 'o' denotes the season when the species can be found blooming but usually not to its fullest extent.
[b] Bloom times from HNF-62689 and Appendix A of this document. Spring refers to March through May, Summer refers to June through August, and Fall refers to September through October.
[c] Where Sand is Sandy Soils, Loam is Sandy Loam or Loamy Sand, and Cobble is Mixed or Cobble Backfill.
N/A = Bloom does not provide floral resources for pollinators.

- If the site is dominated by cheatgrass or other invasive species and sufficient time is available, work with the Site Biological Controls group to spray the site with a glyphosate or other suitable herbicide in spring before cheatgrass seed set and again after cheatgrass germination in the fall.
- Hand pulling should be prioritized over herbicides in pollinator restoration areas to reduce potential effects from herbicide on pollinator species. All herbicides used should be evaluated to determine effects on pollinator species prior to application. When possible, herbicide application should occur outside of the active pollinator season.

3.2.8.3 Site Maintenance

3.2.8.3.1 Weed Control

Weed control is essential to the health of revegetation sites. Common weeds on the Hanford Site flower in the late summer and act as a food resource for generalist bees when other resources are rare. Removing these weeds, though beneficial in the long term, can remove valuable pollinator food resources. It is essential to replace weeds with flowering native species as soon as reasonably possible.

In areas where desirable native forbs or shrubs are not present, hand pull or spot spray invasive broadleaf weeds with a selective herbicide. If desirable forbs and/or shrubs are present, the herbicide application method or timing may need to be adjusted. Consult with Hanford Site Biological Controls to develop weed control strategy and schedule. The herbicide should be thoroughly evaluated to ensure it does not present a threat to invertebrates. If an herbicide cannot be identified that does not present a threat to invertebrates and hand pulling is not a reasonable option, herbicide should be applied before the active season for pollinators.

3.2.8.3.2 Herbivory Control

Young plants of some species of forbs and shrubs, such as spiny hopsage and antelope bitterbrush, are often targeted by herbivores. If herbivory is anticipated to be a significant problem, then use of herbivore protection, such as fencing or protective sleeves, should be considered. Protective sleeves shall be collected after no more than 2 years, and protective sleeves that become dislodged shall be picked up or replaced during routine site inspections. Some forb species are also likely to be targeted. Transplants should be monitored for the first season post-planting and protective actions initiated, if needed. Protective sleeves around forbs should allow for large-bodied bees and butterflies to pass through.

3.2.8.4 Site Monitoring and Success Criteria

Site monitoring and success criteria will vary depending on the goal of the pollinator-focused restoration or enhancement. For a typical restoration project (including pollinator-friendly plants), site monitoring and success criteria can follow the criteria for the appropriate soil type described in the sections above. Monitoring should indicate a steady progression toward the desired future conditions; however, the annual monitoring results may indicate the need for corrective action.

For pollinator-focused sites with the goal of mitigating losses to pollinator habitat, the mitigation plan will include monitoring and success criteria. Comparing pollinator use of the restored area to pollinator use of surrounding habitats or a reference community can indicate relative successfulness of the site. Typically, pollinator monitoring, in addition to revegetation monitoring, can indicate the successfulness of a pollinator-focused restoration. The effort level of monitoring will be dependent on the project resources and ultimate goal.

4.0 Revegetation Site Conditions and Assessment

Developing a successful revegetation strategy requires careful consideration of the individual site attributes, identification of any potential limiting factors to vegetation establishment, and design of strategies or treatments to mitigate those limitations. This chapter describes the factors and conditions, including the ecological setting, that affect the selection of plant materials and methods of establishment for revegetation efforts on the Hanford Site. Next, the site-specific factors that should be evaluated when assessing sites to be revegetated are outlined, and potential treatments to mitigate site-specific limitations are described.

4.1 Ecological Setting

The semi-arid lands of the Hanford Site are located in the lower Columbia Basin in an area referred to as the Columbia Plateau Ecoregion (EPA 2011). Within this ecoregion, the Hanford Site represents one of the last large and relatively undisturbed tracts of shrub-steppe in eastern Washington. The designation shrub-steppe refers to the dominant plants within the plant association, that is, shrubs, and steppe grasses (perennial bunchgrasses). The climate, soils, and topographic relief on the site determine the type of vegetation association that can establish and grow in any specific area and must be considered in planning the appropriate plant species mixture for individual revegetation units.

4.1.1 Climate and Topography

At the Hanford Site, the climate is semi-arid (PNNL-15160) with hot, dry summers and cold, wet winters. The annual precipitation over the past three decades has ranged from a low of 9.53 cm (3.75 in.) recorded in 1999 to a high of 31.27 cm (12.31 in.) recorded in 1995 with a mean of 17.2 cm (6.8 in) (DOE 2011). Most of the effective precipitation is received between October and April, and a precipitation gradient coincides with the elevation gradient (Stone et al. 1983). The highest elevation on the Hanford Site is on the crest of Rattlesnake Mountain (1,150 m [3,500 ft.]), which receives approximately 30 cm (12 in.) of precipitation annually. This northeast-facing anticlinal ridge falls steeply to an elevation of about 487 m (1,600 ft.), where slopes become more moderate and annual precipitation averages 20 to 25 cm (8 to 10 in.). As the landscape continues to descend to approximately 152 m (500 ft.) in Cold Creek Valley and eastward to the Columbia River, annual average precipitation decreases to 15 to 18 cm (6 to 7 in.). The 200 Area Plateau rises a few hundred feet above the rest of the central portion of the site, with Gable Butte and Gable Mountain rising fairly steeply to 236 m (773 ft.) and 331 m (1,085 ft.), respectively. In general, Central Hanford lands consist of relatively gentle rolling hills and swales on the Columbia River Plain descending toward the Hanford Reach of the Columbia River.

4.1.2 Soils

Hajek (BNWL-243) described 15 different surface soil types on the Hanford Site, varying from sand to silty and sandy loam (Table 4.1). In general, the soils of the slopes of Rattlesnake Mountain and Gable Mountain are silt loams, stony silt loams, talus, and basalt scree; on the Columbia River Plain, the soils are sandy loams, loamy sands, sands, and dune sands (Figure 4.1) (BNWL-243; Rickard et al. 1988). The variety of soils on the Hanford Site, along with the elevation and precipitation gradient from the river to the top of Rattlesnake Mountain, allow a variety of shrub-steppe plant communities to exist within a relatively short distance. For this manual, the soils have been reclassified by dominant textural type (Table 4.1) to relate more easily with the soil textural class to the potential native vegetation for that soil type.

Table 4.1. Hanford Site Soil Classes

Hajek (BNWL-243)

Name	Description	Soil Texture
Burbank Loamy Sand	Burbank loamy sand is a dark-colored, coarse-textured soil underlain by gravel. Its surface soil is usually about 40 cm (16 in.) thick but may be as much as 75 cm (30 in.) thick. The gravel content of its subsoil ranges from 20 percent to 80 percent.	Loams
Ephrata Sandy Loam	Ephrata sandy loam is found on level topography on the Hanford Site. Its surface is darkly colored and its subsoil is dark grayish-brown medium-textured soil underlain by gravelly material that may continue for many feet.	Loams
Ephrata Stony Loam	Ephrata stony loam is similar to Ephrata sandy loam. It differs in that many large, hummocky ridges are made up of debris released from melting glaciers. Areas of Ephrata stony loam located between hummocks contain many boulders several feet in diameter.	Loams
Dune sand	Dune sand is a miscellaneous land type that consists of hills or ridges of sand-sized particles drifted and piled up by wind. They are either actively shifted or so recently fixed or stabilized that no soil layers have developed.	Sands
Hezel Sand	Hezel sand, similar to Rupert sands, is laminated grayish-brown strongly calcareous silt loam subsoil usually encountered within 100 cm (39 in.) of the surface. When found as surface soil, it is very dark brown. Hezel sand was formed in wind-blown sands that mantled lake-laid sediment.	Sands
Koehler Sand	Koehler sand is similar to other sandy soil found on the Hanford Site, differing in that it mantles a lime-silica cemented hardpan layer. The sand was developed in a wind-blown sand mantle, exhibits a very dark grayish-brown surface layer, and is somewhat darker than Rupert sand. Its calcareous subsoil is usually dark grayish-brown at about 45 cm (18 in.).	Sands
Rupert Sand	Rupert sand, brown to grayish-brown coarse sand grading to dark grayish-brown at a depth of 90 cm (35 in.), is one of the most extensive soil types on the Hanford Site. Rupert sand developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits that were mantled by wind-blown sand and formed hummocky terraces and dune-like ridges.	Sands
Ritzville Silt Loam	Ritzville silt loam, a dark-colored silt loam soil, is found midway up the slopes of the Rattlesnake Hills. It was formed under bunchgrass from silty wind-laid deposits mixed with small amounts of volcanic ash. Characteristically greater than 150 cm (60 in.) deep, Ritzville silt loam may be separated by bedrock that occurs between 75 and 150 cm (30 and 60 in.).	Silt Loams
Esquatzel Silt Loam	Esquatzel silt loam is a deep dark-brown soil formed in recent alluvium derived from loess and lake sediment. Its subsoil grades to dark grayish-brown in many areas, but the color and texture of the subsoil are variable because of the stratified nature of the alluvial deposits.	Silt Loams

Name	Description	Soil Texture
Kiona Silt Loam	Kiona silt loam occupies steep slopes and ridges. Its surface soil is very dark grayish-brown, is about 10 cm (4 in.) thick, and has dark-brown subsoil containing basalt fragments 30 cm (12 in.) and larger in diameter. Many basalt fragments are found in its surface layer and basalt rock outcrops are often present. Kiona silt loam is a shallow stony soil normally occurring in association with Ritzville and Warden soil.	Silt Loams
Lickskillet Silt Loam	Lickskillet silt loam occupies the ridge slopes of Rattlesnake Hills and slopes greater than 765 m (2,509 ft.) elevation. It is similar to Kiona silt loam except the surface soil is darker. Lickskillet silt loam is shallow over basalt bedrock and exhibits numerous basalt fragments throughout the profile.	Silt Loams
Pasco Silt Loam	Pasco silt loam is poorly drained, very dark grayish-brown soil formed in recent alluvial material. Its subsoil is variable, consisting of stratified layers. Only small areas of Pasco silt loam are found on the Hanford Site, located in low areas adjacent to the Columbia River.	Silt Loams
Scootney Stony Silt Loam	Scootney stony silt loam developed along the north slope of the Rattlesnake Hills, and is usually confined to the floors of narrow draws or small fan-shaped areas where draws open onto plains. It is severely eroded with numerous basaltic boulders and fragments exposed and the surface soil is usually dark grayish-brown grading to grayish-brown within the subsoil.	Silt Loams
Warden Silt Loam	Warden silt loam is dark grayish-brown soil with a surface layer usually 23 cm (9 in.) thick. Its silt loam subsoil becomes strongly calcareous at about 50 cm (20 in.) and becomes lighter in color. Granitic boulders are found in many areas. Warden silt loam is usually greater than 150 cm (60 in.) deep.	Silt Loams
Riverwash	Wet, periodically flooded areas of sand, gravel, and boulder deposits that make up overflowed islands in the Columbia River and areas adjacent to the river.	—

Source: PNL-6415

4.1.3 Vegetation

In describing the shrub-steppe vegetation zones and plant associations of the eastern Washington steppe, Daubenmire (1970) originally included all the Hanford Site in the zone he called the big sagebrush and bluebunch wheatgrass zone (*A. tridentata*/*Pseudoroegneria spicata*). This zone covers the most arid interior of eastern Washington extending west to the Cascade Mountains, north into the Okanogan Valley, and south into portions of north-central Oregon. Within this zone, a number of different shrub-steppe plant community types exist according to climatic conditions, topographic conditions, soil types and depth, and disturbance history.

Plant communities of the shrub-steppe region are usually named and recognized according to the dominant shrub and grass species found within the community. Within the shrub-steppe plant communities on the Hanford Site, big sagebrush is often the dominant shrub. Herbaceous grasses and forbs (herbaceous plants other than grasses, such as wildflowers) grow between and beneath shrub canopies. Other shrub species also occur in sagebrush steppe communities or may be the dominant shrub in seral or edaphic plant communities on the Hanford Site (PNNL-13688, Table 3.3).

The various plant communities found on the Hanford Site are described in more detail in *Vascular Plants of the Hanford Site* (PNNL-13688).

In describing the shrub-steppe communities found on the Hanford Site, it is important to understand the role of introduced invasive plant species. A number of exotic species that have been introduced to the Intermountain West since the turn of the century can successfully invade shrub-steppe communities and drastically change community composition, structure, and function. This type of invasion most often occurs after some type of disturbance or stress to soils and vegetation, such as actions to remove existing vegetation or wildfire. Cheatgrass or downy brome, Russian thistle, and tumble mustard (*Sisymbrium altissimum*) are common annual weedy species that can rapidly invade and dominate disturbed areas on the site.

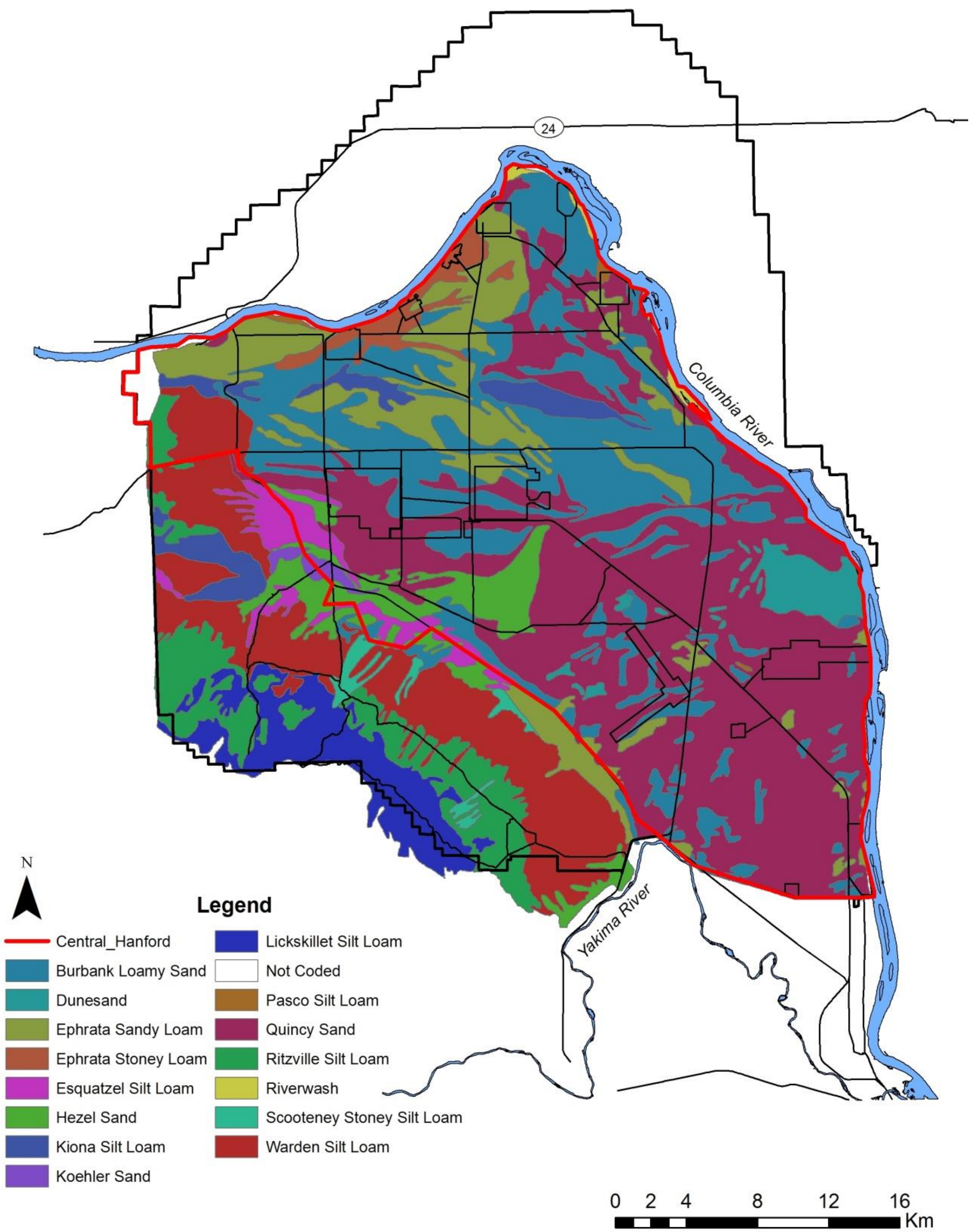
Cheatgrass presents a number of challenges to implementing successful revegetation actions on the Hanford Site. This winter annual grass has a short growth period relative to most native bunchgrasses and completes its annual life cycle in late spring and early summer. Because cheatgrass can germinate in the fall after sufficient precipitation as well as in the spring (Mack and Pyke 1983), cheatgrass can out compete native seedlings for water and nutrients in the early spring. It is established and actively growing when many natives are just initiating root elongation and growth. Cheatgrass completes its reproductive process and becomes senescent before most native plants, producing very large numbers of seeds (5,000 to 17,000 seeds/m^2 in studies in Nevada and Idaho, respectively) (Young and Evans 1975; Stewart and Hull 1949). Dead cheatgrass and litter are extremely flammable, increase the likelihood of wildfire starts, and spread (Pellant 1990). Platt and Jackman (1946) reported that cheatgrass becomes flammable 4 to 6 weeks earlier and remains highly flammable for one to two months longer than native perennials. Invasive exotic species and noxious weeds are becoming increasingly prevalent in both undisturbed and disturbed lands on the Hanford Site and should be considered in planning revegetation actions. Additional aspects of weed control during revegetation are discussed in Section 4.2.5.

Riparian and wetland plant communities and habitats are found along the banks of the Columbia River, along several intermittent streams occurring on the Fitzner and Eberhardt Arid Lands Ecology Reserve, and on the shores of several irrigation wastewater ponds on the Hanford Reach National Monument. Riparian vegetation describes plants occurring at the interface between rivers, streams, or lakes and the adjacent uplands. It is limited in extent, with narrow bands or buffers near the water consisting of a number of forbs, grasses, sedges, reeds, rushes, cattails, and deciduous trees and shrubs. Much of the riparian zone has also been successfully invaded by exotic plant species that can act to displace native species. Along the Hanford Reach, mulberry (*Morus alba*) and Russian olive (*Elaeagnus angustifolia*) trees are more frequent than the native black cottonwood (*Populus balsamifera* ssp. *trichocarpa*).

Wetland plant communities are found in the backwater areas of the Hanford Reach, such as the slough downstream of the 100-F Area and the slough near the Hanford town site. Wetlands are characterized by their soils as well as the types of plants that occur within their boundaries and consist of areas where the soils are saturated with moisture either permanently or seasonally. Wetlands may also be covered partially or completely by shallow pools of water with emergent vegetation. Wetlands located along the Columbia River Hanford Reach area are often characterized by rushes and cattails, and support a diverse plant community.

Figure 4.1. Hanford Site Soil Map (Benton County Portion)

(Hajek BNWL-243)



4.2 Site-Specific Factors and Limitations

As part of site assessment, the project team will evaluate the environmental conditions for each revegetation unit to identify those factors that may provide obstacles to successful revegetation. These include characteristics such as soil attributes, climate (precipitation and wind), topography, potential animal intrusion and herbivory, and presence of invasive or noxious weeds at the site. Potential constraints to revegetation success include over steepened slope gradients, site conditions that allow pooling or limit adequate drainage during heavy rains, encroachment by invasive species, animal damage after planting, and the use of unqualified and unskilled labor to perform planting activities resulting in poor plant establishment.

Revegetation projects can be constrained on multiple levels, regardless of the purpose of revegetation. For instance, interim stabilization projects are most often constrained by limited top soil and a resulting lack of soil fertility and soil organic matter. These constraints to revegetation success are generally easy to mitigate in the short term on this type of project. On the other extreme, revegetation of remediated waste sites will encounter the greatest number of constraints to revegetation success. This subsection addresses some of the more common physical constraints to revegetation success along with some mitigating techniques.

4.2.1 Soil Structure

Soils consist of organic material, air spaces, and different-size clumps and particles of sand, silt, and clay. The soil texture, size, and distribution of the particles comprising the soil are an important characteristic that can influence species selection for revegetation and restoration. Hanford Site soils are described in Table 4.1 and consist primarily of coarse-textured sands, loams, and silt loams. Soil disturbance can result in changes to soil texture, bulk density, organic content, water-holding capacity, nutrient cycling, soil cryptogams, mycorrhizae, and other physical and chemical changes that can affect revegetation success.

A loss of soil structure from compaction, excessive tillage, or tillage when soil is too wet affects soil processes. The breakdown of aggregate stability by the disruptive forces can result in reduced infiltration and crusting of the soil surface. Compaction limits air exchange to roots and the ability of water to percolate through the soil. Increased bulk density usually indicates a poor environment for root growth, reduced aeration, and undesirable changes in hydrologic function.

Bulk density can be lowered and water infiltration increased by tillage and the addition of non-composted organic soil amendments. If organic matter is low or nonexistent on the revegetation site, adding it to the soil prior to tillage can prevent the soil from settling back to higher, pre-tillage densities. Other benefits of adding organic matter include increased water-holding capacity and nutrient availability and improved rooting depth. Noncomposted organic matter to improve soil development is the best choice in terms of weed suppression because the nitrogen is immobilized and not available for plant growth in the short term. However, slow decomposition over time will deliver a steady supply of nutrients to the establishing native plant community for many years.

Compaction of soils on the Hanford Site is often the result of using heavy equipment on temporary roads near staging areas. Compaction limits the number of areas suitable for seed germination and growth. Broadcasted seed will sit atop compacted soil, where it will be vulnerable to wind, water, heat, and predation. At a minimum, soils that become compacted by the use of heavy equipment must be loosened prior to planting in order to allow seeds to germinate and seedlings to become established.

Site-specific soil assessments can reveal problem areas before revegetation, and, in some cases, problematic soil properties can be easily mitigated. Compacted soils at the site can be remedied by seedbed preparation through shallow chiseling, plowing, harrowing, or dragging small chains to loosen the upper layer of soil. This increases the number of safe sites for seed germination. If the revegetation specialist is involved early in the project, these soil-property mitigation needs can be supplied to the project manager early enough to allow the required equipment and labor to be factored into the project schedule and budget.

4.2.2 Soil Fertility

Shrub-steppe soils are typically characterized as nutrient-poor and low in organic matter. However, revegetation sites that are not devoid of topsoil usually do not need organic amendments or fertilizers. Nitrogen fertilizers should be used only when soil tests reveal a gross deficiency. Nitrogen would rarely be needed for native species, especially late-seral grasses such as bluebunch wheatgrass. These grasses have minimal nitrogen requirements, having evolved in low-nutrient environments. In many revegetation cases, reducing the amount of available nitrogen in the soil can increase late-seral grass establishment by reducing weed competition. Research on succession and invasion indicates that additions of nitrogen to test plots generally increase the potential for invasion by weeds and unwanted plants. When soil tests indicate the need for fertilizer, limit the amount, especially of nitrogen. If fertilizer or amendments are used, it is recommended that a chemical analysis be performed to assure that there are no constituents present at levels that may compromise site cleanup goals.

Organic matter content and nutrient analyses should be determined before revegetation. It is a routine procedure carried out in soil analysis and testing laboratories. Organic matter adds erosion resistance to soils and is fundamental in the promotion of nutrient cycling and the support of symbiotic microbial communities, the promotion of soil structure, and water holding capacity. Nitrogen, phosphorous, sulfur, and micronutrients are stored as constituents of soil organic matter, and through the process of mineralization, are slowly released to the soil, aiding in plant growth. Humic acids (a form of organic matter) accelerate soil mineral decomposition releasing essential macro- and micronutrients as exchangeable cations.

An increasing amount of evidence suggests that the availability of soil resources strongly influences both the potential for invasion of the site by weeds and the trajectory of succession (Svejcar 2003). After disturbance, nitrogen availability is usually initially increased (Vitousek et al. 1989), and a number of studies indicate that soil disturbance increases nitrogen mineralization (Binkley and Hart 1989; Stenger et al. 1995). Tilman and Wedin (1991) and Frederick and Klein (1994) found that later-successional species devote more resources to roots (compared with early-successional species) and release more recalcitrant substrates into the rhizosphere, slowing decomposition and increasing nitrogen immobilization. This suggests that succession is driven by the ability of later-successional species to reduce soil nitrogen. McLendon and Redente (1991) showed that added nitrogen slowed succession and increased the period of dominance by annual species. Research on the link between nitrogen availability and spread of invasive species is limited. Stohlgren et al. (1999) studied exotic species abundance in nine vegetation types in the Colorado Rockies and Central Grasslands and concluded that 1) sites high in herbaceous foliage cover and soil fertility are subject to invasion in many landscapes, and 2) this pattern may be related to soil resource availability and is independent of species richness.

4.2.3 Loss of Topsoil and Function

Some of the typical revegetation actions on the Hanford Site are accomplished on drastically disturbed areas such as remediated waste sites with little or no topsoil for plant establishment. Instead, revegetation takes place in backfill and subsoil materials that are generally deficient in organic matter and nutrients. In these cases, the use of stockpiled topsoil may be an option to increase revegetation success.

When surface soils are removed, both soil organic matter and function of the microbial, decomposer subsystem may be lost. Many of the transformations that occur during the cycling of nutrients are accomplished by microorganisms. In addition, many plant species form mutualistic associations with mycorrhizal fungi that increase the plant's ability to absorb phosphorus and water in otherwise limiting conditions. The lack of topsoil, soil organic matter, and microbial subsystem function may limit the success of restoration plantings.

Surface soils may need to be removed and stockpiled before construction activities for later use. Topsoil stored for any length of time will have reduced biological activity, in part due to a loss of mycorrhizae, bacteria, and invertebrates. Stockpiled surface soils will also lose organic matter and nutrients over time. Therefore, surface soils that have been stored for a period of several months or years may require the addition of organic amendments to encourage new microbial populations and initiate nutrient cycling. If topsoil will be stockpiled, it is best stored in shallow piles less than 0.6 m (2 ft.) high, exposing as much soil to air as possible to avoid damaging microorganism numbers with anaerobic conditions. This may not always be possible, especially when topsoil storage space is limited.

Topsoil piles that will be stored for longer than a few weeks can be planted with a protective, sterile cover crop such as Regreen, a sterile hybrid cross between common wheat and tall wheatgrass (*Triticum aestivum* x *Elytrigia elongata*), or triticale, a sterile hybrid cross between common wheat and cereal rye (*T. aestivum* x *Secale cereale*). Small amounts of native grass species may also be added with the cover crop to increase survival of native mycorrhizae. If stockpiles will be held for long periods (years), then native plant species should be used for stabilization and natural addition of seeds to the soil seed bank. The benefits of this practice are erosion control and maintenance of mycorrhizae inoculum through the presence of live roots. The stored topsoil should be monitored often, and any invasive weeds removed.

4.2.4 Topography

The topographic relief of the area to be revegetated can play an important role in success or failure of revegetation efforts. Aspect, slope angle, and the length of slopes on the site affect potential evapotranspiration, site drainage, potential erosion, seed stability, and rooting stability. Slope angle or gradient is important in surface stability because it directly affects erosion of soil particles, the steeper the slope, the greater the erosional forces. The length of the slope also influences soil erosion and seed transport, and longer slopes have increased potential for transport of sediment and seeds. Aspect is the direction a slope is facing and is one of the predominant site characteristics affecting evapotranspiration. South and west aspects receive more solar radiation during the day, have higher evapotranspiration rates than north-and east-facing slopes, and are therefore warmer and drier. Soils on sites with south and west aspects dry out faster than north- and east-facing slopes and may need differing treatments or amendments to establish successfully plants. South-facing slopes are also more susceptible to invasion by cheatgrass.

Several types of treatments can be devised to mitigate obstacles to revegetation presented by topographic relief. Mulching can be accomplished on slopes before or after seeding to provide many benefits. For example, mulching reduces water and wind erosion, reduces soil crusting, decreases rainfall impact, insulates the soil surface, and decreases evaporation. Mulching can be applied on slopes where erosion concerns require temporary stabilization before establishment of seeded or planted vegetation. Mulching materials include wheat or barley straw, native grass straw, coconut fibers, erosion control fabric, hydromulches, and others. Care should be taken with all mulch to avoid introduction of weed seed and to avoid introducing excessive amounts of seed (such as fugitive wheat or barley seed in straw mulch) that would compete with the established or desired species. Mulch and all other materials added to a site should be certified weed-free. Mulch should be secured to the soil surface by crimping grass or straw mulch into the soil or by stapling when using erosion control fabric. Erosion control fabrics should be placed in close contact with the soil without large air voids.

Problems associated with the topography of smaller sites might also be mitigated by recontouring the areas to be revegetated to minimize steepness and length of slopes and provide more undulating topographic relief. A more undulating surface can also reduce the potential for wind erosion and reduce soil evaporation. A heterogeneous surface topography is more likely to provide safe sites for germination and establishment, which will provide a more diverse cover for wildlife habitat. Recontouring should not increase the area of disturbance or the area requiring revegetation.

4.2.5 Invasive Plant Species and Weed Control

Invasive weed control both before and after planting is an important contributor to revegetation success. Disturbed areas—waste sites, building demolition sites, and the surrounding areas used to support these actions; disked firebreaks created to help control wildfires; and even roadside areas treated with herbicides—provide favorable environments for the establishment of both invasive and noxious weed species. There are many options and methods for preventing the encroachment of weedy plants, each with its own advantages and disadvantages (CIPM 2002). Disturbed areas should be revegetated as soon as possible following the disturbance to limit the opportunity for weeds to invade the site. In some cases, control strategies will need to be developed using either chemical or physical methods or a combination of both to eliminate the current crop of weeds and reduce or eliminate weed seeds in the soil seed bank. These strategies may be applied before or in concert with planting and seeding activities.

The best management strategies focus on quickly establishing healthy, weed-resistant communities of desirable native vegetation. Strategies to reduce weed interference before planting include applying a late-season nonselective herbicide, such as glyphosate, to remove weeds and invasive grasses such as cheatgrass followed by a fall-dormant no-till drilling operation. When cheatgrass is present, this strategy can substantially reduce competition for early-season moisture the following spring. Use of herbicides is often an important component of restoration actions, but the potential long-term effects on plant establishment and succession must be carefully researched and well understood. The consequences of using various herbicides in shrub-steppe communities and as part of restoration strategies are not well known.

Prevention of noxious weed invasion will require integrative management of many different factors including preexisting weedy vegetation, proximity of weed seed source, density of vegetation established during reclamation, disturbances following reclamation, competition between other species present, herbicide control programs, biological controls indigenous to the site, and other factors. Achieving the goal of low weed density and low-cost maintenance can be accomplished through establishing robust native cover and consistent weed management following initial revegetation activities. Spot treating with herbicides or hand-pulling weeds should be done when possible to protect and enhance the growth and vigor of desired native species. In some cases, mowing dense infestations of weeds (before flowering and seed set) may be part of a control strategy. Without attainment of a healthy soil-plant system, significant efforts may be expended following reclamation to control noxious weeds in perpetuity.

4.2.6 Herbivory Control

Depending on the revegetation site, the species, and the time of year, it may be necessary to protect seedlings or transplants from herbivory. In addition to insects, both birds and mammals may eat portions of plants or entire plants and may significantly decrease the establishment of plants and the success of the revegetation project. In general, insect herbivory is usually most damaging to small seedlings of bunch grasses and forbs that have been broadcast seeded or drilled into an area. Small mammals such as pocket mice, deer mice, and gophers may also be problematic over small areas when establishing new seedlings. However, these same small mammals may play an important role in seed dispersal, especially for grasses, and pesticides or poisons to control small mammals are generally not necessary. Rabbits and deer can browse on shrub seedlings or transplants and kill them. Shrubs such as bitterbrush (*Purshia tridentata*) and hopsage (*Grayia spinosa*) have proven to be susceptible to browsing by rabbits and deer and may require protection to survive. If browsing is believed to be a potential problem at a site, plants may be protected using fencing, plastic netting around seedlings (Figure 4.2), tree shelters (translucent plastic sleeves), or application of animal repellants (Steinfeld et al. 2007b). Tree shelters and even netting around seedlings can also have deleterious effects on plant growth and survivability, so plants with these protective measures must be monitored during the initial growing season, and the shelters should be removed when portions of the crowns of the protected plants emerge from the shelter. If shelters are removed before the plant grows out the top of the cylinders, the plant may not be capable of supporting itself. All protective devises must be removed within 2 years of installation.

Additional factors that must be considered with regard to the installation of herbivory control devices include the need to re-deploy a crew to remove installed shelters, the potential for the shelters to collect tumbleweeds, and the potential for shelters to blow away, causing a litter problem. In some cases, these control mechanisms could do more harm than good, and the money spent on them may be better put toward more seed or more seedlings to counteract herbivory losses.

Rigid netting is installed three inches below the ground surface to deter burrowing mammals and protect plant from browsing by other mammals

Figure 4.2. Rigid Netting Protecting Plants from Herbivory

5.0 Revegetation Planning and Implementation

As previously described in this manual, each of the three categories of revegetation actions (interim stabilization, revegetation to restore or recreate plant communities, and revegetation to improve existing conditions, including mitigation plantings) has a different objective for the endpoint or desired future condition. The environmental conditions and site-specific factors that must be considered in developing the overall revegetation strategy are described in the preceding chapters.

In each site-specific revegetation plan, the revegetation and restoration specialist will work with the project team to assess the site (Chapter 4 and outlined in Section 2.5) and identify the key limiting characteristics of the site to be revegetated (Section 4.2). The project team must determine if the site characteristics are relatively continuous and homogenous across the land area to be revegetated. Areas within the project site that are similar can be delineated as a revegetation unit in which similar strategies and treatments can be applied. Areas that exhibit heterogeneous site characteristics will likely need to be stratified into two or more separate revegetation units depending on the variability.

The next steps are to select an appropriate species mixture (Chapter 3) and implement the treatments that will most likely result in the desired future condition. Determining the appropriate species mix and the treatments to mitigate site-specific obstacles to revegetation depends on the site's location as well as physical attributes of the area to be planted. Interpretation of a site's vegetation potential can be complicated because of the disturbance history and current condition of the project site. In addition to the species lists for presented in Chapter 3, other references and information sources are available for planning and implementing restoration actions in shrub-steppe, riparian, and wetland communities (see Appendix B).

To aid in defining the desired future conditions for Hanford revegetation actions, Table 5.1 is provided to describe the range of species and expected relative abundance of forbs, grasses, and shrubs that are representative of reference communities for each generalized soil type and for lithosol communities. The success criteria tables provided in Section 3.2 are based on the information in Table 5.1. The species identified and the relative abundances are based on the analysis of numerous vegetation data sets for reference vegetation communities occurring on the Hanford Site as well as consideration of the processes and stages of succession in shrub-steppe and riparian communities. This information should be considered in conjunction with information from the site assessment that describes the composition and abundance of vegetation surrounding the site to be revegetated. However, in many cases, such as along the river corridor, much of the native shrub-steppe was previously disturbed by farming and does not currently support native plant communities. Previously farmed lands on the Hanford Site are often typified by a cheatgrass meadow with varying amounts of native bunchgrass or other grasses such as bulbous bluegrass (*Poa bulbosa*) and native and exotic annual plants. These areas should not be used as reference communities for revegetation actions.

The relative abundance of individual species and general composition of the species mixture used at a revegetation site should be based on the abundance and composition of species found in reference communities for the appropriate soil types. Presence, absence, and abundance can be determined through plant survey and measurements on reference native plant communities in the same soil type or through the review of literature, which describes the presence and abundance of the species in similar native plant communities and soils. Table 5.1 describes the species composition and relative abundance of species found in the most common upland shrub-steppe plant communities on the Hanford Site. These values are based on measurements made in late seral stage plant communities during the past two decades.

Table 5.1. Hanford Site Shrub-Steppe Plant Communities Representative Canopy Cover

		Percent Canopy Cover			
Plant Types	**Species**	**Sands**	**Loams**	**Silt Loams**	**Lithosols**
Shrubs	Big sagebrush	5	10 to 15	10 to 15	0 to 5
	Bitterbrush	5	-	-	-
	Green rabbitbrush	5	-	-	-
	Gray rabbitbrush	-	5 to 10	2 to 5	-
	Spiny hopsage	-	5 to 10	5 to 10	-
	Snow buckwheat	5	5	-	-
	Thyme buckwheat	-	-	-	0 to 15
	Three-tip and/or rigid sage	-	-	0 to 10	0 to 15
	Total shrubs	10 to 15	10 to 15	10 to 15	2 to 20
Perennial grasses	Indian ricegrass	5 to 10	2 to 5	-	-
	Needle-and-thread grass	5 to 10	2 to 5	5 to 10	-
	Sandberg's bluegrass	5 to 10	10 to 25	15 to 20	10 to 20
	Bottlebrush squirreltail	2 to 5	2 to 5	2 to 5	-
	Thickspike wheatgrass	2	-	-	-
	Bluebunch wheatgrass	-	2 to 5	20 to 30	5 to 20
	Idaho fescue	-	-	0 to 5	0 to 10
	Total perennial bunchgrass	10 to 25	15 to 25	35 to 50	15 to 30
Native forbs	5 to 7 species	2 to 5	2 to 5	2 to 5	2 to 5

5.1 Implementation Considerations for Different Revegetation Endpoints

The following sections identify some of the principal factors that need to be considered for different revegetation endpoints. The general guidelines provided in Section 3.2 for different soil type and endpoint combinations may need to be modified based on the considerations in the following sections.

5.1.1 Upland Sites Community Restoration

Plant community restoration may be performed on land areas that are essentially barren of vegetation with the intention of recreating an ecologically appropriate native plant community for that soil type and location. Examples of sites that would require plant community restoration include remediated waste sites, sites of demolished buildings, parking lots, laydown yards, roads, short-term operational surface barriers, and the surfaces of long-term protective barriers. In such areas, native vegetation, soil microbes, and animal life have generally died out or been removed and most of the topsoil may have been lost, altered, or buried. In many cases, the planting substrate is the result of backfill operations, and the soil lacks natural structure and profile and may not have the same textural characteristics as the surrounding areas.

Native plant community restoration is a long, slow process. It takes decades for the physical structure of the community to begin to resemble natural conditions and even longer for processes such as soil formation, cryptogamic crust development, nutrient cycling, and biological complexity and diversity to recover to levels that resemble those found in native communities. Revegetation strategies should strive to promote the establishment of an assemblage of species that reinitiate natural processes of succession and aid recovery to a fully functioning ecological community.

The primary constraints at remediated wastes sites, construction areas, and many other sites that require plant community restoration will be highly compacted soils, very rocky or cobbly soil substrate, low organic matter, and minimal soil microbial activity. The site must be evaluated prior to planting to determine if deep ripping or some other technique is required to loosen the soil.

Low fertility and low soil organic matter sometimes can be alleviated with the addition of supplemental fertilizer, but in many cases may best be accomplished by adding topsoil, either stockpiled from the site prior to remediation or brought in from another location. However, some experience (e.g., the 116-C-1 waste site) suggests that the topsoil may favor the establishment of cheatgrass over the perennial grasses and that the perennial species can establish in rocky backfill (BHI-01694). At the 120-N-1 and 120-N-2 waste sites, Gano and Lindsey (2007) found that straw mulching with light fertilization provided nutrients and organic matter without favoring cheatgrass over the natives.

Restoration sites with a rocky backfill substrate, such as 116-K-1, may need a higher seeding rate than sites with finer soils. In some cases, drill seeding may be difficult and broadcast or hydroseeding may be preferred (Lindsey and Gano 2008).

Restoration of borrow sites presents a unique combination of difficulties. Because in most cases the topsoil has been long lost, the workable substrate is often coarse-textured with very low fertility or water holding capacity. These issues are similar to those found at many remediated sites with rocky backfill, and can be at least partially solved in the same way, but because of the coarse substrate, the community is not likely to resemble the surrounding areas. However, other issues may be present, such as steep sidewalls that may require the use of different equipment, such as hydroseeding. It is difficult to recreate the aesthetic quality of original topography at borrow sites, thus the revegetated borrow pit will always look like a hole. This can be partially alleviated by sloping the sides to the greatest extent possible, but this can result in additional loss of existing vegetation around the edges of the borrow pit. Tribes and stakeholders should be engaged early in the borrow site reclamation process to determine an acceptable and achievable endpoint.

5.1.2 Upland Sites Plant Community Enhancement or Improvement Revegetation

Native plant community enhancement or improvement may be conducted for several reasons, and can vary in the level of effort required and the degree of habitat transformation. The simplest enhancement actions may be the planting of shrub seedlings in an otherwise intact community to reestablish community structure and to provide the ecological base (i.e., sagebrush) upon which many shrub-steppe–dependent wildlife species rely. This type of enhancement has been performed numerous times on the Hanford Site as mitigation for the loss of shrub-steppe habitat due to site activities elsewhere. Although sagebrush has been the primary species planted for this purpose, the same techniques can be used to reintroduce other shrubs, perennial forbs, or even bunchgrass plugs.

More intensive revegetation efforts are required to enhance or improve areas that were once biologically productive but have been disturbed to the point that their biomass production and/or biological diversity are significantly impaired. Biological production and diversity may be lost due to events such as fire that may have effects ranging from minor impacts to the grasses and forbs to complete loss of the vegetative community. Diversity is also limited in previously disturbed areas that are now in a permanent early-successional developmental stage.

5.1.2.1 Mitigation Plantings

Mitigation plantings are performed to provide replacement habitat as compensation for habitat loss due to other Hanford Site activities. Generally, this has entailed planting sagebrush seedlings at a density of approximately 1000 plants/ha (400/ac) within areas with a reasonably healthy native grass understory. However, mitigation plantings will be implemented on a case-by-case basis. As such, they will require the plant ecologist or revegetation specialist to develop site-specific species selection based upon various factors and objectives involved with the planting. Mitigation planting does not need to be limited to shrub transplants; it may also include transplanting forbs or grass plugs or even larger-scale understory enhancement or rehabilitation, as discussed in Section 5.1.2.3, *Improvement of Degraded Communities*.

One concern when transplanting shrub seedlings into an otherwise intact community is to minimize damage to the existing plant community, soils, and surface crusts. Therefore, minimal intrusion is desired, and, in general, all access should be on foot. Pre-irrigation of the planting site for each shrub has been used successfully to enhance transplant survival in the 200 West expansion areas following the 24 Command fire. However, the technique required significant foot and vehicular traffic and is thus best suited to situations where the understory will also receive significant enhancement.

Shrub plantings on the Hanford Site have used both bare-root material and containerized seedlings (i.e., tubelings). Quality control is a concern with both bare-root plants and tubelings; the nursery contract must specify the desired plant dimensions for both the above- and below-ground portions of the plant and must specify pre-harvest root pruning of bare root plants to achieve the desired root system dimensions. When quality material is available, bare-root plantings have proven to be the most cost-effective way to transplant shrub seedlings. Tubelings are typically easier for the planting crews to work with but, under similar planting conditions, have lower survival than bare-root plants. Survival of both plant types has been lower on sandy soils than on other soil types. (PNNL-14901, Durham and Sackschewsky 2008)

5.1.2.2 Post-Fire Plantings

Post-fire planting may occur for several reasons, including the enhancement of a plant community following wildfire or following controlled burns. Planting following wildfires or controlled burns may be appropriate when the pre-fire plant community is highly degraded and contains few native species. Planting native bunchgrasses in these cases can improve the overall quality of the plant community. However, areas burned by wildfire must be carefully assessed using burned-area index models or similar techniques (Key and Benson 2006) to determine if replanting is advisable or necessary. The use of heavy equipment can damage intact cryptogamic crusts and existing bunchgrass crowns (which are often not damaged by fire), and can thus exacerbate short-term erosion and dust problems and reduce the ability of the existing perennial grasses to recover. Likewise, if controlled burns are implemented for fuels reduction or community enhancement, post-fire revegetation must be an integral part of the project planning. Areas with intact native perennial bunchgrass communities normally would not be suitable candidates for controlled burns because the amount of fuel is probably as low as can be expected. Sites without an existing native bunchgrass component in the community or sufficient native plant propagules might benefit if a native plant revegetation plan is successfully implemented. Burned areas without a pre-existing perennial cover are especially susceptible to invasion by cheatgrass and other invasive weeds, and control of this invasion should be considered as part of the burned-area revegetation plan.

5.1.2.3 Improvement of Degraded Communities

Improvement of degraded communities is differentiated from plant community restoration by the fact that the starting point is an existing plant community rather that the barren soil substrate found at remediated waste sites, construction areas, and other sites where restoration techniques are applied. Because there is an existing community, there is less likelihood that the soil surface would be highly compacted, and it is likely that there will be a reasonable amount of organic matter in the soil. However, the soil microbial community may be incomplete if the stand has been dominated by cheatgrass for a long time, and there may not be suitable mycorrhizae for the desired native grasses.

On the Hanford Site, low-quality upland plant communities are normally dominated by cheatgrass and may have noxious weeds present. Cheatgrass can be very difficult to eradicate from a site and may require a series of carefully timed treatments that could include fire, herbicides, and tilling. These treatments might need to be repeated for two or more years, at which time a perennial community can be planted. Mycorrhizal additions may be needed as a seed treatment, applied to the soil at planting, or introduced through transplanting soils and plants from sites supporting mature vegetation. Commercial mycorrhizal inoculates are available and may be useful in some situations (CTIP 2007), but these may not provide the appropriate species or mix of species to fully benefit native grasses, shrubs, and forbs.

5.1.3 Lithosols Revegetation

A lithosol (literally *stone soil*) is a shallow, stony soil lacking well-defined horizons. On the Hanford Site, natural lithosols are found on the summits of Rattlesnake Mountain, Yakima and Umtanum Ridges, Gable Butte, Gable Mountain, West Haven, and other basalt outcrops. These lithosols tend to be very harsh, windy environments that have very little soil, resulting in very dry and growth-limiting environments. Many native plant species found in the most open or exposed portions of these sites are very short stature, although some taller species can occur in more protected locations.

Because of the harsh physical conditions, restoration of lithosol sites tends to be difficult, and require careful planning. Most of the lithosol areas on the Hanford Site are also considered very sensitive cultural resource areas, which further emphasizes the need for careful and thoughtful restoration planning and execution. The plant species mix should be selected based on the site conditions and the species in the immediate vicinity (Table 3.15). Seed should be collected from near the site to be restored, as the nearby plants are likely to be the best adapted for the specific conditions of the site.

Some form of broadcast or hydroseeding will be required at most lithosol sites because drilling or imprinting is likely to be impractical. Aerial application may be needed in some situations. In some cases, silt material can be spread or applied with hydromulch equipment to provide a minimal soil substrate for plant establishment. Seeding rates for grasses may be increased to account for the harsh conditions.

5.1.4 Riparian and Wetland Sites Revegetation

Riparian communities on the Hanford Site exist along the Columbia River, Cold Creek, Snively Canyon, and several smaller draws and springs on Rattlesnake, Yakima, and Umtanum ridges. Portions of these riparian communities may be classified as wetlands. Other potential wetlands on the site include West Lake and vernal pools on Gable Mountain and Gable Butte. Communities along the Columbia River are the most likely to require restoration because of disturbance by Hanford-related activities, but all could be subject to enhancement actions. This discussion is not meant to provide details on wetland or riparian restoration. Many guides and manuals are available that describe restoration techniques for these areas, and these should be consulted prior to wetland restoration actions.

Wetlands and riparian areas are highly susceptible to invasion by non-native species such as reed canarygrass, and nearly all of the Hanford Site wetlands and riparian zones are now dominated by non-native species. Table 3.13 provides a partial list of native trees and shrubs, perennial grasses, and forbs that are suitable for use in Hanford Site wetland or riparian restoration.

Restoration projects in these areas will likely require two or more distinct planting zones as the site grades from inundation to the surrounding upland areas. Along the river, the lowest zone is often open cobble or gravel with a relatively sparse vegetative cover of species such as tickseed (*Coreopsis tinctoria var atkinsoniana*) and dogbane (*Apocynum cannabinum*), with widely scattered willows. Slightly higher up the bank is a dense vegetation zone dominated by grasses such as reed canarygrass, numerous forbs, and trees such as peachleaf willow (*Salix amygdaloides*) or white mulberry (*Morus alba*); this zone can range from one to tens of meters in width and is subject to periodic inundation. Above this level, the community grades into the surrounding upland areas through a zone dominated by sand dropseed (*Sporobolus cryptandrus*), thickspike wheatgrass (*Elymus lanceolatus*), red three-awn (*Aristida longiseta*), as well as forbs such as Pacific sage (*Artemisia campestris*), horsetail (*Equisetum* spp.), and plantain (*Alisma* spp.). The restoration plan should, at a minimum, account for replacement of both the inundated zone and the transition zone and will likely require different seed mixes to accomplish this.

Many trees, shrubs, and forbs are best established as plugs or transplants in wetlands. For some trees, such as willows, this can be a simple matter of planting branch cuttings; others should be prepared as potted material. Grasses can be established from either plugs or seed.

5.1.5 Upland Sites Interim Stabilization

Interim stabilization is an appropriate form of revegetation in areas that will be re-disturbed in the near future. If the revegetation unit will be re-disturbed (excavated, bladed, or used for an industrial or construction purpose) within a five year period of initial revegetation, then an interim stabilization may be appropriate. These areas include inactive waste sites such as burial grounds and cribs awaiting remediation, soil stockpiles, and areas disturbed by construction or cleanup activities in locations that will be subject to future industrial development (e.g., the 300 Area). Revegetation in these cases is performed primarily to provide erosion protection to the soil surface, minimize weed establishment, and, in the case of inactive waste sites, minimize the establishment of deep-rooted vegetation that could contact the underlying waste materials.

Establishment of an interim vegetation cover generally requires a relatively short amount of time, especially if vigorous plant species are incorporated into the species mixture. Normally, some cover can be established in a matter of months, and a functional perennial cover can be established within a couple of years.

The soil substrate at interim stabilization sites may be highly compacted, poorly graded, or have very low fertility. The site should be evaluated prior to planting to determine appropriate techniques to alleviate these potential problems.

5.2 Factors Affecting Selection and Establishment of Plant Materials

This section describes factors and conditions that are germane to any of the types of revegetation actions that might be conducted across Central Hanford lands. Designing a successful revegetation strategy depends on the timing of the revegetation action as described in Chapter 2 (Figure 2.1), and the availability of the desired plant materials for the type of action. These factors can be outside the control of the revegetation specialist and need to be considered well in advance of implementing any revegetation strategy. The selection and availability of plant materials must also be considered in determining the appropriate planting methods.

5.2.1 Timing of Revegetation Actions

The timing and season for planting or seeding at the Hanford Site is one of the most critical factors affecting the potential success of revegetation actions. The climate at the Hanford Site is on the dry end of semi-arid or steppe climate, based on the historical averages through 2000 at the Hanford Meteorological Station (PNNL-15160, Appendix A). This classification is based on a mean annual temperature of 11.9ºC (53.4ºF) and mean annual precipitation of approximately 16.5 to 18 cm (6.5 to 7 in.), of which 66.6 percent falls from October through March. In most cases, planting should be performed when moisture is available to germinate seeds and when sufficient moisture is retained in the soil profile to support root elongation and seedling development that will enable plants to become well established before the summer period of drought. In general, based on the historic temperature and rainfall data for the site, the optimum planting window for Central Hanford is between mid-October or early November (depending on the year) and early February, depending on the timing and amount of precipitation received that year. The planting window may be further limited if winter temperatures are cold enough for a period long enough to cause the top 8 to 15 cm (3 to 6 in.) of soil to freeze.

Supplemental irrigation can be used for revegetation actions on small land areas or for plantings intended to develop plant cover for interim stabilization. Supplemental irrigation can expand the planting period beyond the October to March window; however, irrigation often is not a realistic option at most sites and can pose the risk of increasing germination of invasive or noxious species. Certain situations such as engineered barriers may be well suited to the use of irrigation, especially those that are in proximity to existing water distribution infrastructure.

5.2.2 Plant Materials

Plant materials are a general term for anything that can be used to establish a plant: seeds, cuttings, or seedlings. Obtaining the appropriate species and stock type (i.e., seed, bare root seedling, container-grown) for a revegetation project takes good planning and lead-time. These materials must be genetically suited to the specific environment where they will be planted. Acquiring genetically adapted materials often requires the collection of plant materials near or in the general geographic area of the project site, and may require collecting plant materials several years in advance of project implementation.

Depending on the needs of the project and the site conditions, plants can be established by sowing seed, transplanting plants collected in the wild, planting nursery seedlings, or rooted cuttings, or in riparian areas, planting unrooted cuttings (i.e. willows). In general, it will be advantageous to consider the broader site revegetation needs when determining how much plant material will be needed each year.

5.2.2.1 Seed Sources and Availability

It is important to consider the source and availability of seeds and plant materials needed for the revegetation action early in the planning process. Two questions must be answered in choosing the best source of plant material for revegetation and restoration projects:

- What are appropriate sources of origin for the plants and seeds to be used in the project? The source of origin refers to the geographic area where the seeds or cuttings originally were collected. If the geographic origin is far from the revegetation site and/or does not closely match the environmental conditions at the revegetation site, the plants and seeds may not be well adapted to grow in the local environment and the revegetation efforts may fail.
- Does the selected plant material maintain adequate genetic diversity? The genetic diversity of the plant materials used in the revegetation must be sufficient to allow the established plant population to adapt to environmental changes in the short term (years) and over the long term (decades) (Withrow-Robinson and Johnson 2006).

There are no specific rules to define an acceptable level of genetic diversity except that the source collection should draw from as many different parent individuals and as many source sites as possible. Commercially increased native seed should be from as early a generation as possible. Otherwise, the grower will have likely inadvertently selected for specific genotypes that produce best under the cultivated agricultural-field conditions.

It is also important to understand and agree upon the definition of *local* and *native*. Native plants are the indigenous species that have evolved and occur naturally in a specific region, ecosystem, and habitat. The concept of local species is less well defined and cannot be defined by occurrence of the species within a specified distance of the revegetation site. For plants, local is best defined ecologically in terms of climate and environment. Transfer guidelines assist in defining local by recommending how far seeds or other plants can be transferred. These vary from species to species and between regions, and formal guidelines are available for only a few species. Seed zones, mapped areas where environmental conditions are uniform and ecoregions are sometimes used as surrogates to guide transfer of plant materials. Some small-scale field-testing may be needed to determine the suitability of plant material from farther away.

The volume of locally adapted native seeds needed for a revegetation project may not always be readily available in sufficient quantities. Seeds of cultivars of common native grasses are readily available from commercial seed growers, and appropriate cultivars for use in interim stabilization projects on the Hanford Site are identified in Chapter 3. Cultivars are cultivated varieties of native plants that have been deliberately selected and propagated to maintain specific desirable characteristics of the species. However, cultivars do not support the same level of genetic diversity as local native species; and therefore are not recommended for revegetation to restore or enhance native plant communities. In addition, the use of cultivars raises concerns over adaptability, genetic diversity level, and the potential for genetic contamination or 'swamping' of local native gene pools (Millar and Libby 1989; Knapp and Rice 1994;

Linhart 1995; Montalvo et al. 1997; Lesica and Allendorf 1999; Hufford and Mazer 2003). Because commercial cultivars are typically selected for agronomic traits, such as high fecundity, vegetative vigor, and competitive ability, their use may also adversely affect resident natural populations through direct competition and displacement (Aubry et al. 2005).

Local seed of native plants can be collected from the Hanford Site and nearby locations. Successful seed collection involves planning and monitoring to determine when seeds of target species are mature. It also requires knowledge of the locations of suitable source populations. It is essential that a knowledgeable botanist familiar with the target species leads the collection and is involved in identifying the most suitable population(s) for sampling and the timing for collection.

Appendix C contains protocol for the collection of seed from native plant populations on the Hanford Site.

Seed collections on the Hanford Site should be conducted only after coordination and approval of DOE-RL EMC staff. Seeds shall not be collected from the following:

- Any native plant species listed as Threatened or Endangered under the *Endangered Species Act*
- Any Candidate, or any species Proposed for listing, under the *Endangered Species Act*
- Any species listed as G1 or G2 by the Washington State Natural Heritage Program (WNHP 2012).

The window for collection is highly variable among species, ranging from only a few days to several weeks or longer. Information from the Natural Resources Conservation Service Plant Materials Center (Winslow 2007) describes the process and time required to collect native seed and indicates that labor requirements to collect native seed can range from three to 85 person-hours per pound of native seed.

Seeds that are collected from the wild can be used in revegetation efforts in several ways. One is direct seeding of seeds collected in the wild onto the revegetation unit. This approach is best used on small revegetation projects that do not require large volumes of seed. A second method involves sending seeds to a nursery to have plants grown up for transplanting. The quantity of wild seeds needed for propagating seedlings at plant nurseries will be based on an estimate of 1) quantity of seedlings needed, 2) percentage of seed germination, 3) percentage of seed purity, 4) seeds per pound, and 5) nursery factor. An estimate of germination, purity, and seeds per pound can be obtained through published sources or seed inventories. The nursery factor refers to a calculated factor that predicts the percentage of viable seeds that will survive and flourish for later transplant. Each nursery's factor is based on culturing experience and practices and is often less than 50 percent. Using the following equation, the amount of wild seed to be collected can be estimated (Steinfeld et al 2007b):

$$\textbf{Wild Seed to collect} = \frac{\text{Quantity of Seedlings Needed}}{\frac{\%\text{ germ}}{100} \times \frac{\%\text{ purity}}{100} \times \frac{\text{seeds}}{\text{pound}} \times \frac{\text{nursery factor}}{100}}$$

Another method is to increase the collected native seeds by having a nursery or local grower sow and grow the species through one or more generations. Increasing native seed stocks involves a longer time. The first seeding increases the original collected seed quantity and establishes a seedbed. This seed can then be harvested and sown back in the wild, or used to further increase quantities in future plantings. Larger quantities will require more years of increasing the size of production stands (Huber 1993).

5.2.2.2 Pedigreed (Certified) Seed and Commercial Production

When purchasing or having seed increased by nurseries or growers, it is critical that seeds be certified to ensure high quality seed is distributed to seed growers and users. Certification is intended to protect the genetic identity of seed and provide the user with a known pedigree.

Certification guidelines have been developed by the Association of Official Seed Certifying Agencies (AOSCA 2003) and the guidelines are beginning to be used for native seed production. This system allows for certification within four classes:

- source identified

- selected
- tested
- cultivar

Native seed may be bought and sold with one of these four designations. Of these, source-identified is of most use for Hanford Site applications, and should be used for all revegetation actions on the Hanford Site. Plant material in the other three classes that is based on Hanford Site or near-Hanford populations is not currently available, and is not likely to be developed in the near future. If such material becomes available, it may be considered for Hanford Site applications.

5.2.2.2.1 Source Identified

Source identified seeds or plants are from a naturally growing population occupying a known or defined geographic area. Source identified seed has been through no selection or testing. Seeds for commercial sale may be collected directly from the wild stand or grown under cultivated conditions for a limited number of generations. This agronomically produced material should strive to be representative of the entire germplasm of the wild stand and have undergone no selection during the initial collection. This requires the collector to be diligent in taking a representative sample. Source identified seed may be certified by the seed certifying agency of the source state.

5.2.2.2.2 Selected

Seeds or plants are the progeny of phenotypically selected plants of untested parents. The seeds or plants will be produced to ensure genetic purity and identity from either natural stands or seed production areas. Selection for particular traits may or may not be conducted on the selected material; if no selection is conducted, the plant material may be eligible for a 'natural' designation on the certification label. Progeny of this material may produce offspring that are diverse and dissimilar from the parents.

5.2.2.2.3 Tested

Tested seeds or plants are the progeny of plants whose parentage has been tested and has proven genetic superiority or possesses distinctive traits for which the heritability is stable, as defined by the certifying agency. This material has been through additional testing on more than one generation on multiple sites. Replicated plots are used to verify performance and heritability of desirable traits. Selection may or may not be conducted on the selected material; if no selection is conducted, the plant material may be eligible for a *natural* designation on the certification label.

5.2.2.2.4 Cultivar

Cultivar plant material has been through replicated testing at multiple sites over two or more generations. This material is clearly distinguished by documented characteristics, and when reproduced, it will retain these characteristics. Testing has proven and documented the heritability of traits, performance, and the range of adaptation. The traditional seed classification system in the United States recognized the cultivar seed class only for both native and introduced plants and allowed the following seed increase generations: breeder, foundation, registered and certified. With the new classes, the seed increase designations for the cultivar Class 5 remain the same, but for the source identified, selected, and tested classes, the seed increase generations are designated as Generation 1 (G1), Generation 2 (G2), and so on.

5.2.2.3 Seed Treatments

Requirements for seed germination can differ significantly for the various grass, forb, and shrub species routinely used in wildland seed mixes. For example, when a viable seed mix is applied to an uneven surface, the resulting community will be dictated by the germination requirements of the various species and the environmental conditions of the seedbed. Large seeds will establish in depressions where deeper seed cover occurs, while optimum germination environments for small seeds that need less cover or more light will occur on the ridges. In any case, some seeds will not germinate immediately but may remain viable in the seedbank for days, weeks, months, and, in some cases, many years. One reason for this delay in germination is seed dormancy. Uniformity in wildland revegetation is generally not desirable, and the various germination environments provided by the seedbed should provide a range of optimum germination environments that will result in a planting that will fit with the surrounding environment.

Nearly all the forb species that have been studied within the temperate steppe zone have seed that exhibit some type of dormancy at seed maturity (Baskin and Baskin 1998). The mechanisms of seed dormancy have been well studied, but the numerous attempts to systematically group or classify these mechanisms are complex and somewhat controversial. One of the most widely accepted classification schemes makes the distinction between regulatory mechanisms that originate from outside the embryo (exogenous) and those that originate from within (endogenous). Exogenous mechanisms can be physical, chemical, or mechanical. Examples of exogenous mechanisms are seed coats that are impermeable to water or gas exchange, growth regulators that are present in the coverings around embryos, and seed coats or other woody coverings that are hardened and restrict embryo growth. Endogenous mechanisms can be physiological or morphological or some combination of both (morphophysiological). Physiological dormancy prevents germination until a chemical change takes place in the seed. An example of morphological dormancy is seeds that are immature when shed and require some period of after-ripening before germination can occur. Morphophysiological dormancy is common, but physical and physiological dormancy are rarely combined (Fenner and Thompson 2005).

To increase the germination rate for collected seeds, several strategies can be used, depending on the type of dormancy. Physical, physiological, and morphophysiological dormancy can often be broken by warm and/or cold stratification (Baskin and Baskin 2004). Physical dormancy also can be reduced with abrasion (scarification) or freezing and thawing to allow water uptake. These process have been found to enhance germination for seeds of the Fabaceae (pea), Geraniaceae (geranium), Malvaceae (mallow), Lamiaceae (mint), and Poaceae (grass) plant families; all of which are represented on the Hanford Site.

Other forms of scarification to break physical dormancy include percussion or impaction (Baskin and Baskin 1998). This treatment appears to improve the permeability of Munroe's globemallow (*Sphaeralcea munroana* spp.) seeds. Other treatments such as acid scarification, mechanical scarification, and immersion in dioxane have been documented as effective treatments for species within the Malvaceae (Roth et al. 1987; Page et al. 1966; Winter 1960; Pendery and Rumbaugh 1990; Sumner and Cobb 1967). However, these treatments have some drawbacks, such as worker health and safety hazards and potential embryo damage.

Chemical dormancy can be due to inhibitors that prevent germination. The balance or ratio between inhibitors such as abscisic acid and growth-promoting enzymes such as gibberellins can be manipulated to allow germination to proceed. Soaking the seed before sowing can enhance germination, because many of these chemicals are water-soluble and can be leached from the seed. Other inhibitors must be degraded into other forms or chemicals to reduce their concentration. In the case of inhibitors that are found within the embryonic axis, temperature and sometimes light, control this shift.

Other treatments such as seed priming, fungicides, film coating, and pelleting can be used to protect the seed from pathogens and/or improve germination. Seed priming is a technique that partially hydrates a seed to the point where germination processes begin but radicle emergence does not occur. This treatment is often used in hydroseeding applications and agricultural settings and can be helpful on revegetation sites where competition for resources may be high. In theory, primed seeds are ready to continue germination in the field as soon as conditions are favorable.

Application of a fungicide protects seeds from numerous soil-borne organisms. This treatment is advantageous in moist environments, such as riparian or wetlands, especially for slow-germinating forbs. However, even in arid environments, small amounts of litter may harbor pathogens that reduce germi-nation and seedling survival when soil moisture and surface relative humidity increase following rainfall (Call and Roundy 1991).

Film-coating methods allow chemicals to be applied in a synthetic polymer that is sprayed onto the seeds. The advantage of the polymers is that they adhere tightly to the seed and prevent loss of active materials like fungicides, nutrients, or plant hormones. Some applications of film coating have been used to modify the absorption of water and germination of the seed. Coatings can confer temperature-sensitive water permeability to seeds or affect gaseous exchange and thus control the timing of seed germination and seedling emergence. Temperature-dependent, water-resistant polymers are available that can delay water absorption until climatic conditions become suitable for continued seedling growth. Seed coating with growth regulators such as cytokinin or diatomaceous earth can also improve seedling establishment (Greipsson 1999).

Seed pelletizing is used to increase the size of very small seeds. This process makes distribution of the seed easier, and has grown big sagebrush bare rootstock for Hanford Site plantings. Pelletizing can also be used to add chemicals to the pellet matrix.

5.2.2.4 Nursery Stock

DOE-RL is supportive of any combination of nursery location and management that would provide quality plant materials in suitable quantities for Hanford Site revegetation needs. Nurseries could be located either onsite or offsite, and they could be operated and managed by onsite contractors, offsite private businesses, or through cooperative agreements with tribes or universities.

Nursery stock or plants grown by a nursery or grower from wild seed, cuttings, or rhizomes are useful for several applications. Seedlings can be produced in flats and containers or as bare rootstock from wild-collected seeds. Bare rootstock is grown in native soil in open fields and harvested without soil around the roots. Container stock is grown in artificial growing media in a controlled environment such as a greenhouse, and the plant root systems form cohesive plugs when harvested. Woody shrubs (sagebrush or bitterbrush), are often propagated by growing seedlings under nursery or field conditions for later transplant to the revegetation site. Planting shrubs grown in containers or as bare rootstock provides faster development of vertical structure in the plant community and may be necessary to ensure the growth of shrubs in revegetation actions on Hanford. Grasses and forbs usually establish easily and quickly from seeds so are often not grown as nursery stock. However, growing forbs and grasses under controlled conditions for later transplant to the revegetation site may be warranted when

- Collecting or acquiring sufficient quantities of the grass and forb species of interest is very difficult
- Increasing the target species by seed growers is too difficult or too expensive.

Producing a seedling usually takes from two to six months, depending on the time of year the seed is sown and the stratification requirements of the seed. Selecting the stock for the project will depend on the needs of the project, and there are multiple options for propagation and establishment of different species.

Cuttings are taken from stems, roots, or other plant parts and directly planted on the project site or grown into rooted cuttings at a nursery for later out planting. Only a few species, such as willow (*Salix* spp.) and cottonwood (*Populus* spp.), can be easily established with this method. Other species, such as quaking aspen (*Populus tremuloides*), can be established from cuttings in a controlled nursery environment but not in the field.

5.3 Planting Methods

Revegetation can be accomplished by planting seeds, seedlings, cuttings, or young plants at the site. The choice of planting method(s) will depend on site-specific characteristics and limitations identified during the planning phases of the project and on the mixture of species necessary to meet revegetation objectives and achieve desired future conditions. If a relatively large land area (i.e. tens to hundreds of acres) must be revegetated, consideration should be given to planting seeds or a mixed approach of planting seeds and developing islands of shrubs and forbs within the larger area by transplanting container-grown plants or bare rootstock.

Transplanting seedlings or young plants over large land areas is labor intensive and expensive but may be the only reliable method of establishing some types of plants.

5.3.1 Seeding Options

A variety of methods and equipment are available for spreading and planting seeds in natural landscapes. In some cases, traditional agricultural equipment may also be employed; however, drills and equipment designed for use in flat, level fields to plant a single species will not be readily adapted for use over rough ground where multiple species are to be planted.

Drill seeding has been successful on the Hanford Site for restoring grasses to barren soils and seeding areas for interim stabilization; it tends to require less seed than other methods. Drilling ensures a uniform seed placement of about 6 mm (1/8 to 1/4 in.). Drill seeding is considered by many to provide the most consistent level of seed–soil contact, which is critical to seeding success. Disadvantages to drill seeding are that the equipment is easily damaged in rocky soils; it is difficult to maintain the correct planting depth in rough, uneven soil surfaces or for multiple species requiring differing seed depths; it produces an unnatural appearance of grasses growing in distinct rows; long-awned species such as needle-and-thread grass and bottlebrush squirreltail can be difficult to drill because they can block the feed tubes, and the equipment is large and heavy. Drill seeding tends to be better for larger areas than small, although any area greater than about 0.4 ha (1 ac) can be drill seeded.

Broadcast seeding also has been successful on the Hanford Site and in other shrub-steppe revegetation projects. Broadcast seed can be harrowed and/or cultipacked to ensure good seed soil contact if the soil conditions are favorable, then covered with mulch to reduce seed predation and maintain surface soil moisture. Seed rates should be increased by 50 percent when broadcast seeding (compared to drill seeding rates) to account for reduced seedling emergence. Advantages of broadcast methods include the ability to scale the equipment to the size of the area to be planted and the more natural appearance (compared to drill seeding) provided to the established community because the seeds are not planted in rows. Small areas can be seeded using a small all-terrain vehicle either pulling just a seed box and a chain or small harrow or pulling a cultipacker to firm the soil and increase soil seed contact. Larger areas can be planted with full-size tractors and larger equipment. The primary disadvantages of broadcast methods are an increase in seed required, less control of planting depth, and potentially less control over soil–seed contact compared to drill seeding.

Hydroseeding may provide the best option for quick soil stabilization and in certain other situations. This method is more expensive and requires significantly more seed than other planting methods. Hydroseeding has been used to establish forbs and grasses in many revegetation actions on the Hanford Site, especially on steep sites or in difficult soil conditions. Mulch and other additives, such as mycorrhizae inoculants, are easily applied using this method.

Considerations, methods, and procedures used to enhance establishment in revegetation and restoration of shrub-steppe communities include

- Using species adapted to local site conditions
- Using high-quality, certified source-identified seed
- Reducing weed competition through management or nutrient reduction with early-seral cover crops when planting native species
- Inoculating seed or using locally collected legumes with proper bacteria to ensure maximum nitrogen fixation in sites lacking a healthy nitrogen cycle – This will improve phosphorus uptake, water transport, drought tolerance, and resistance to pathogens. Seed inoculation also may increase the quality of seed produced by the resulting plants, which can contribute to increased long-term reproductive success and fitness of seeded species.
- Increasing seedling survival by using a drill seeder or preparing the seedbed before and after broadcast seeding and lightly packing the soil – consider applying hydromulch following broadcast seeding. Avoid covering wetland and riparian species with soil; light is needed for proper germination.

- Planting plugs to establish wetland and riparian grass-like species
- Using a land imprinter to form depressions in the soil – These depressions retain moisture at the surface longer than smooth soil surfaces. Soil depressions create good conditions for soil coverage of broadcasted seeds (Chambers 2000). The sides of the depression slough off and trap windblown particles.
- Increasing seeding rates to make desired species more competitive with invasive weeds – For instance, Velagala et al. (1997) found that increasing intermediate wheatgrass densities removed the competitive abilities of spotted knapweed. It also increases the likelihood that adequate amounts of broadcasted seeds find safe sites (Sheley et al. 1999).
- Adding small amounts of water to temporarily encourage establishment—but only in cases when natural precipitation has proved inadequate – An initial watering is always recommended after transplanting seedlings, cuttings, or young plants during the growing season. Be aware that frequent watering may result in poor plant adaptation and only short-term success followed by failure, once supplemental water is withdrawn. In one study, supplemental watering stimulated germination but had little lasting long-term effect (Padgett et al. 2000). Consider using commercial water-holding polymers and similar products during the establishment period to provide young plants with moisture.

5.3.2 Planting and Transplanting Considerations

When planning to use whole plants as seedlings or cuttings in the revegetation sites, a number of issues must be considered:

- What is the planting area, what is the individual plant spacing, and are there particular species that should be planted together?
- What tools are needed?
- How will plants get to the site?

Patterns of planting will influence the final appearance of the community, and consideration should be given to randomizing the locations at least some of the time to avoid a uniform appearance. If some species are known to co-occur in reference plant communities, they should be planted together on the revegetation site. Planting seedlings in groups or clumps is more visually appealing and may provide significant improvement in ecological function. In some cases when numbers of some of the target species for the revegetation effort are limited, groups of plants may be planted to form islands within the larger revegetation site. For instance, if seeds or seedlings for specific forbs are extremely scarce or limited, they may be added to islands or patches of shrub and grass within the larger revegetation site. Although few in number, these plants provide a seed source for future plant establishment and provide a more diverse system. Plants also may be planted into islands or pockets within the site to take advantage of site-specific topography, provide better access to water, or to take advantage of specific soil conditions that do not occur across the site or amendments that are not practical to apply across the entire area.

The type of nursery stock and the conditions on the revegetation site usually dictate the specific planting methods and tools; no single tool will work for all types of nursery plants and under all site conditions. The depth and the width of the root plug are critical characteristics that must be considered in choosing the right methods. The most common type of planting method is manual planting using a shovel or a dibble. Recent developments in mechanized planting equipment have increased tools available, including power augers, expandable stingers (specialized planting equipment for rocky and steep slopes that creates a hole and plants a seedling in one operation), and pot planters, which hydraulically creates a plant hole by pushing water through a high-pressure nozzle as it is pushed into the soil.

5.3.3 Upland Community Species Seeding and Planting Rates

Over the past two decades, a number of documents and reports have been published that provide useful information on seeding methods and seeding rates for revegetation of shrub-steppe communities across the Intermountain West. The revegetation specialist is encouraged to review these documents for information helpful to planning and implementation. At the same time, caution should be exercised in applying techniques, planting rates, and information developed for similar species in similar plant communities without serious consideration of the magnitude and range of environmental differences between the communities found at the Hanford Site and shrub-steppe areas in Utah, Wyoming, Nevada, Oregon, and Idaho. The closest environmental analogue to shrub-steppe on the Hanford Site in the lower Columbia Basin would be the Snake River Plains region of Idaho. Most other regions that support shrub-steppe communities have significantly different soils, elevation, seasonality, and precipitation regimes, and amounts than the Hanford Site.

5.3.3.1 Grasses

The seeding rate refers to the number of seeds per unit area of soil; however, the rate is usually specified in terms of kilograms per hectare or pounds per acre. Although recommended rates vary by species, a rate of approximately 400 seeds per square meter or about 40 seeds per square foot is recommended for drill-seeded applications. Planting at this rate assumes approximately 30 percent to 50 percent emergence. All seeding rates must be calculated on a pure live seed (PLS) basis. The PLS is calculated by multiplying the percentage of germination by the percentage of purity of the seed lot and dividing by 100. The percentage of germination is the ratio of viable seed relative to the total amount of seed. Especially in wild-collected seed lots, there can be considerable quantities of nonviable seed due to factors such as uneven seed maturation, insect predation, or abortion prior to seed set. Cultivated seed will often, but not always, have higher proportions of viable seed. The percentage of purity refers to the proportion of the seed lot that is seed of the desired species. Seed lots will have varying proportions of chaff, leaf material, inorganic matter, and seeds of other species, including weeds. As an example, if a lot of bluebunch wheatgrass seed has 60 percent germination and 80 percent purity, the percent PLS value is:

Percent PLS = $(60 \times 80)/100 = 48$ percent

Thus, 10 pounds of bulk seed would contain 4.8 pounds of viable seed. If the goal were to plant 8 pounds of PLS per acre, purchasing and planting 16.7 lb of bulk seed would be required per acre (8 lb PLS/ac)/48 percent PLS).

Table 5.3 provides recommended seeding rates for single-species grass stands using a seed drill. These rates should be approximately doubled for broadcast seeding, and perhaps more for hydroseeding or for applications to especially harsh environments. The seeding rates listed in Table 5.3 must be adjusted for multi-species mixtures by multiplying the recommended rate by the desired proportion of the species in the total mix.

5.3.3.2 Shrubs

Shrubs can be either transplanted as seedlings or seeded. When sagebrush is planted as seed, it should be broadcast with little or no harrowing or other soil surface treatment. Sagebrush seeding rates of between about 0.25 and 0.5 lb PLS/ac were recommended by McLendon and Redente (1997), although higher rates have been used in mine-land reclamation (e.g., Hild et al. 2006). Sagebrush seedling transplant densities on the Hanford Site have normally been at least 1000/ha (400/ac). This planting density is expected to result in at least a 10 percent sagebrush cover, assuming about 60 percent survival.

Rabbitbrush, bitterbrush, and hopsage also have been successfully planted on the Hanford Site and have been used for waste site restoration plantings. McLendon and Redente (1997) recommend seeding rates for rabbitbrush between 0.25 and 0.5 lb/ac, and up to 1 lb/ac for bitterbrush. The seedling transplant density should be up to 400 plants/ac.

5.3.3.3 Forbs

Forbs can be either transplanted as seedlings or drill-seeded in mixtures or inter-seeded with grasses. Forb seeding can be accomplished using a specialty drill or special practices to seed small and fluffy forb and shrub seed. Equipment such as a Truax drill or a Brillion drill is designed for forb and shrub seeds. Because the size and number of forb seeds per pound of PLS varies significantly for the different types of forbs, it is difficult to specify seeding rates by species. However, a general rule of thumb would be to use 2 to 8 oz. /ac for a specific forb species when seeding with a mixture of four to five forb species.

Many forb species also can be successfully grown out as nursery stock for transplanting directly into a revegetation unit. Seed availability for a number of forb species is likely to be limited for the short term, and growing out stock for transplanting may be the most economical and viable method for including some types of forbs in revegetation actions. If the amount of seed for forb species is limited, planting nursery stock can complement reseeding and increase the chances of revegetation success with rapid plant establishment. Planting also bypasses the germination and establishment stages.

Where forb seed availability is severely limited, available individuals can be planted in 'islands' or as strips to form central, established stands of forbs that can reproduce and eventually spread into the larger revegetation unit. Results of planting these types of islands will occur over the long term, and should not be expected to result in an immediate increase in the number of non-seeded species (Sheley et al. 2008). However, establishing these types of islands within the larger revegetation unit has been shown to increase diversity over the short term.

Table 5.2. Perennial Grass Species Seeding Rates and Seed Sowing Density

Common Name	Scientific Name	Single Species Seeding Rate [(1)]		Number Seeds/kg	Number Seeds/lb[(2)]	Number Seeds/m²	Number Seeds/ft²
		kg PLS/ha	lb PLS/ac				
Thickspike wheatgrass	*Elymus lanceolatus*	13.4	12	336,600	153,000	451	42
Bluebunch wheatgrass	*Pseudoroegneria spicata*	13.4	12	277,200	126,000	371	35
Prairie Junegrass	*Koeleria cristata*	2.2	2	5093,000	2,315,000	1120	106
Indian ricegrass	*Achnatherum hymenoides*	13.4	12	356,400	162,000	478	45
Sandberg's bluegrass	*Poa secunda*	4.5	4	2,303,400	1,047,000	1037	96
Sand dropseed	*Sporobolus cryptandrus*	2.2	2	12,320,000	5,600,000	2710	257
Needle-and-thread grass	*Hesperostipa comata*	13.4	12	303,600	138,000	407	38
Thurber's needlegrass	*Achnatherum thurberianum*	9.0	8	495,000	225,000	446	41
Great basin wildrye	*Elymus cinereus*	12.3	11	316,800	144,000	390	36
Bottlebrush squirreltail	*Elymus elymoides*	13.4	12	422,400	192,000	566	53
Idaho fescue	*Festuca idahoensis*	9.0	8	990,000	450,000	891	83
Sand wildrye	*Leymus flavescens*	6.0	5	220,000	100,000	132	11

(1) Recommended seeding rates for single-species grass using a seed drill; if broadcast or hydroseeding, or if planting in especially harsh environments, the rates can increased 50 percent to 100 percent. Rates should be decreased proportionally for multi-species mixes.

(2) Source: PLANTS database (http://plants.usda.gov/characteristics.html)

6.0 Monitoring and Management

Information developed through monitoring the revegetation site and evaluation of the planting with respect to the revegetation objectives is used to guide the management and maintenance activities for the site. Even when all the best revegetation practices are applied and the revegetation plan is followed carefully, the resulting vegetation may not turn out as intended. Factors outside our control, such as unfavorable weather, disease, or unforeseen issues, can affect the success of the revegetation efforts. Monitoring and observation of the site is needed to evaluate success of the revegetation effort and determine whether further actions are needed to correct, manage, or maintain the restored area.

Monitoring allows managers and stakeholders to answer the following questions, in addition to improving revegetation efforts on future Hanford Site projects:

- Has native vegetation become well established on the revegetation site, or are corrective actions necessary?
- Have revegetation and/or restoration objectives and commitments been met?
- Do different revegetation treatments result in different plant responses?

Efforts to answer these questions begin during implementation of the revegetation project and continue after revegetation is complete. Data collected during monitoring plays an important role in advancing the knowledge and understanding regarding the establishment of native plants on the Hanford Site.

Monitoring and management of the revegetation site involves several steps:

- Revisit project objectives and desired future conditions
- Develop monitoring strategy and protocol(s)
- Record data and observations
- Evaluate data and compare to criteria for successful revegetation (desired future conditions)
- Develop and apply any corrective measures necessary to achieve success
- Share lessons learned

The intensity and duration of the monitoring effort for a revegetated site should be commensurate with the purpose and goal of the project. A revegetation effort intended to restore a plant community following a CERCLA cleanup action will likely require a longer and more intensive monitoring effort than a site that has been revegetated solely to provide short-term dust control.

6.1 Revegetation Site Monitoring

The desired future conditions will identify what site and vegetation characteristics will be monitored and define the minimum acceptable values for those characteristics. Each project shall develop a monitoring strategy that defines what criteria will be measured and how they will be evaluated. The monitoring protocols will define the methods, locations of samples, and timing and frequency of monitoring. Some Hanford Site revegetation actions, such as interim stabilization, might require only annual visits and recorded observations or qualitative assessments to determine whether the stabilization revegetation is successful or not. However, many of the revegetation and restoration projects will require statistically based sampling of specific characteristics to ensure regulatory compliance and accountability.

6.1.1 Monitoring Considerations

The monitoring protocols and overall monitoring plan are part of the revegetation plan and are written to define carefully those measurements necessary to determine whether the desired future conditions and revegetation objectives are met. To prepare a monitoring plan, three questions must be answered:

- What are you monitoring?
- How will you sample (including where, how many samples, and the shape or type of sampling planned)?
- How will achievement of desired future conditions be assessed, or what are the objectives of monitoring?

In general, four characteristics are of interest in monitoring revegetation success: the amount of bare ground, the abundance of species (cover and density of native plants in comparison to cover and density of exotic plants), the species diversity, or richness, and the measurement of attributes that indicate the survival and growth of the planted species. Additional attributes may be identified for specific species or for specific revegetation actions. The most efficient strategies and sampling unit sizes and shapes to acquire monitoring data depend on the attribute being measured as well as the growth form and spatial distribution of the species being evaluated. The most efficient design is usually the one that yields the highest statistical precision (smallest standard error and narrowest confidence interval around the mean) for either a given area sampled or a given amount of time or money.

Many different resources provide detailed information on how to measure and monitor plant populations and plant communities. A comprehensive reference that should be consulted in designing site-specific monitoring protocols is *Measuring and Monitoring Plant Populations* (BLM 1730-1), a technical reference document prepared by the Bureau of Land Management in collaboration with The Nature Conservancy. Following the guidance in this technical reference will ensure that the considerations associated with sampling frequency, sample placement, and timing of sampling will be adequately addressed.

Monitoring should generally be conducted during the season of maximum plant biomass and growth, for the largest number of species found on the revegetation unit, although there may be exceptions to this case. Monitoring during this period usually makes it easier to identify all the species found in the revegetation unit.

6.1.2 Measuring Abundance–Cover and Density

Measurements of density, frequency, or biomass generally employ a quadrat as the sampling unit. For cover, however, the sampling unit can be a line, a point, or a quadrat, depending on the vegetation type being measured. Density is measured by counting some entity (e.g., individuals, ramets, stems) within quadrats and the size and placement of the quadrats is based on the dispersion of the species of interest. In general, measurements of herbaceous species on the Hanford Site have traditionally been conducted using quadrats ranging in size from 0.1 m^2 to 0.5 m^2 to 1 m^2, depending on the size and distribution of the species of interest. In sandy and loam soils where bunchgrasses and forbs are less dense than on silt loam soils, the larger quadrat sizes are more likely to provide a representative sample using fewer quadrats. Quadrats can be used to estimate visually cover. Much of the historic vegetation sampling data available for Hanford has relied on visual estimates of canopy cover within quadrats.

Line interception and point interception are two techniques often used to estimate cover. The line or the point is the sampling unit. When line-intercept methods are applied to estimate shrub cover, the precision of the cover estimates depends on the variation among the lines and thus on the length of the lines. A single line (single sample) should never be assumed to adequately represent the cover of a target species.

Sampling quadrats, transects, or points can be placed systematically across the revegetation unit (such as along transects or grids equally spaced) or randomly located within the revegetation unit. Each of these strategies will provide adequate monitoring data to represent the stand if sufficient quadrats are sampled. Additional guidance for determining the number of samples and sampling quadrat placement within the revegetation units can be found in (BLM 1730-1) and in Steinfeld et al. (2007b). Both references provide detailed guidance for designing a monitoring strategy and protocols.

Sampling cover and density of shrub species usually requires larger sampling quadrats or plots to assess larger woody species. Density can be measured easily by counting the number of shrubs located in square or rectangular plots that encompass tens of square meters (i.e., such as a rectangular plot that measures 5 m by 20 m (16 ft. by 66 ft.) in width and length or a 10-m by 10-m (33-ft by 33-ft plot). Density can also be assessed by measuring and/or mapping species along a belt transect; each shrub occurring within a specified distance from a transect line can be identified by species and measurements recorded to document its location as a distance along the line and distance from the line.

6.1.3 Measuring Diversity—Species Richness

It is important to determine the number of species that establish on the revegetation site as well as whether the majority of the species are native or exotic. Species richness can be determined by a pedestrian survey of the site or by sampling in quadrats or along transects. If the number of species is counted in quadrats or along lines, it is generally expressed as a number of species and unit of measure.

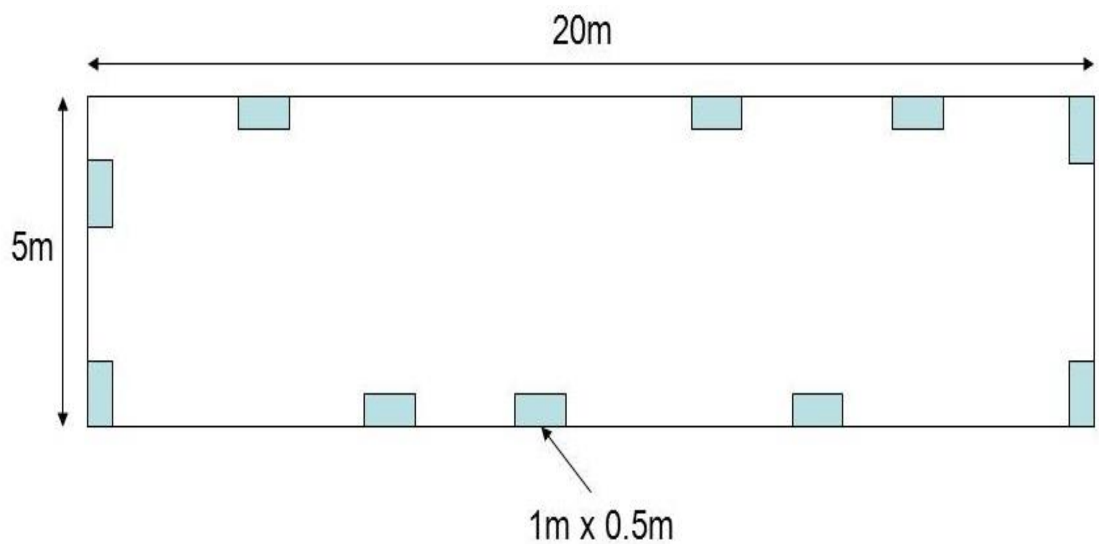
6.1.4 Measuring Growth and Survival

Another important metric for assessing the success or failure of the revegetation effort involves determining the survival rates for planted species as well as the growth rates of those plants and species that become established. Measurements of survival during the first and second years of monitoring after revegetation are usually critical metrics for evaluating whether the initial revegetation objectives have been met.

6.1.5 Suggested Monitoring Procedure

The suggested method for monitoring revegetation areas is to use a nested plot technique that allows different monitored parameters to be sampled at an appropriate scale. Each nested plot will consist of a 5 m × 20-m rectangular macro plot used to determine shrub density and overall species richness, and ten 0.5 m × 1-m small plots used to estimate herbaceous species cover and the density of bunchgrasses and forbs (Figure 6.1). The sampling method or details of the sampling design can be adjusted depending on the specific revegetation action and size or shape of the revegetation site. For instance, in mitigation plantings that include only shrub transplants, two to three 100-m-long × 10-m-wide permanent belt transects may be a preferred monitoring method.

Figure 6.1. Nested Sampling Plot Design for Monitoring Revegetation Areas



A minimum of three sample plots per revegetation unit is preferable. A revegetation unit is a contiguous area with similar environmental constraints treated with the same revegetation actions. A single revegetation site will often consist of one revegetation unit, but it could consist of two or more if there is enough variation in soils, topography, aspect, or some other environmental constraint. For sites up to three ha, three sample plots should be used. A 10-ha site should have five sample plots, and one additional plot should be added for each additional five ha of revegetation area. The revegetation unit should be divided into approximately equal sections; one sample plot then should be randomly placed in each section.

The corner points of each large sample plot should be permanently marked with rebar. A 50-m tape will fit around the perimeter of the larger sample plot. As one progresses clockwise from the beginning of the tape (upper left-hand corner in Figure 6.1), it is recommended that a 0.5-m × 1-m plot frame be laid, long axis parallel to the tape, on the inside of the tape at the following meter points: 3, 12, 16, 20, 24, 30, 36, 39, 45, and 48.

Within each plot frame, visually estimate the canopy cover for each species to the nearest percent. Density for each species is then determined by counting the number of individual grasses or forbs that are rooted within the frame. For small and very numerous plants or seedlings, one can subsample and average three 10 cm x 10 cm subportions of the plot frame. For analytical purposes, the 10 small plots are considered subsamples of the larger plot; therefore, the averages of each of the large plots are used to determine the mean and variance of the cover and density estimates.

After sampling the small plots, walk around the perimeter of the larger plot and record every species that is present inside of the plot. Count the number of shrubs that are present, by species. Measure the height, longest diameter, and perpendicular diameter for each shrub present within the larger plot. If shrub transplants are present, the larger plots should be surveyed shortly after planting so that transplant survival can be accurately estimated. The starting position can be used as a permanent photo-point, aimed at the opposite corner, for photo-documentation of vegetative growth and community structure.

6.2 Management of Revegetation Sites

The revegetation process does not end with the planting of the last seed or transplant. Revegetated sites must continue to be protected, monitored, and managed. Management of the revegetation site includes the following:

- Protecting the site from new disturbances, such as project construction or invasion by weeds
- Ensuring that adequate monitoring is conducted and that the results of the monitoring are available for review
- Using results of monitoring to guide management strategies and actions

6.2.1 Site Protection

Because of the expense and effort required to restore or enhance native plant communities on the Hanford Site and the important role these sites play in maintaining the diversity of native-dominated community's onsite, plant community restoration sites are considered high-priority resources within the *Hanford Site Biological Resources Management Plan (BRMaP)* (DOE/RL 96-32). Areas designated as onsite restoration or rectification areas under a record of decision or mitigation action plan or as part of a proposed NEPA action are considered Level 3 habitat resources under BRMaP. Areas designated as compensatory mitigation areas are considered Level 4 resources, the most-protected resource level in BRMaP.

Once a revegetated site has become established (other than interim stabilization sites), administrative and physical site protection measures should be instituted as appropriate. Administrative protection includes providing site coordinates for inclusion in site land-use and development maps and geographic information systems. Physical protective measures could include installing signs around the perimeter or at major access points but could also include installing physical barriers (e.g., fences, gates, or items such as boulders) to physically prevent vehicular entry.

6.2.2 Monitoring, Reporting, and Contingency Planning

Revegetated sites intended to restore or enhance native communities will be monitored for a minimum of five years post-planting using techniques as described in Section 6.1.2. The monitoring results will be compared with the predetermined criteria for the site. The criteria will normally be based on the desired future conditions for the site (Table 5.1), the interim success criteria described in Section 3.2, or measured values such as cover, density, and diversity obtained from a reference site. The comparison of the site's measured parameters with the predefined values helps to determine if the community is developing in the desired direction or if corrective actions should be taken. Sites planted for interim stabilization will be monitored to the extent needed to determine if the planted vegetation is performing its intended functions.

Monitoring results will be documented in annual revegetation monitoring reports. Reports for each site will include the measured values such as native and invasive plant cover, native and invasive species found on the site, transplant survival, and will compare these measured values to values from previous monitoring efforts, if available. The monitoring results will be accompanied with a written summary describing the revegetation of the site, including seeding rate and species, along with the number and type of transplants per acre. Annual monitoring reports will be provided to the Hanford Site integration contractor, currently Mission Support Alliance. For an example of revegetation monitoring reporting, see the Hanford Site Revegetation Monitoring Report for Fiscal Year 2019, available here (https://www.hanford.gov/files.cfm/HNF-64134_-_Rev_00.pdf).

Monitoring may also indicate that undesirable conditions have developed or are threatening to develop. Examples include invasion by noxious weeds or other undesirable species or unacceptable levels of herbivory. When monitoring indicates that the desired conditions have not been met, or it is unlikely that the conditions will be met within the desired timeframe, corrective actions must be taken unless otherwise approved by DOE-RL ESQ staff. Specific corrective actions would depend on the specific conditions or deficiencies encountered but could include relatively simple actions such as transplanting additional shrubs (PNNL-18824) or forbs or interseeding with additional grass seed. Additional corrective actions may be needed in some cases, such as removal of invasive species by physical or chemical means or even repeating much of the original revegetation actions. DOE expects projects or their responsible contractors to set aside or identify sufficient funding to implement appropriate corrective actions if monitoring indicates that the desired future conditions will not be met.

This page intentionally left blank

7.0 References

16 USC §1531. Endangered Species Act of 1973. Available at http://uscode.house.gov/download/pls/16C35.txt

33 USC §1251. *Clean Water Act of 1972*. Available at http://epw.senate.gov/water.pdf

42 USC §4321. *National Environmental Policy Act of 1969*. Available at http://www.fsa.usda.gov/Internet/FSA_File/nepa_statute.pdf

42 USC §9601. *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*. Available at http://frwebgate.access.gpo.gov/cgi-bin/usc.cgi?action=browse&title=42uscc103

43 USC §1700. *Federal Land Policy and Management Act of 1976*. Available at http://www.blm.gov/flpma/FLPMA.pdf

65 FR 37253-37257. Proclamation 7319 of June 9, 2000. *Establishment of the Hanford Reach National Monument*. June 12, 2000. Available at http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=2000_register&docid=00-15111-filed.pdf

79 FR 35903-35907. *Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators*. June 24, 2014. Available at https://www.govinfo.gov/content/pkg/FR-2014-06-24/html/2014-14946.htm.

AOSCA. 2003. *The AOSCA Native Plant Connection*, Association of Official Seed Certification Agencies. Available at: http://www.aosca.org/aoscanativeplantbrochure.pdf

Aubry, C, R Shoal, and V Erickson. 2005. *Grass Cultivars: Their Origins, Development, and Use on National Forests and Grasslands in the Pacific Northwest*. U.S. Department of Agriculture Forest Service. Available at http://www.fs.fed.us/wildflowers/nativeplantmaterials/documents/cultivars_maindoc_040405_appendices.pdf

Baskin, CC and JM Baskin. 1998. *Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination*. Academic Press, San Diego, California.

Baskin, JM and CC Baskin. 2004. *A Classification System for Seed Dormancy*. Seed Science Research 14:1-16. Available at: http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=704528&fulltextType=RA&fileId=S0960258504000017

BHI-00971. 1997. *Revegetation Manual for the Environmental Restoration Contractor*. McLendon T and EF Redente. Bechtel Hanford, Inc., Richland, Washington. Available at: http://www2.hanford.gov/arpir/?content=findpage&AKey=0093415

BHI-01694. 2003. *2003 Environmental Restoration Contractor Revegetation Monitoring Report*. BHI-01694, Rev. 0. Johnson AL. Bechtel Hanford, Inc., Richland, Washington. Available at http://www5.hanford.gov/pdw/fsd/ar/fsd0001/fsd0042/da06642343/1.pdf

Binkley, D and S Hart. 1989. *The Components of Nitrogen Availability Assessments in Forest Soils*. Advances in Soil Science 10:57-116. Available at: http://www.cnr.colostate.edu/%7Edan/papers/AdvancesSoilScience_10_1989.pdf

BLM 1730-1. 1998. Elzinga CL, DW Salzer, and JW Willoughby. 1998. *Measuring and Monitoring Plant Populations*. BLM Technical Reference 1730-1, U.S. Department of the Interior, Bureau of Land Management. Available at http://www.blm.gov/nstc/library/pdf/MeasAndMon.pdf

BNWL-243. 1966. *Soil Survey Hanford Project in Benton County, Washington*. BF Hajek, Pacific Northwest Laboratory, Richland, Washington. Available at http://www5.hanford.gov/arpir/?content=findpage&AKey=D196018787

Call CA and BA Roundy. 1991. Perspectives and Processes in Revegetation of Arid and Semiarid Rangelands. Journal of Range Management 44:543–549.

CIPM. 2002. *Invasive Plant Prevention*. Adapted from BLM Guidelines for Coordinated Management of Noxious Weeds. Chapter 10 in *Invasive Plant Management: CIPM Online Textbook.* Center for Invasive Plant Management, Bozeman, Montana. Available at http://www.weedcenter.org/textbook/index.html

Chambers, J. 2000. Seed Movements and Seedling Fates in Disturbed Sagebrush Steppe Ecosystems: Implications for Restoration. Ecological Applications 10(5):1400–1413. Available at: http://sfc.smallfarmcentral.com/dynamic_content/uploadfiles/152/seed%20movements%20and%20seedling%20fates.pdf

Clinton, W.J. 1994. *Environmentally and Economically Beneficial Practices on Federal Landscaped Grounds* . Memorandum from W. J. Clinton (President, United States of America) to Heads of Executive Department and Agencies, April 26, 1994. Available at www.gpo.gov/fdsys/pkg/WCPD-1994-05-02/pdf/WCPD-1994-05-02-Pg916.pdf

Clinton, W.J. 2000. *Memorandum on the Hanford Reach National Monument.* Memorandum from WJ Clinton (President, United States of America) to Secretary of Energy, June 9, 2000. Available at http://www.gpo.gov/fdsys/pkg/WCPD-2000-06-12/html/WCPD-2000-06-12-Pg1324.pdf

CTUIR. 2009. Confederated Tribes of the Umatilla Indian Reservation (CTUIR), Yakama Nation, Nez Perce, Pacific Northwest National Laboratory, U.S. Department of Energy, U.S. Fish and Wildlife Service, Wanapum, Washington Closure Hanford, and Washington State University–Tri Cities. 2009. *Revegetation of Disturbed Soils in the Columbia Basin Using Native Plants*. Richland, Washington.

CTIP. 2007. *Roadside Revegetation – An Integrated Approach to Establishing Native Plants*. Federal Lands Highway Office, Federal Highway Administration, Coordinated Technology Implementation Program. Available at http://www.nativerevegetation.org/

Daubenmire RF. 1970. *Steppe Vegetation of Washington.* Technical Bulletin 62, Washington Agricultural Experiment Station, Pullman.

DOE/EIS-0222-F. 1999. *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement and Comprehensive Land-Use Plan*, U.S. Department of Energy, Richland, Washington. Available at http://www5.hanford.gov/arpir/?content=findpage&AKey=D199158842

DOE/EIS-0222-SA-01. 2008. *Supplemental Analysis for the Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS)*. U.S. Department of Energy, Richland, Washington. Available at http://energy.gov/sites/prod/files/nepapub/nepa_documents/RedDont/EIS-0222-SA-01-2008.pdf

DOE/RL 96-32. 2001. *Hanford Site Biological Resources Management Plan (BRMaP)*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at https://www.hanford.gov/files.cfm/DOE-RL-96-32-01.pdf

DOE. 2011. Hanford Meteorological Station. *Monthly and Annual Precipitation*. Available at http://www.hanford.gov/page.cfm/hms/products/totprcp

Dorner, J. 2002. *An Introduction to Using Native Plants in Restoration Projects*. Plant Conservation Alliance Bureau of Land Management, US Department of Interior, U.S. Environmental Protection Agency, Seattle, Washington. Available at http://www.nps.gov/plants/restore/pubs/intronatplant/intronatplant.pdf

EPA. 2011. *Level III Ecoregions of the Continental United States*. National Health and Environmental Effects Research Laboratory, U.S. Environmental Protection Agency, Washington, D.C. Available at ftp://ftp.epa.gov/wed/ecoregions/us/Eco_Level_III_US.pdf

Fenner, M and K Thompson. 2005. *The Ecology of Seeds*. Cambridge University Press, New York. Available at: http://assets.cambridge.org/97805216/53688/copyright/9780521653688_copyright.pdf

Frederick, BA and DA Klein. 1994. Nitrogen Effects on Rhizosphere Processes of Range Grasses from Different Successional Series. Plant and Soil 161:241–250.

Gano, KA and CT Lindsey. 2007. *2007 River Corridor Closure Contractor Revegetation and Mitigation Monitoring Report*. WCH-223, Rev. 0, Washington Closure Hanford, LLC, Richland, Washington. Available at http://www.osti.gov/bridge/servlets/purl/944089-fWGpYD/944089.pdf

Greipsson, S. 1999. Seed Coating Improves Establishment of Surface Seeded Poa pratensis Used in Revegetation. Seed Science and Technology 27(3):1029–1032.

Hild, A, G Schuman, L Vicklund, and M Williams. 2006. *Canopy Growth and Density of Wyoming Big Sagebrush Sown with Cool-Season Perennial Grasses*. Arid Land Research and Management 20(3):183-194. Available at: http://ddr.nal.usda.gov/dspace/bitstream/10113/31823/1/IND43883354.pdf

HNF-62689. 2018. *Hanford Site Pollinator Study.* Rev. 0. Mission Support Alliance, Richland, Washington. Available at https://www.hanford.gov/files.cfm/FINAL_POLLINATOR_REPORT_HNF-62689_-_Rev_00_-_Copy-pages-4-115.pdf

HNF-64134. 2019. *Hanford Site Revegetation Monitoring for Fiscal Year 2019*. Rev. 0. Mission Support Alliance, Richland, Washington. Available at https://www.hanford.gov/files.cfm/HNF-64134_-_Rev_00.pdf

Huber, LS. 1993. *Native Seed Collection Guide for Ecosystem Restoration*. Wallowa–Whitman National Forest, Baker City, Oregon. Available at http://www.fs.fed.us/r6/nr/botany/pdf_files/seed.pdf

Hufford, K and SJ Mazer. 2003. *Plant Ecotypes: Genetic Differentiation in the Age of Ecological Restoration*. Trends in Ecology & Evolution 18:147–155. Available at: http://www.globalrestorationnetwork.org/uploads/files/LiteratureAttachments/225_plant-ecotypes---genetic-differentiation-in-the-age-of-ecological-restoration.pdf

Key, CH and NC Benson. 2006. *Landscape Assessment (LA) Sampling and Analysis Methods.* General Technical Report RMRS-GTR-164-CD, U.S. Department of Agriculture, Forest Service. Available at http://www.fs.fed.us/rm/pubs/rmrs_gtr164/rmrs_gtr164_13_land_assess.pdf

Knapp, EE and KJ Rice. 1994. *Starting from Seed: Genetic Issues in Using Native Grasses for Restoration*. Restoration and Management Notes 12(1):40–45.

Lesica, P and FW Allendorf. 1999. *Ecological Genetics and the Restoration of Plant Communities: Mix or Match?* Restoration Ecology 7:42–50. Available at: http://onlinelibrary.wiley.com/doi/10.1046/j.1526-100X.1999.07105.x/pdf

Lindsey, CT and KA Gano. 2008. *2008 River Corridor Closure Contractor Revegetation and Mitigation Monitoring Report*. WCH-288, Rev. 0, Washington Closure Hanford, LLC, Richland, Washington. Available at http://www.osti.gov/bridge/servlets/purl/973161-erJ0TK/973161.pdf

Linhart, YB. 1995. *Restoration, Revegetation, and the Importance of Genetic and Evolutionary Perspectives*. In: Roundy BA, McArthur ED, Haley JS, Mann DK, compilers. Proceedings: Wildland Shrub and Arid Land Restoration Symposium. Ogden (UT): USDA Forest Service, Intermountain Research Station. General Technical Report INT-GTR-315. p 271–287. Available at: http://www.fs.fed.us/rm/pubs_int/int_gtr315/int_gtr315_271_287.pdf

Mack, RN and DA Pyke. 1983. *Demography of Bromus tectorum: Variation in Time and Space*. Journal of Ecology 71:69–93. Available at http://pnw-ipc.org/docs/Demography%20of%20Bromus%20tectorum,%20time%20and%20space.pdf

McLendon, T., E.F. Redente. 1991. *Nitrogen and Phosphorus Effects on Secondary Succession Dynamics on a Semi-Arid Sagebrush Site*. Ecology, 72: 2016-2024. Ecological Society of America. Available at http://www.jstor.org/stable/1941556

Millar, CI and WJ Libby. 1989. *Disneyland or Native Ecosystem: Genetics and the Restorationist*. Restoration and Management Notes 7:18–24. Available at: http://www.floralocale.org/content.asp?did=23933

Montalvo, AM, SL Williams, KJ Rice, SL Buchmann, C Cory, SN Handel, GP Nabhan, R Primack, and RH Robichaux. 1997. *Restoration Biology: A Population Biology Perspective*. Restoration Ecology 5:277-290. Available at: http://onlinelibrary.wiley.com/doi/10.1046/j.1526-100X.1997.00542.x/pdf

National Invasive Species Council. 2008. 2008 – 2012 National Invasive Species Management Plan. 36 pp. August 2008. Available at http://www.invasivespecies.gov/home_documents/2008-2012%20National%20Invasive%20Species%20Management%20Plan.pdf (October 2011)

Padgett, PE, SN Kee, and EB Allen. 2000. *The Effects of Irrigation on Revegetation of Semiarid Coastal Sage Scrub in Southern California*. Environmental Management 26:427–435. Available at: http://www.ncbi.nlm.nih.gov/pubmed/10954806?dopt=Abstract

Page, RJ, DL Goodwin, and NE West. 1966. *Germination Requirements of Scarlet Globemallow*. Journal of Range Management 9:145–146.

Pellant, M. 1990. The Cheatgrass-Wildfire Cycle: Are There Any Solutions? In Proceedings -- Symposium on Cheatgrass Invasion, Shrub Die-Off, and Other Aspects of Shrub Biology and Management, ED McArthur, EM Romney, SD Smith, and PT Tueller (comps), pp. 11–18. General Technical Report INT-276, U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, Utah.

Pendery, BM and MD Rumbaugh. 1990. Survival and Growth of Globemallow (Sphaeralcea) Species in Dry Land Spaced-Plant Nurseries. Journal of Range Management 43(5):428–432.

Platt, K and ER Jackman. 1946. *The Cheatgrass Problem in Oregon*. Extension Bulletin 668, Oregon State College, Corvallis.

PNL-6415. 2007. *Hanford Site National Environmental Policy Act (NEPA) Characterization*. Duncan JP (ed.). PNL-6415, Rev 18, Pacific Northwest National Laboratory, Richland, Washington. Available at http://www2.hanford.gov/arpir/?content=findpage&AKey=D196042568

PNL-4622. 1983. *Climatological Summary for the Hanford Area*. Stone, WA, JM Thorp, OP Gifford, and DJ Hoitink. Pacific Northwest Laboratory, Richland, Washington.

PNNL-13688. 2001. *Vascular Plants of the Hanford Site*. Sackschewsky MR and JL Downs. Pacific Northwest National Laboratory, Richland, Washington. Available at http://ecology.pnnl.gov/library/pnnl13688.pdf

PNNL-14901. 2004. *W-519 Sagebrush Mitigation Project FY-2004 Final Review and Status*. Durham RE and MR Sackschewsky. Pacific Northwest National Laboratory, Richland, Washington. Available at http://www.pnl.gov/main/publications/external/technical_reports/PNNL-14901.pdf

PNNL-15160. 2005. *Hanford Site Climatological Summary 2004 with Historical Data*. Hoitink DJ, KW Burk, JV Ramsdell, Jr, and WJ Shaw. Pacific Northwest National Laboratory, Richland, Washington. Available at http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15160.pdf

PNNL-17927. 2008. *IDF Sagebrush Habitat Mitigation Project: FY2008 Compensation Area Monitoring Report*. Durham R and M Sackschewsky. Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=0093416

PNNL-18824. 2009. *L-325 Sagebrush Habitat Mitigation Project: FY2009 Compensation Area Monitoring Report* . Durham RE, and MR Sackschewsky. Pacific Northwest National Laboratory, Richland, WA. Available at http://www.pnl.gov/main/publications/external/technical_reports/PNNL-17926.pdf

Pollinator Health Task Force. 2015. *Pollinator Research Action Plan.* The White House, Washington, D. C. Available at https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/Pollinator%20Research%20Action%20Plan%202015.pdf

Rickard, WH, LE Rogers, BE Vaughn, and SF Liebetrau (eds). 1988. *Shrub-Steppe Balance and Change in a Semi-Arid Terrestrial Ecosystems*. Developments in Agricultural and Managed Forest Ecology 20, Elsevier, New York.

Roth, TE, JL Holechek, and MY Hussain. 1987. *Germination Response of Three Globemallow Species to Chemical Treatment*. Journal of Range Management 40(2):173–175.

SER. 2004. Society for Ecological Restoration International Science & Policy Working Group (Version 2: October, 2004). *The SER International Primer on Ecological Restoration*. Available at: http://www.ser.org/pdf/primer3.pdf

Sheley, R, J Mangold, K Goodwin, and J Marks. 2008. *Revegetation Guidelines for the Great Basin:* Considering *Invasive Weeds*. U.S. Department of Agriculture, Agricultural Research Service, Washington, D.C.

Sheley, RL, JS Jacobs, and RP Valagala. 1999. High Seeding Rate Enhance Intermediate Wheatgrass Establishment in Spotted Knapweed Infested Rangeland. Journal of Range Management 52:67–73.

Soil Survey Staff. 1994. *Keys to Soil Taxonomy*. 6th edition. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C. Available at ftp://ftp-fc.sc.egov.usda.gov/NSSC/Soil_Taxonomy/keys/1994_Keys_to_Soil_Taxonomy.pdf

Steinfeld, DE, SA Riley, KM Wilkinson, TD Landis, and LE Riley. 2007a. *A Manager's Guide to Roadside Revegetation Using Native Plants*. FHWA-WFL/ TD-07-006, Technology Deployment Program, Western Federal Lands Highway Division, Federal Highway Administration, Vancouver, Washington. Available at http://www.wfl.fhwa.dot.gov/programs/td/publications/documents/managers-guide.pdf

Steinfeld, DE, SA Riley, KM Wilkinson, TD Landis, and LE Riley. 2007b. Roadside Revegetation: An Integrated Approach to Establishing Native Plants. FHWA-WFL/TD-07-005, Technology Deployment Program, Western Federal Lands Highway Division, Federal Highway Administration, Vancouver, Washington. Available at http://www.wfl.fhwa.dot.gov/programs/td/publications/documents/reveg-documents/roadside-revegetation-manual.pdf.

Stenger, R, E Priesack, and F Beese. 1995. *Rates of Net Nitrogen Mineralization in Disturbed and Undisturbed Soils*. Plant and Soil 171(2):323–332. Available at: http://www.mendeley.com/research/rates-net-nitrogen-mineralization-disturbed-undisturbed-soils-1/

Stewart, G and AC Hull. 1949. *Cheatgrass (Bromus tectorum) - An Ecologic Intruder in Southern Idaho*. Ecology 30(1):58–74. Available at: http://www.jstor.org/pss/1932277

Stohlgren, TJ, D Binkley, and GW Chong. 1999. *Exotic Plant Species Invade Hot Spots of Native Plant Diversity*. Ecological Monographs 69:25–46. Available at: http://www.fort.usgs.gov/Products/Publications/3493/3493.pdf

Sumner, DC and RD Cobb. 1967. *Germination Characteristics of Cheeseweed (Malva parviflora L.) Seeds*. Agronomy Journal 59:207–208. Available at: https://www.agronomy.org/publications/aj/abstracts/59/2/AJ0590020207

Svejcar, T. 2003. *Applying Ecological Principles to Wildland Weed Management*." Weed Science 51(2):266-270. Available at: http://oregonstate.edu/dept/EOARC/sites/default/files/researchhome/documents/470.pdf

Tilman, D and D Wedin. 1991. *Dynamics of Nitrogen Competition Between Successional Grasses*. Ecology 72:1038–1049. Available at: http://www.jstor.org/pss/1940604

USDA. 2011. *Plants Database*. U.S. Department of Agriculture. Available at http://plants.usda.gov

USFS and DOI. 2002. A Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment: 10-Year Comprehensive Strategy Implementation Plan. U.S. Forest Service and U.S. Department of the Interior. Available at http://www.westgov.org/reports?start=24

USFS. 2008. Forest Service Manual National Headquarters, Washington, DC. *FSM 2000 - National Forest Resource Management, Chapter 2070 – Vegetation Ecology*. U.S. Forest Service. Available at http://wvvw.amseed.org/pdfs/FSM-VegEcology.pdf

USFWS. 2008. *Final Hanford Reach National Monument Comprehensive Conservation Plan and Environmental Impact Statement*. Burbank, Washington. U.S. Fish and Wildlife Service. Available at http://www.fws.gov/hanfordreach/management.html#finalccp

Velagala, RP, RL Sheley, and JS Jacobs. 1997. *Influence of Density on Intermediate Wheatgrass and Spotted Knapweed Interference*. Journal of Range Management 50:523–529.

Vitousek, PM, PA Matson, and K Van Cleve. 1989. *Nitrogen Availability and Nitrification during Succession: Primary, Secondary, and Old-Field Series*. Plant and Soil 115:229–239. Available at: http://www.springerlink.com/content/f6022krm3v015624/

Winslow, SR. 2007. *Native Plant Seed Collection and Seed Production for Reclamation*. U.S. Department of Agriculture, Natural Resources Conservation Service Plant Materials Center, Bridger, Montana. Available at www.plant-materials.nrcs.usda.gov/pubs/mtpmcsy3202.pdf

Winter, DM. 1960. The Development of the Seed of Abutilon Theophrasti, II Seed Coat. American Journal of Botany 47(3):157–162.

Withrow-Robinson, B. and R. Johnson. 2006. *Selecting Native Plant Materials for Restoration Projects Ensuring Local Adaptation and Maintaining Genetic Diversity*. USDA Forest Service, Pacific Northwest Research Station, Oregon State University, Corvallis.
Available at http://extension.oregonstate.edu/catalog/pdf/em/em8885-e.pdf

WNHP. 2012. *Rare Plants Information Available from the Washington Natural Heritage Program*. Washington Natural Heritage Program. http://www1.dnr.wa.gov/nhp/refdesk/plants.html.

Young, JA and RA Evans. 1975. *Germinability of Seed Reserves in a Big Sagebrush Community*. Weed Science 23:358–364.

This page intentionally left blank.

Appendix A Phenological Information on Plants Native to the Hanford Site

Common Name	Scientific Name	Growth Habit	Family	Bloom Period	Seed Collection Times	Source
Carey's balsamroot	Balsamorhiza careyana	forb/herb	Asteraceae	spring	early spring	b
cushion fleabane	Erigeron poliospermus	forb/herb	Asteraceae	April–June	May-June	c
hoary aster	Machaeranthera canescens	forb/herb	Asteraceae	August–October	fall	a
hoary false-yarrow	Chaenactis douglasii	forb/herb	Asteraceae	June–July	fall	a
Piper's daisy	Erigeron piperianus	forb/herb	Asteraceae	May–June	June	d
shaggy fleabane	Erigeron pumilus	forb/herb	Asteraceae	April–June	May-June	
slender hawksbeard	Crepis atribarba-	forb/herb	Asteraceae	April-May	May-June	
threadleaf fleabane	Erigeron filifolius	forb/herb	Asteraceae	April–June	May-June	
yarrow	Achillea millefolium	forb/herb	Asteraceae	April–June	May-June	
Columbia cutleaf	Hymenopappus filifolius	forb/herb, subshrub	Asteraceae	April-May	May-June	
Cusick's sunflower	Helianthus cusickii	forb/herb, subshrub	Asteraceae	April–August	early summer	c
big sagebrush	Artemisia tridentata	shrub	Asteraceae	mid-summer	early October to end of December	b
gray rabbitbrush	Ericameria nauseosa	shrub	Asteraceae	August–September	early September to mid-November	c
threetip sage	Artemisia tripartita	shrub	Asteraceae	late summer	fall	b
green rabbitbrush	Chrysothamnus viscidiflorus	shrub, subshrub	Asteraceae	spring	late fall- early winter	b
antelope bitterbrush	Purshia tridentata	shrub, tree	Asteraceae	May–July	mid-summer	a
Western gromwell	Lithospermum ruderale	forb/herb	Boraginaceae	Late sp[ring	summer	b
Franklin's sandwort	Arenaria franklinii	forb/herb, subshrub	Caryophyllaceae	April-May	June	
spiny hopsage	Grayia spinosa	subshrub, shrub	Chenopodiaceae	April-May	May-June	b
winterfat	Krascheninnikovia lanata	subshrub, shrub	Chenopodiaceae	spring	Late summer-fall	b
buckwheat milkvetch	Astragalus caricinus	forb/herb	Fabaceae	April-June		
crouching milkvetch	Astragalus succumbens	forb/herb	Fabaceae	April–June	early summer	c
dune scurfpea	Psoralea lanceolata	forb/herb	Fabaceae	May–September	summer-fall	c
lupine sp.	Lupinus sp	forb/herb	Fabaceae	May–August	summer	c
stalked-pod milkvetch	Astragalus sclerocarpus	forb/herb	Fabaceae	spring	Early summer	
Western prairie clover	Dalea ornata	forb/herb	Fabaceae	spring	Early summer	
threadleaf scorpionweed	Phacelia linearis	forb/herb	Hydrophyllaceae	April-May	Early summer	
whiteleaf scorpionweed	Phacelia hastata	forb/herb	Hydrophyllaceae	April-June	Early summer	b
Mariposa lily	Calochortus macrocarpus	forb/herb	Liliaceae	May-June	Summer	b
yellowbell	Fritillaria pudica	forb/herb	Liliaceae	Early spring	spring	b

Common Name	Scientific Name	Growth Habit	Family	Bloom Period	Seed Collection Times	Source
Munro's globemallow	*Sphaeralcea munroana*	subshrub, forb/herb	Malvaceae	May–July	summer	b
Pale evening primrose	*Oenothera pallida*	forb/herb	Onagraceae	late spring	early summer	b
Idaho fescue	*Festuca idahoensis*	graminoid	Poaceae	March–April	mid- to late summer	b
Indian ricegrass	*Oryzopsis hymenoides*	graminoid	Poaceae	spring	mid-summer	b
needle-and-thread grass	*Stipa comata*	graminoid	Poaceae	June	July	b
prairie junegrass	*Koeleria macrantha*	graminoid	Poaceae	April–June	July–August	b
sand dropseed	*Sporobolus cryptandrus*	graminoid	Poaceae	late summer	Fall	b
sand wildrye	*Elymus flavescens*	graminoid	Poaceae	late spring	summer	b
Sandberg's bluegrass	*Poa secunda*	graminoid	Poaceae	early spring	late spring	
sterile rye	*Secale cereale*	graminoid	Poaceae	spring	summer	b
sterile wheat	*Triticum aestivum*	graminoid	Poaceae	spring	summer	b
thickspike wheatgrass	*Elymus lanceolatus*	graminoid	Poaceae	spring	early summer	b
Thurber's needlegrass	*Achnatherum thurberianum*	graminoid	Poaceae	spring	early summer	
bluebunch wheatgrass	*Agropyron spicatum*	grass, graminoid	Poaceae	early summer	mid-July to mid-August	b
bottlebrush squirreltail	*Elymus elymoides*	grass, graminoid	Poaceae	mid-spring	July–September	b
Cusick's bluegrass	*Poa cusickii*	grass, graminoid	Poaceae	June–August		
long-leaf phlox	*Phlox longifolia*	subshrub, shrub, forb/herb	Polemoniaceae	May–June	summer	b
snow buckwheat	*Eriogonum niveum*	subshrub, forb/herb	Polygonaceae	Late summer	Late summer - fall	b
sand beardtongue	*Penstemon accuminatus*	subshrub, forb/herb	Scrophulariaceae	May–June	summer	b

(a) http://www.wildflower.org/plants/.
(b) http://plants.usda.gov/characteristics.html.
(c) http://biology.burke.washington.edu/herbarium/imagecollection.php.
(d) http://www1.dnr.wa.gov/nhp/refdesk/fguide/htm/fsfgabc.htm.

Appendix B Resources for Revegetation Planning and Implementation

Many Internet-based resources and reports are focused on developing information needed for restoring native landscapes. A sample of the resources currently available to plan and implement revegetation actions using native plant species is provided below:

Native species recommendations for shrub-steppe ecoregions, and potential seed vendors can be found at The Native Seed Network. Available at http://www.nativeseednetwork.org/

U.S. Department of Agriculture, Natural Resources Conservation Service Plants Database provides plant profiles with synonyms, classifications, distribution maps, images, and additional sources and references for plant species. Available at http://plants.usda.gov/

VegSpec. Internet-based decision support system that assists land managers in planning and designing revegetation projects. VegSpec utilizes soil, plant, and climate data to select plant species that are site-specifically adapted, suitable for the selected practice, and appropriate for the goals and objectives of the revegetation project. Available at http://vegspec.nrcs.usda.gov/vegSpec/index.jsp

The *Intermountain Planting Guide* published by the U.S. Department of Agriculture, Agriculture Research Service. Available at http://extension.usu.edu/files/publications/publication/pub__7717229.pdf

Restoring Western Ranges and Wildlands, a three-volume guide published by the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
Available at http://www.treesearch.fs.fed.us/pubs/.

Roadside Revegetation – An Integrated Approach to Establishing Native Plants. Federal Lands Highway Office, Federal Highway Administration Coordinated Technology Implementation Program (CTIP).
Available at http://www.nativerevegetation.org/

Benson, J. E., R.T. Tveten, M. G. Asher and P.W. Dunwiddie. 2011. Shrub-Steppe and Grassland Restoration Manual for the Columbia River Basin.
Available at http://wdfw.wa.gov/publications/01330/

This page intentionally left blank.

C.1 Introduction

Revegetation actions with the goal of restoring native plant communities aim to restore functional plant communities dominated by locally derived, native species. As prescribed by DOE/RL-2011-116, *Hanford Site Revegetation Manual*, all seed used in revegetation projects must be locally derived or source-identified from a nearby location with similar climatic and soil conditions, ideally within 50 mi of the Hanford Site. Locally derived seed is better adapted to the unique climate conditions of the Hanford Site and is more likely to survive than seed from areas with different climate conditions.

The requirement to revegetate with locally derived seed limits the seed stock available to revegetation projects, as many of the species recommended by the *Hanford Site Revegetation Manual* are not readily available at local nurseries. Seed collection on the Hanford Site is a way to provide locally-sourced native seed for revegetation projects.

Many factors must be considered when collecting native seed. The collection of too much native seed can disrupt successful plant reproduction and have negative effects on entire plant populations. Over-collecting from a certain area can result in a lack of genetic variation in the seed, making the seeded populations more vulnerable to detrimental environmental effects. Incorrect seed storage can lead to total loss of seed viability, resulting in a wasted collection and no net benefit to the environment.

An established seed collection protocol is necessary to reduce the negative effects of seed collection to the environment, as well as to ensure collections are done correctly and the seed remains viable. This document describes seed collection protocol for the Hanford Site, with the purpose of collecting seed for use in revegetation projects.

C.2 Seed Collection

C.2.1 Identify Need

The first step in a successful seed collection is to identify the purpose and need for the collection. Seed collection should not occur without a defined need, as collection for the sake of collection is detrimental to the environment. Seed collection needs on the Hanford Site can be generally split into two categories: short-term needs and long-term needs. Short-term needs are time-sensitive and collections would need to occur on certain years in order to meet them. Short-term needs for seed collection would include collecting seed to be broadcast-seeded in a planned revegetation project, collecting seed to be grown-out at a nursery and planted as plugs the following year, or collecting seed from an area that is being converted to industrial use. Long-term needs for seed collections would be to supplement any existing collections of commonly used seed (e.g., big sagebrush [*Artemisia tridentata*] seed) with crops from multiple years.

By identifying the need prior to collection, the planner will have a better idea of the amount of seed necessary. These guidelines are for seed collection for restoration purposes and are not intended to be followed for collections with the goal of conservation or seed banking.

C.2.2 Timing of Collection

One of the more difficult elements of planning seed collection is identifying when seed will be mature enough for collection to take place. Weather conditions will vary year to year and affect both the bloom time of plants and how quickly seed matures. Herbaceous annuals and perennials may take 2 to 5 weeks to produce mature seed after blooming, while shrubs can take up to 8 weeks (Wall 2009). Seeds that are dispersed by wind present another challenge, as a strong rain or windstorm can disperse the seed before there is a chance for it to be collected.

Generally, the most effective way to identify when seed is mature enough for collection is to visit plants on the collection site periodically after peak bloom, with frequency of site visits increasing as the seed gets closer to maturation. Plants in different locations (higher elevation, north-facing aspects, further north or south) will mature at different times so it is important to visit plants in multiple locations to determine readiness (Wall 2009).

Beginning seed collection at the same time as natural dispersal will help ensure mature seed is being collected (Barton et al. 2016). Approximate seed collection times for common Hanford Site species are summarized in Appendix A of the *Hanford Site Revegetation Manual*. Mature seed should easily fall off the plant with a shake or light pull. For most species on the Hanford Site, mature seed will appear brown and dried with little to no green coloration and the seed will be hardened and difficult to pierce with a thumbnail. Research the target species before collecting to determine mature seed characteristics.

Each species will have a collection window, or the amount of time the seed is mature and has not yet dropped from the plant. Plan seed collection to occur within this window, ideally before disruptive weather events like rain or windstorms that may cause seed to naturally disperse. Seed should be collected when it is dry and it may be necessary to wait until moisture from rain, frost, or morning dew has evaporated. For some seeds that mature in the winter, like big sagebrush, it may be necessary to collect seed while moist from frost or snow. In those cases, follow drying protocol described in Section C.3 *Short-Term Seed Storage*.

C.2.3 Determining Source Populations

The source population is the population from which seed will be collected. These populations will ultimately provide the genetic material for the restoration site. When using native seed in habitat restoration, it is important to have diverse representations of species. A genetically diverse population is more resilient to environmental change, resulting in a more stable restoration site (Smith et al. 2007, Vander Mijnsbrugge et al. 2009). The approach to determining source populations will vary depending on the goal of the collection.

For seed collections without a defined restoration site (long-term collections), it is important to choose populations that will maximize the genetic variation within the seed collection. This increases the chance that at least some of the native seed will be suitable for the conditions of the restoration site where they are eventually used. In order to maximize genetic variation within the seed collection, seed should be collected from a variety of populations for each species on the Hanford Site. The extent and boundaries of different populations will vary from species to species, a general rule of thumb is that 0.25 mi between populations will prevent most pollen or seed exchange, resulting in somewhat defined populations (Huber 1993). *Ex Situ Plant Conservation* (Guerrant et al. 2009) and Center for Plant Conservation guidelines recommend sampling up to 50 populations and 50 individuals within each populations in order to reasonably capture a species' genetic diversity. This recommendation is for the purposes of seed banking and conservation but can still be applied to maintaining a diverse seed collection for restoration projects.

Collecting from 50 individuals in 50 separate populations is often not possible given the time and resources available for seed collection. When fewer resources are available, targeting populations in a variety of habitats within the Hanford Site can increase the genetic diversity of the collection. Habitats that differ even slightly may favor certain traits that prove advantageous in a restoration site. Collecting seed from as many populations as time and resources allow for will likely increase genetic diversity within the collected seed.

For seed collections intended for use in a defined restoration site, it is important to collect from source populations in habitats similar to the restoration site. Collecting from populations of the target species that grow in similar habitats as the restoration site, such as on the same soil type and at approximately the same elevation, will increase the likelihood the seed is adapted to the restoration site (Jones 2013, Vander Mijnsbrugge et al. 2009). This may ultimately help ensure the persistence of local eco-types and local genetic information (Barton et al. 2016). Collecting from similar habitats is more important than collecting from habitats nearby to the restoration site in terms of selecting genetically, well-adapted individuals (Vander Mijnsbrugge et al. 2009).

When collecting for a defined restoration area it is still important to collect from a large number of individuals and as many populations as possible to reduce inbreeding depression at the restoration site. Restoration-specific guidelines recommend collecting seed from at least 30 to 50 individuals per source populations to maximize genetic diversity (Wall 2009, Vander Mijnsbrugge et al. 2009).

C.2.4 Collection Intensity and Frequency

Collection intensity and frequency should be determined based on the goal of seed collection. For restoration project collections, the planner should determine the amount of Pure Live Seed (PLS) needed for the restoration project and use available, stockpiled seed when possible. PLS refers to the percentage of living seed in a seed collection that is the target species and will germinate. Determining the amount of uncleaned seed needed for a specific project is impossible, as the seed will vary in both purity and viability. It should be expected that the end quantity of PLS after cleaning and testing will be significantly less than what was collected, especially for species with small seeds that are easily mixed with debris.

Maintaining long-term stability of the source population should be the first priority when collecting seed. Increased frequency and intensity of seed harvest increases extinction risk for perennial plants, especially for plants with small populations (Menges et al. 2009). Different species, and even different populations of the same species, will react to seed collection differently so it is best to take the most conservative approach when collecting seed from a population.

The Center for Plant Conservation research and guidelines provide a conservative approach to follow when collecting seed, as outlined in *Ex Situ Plant Conservation*. Seed collection can be thought of both in terms of percent harvest and percent frequency. Percent harvest refers to the percentage of viable seed removed from one plant. Percent frequency refers to the percentage of years where seed collection takes place from a source population. A seed collection regime with 50% harvest at 10% frequency would harvest 50% of the viable seed from individual plants in 10% of years, or once every 10 years.

For most perennial species, frequent low-intensity harvests are less harmful than infrequent high-intensity harvests, and much less harmful than frequent high-intensity harvests. Harvest effects varied by species with woody species generally less harmed by seed collection when compared to herbaceous species; woody perennials were found to tolerate short-term seed harvests of any intensity without increasing short-term extinction risk (Guerrant et al. 2009).

Population size must be considered before determining the seed collection rate. According to *Ex Situ Plant Conservation*, larger populations should be able to tolerate higher intensity collections. A reasonable and safe harvesting level for most perennial species with populations of at least 100 individuals is 10% harvest at 90% frequency, or the 10/90 rule. For small populations or populations sensitive to seed harvest, a safe level of seed collection will be 10% harvest at 10% frequency. *Ex Situ Plant Conservation* refers to this as the 10/10 rule, which did not increase extinction risk for all of the species investigated. Recommended seed collection rates range in the literature from 5% (Barton et al. 2016) to 20% (BLM 2016), but these rates do not consider the frequency of collection. For the purposes of stable populations of over 100 individuals on the Hanford Site, the 10/90 rule from *Ex Situ Plant Conservation* can be followed and is considered a safe collection rate.

Rare plants are an exception to the 10/90 rule and should be treated conservatively, as the persistence of the existing rare plant population is the first priority. If research shows a conservative seed collection will not cause long-term harm to the population, follow the 10/10 rule presented in *Ex Situ Plant Conservation*, which was found to be a safe approach for all species.

For collections targeting seed in areas that will be converted to industrial use, long-term stability and extinction risk of the affected population is not a consideration, as it will ultimately be removed. These collections can take 100% of mature seed from the targeted plants but should consider dispersal distance of the seed if the project area is adjacent to a natural area. Plants within dispersal distance of the natural area should be collected from as if they were part of the natural area and not being removed (collect 10% of seed). This will help ensure the seed bank of the surrounding area is not being depleted as a result of seed collection.

C.2.5 Collection Methods

Once the collection intensity and frequency has been determined, the collection method must be determined. Collection methods will typically vary depending on the target species. General guidelines are provided below but researching how the target species disperses seed prior to collection is critical. Mechanical methods can be used to collect seed, but non-mechanical methods are generally least disruptive to the plants and the environment. Non-mechanical methods are described below.

Seed collection techniques can include the following:

- Hand Stripping – the collector pulls along the seed head to dislodge seed into a container beneath. Ideal for plants with upright seed heads where seeds mature at the same time.
- Shaking – the collector lightly shakes branches to dislodge seeds into a container or tarp beneath. Ideal for plants with medium to large seeds.
- Picking – the collector picks individual seeds off the seed heads and deposits them into a container or bag. Ideal for precisely selecting mature seeds and fleshy fruits.
- Cutting – the collector cuts the seed heads below the spikelet and harvests them whole. Ideal for harvesting indeterminate seed heads or species with explosive dehiscence.

Shrubs like big sagebrush, antelope bitterbrush (*Purshia tridentata*), and spiny hopsage (*Grayia spinosa)* have seed that can be picked, hand stripped, or shaken into a bucket or tarp spread under the plant. Shaking will dislodge seeds ready for dispersal and it is an effective method to collect mature seed (Way and Gold 2014). Rabbitbrush (*Ericameria nauseosa* and *Chrysothamnus viscidiflorous*) seed can be picked into a bucket or harvested using a method where the seed is not susceptible to being blown away by wind.

Grass species can be hand stripped or shaken off the stem, or the seed heads can be cut below the spikelet and harvested whole. Forb seeds will vary from species to species but can typically be picked or shaken into a paper bag or bucket. For species that dehisce explosively, it may be advantageous to clip entire seed heads before maturity and allow them to mature in a paper bag or well-ventilated area in order to catch the seed.

Care should be taken in all seed collection activities to avoid accidentally collecting seed from non-native weedy species, most notably from cheatgrass (*Bromus tectorum*). Cheatgrass is ubiquitous on the Hanford Site and will most likely be near the target species. Harvesting seed from the ground is generally not recommended as it is likely mixed with cheatgrass seed. Though some non-native seed can be removed during the seed cleaning process, often it will remain in the cleaned seed and will end up being distributed in restoration sites.

Seed can be initially harvested into a bucket or tarp, but should be moved into a breathable bag as soon as possible, as described in Section C.3 *Short-Term Storage*.

C.2.6 Estimated Effort

Determining approximate labor hours in relation to amount of seed collection is difficult as it varies based on the species, seed size, size of population, time of year, and amount of seed produced in the growing season. Generally, smaller forb species will require the most effort to collect seed from (Majerus 1999). The collection window, or the amount of time mature seed will be available, will vary from species to species and should also be considered when determining team size. Species with extensive populations and a high amount of seed produced per individual will require less effort to collect from than scattered species with a low amount of seed per individual.

Collection planners should consider the amount of seed needed, seed size/weight of the target species, the collection window, population density, and location of source populations when determining effort required. For species that are expected to be high effort, having a larger collecting team will allow more populations to be sampled within the collection window.

C.2.7 Documentation

Collections of the same species occurring over multiple years have the risk of targeting a single population too intensely. Though the guidelines in Section C.2.4 *Collection Intensity and Frequency* provide safe collection levels, adhering to the safe collection frequency of a population is not possible without documentation of the sites from which collection has previously occurred.

All seed collection sites at the Hanford Site should be documented using the Seed Collection Site Form (Figure C.1), provided at the end of these guidelines (Site Form A-6007-899). One form should be completed for each source population. This form will allow seed collection sites to be entered into a Geographic Information Systems database and tracked over multiple years. Collection planners can use this database to determine how frequently seed collection occurs at each source population.

C.3 Short-Term Seed Storage

Proper seed storage is essential to ensure seed is still viable when it is planted. Seed collection is futile without proper seed storage. This section addresses short-term seed storage, referring to the time between collection and seed cleaning. See *Long-Term Seed Storage* for seed storage recommendations post-cleaning.

Three factors play an important role in seed storage: moisture/humidity, temperature, and light. Lowering the exposure of seed to light, heat, and high humidity throughout the storage process will result in a more successful seed collection (Guerrant et al. 2009; USDA 1978). These factors will have a greater effect on seed viability the longer seeds are in storage (USDA 1978).

Humidity and moisture are the most important factor affecting seed longevity and steps should be taken to prevent high humidity through all steps of the seed collection and storage process (Gold 2014). Collectors should avoid harvesting seed when it is moist (to the extent possible), such as after a rainstorm, frost, or morning dew. After collection in a bucket or tarp, dry seed should be moved into breathable bags made of cloth or paper to prevent moisture buildup (Way and Gold 2014). Plastic bags should be considered a last resort and special care will have to be made to ensure the seed does not mold, such as increased stirring post-harvest.

Harvested seed should be stored in a shaded area or vehicle until fieldwork is complete. After collection, seed should be stored indoors in a short-term storage location on the Hanford Site that is dry, dark, relatively cool, and has no known rodent infestations. At the end of each day, drop off seed at this location. Harvested seed should not be stored in vehicles for multiple days, especially in warm months, as the heat will cause the seeds to degrade. Additionally, seed collected on the Hanford Site cannot be removed from the site without a radiological survey, so the storage location must be within the boundary of the Hanford Site.

The majority of seed collected from the Hanford Site is dry, without a fleshy exterior. When processing fleshy fruit, remove the seed as soon as possible and leave it to dry outside of the collection bag. The seed will need to dry slowly for 1 to 2 weeks before moved to long-term storage (Gold 2014). Alternatively, fleshy seed can immediately be sent to a nursery to be grown out.

Even if the seed appears dry, if it is stored in bags or thick piles it should be stirred periodically to prevent buildup of moisture. Stirring the seed one to two times a week should be sufficient for most species, but the collector will have to use their best judgement. For seed being stored in non-breathable bags, the seed should be stirred at least twice weekly. If seed is noticeably moist when collected, it should be spread into a thin layer on a tarp when stored to allow moisture to evaporate. Once moisture evaporates, move seed back into a container and stir periodically. The stirring process should continue until seed is completely dried and ready to be shipped to a seed cleaner.

C.4 Seed Cleaning and Testing

Seed cleaning and testing is most efficiently performed by an offsite contractor. All seed must be radiologically surveyed and released before removal from the Hanford Site and prior to seed cleaning and testing. After the material is cleared, it can be shipped to a nursery or business that specializes in cleaning and testing seed. When shipping seed, ensure it is completely dry and securely packed.

The seed test should determine seed purity and viability, as these two percentages are used to calculate the amount of Pure Live Seed in the seed mix. Seed purity will identify the percentage of the target species present in the cleaned seed compared to inert matter and other species. It should also identify the percentage of other weed species or noxious weeds present in the cleaned seed. Seed viability is typically determined by a tetrazolium chloride test, which predicts percent germination by identifying living tissue in seeds. After testing, ensure seed is placed in long-term storage as soon as possible in order to preserve living material and keep test results accurate.

Use seed purity and viability measurements to calculate Pure Live Seed with the following formula:

$$\frac{\%\, Purity\ \times\ \%\, Viability}{100} = \%\, Pure\ Live\ Seed$$

This calculation can then be used to determine seeding rate at the restoration site with the following formula:

$$\frac{Seeding\ Rate}{\%\, Pure\ Live\ Seed} = Actual\ Seeding\ Rate$$

Though there are steps taken throughout the collection process to preserve seed viability, low tetrazolium chloride test results are not uncommon. For some indeterminate species, only 5 to 10 percent of seed on a plant may mature at any one time, resulting in inadvertent collection of immature seed (Dunne 1999). Additionally, during years with unfavorable weather conditions, seed may be lower in viability and longevity (Dunne 1999).

C.5 Long-Term Seed Storage

Immediately after seed cleaning and testing, the collected seed will go into long-term storage. The goal of long-term seed storage is to prolong the life of the seed and to ensure the seed is viable when it is used. Seeds in long-term storage should be used within a few years of being collected to ensure viability; ideally, they should be used the following planting season. Similar to short-term storage, moisture and temperature are the two most important factors to consider when storing seeds long-term.

There is not much existing research regarding native seed storage for use in restoration projects (Shaw et al. 2005). Native seed storage for conservation purposes in seed vaults often involves cryo-preservation, drying to precise seed moistures, and low storage temperatures; these seeds are meant to be stored for centuries (Linington and Manger 2014). For the purposes of storing seed for Hanford Site restoration projects, some of these best practices can be followed in order to extend the life of seeds.

Drying and freezing native seed is the most common form of long-term storage to preserve seed viability (USDA 1978, Prichart 2009, Linington and Manger 2014). Seed type will determine if it can be successfully dried and frozen. Orthodox seed, or seed that is tolerant of desiccation and long-lived, can tolerate freezing (Prichart 2009). To check if the collected seed is orthodox, research the species or visit the Royal Botanic Garden Seed Information Database[1], which provides seed information about a wide range of species. The majority of seeds collected from the Hanford Site are orthodox. Recalcitrant seed, or seed that is short-lived and not desiccation-tolerant, loses viability upon drying and typically do not retain viability when stored below 0 °C (Prichart 2009). Recalcitrant seed types are not common in the arid environment of the Hanford Site but when collected should be thoroughly researched to determine proper storage protocol, as minimum storage temperature will vary by species. The following guidelines apply to orthodox seed.

If the seed is properly laid out and stirred during short-term storage, the time between collection and long-term storage should be sufficient to dry orthodox seed. Though not a precise drying regime, for the purposes of storage for use in

[1] Accessed online at http://data.kew.org/sid/.

restoration projects this is an efficient method. If seed has collected moisture during the cleaning and/or shipping process, repeat the drying process on tarps. For smaller collections, a natural desiccant such as charcoal or rice can be put into a container alongside the seed bags to draw out moisture; use a 1:3 weight ratio for charcoal/rice to seed (Gold 2014).

As soon as possible after receiving the seed from being cleaned, place the seed in a breathable bag and label the bag with the species, collection year, and associated Seed Collection Site Form(s) and seed testing paperwork information. A sample label is included at the end of these guidelines (Figure C.2). Then move the collected seed to a freezer for storage until it is used. The ideal storage temperature for seed banking and conservation is -20 °C (Linington and Manger 2014). Seed collected from the Hanford Site will need to be stored between 1 and 5 years for use in restoration projects. Ideal storage temperatures will vary based on the species, but should be no higher than 0 °C, and ideally between -15 and -20 °C (USDA 1978, Prichart 2009, Linington and Manger 2014).

C.6 Risks and Biases of Seed Collection

There are potential risks to native populations that must be considered when planning and performing seed collection. Though there are acceptable standards and collection rates presumed to be safe for most plant populations, no seed collection rate is absolutely safe. Potential variation in population health due to disease, weather, and environmental events like wildfire or drought may make a population more susceptible to extinction after seed collection. The smaller the population, the more the collector must consider environmental events that may occur post-collection.

In addition to recognizing risks, seed collectors should address possible bias in their collection protocol. There is inherent bias when harvesting seed that will affect the genetic makeup of the restoration seed mix. An example of bias when collecting seed is the collector will harvest what is available at the time collections take place, favoring plants with mature seed at a specific time. Additionally, plants producing more seed at the time of collection will be more represented in the final seed mix. If seed is shipped to a nursery to be grown out, the seed that germinates first will most likely be selected to grow into a plug. All of these biases will affect the final seed mix and genetic makeup of plants used in the restoration site.

These biases can be reduced by collecting multiple days within the collection window, not overly targeting plants with heavy seed loads, or by giving nurseries ample time to germinate seed. Acknowledging and working to reduce these biases can increase the genetic diversity of the plants in the restoration site and may result in a more successful restoration.

C.7 Conclusion

Following these guidelines will help ensure a successful seed collection. By carefully researching the target species, selecting the appropriate source populations and collection methods, and following proper storage techniques, collectors can harvest viable seeds without causing undo harm to the environment. Providing locally derived seed for Hanford Site restoration projects will ultimately play a role in sustaining the plant populations and genetic diversity of the Hanford Site for years to come.

Figure C.1. Seed Collection Site Form

SEED COLLECTION FORM

Target Species:	
Collector Name(s):	
Date:	
Form Number: *(number format):*	*SpeciesCode_DDMMYY_Letter (ex: ARTR_081219_A)*

SOURCE POPULATION DATA				
Describe General Location:				
Elevation:				
GPS Coordinates of Population *(Center)*:				
Approximate Area of Population:				
Approximate Number of Seed Producing Plants:	< 50	50 – 100	100 – 500	> 500

PHENOLOGICAL STAGE	
Stage	*Approximate % of Source Population*
Vegetative:	
Flowering:	
Immature Seed:	
Mature Seed:	
Post-Dispersal:	
NOTES	

Page 1 of 1 A-6007-899 (REV 0)

Figure C.2. Label for Seed in Long-Term Storage

SEED FOR HABITAT RESTORATION	
Species:	
Collection Date:	
Site Collection Form Number(s):	
TZ Test %	
Purity %	
Initial Quantity:	
Date:	Amount Removed:

C.8 References

Barton, M. L., Medel, I. D., Johnston, K. K., and C. R. Whitcraft. 2016. *Seed Collection and Germination Strategies for Common Wetland and Coastal Sage Scrub Species in Southern California*. Bulletin of the Southern California Academy of Sciences 115:1. Available at: https://scholar.oxy.edu/scas/vol115/iss1/3

BLM. 2016. *Technical Protocol for the Collection, Study, and Conservation of Seed from Native Plant Species for Seeds of Success*. U.S. Department of the Interior, Bureau of Land Management. Available at: https://www.blm.gov/sites/blm.gov/files/program_nativeplants_collection_quick%20links_technical%20protocol.pdf

DOE/RL-2011-116. 2013. *Hanford Site Revegetation Manual*. Rev. 1. U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: https://www.hanford.gov/tocpmm/files.cfm/DOE-RL-2011-116_-_Rev_01.pdf.

Dunne, R. 1999. *Common Difficulties Encountered in Collecting Native Seed*. U.S. Department of Agriculture, Forest Service. Available at: https://www.fs.fed.us/rm/pubs/rmrs_p008.pdf

Gold, K. 2014. *Post-Harvest Handling of Seed Collections*. Kew Royal Botanic Gardens and Millennium Seed Bank Partnership. Available at: http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/04-Post-harvest-handling.pdf

Guerrant, E. O., K. Havens, and M. Maunder. 2009. *Ex Situ Plant Conservation: Supporting Species Survival in the Wild*. Center for Plant Conservation, Washington D.C.

Huber, L. S. 1993. *Native Seed Collection Guide for Ecosystem Restoration*. Wallowa-Whitman National Forest, Baker City, Oregon. Available at: http://www.ntfpinfo.us/docs/other/HuberBrooks1993-NativeSeedCollectionGuideEcosystemRestoration.pdf

Jones, T.A. 2013. "Ecologically Appropriate Plant Materials for Restoration Applications." *BioScience* 63: 211–219. Available at: https://www.jstor.org/stable/10.1525/bio.2013.63.3.9?seq=1

Linington, S., and K. Manger. 2014. *Seed Bank Design: Cold Rooms for Seed Storage.* Kew Royal Botanic Gardens and Millennium Seed Bank Partnership. Available at: http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/12-Cold-room-design.pdf

Majerus, M. 1999. *Collection and Production of Indigenous Plant Materials for National Park Restoration*. U.S. Department of Agriculture, Forest Service. Available at: https://www.fs.fed.us/rm/pubs/rmrs_p008.pdf

Menges, E.S., E.O. Guerrant, and S. Hamze. 2009. "Effects of Seed Collection on the Extinction Risk of Perennial Plants." In *Ex Situ Plant Conservation: Supporting Species Survival in the Wild.* Center for Plant Conservation, Washington, D.C.

Prichart, H.W. 2009. "Classification of Seed Storage Types of Ex Situ Conservation in Relation to Temperature and Moisture." In *Ex Situ Plant Conservation: Supporting Species Survival in the Wild.* Center for Plant Conservation, Washington, D.C.

Shaw, N.L., S.M. Lambert, A.M. DeBolt, and M. Pellant. 2005. "Increasing Native Forb Seed Supplies for the Great Basin." *National Proceedings: Forest and Conservation Nursery Associations*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Available at: https://www.fs.fed.us/rm/pubs/rmrs_p035/rmrs_p035_094_102.pdf

Smith, S. L., A. A. Sher, and T. A. Grant III. 2007. "Genetic Diversity in Restoration Materials and the Impacts of Seed Collection in Colorado's Restoration Plant Production Industry." *Restoration Ecology* 15:3 pp. 369–374. Available at: https://www.academia.edu/12730205/Genetic_Diversity_In_Restoration_Materials_and_the_Impacts_of_Seed_Collection_In_Colorados_Restoration_Plant_Production_Industry

USDA. 1978. *Principles and Practices of Seed Storage*. U.S. Department of Agriculture, Agriculture Handbook No. 506. Available at: https://naldc.nal.Usda.gov/download/CAT87208646/PDF

Vander Mijnsbrugge, K., A. Bischoff, and B. Smith. 2009. "A Question of Origin: Where and How to Collect Seed for Ecological Restoration." *Basic and Applied Ecology* 11:4 pp. 300-311. Available at: https://doc.rero.ch/record/17231/files/bischoff_qow.pdf

Wall, M. 2009. *General seed collection guidelines: For California native plant species*. Rancho Santa Ana Botanic Garden. Available at: http://www.hazmac.biz/aboutus/Seed%20Collecting%20Guidelines.pdf

Way, M., and K. Gold. 2014. *Seed Collection Techniques*. Kew Royal Botanic Gardens and Millennium Seed Bank Partnership. Available at: http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/03-Collecting-techniques.pdf

This page intentionally left blank.