Shrub-Steppe and Grassland Restoration Manual

For the Columbia River Basin

BONNEVILLE
POWER ADMINISTRATION

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Updates, Feedback, Questions.

Questions, comments or ideas regarding how to improve the manual can submitted to Richard Tveten at WDFW. Contributions to the manual in the form of case histories, seedling identification images, descriptions of new techniques, new information sources, etc. are most welcome.

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1.0 Introduction

1.1 Purpose

This manual was prepared to help shrub-steppe and grassland restoration practitioners capitalize on the experiences of their predecessors and colleagues within the Columbia River Basin. It also identifies potential resources, and provides tools for documenting work and sharing information. This manual is intended to be a work in progress, and will be updated periodically as new information becomes available.

1.2 Overview

1.2.1 Why was a manual needed?

In 2010, restoration practitioners at the Washington State Department of Fish and Wildlife (WDFW) and the Bureau of Land Management (BLM) recognized the need for a technical manual focused on shrub-steppe and grassland restoration in the Columbia River Basin. These practitioners had accumulated decades of hard-earned knowledge, mainly through trial and error, but this anecdotal information had never been compiled or widely disseminated. As retirement approached for experienced practitioners, this body of knowledge and experience had the potential to be lost. This manual was developed to capture restoration experiences and disseminate knowledge to new practitioners, thereby ensuring more successful and cost-effective habitat restoration projects in the future.

1.2.2 What does the manual contain?

The manual includes technical information that veteran shrub-steppe and grassland restoration practitioners in the Columbia Basin indicated were necessary for new restoration project managers to properly plan and successfully execute habitat restoration projects. This manual, however, does not treat all subjects equally. The manual focuses disproportionately on technical topics which restoration experts indicated are in greatest need of attention to ensure success. In addition to providing general guidance, this manual provides specific recommendations, tools and templates to help people quickly take advantage of existing resources and contribute to the growing restoration knowledge base.

Case studies are provided for a variety of restoration scenarios so that project planners can see what actions are needed, and learn from the experiences of predecessors as to what worked, how successful they were, what obstacles they had to overcome, and how they overcame those obstacles. The case histories also illustrate how documentation of one's project can be efficiently packaged to benefit others.

1.2.3 What is not included in the manual?

Several important subjects that are not directly related to the ecological aspects of restoration, e.g. permitting, funding, and equipment maintenance, are already covered in great detail in other available sources. This manual only lightly touches upon such subjects or directs readers to information sources as appropriate. Since the Bonneville Power Administration (BPA) funds much of the restoration work in the Columbia River Basin, information on how to comply with their requirements is essential. Guidance related to regulatory requirements for BPA funded projects is provided on the **BPA environmental Compliance web site**.

1.2.4 How is the term restoration used in this manual?

Restoration is a term that is often loosely used and often misinterpreted. In this manual the term restoration includes both restoration and rehabilitation as defined in ***Ecological Restoration Primer, Society for Ecological Restoration (SER International Science and Policy Working Group 2004)***.

- Restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed." Also, "Restoration attempts to return an ecosystem to its historic trajectory… Restoration projects require no attendance once they are mature."
- Rehabilitation emphasizes "the reparation of ecosystem processes, productivity and services…" but does not necessarily mean a return to pre-existing biotic conditions. Rehabilitation projects may require some attendance once they are mature…"

While full restoration may be ideal, practical limitations relating to the ability to obtain or successfully grow native plants, exclude invasive species, or allow the return of historic processes often results in "restoration" projects with "rehabilitation" aspects.

1.2.5 How can I become familiar with the plants mentioned in this manual?

The **Seedling Identification Guide** contains photographs of nearly every plant mentioned in this manual both as seedlings and as mature plants. While common names are used within the manual, a table is provided within the Seedling Identification Guide with both the common and Latin names for each species along with their status as native or introduced.

1.2.6 What is the best way to use this manual?

This manual was created with the knowledge that users will vary from novices who wish to study various topics for the first time, to seasoned veterans who primarily want to quickly access specific tools. Many of the tools and templates in this manual are posted where they can be downloaded for personal use. Readers who are interested in specific tools or information sources can go directly to the tools via hyperlinks in the Table of Contents, **Section 6.0** Technical Resources or throughout the manual as indicated with bold font. Readers who are interested in first learning more general information and context about the tools should read the manual. It is presumed that the manual will largely be used in its electronic format. For those who use hard copies, the pathways for hyperlinks within the electronics version are shown in **Section 6.0** Technical Resources**.** The manual is organized to answer the following questions:

Section 2: What should I do with a degraded site? To answer this question one must answer the following questions: What do I have? What was the historical condition? What does the site have going for it or against it? What is a site capable of becoming? What do I have to work with? What do I want the site to look like?

Section 3: How do I go about restoring a site? To answer this question one must first answer the following questions: Do I need to clean the slate, and if so, how do I go about doing so? What should I plant? How should I plant? How do I protect/nurture what I plant? How do I define success and know when I have succeeded?

Section 4: How can I apply this manual to maintenance or enhancement of sites? This section identifies specific tools that can be used to help maintain or enhance sites not needing full restoration. It helps answers the following questions. How do I kill weeds without harming desirable vegetation and how do I increase diversity?

Section 5: What's working and how can we help each other do better? This section helps answer the following questions: How should I document my work? How can I share what I observe or learn with others? The section includes downloadable forms and instruction that can be used to build a complete project case history. A link is provided to a case history library showing documentation for past WDFW projects.

Section 6: What tools are available to help me get the job done?
This section is organized to help users efficiently find particular resources or tools. Several larger tools are included within this section, for example the Local Expertise Directory in **6.2 Local** Expertise Directory In cases where the tools or recommendations have already been included elsewhere in the manual, those sections are identified in section 4 and hyperlinks to them are provided for those using the manual electronically. Finally, hyperlinks are provided to download sites for tools and documents that must be downloaded like the Seedling Identification Guide, seed mix calculators, and project documentation forms.

1.2.7 How you can help ensure that this manual provides lasting value.

The manual is intended to be a means of disseminating information and helping restoration practitioners capitalize on recent discoveries. It contains links to associated files so that land managers throughout the Columbia River Basin can view or download materials. Manual users are encouraged to record project details on a Restoration Project Documentation Form that can also be downloaded from the same site. Completed forms constitute case histories that can be of great value in identifying what does and doesn't work and sharing lessons learned. Project managers are encouraged to submit completed Restoration Project Documentation Form so that they can be added to the **Case History Library** so others can review them and capitalize on their experiences. This sharing of information can reduce repetition of costly mistakes and accelerate learning curves. It also encourages dialogue among project managers dealing with similar issues.

2.0 Planning

2.1 Historical Conditions Research

The purpose of this section is to describe approaches and resources for identifying historical conditions and associated ecological processes. As a basic goal of restoration is to bring a site back to an original state or trajectory, the original or presumed historical condition should be defined to the maximum degree possible. Accurate information regarding historical conditions is critical to setting realistic goals, selecting plant species, and identifying management approaches that will promote or sustain restored conditions. As historical vegetation was a function of historical site characteristics including climate, soils, soil moisture, herbivory, disturbance regimes and other factors it is important to also characterize the conditions that allowed for the historical vegetation. It is important to consider that all natural systems vary in space and time and that restoring a range of target vegetative conditions may be desirable (SER 2004). This section provides instructions on how to gather information that will be used in the Restoration Project Documentation File related to site attributes, soils. This information will also be used to make decisions relating to goal setting, seed mix development, and restoration of ecological processes.

Figure 1. Example reference site

2.2 Vegetation

As vegetation is the main component of restoration projects it is critical that the historical vegetation be understood to the greatest degree possible. Section 3.1 Seed Mix Development, Seed Acquisition and Seed Propagationprovides guidance on how to estimate historic vegetation based on reference sites (Figure 1), Ecological Sites Descriptions, historical records research and expert opinion. It then provides guidance on developing seed mixes based on project wildlife habitat goals and other factors.

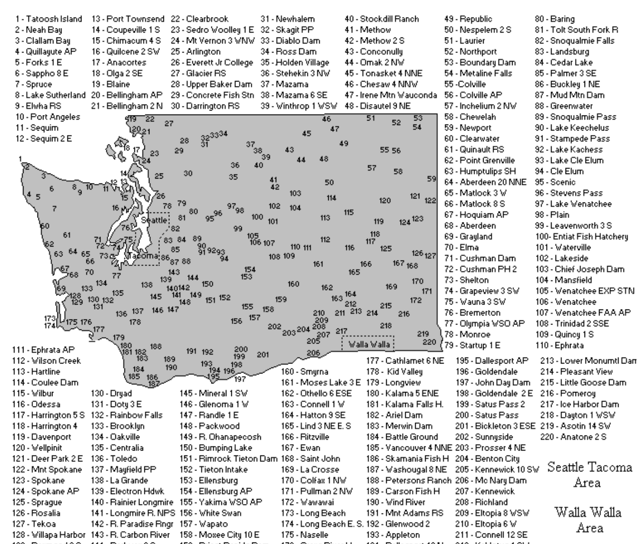


Figure 2. WRCC weather information locations

2.3 Soils

A site-specific soils report that can be downloaded from the [Web Soil Survey](). These soils reports have information on the chemical and physical properties of soils as well as their productivity. Record information that is deemed to be of greatest value to the project in the soils section and Table 1 of the **Restoration Project Documentation Form.**

2.4 Climate

Local climate summaries (Figure 2) can be downloaded from the **Western Region Climate Center** to determine local rainfall and temperature patterns. This information can help when planning weather dependent activities. Record annual precipitation in the Location and Site Attributes section of the Restoration Project Documentation Form**.** This information provides valuable project context

2.5 Ecological Processes

Ecological processes like fire, floods, wind storms, landsides, herbivory and insect outbreaks often serve to create or maintain vegetation communities. WDNR Natural Heritage Program's **Draft Field Guide to Washington's Ecological Systems** includes brief descriptions of ecological processes like fires and flooding that historically maintained plant communities. In cases where the disruption of those processes leads to a significant departure from historic conditions, the interruption of those processes is identified as a threat. In cases where disturbances like fire or flooding were important factors, it is useful to determine what the typical return intervals were for such events. In cases where the re-establishment of historic processes is not likely, full restoration may not be possible. Findings should be recorded in the Site History section of the **Figure 38. Restoration Project** Documentation Form **(Figure 38).**

2.6 History and Existing Conditions

It is important to determine a site's level of variance from historical conditions to characterize the need for restoration, and to identify the challenges and possible limitations to successful restoration. This section describes what information should be gathered, identifies potential information sources, and explains why such information is important.

Most lands that WDFW restores were agricultural fields that were either abandoned or seeded with non-native grasses to stabilize soils. Such land use history often results in the following:

- Reduced or no native vegetation
- Reduced species diversity
- Reduced structural diversity
- Altered soil chemistry and structure
- Lack of cryptogamic crust
- Reduced resistance to noxious weed invasions

While several of these issues can be evaluated via a simple site visit, studying the site history provides valuable insights regarding potential restoration-related challenges or limitations. It is important to learn as much as possible regarding past agricultural activities related to herbicides, pesticides, fertilizers, erosion history, crop timing, as well as challenges associated with working the soil, problem weeds, and the time period during which the land was farmed. Such research may reveal currently invisible threats and insights regarding:

- Residual herbicides that may prevent germination of native forbs
- Nutrient enrichment
- Site-specific crop and weed responses to fertilizers
- Erosion risk
- Optimal times to plant
- What types of equipment may work best
- The potential seed bank
- Site susceptibility to specific weeds

Documenting the history of a field since farming ended can help one can gain additional insights including:

- The likelihood of residual herbicides
- How well the planted species performed
- What species are apt to naturally invade and persist on the site
- What native species do not naturally return to the site
- Seed bank composition
- Potential weed control challenges
- Degree of success associated with past weed control efforts
- Efficacy of seeding methods
- How grazing may have influenced vegetation

Potential information sources for learning about site history include:

- Wildlife area records
- Past landowners or lease holders
- Neighbors or other people in the community with historical knowledge

2.7 Site Challenges

Occasionally, exploring the degradation history of a site helps reveal unique challenges that wildlife area managers will encounter during restoration projects. These challenges are often obvious, for example severe compaction or weed infestation. Sometimes, however, challenges are more subtle and difficult to diagnose, such as long-term residual herbicide effects. Often, the presence of one or more such challenges will temper expectations and restoration goals; rarely, they may preclude restoration completely, or suggest shift limited funding to a more promising site.

Site histories, along with an analysis of current site conditions, can typically be used to plan for, mitigate, or avoid potential pitfalls. The goal of this section is to highlight major site challenges that have been, or are likely to be, encountered by wildlife area managers. These challenges include soil compaction, excess nutrients, high alkalinity, residual herbicides, and weeds. The narrative of each section will include common causes, symptoms, and potential solutions.

2.7.1 Compaction

Compacted soil restricts root growth and water infiltration, which can result in decreased seedling survival and plant growth (Bassett et al. 2005, Batey 2009). The most common causes of compaction on wildlife areas include concentrated livestock feeding or watering, farming, and roads.

Most wildlife areas have a history of homesteading, farming, and ranching. This is evident by numerous old structures, including fences, barns, feed bunks, troughs, etc., currently scattered across wildlife area land. During the winter, ranchers and homesteaders provided feed in discrete areas, typically around the barn or in feed bunks, consequently creating areas of heavy soil compaction. This effect can be apparent decades after livestock removal, and is evidenced by stunted vegetation, poor water infiltration, and the presence of one or more of the following weeds: white-top, prostrate spurge, and Russian knapweed.

Compaction from farming is typically caused by operating the same piece of equipment, in the same fashion, over multiple years or even decades. Some farmers run their tractors in the same direction, using the same pattern, year after year. This results in compaction along the wheel track, and an uneven, wavy surface appearance of the planted crop, with stunted rows alternating with unaffected rows. Tillage to the same depth each year often results in a "tillage pan", or a highly compacted soil layer beneath the surface. Sweep chisel plows and offset discs are two implements most likely to result in a tillage pan. Unlike compaction caused by tractor activity, tillage pans are typically uniform, and result in a stunted crop across the entire field.

Figure 3. Para-till sub-soiler pulled with a tractor

Compaction caused by repetitive vehicle use is typically present for decades after road abandonment. In areas where gates are easily bypassed, the only effective method for closing roads is restoration such that jeep tracks are completely obliterated.

Compaction layers can be detected by inserting a knife horizontally at increasing depths along the walls of a shallow hole, feeling for layers with increased resistance (Pellant et al. 2005). For overall soil compaction, a soil probe or shovel may be inserted into the ground, both in the area of concern and an adjacent control area, and the difference in resistance can be compared. Should the project site contain large areas of compaction, restoration should not proceed until compaction has been addressed. Small areas of compaction within a site should also be addressed if feasible, or expectations for these areas should be reduced. Higher expense plantings, such as forb and shrub plantings, should be avoided on compacted sites due to the reduced likelihood of success.

Compaction is often reversed by sub-soiling or ripping the soiling or ripping the soil (Luce 1997). In soils with little rock or clay, an agricultural ripper pulled behind a tractor is often sufficient. A commonly used implement is a paratill followed by a cultipacker to firm the soil (Figure 3). When pulled behind a wheel tractor, this implement can rip the soils up to 24 inches deep.

In more challenging soils, however, a ripper mounted on the back of a crawler bulldozer (D5 or D6) may be necessary. Depth of ripping depends on the depth of compaction or tillage pan, along with soil type, but commonly ranges from 8 to 24 inches deep. Spacing of tines depends on available implements; however, heavily compacted sites should be overlapped and ripped in several directions to effectively shatter soil compaction. Linear features such as roads can be ripped in both directions to shatter soil compaction and eliminate tracks, then packed to help firm the seedbed. A more comprehensive discussion of soil ripping implements is included in Steinfeld et al. 2007.

In summary, soil compaction reduces root growth and water infiltration, and can greatly reduce the success of a restoration project. Signs and symptoms of compacted soil include the presence of structures that promote livestock congregation, stunted vegetation, poor water infiltration, and the presence of white-top, prostrate spurge, and Russian knapweed. Compaction can be easily tested by inserting a soil probe or shovel into the soil and comparing resistance with an unaffected area. Large areas of compaction should be treated prior to beginning restoration work, typically by ripping or sub-soiling.

2.7.2 Excess nutrients

Excessive amounts of soil available nutrients, including nitrogen (nitrate-N or ammonium-N), phosphorus (P), and potassium (K), among others, have been encountered on several occasions during WDFW restoration work. The most common cause involves the over-application of fertilizers when growing corn, and less commonly, wheat or alfalfa. Excessive nutrient levels also accumulate in areas of livestock congregation, i.e. around corrals, feed bunks, and water troughs. Areas where alfalfa has been fed to livestock over numerous years often have Boron (B) and Zinc (Zn) accumulations that can be toxic to native grass seedlings.

Symptoms of excessive P and K include burnt tips on grass leaves, as well as stunted growth and seedling mortality. Excess K above 1,000 ppm or P above 100 ppm creates extreme soil salinity, which can be toxic to young grass seedlings. Excess soil nitrates typically manifest as vigorously growing vegetation, particularly weedy species such as cheatgrass and quackgrass.

For newly acquired land, fertilizer application data can often be obtained from the local fertilizer company, which tracks application site, date, and type for their clients. A soil test is usually recommended, especially if high soil nutrients are suspected. Soil testing labs in eastern Washington, along with recommended soil tests, are listed in Figure 4. These tests typically come grouped in a package, and generally cost less than $50. Soil test results typically also come with interpretations that highlight extremely high or toxic nutrient levels.

High soil nitrates can be reduced by planting and harvesting a grain crop, such as wheat or barley, for several years. Nitrates are immobilized in the tissues of these crops, and are therefore removed from the site during harvest. If nitrate levels are only moderately elevated, another option is to include a large component of Great Basin wildrye in the seed mix. This species is highly competitive with weeds in high nitrate soils. When using this approach, however, managers should plan on several years of vigilant broadleaf weed control following planting, and therefore several years delay for planting native forbs and shrubs.

High P, K, and micro-nutrients can be a little more challenging to manage than nitrates. The process used on WDFW land in the past took multiple years, and involved tilling the field each year to incorporate weed residue. This process built organic matter in the soil, which in turn increased microbial activity and consumption of nutrients. Another option that has recently become available is the use of bio-deactivators, such as SoilCure, which are commercial microbial soil amendments. When applied to the soil, these amendments boost microbial activity, and therefore consumption of soil nutrients. Cost for this type of product ranges from $18 to $36 per acre, not including application.

In summary, excessive soil available nutrients are typically the result of over-fertilization when growing corn, or by concentrated livestock feeding and watering. Fertilizer application records, if not on file at the wildlife area, can often be obtained from the local fertilizer company. Excess N can be reduced by growing and harvesting grain crops for several years. Excess K above 1,000 ppm or P above 100 ppm will typically require treatment or modification of the restoration plan.

2.7.3 High alkalinity

High alkalinity (pH greater than 8.5) is a common occurrence on sub-irrigated soils in the Columbia Basin. High alkalinity is caused by upward vertical movement of water that is not balanced by downward leaching. This occurs naturally where the water table is high enough that capillary action draws water to the soil surface, and

Local Soil Testing Laboratories

(Not an endorsement of identified firms)

SoilTest Farm Consultants, Moses Lake

Best-Test Analytical Services, Moses Lake

Cascade Analytical, Wenatchee

Kuo Testing Laboratories, Othello

Recommended Soil Tests

pH, NO3-N, NH4-N, OM, P, K, Ca, Mg, Na, S, B, Zn, Mn, Cu, Fe, , Total Bases

Figure 4. Soil testing labs and recommended tests

evaporation leaves behind salts. Improper irrigation can also result in alkalinity, typically by watering lightly and frequently. In arid and semi-arid climates, there is generally insufficient rainfall to balance this deposition.

High alkalinity develops in areas where the water table is naturally high, such as floodplains, or in areas where irrigation infrastructure creates an artificially high water table, such as along waste-ways. Signs of high alkalinity include mineral accumulations on the soil surface, as well as the presence of one or more of the following species: kochia, bassia, poverty weed, foxtail barley, perennial pepperweed, Great Basin wildrye, greasewood, inland saltgrass, tall wheatgrass, and alkaligrass.

In the short term, alkalinity is generally only reversible through manipulation of the water table and/or the application of irrigation water to leach out salts. This is generally not feasible on wildlife area land.

There are a number of native plant species adapted to alkaline soils, however, and seed availability for these species improves each year. Where control over irrigation or the water table is not available, the best solution for alkaline soils is to plant alkaline-tolerant species, primarily Great Basin wildrye, saltgrass, Sandberg's bluegrass, and greasewood. Native forb diversity is often low to absent on alkaline sites. Reference areas, if available, should be used to determine native forb adaptation to local conditions. See Table 1 for a commonly used alkaline-tolerant grass seed mix.

Saltgrass is planted by both seeding and sprigging (planting of individual stolons and runners). Sprigging tends to be the most effective, and can be effectively utilized on small-scale projects. Due to limited seed availability, greasewood seedlings are typically grown in the nursery and transplanted into restoration sites.

Table 1. Alkaline tolerant grass seed mix

Species	PLS lbs/Acre
Great Basin wildrye	6
Sandberg's bluegrass	1
Inland saltgrass	2
Total	9

2.7.4 Residual herbicides

Long-term residual herbicide effects are often difficult to discern, and are frequently forgotten. Ownership changes hands, or land managers move on, and herbicide application history is not communicated to new managers. A number of commonly used herbicides have significant soil residual intervals, which can alter or preclude restoration of certain functional groups. The below discussion of residual effects is broken into chemical families in order to combine common symptoms and implications for restoration. For easy reference, this section uses commonly used trade names. This does not constitute an endorsement by WDFW for specific herbicide manufacturers. Table 18. Restoration site herbicides contains a list of commonly available herbicides by trade names, referenced by chemical name.

Herbicide application history for the recent past can be obtained from the wildlife area headquarters files or from the WDFW State Weed Specialist (Dave Heimer). For new acquisitions, herbicide application history can often be obtained from the local herbicide vendor. As with fertilizer, herbicide sales and application data are often tracked by the local chemical consultant.

Picolinic Acids

Tordon (Picloram), *Transline (Clopyralid)*, and *Milestone (Aminopyralid)* are synthetic auxin herbicides, which mimic plant growth hormones and trigger uncontrolled and unsustainable growth. Symptoms of synthetic auxin herbicides include leaf cupping and curling, stem elongation and swelling, followed by chlorosis, leaf withering, and eventually plant death. Synthetic auxins are degraded by microbial activity in the soil; residue is longer lasting in arid or semi-arid areas with reduced moisture and soil organic matter, and therefore decreased microbial activity. While synthetic auxins primarily affect dicots, minor epinasty (downward curving of leaves) in some grasses has also been noted (WSSA 2007).

Historically, Tordon was used for hard-to-control broadleaf weeds in CRP and rangeland and along roadsides. The recent introduction of Transline and Milestone has reduced the use of Tordon for Russian knapweed and Scotch thistle, but it is still commonly used for controlling rush skeletonweed. High application rates (up to 2 quarts per acre) of Tordon are often used, resulting in long-term residual effects for many broadleaf species.

Signs of Tordon residue include the physiological effects mentioned above, along with an absence of susceptible broadleaves, legumes in particular. Many areas where Tordon was applied in successive years have few or no broadleaf species, with the exception of big sagebrush, which is not affected by Tordon. An absence or reduction in cheatgrass is also common in areas with Tordon residue.

Areas treated with Tordon may have residual effects for 2 to 20+ years, depending on climate and application rate. Legumes, which are particularly susceptible to Tordon, may be affected for 20 or more years following high application rates, while less susceptible species such as yarrow may be planted within 2 to 3 years after treatment. A bioassay should be performed prior to broadleaf plantings in order to determine potential residual effect (**Figure 5**). If any Tordon residue remains in the soil, plant growth will be affected in the manner described above.

Milestone and Transline are recent herbicide releases; both are extremely effective in the control of knapweeds and thistles at relatively low rates. The residual effect when applied at label rates generally lasts 2 to 3 years. Partial application rates of Transline have residual effects for 12 to 18 months. As with Tordon, a soil bioassay should be performed with garden peas and/or desired native forbs prior to planting broadleaves.

Figure 5. Soil bioassay method

A simple soil bioassay can be performed with the restoration seed mix or typical garden seeds, such as garden peas and tomatoes. Due to the stratification requirements and slow germination of native forbs, most are not a good choice for bioassays. Yarrow is a notable exception. Depending on the selectivity of the suspected herbicide residue, the bioassay should utilize grass seeds, broadleaf seeds, or a combination of both. Garden peas and tomatoes are very sensitive to herbicides, and would be good indicators for broadleaf-selective or non-selective residues.

1. Plant several seeds of each target species in a small pot containing project soil. The pot should have holes in the bottom to allow drainage. Garden peas should be soaked in water for 24-hr prior to planting. Cover seeds with a thin layer of soil, and press to firm.

2. Place pot in a warm, sunny place inside, and keep moist until seeds germinate. This should take 7 to 10 days for most species.

3. Watch for symptoms as described under each chemical family.

Triazines and Uracils

Velpar (Hexazinone), Princep (Simazine), Atrazine, and *Hyvar* (*Bromacil*) are photosystem II inhibitors; these herbicides inhibit photosynthesis by blocking electron transport. Symptoms of photosystem II inhibitors include browning of cotyledon leaves, interveinal chlorosis of older leaves, and yellowing of the leaf margins. This is followed by necrosis of leaf tissue, and eventually plant death. Symptoms appear first in older and larger leaves before affecting younger leaves. Photosystem II inhibitors may be absorbed through either roots or foliage, but translocation occurs primarily through root uptake. Triazine and uracil herbicides are non-selective, affecting many broadleaf and grass species. Decomposition occurs primarily through microbial activity; rate of decomposition increases with soil moisture and organic matter content (WSSA 2007).

Velpar is used for weed control in established alfalfa, as well as in forest plantation management, as it controls alders and other broadleaves but not conifers. Velpar is the most water soluble triazine herbicide; leaching or transportation offsite with runoff often occurs and reduces residual effects. If applied at high rates over multiple years, residual effects can last 4 to 5 years.

Princep and Hyvar are used primarily as soil sterilants along roadsides and in parking lots. Heavy rainfall that leads to overland flow will often move active compounds from the application site, resulting in substantial damage to surrounding vegetation. Residual effects generally last less for 4 to 12 months, if applied at label rates.

In Washington State, Atrazine is used primarily for weed control in corn fields. The introduction of Round-Up ready corn has recently reduced the use of this herbicide, but across the US, Atrazine is still one of the most widely used agricultural herbicides. Atrazine has very limited water solubility; farmers apply it to the soil surface and it stays within the top two inches, where it controls emerging weeds while minimally affecting corn growth. Length of residual effects depends on application rates;

generally in eastern Washington soils, decomposition occurs at a rate of ½ lb active ingredient per acre per year.

Should application records indicate that triazine or uracil herbicides have been applied within the last 5 years, a soil bioassay should be conducted with target species prior to commencing work. If residual effects are detected, microbial decomposition can be improved by the incorporation of residue to build organic matter, or the application of products such as SoilCure to increase microbial activity. These steps might reduce residual effects, but restoration may still need to be postponed for several years in order for herbicides to fully decompose.

2.7.5 Special considerations for weeds during site preparation.

This section focuses on a subset of weeds that experience has shown require special consideration during the site preparation process. Recommendations in this manual are limited to species that practitioners commonly encounter; additional weed control recommendations can be found in the **Pacific Northwest Weed Management Handbook**. Weeds that do not require special attention during site preparation, but pose significant challenges after planting are discussed in **Section 3.4** Post Planting Weed Control**.**

Large populations of difficult weed will typically require an additional step or two to the restoration process, but generally do not preclude restoration. Most herbicides used to target such weeds can be damaging to young grass seedlings. Therefore, it is essential that the bulk of the treatment occurs in the year or two preceding grass planting, so that the population is largely controlled and only spot-spraying is needed after planting. The following sections discuss difficult weed species commonly encountered on WDFW lands.

It should be noted that many of the herbicides used to control weeds have medium to long term residual effects. With proper planning, delays for herbicide residue decomposition can be factored into the restoration plan, or broadleaves may be planted only in areas without weed treatment.

One change to the site preparation process should be common to all projects with rhizomatous weed infestations. If the outlined process includes any cultivation where implements are dragged through the field (rod-weeding, cultivators, etc.), consider substituting a different type of tillage, such as disking, in order to minimize spreading weed rhizomes around the field.

Bio-controls are available for most of the below-listed species, and should be considered for long-term integrated management of large weed populations. Discussions below focus on chemical and mechanical control strategies, as these are the most effective in a relatively short-term restoration process. Additional information on available bio-controls can be obtained from the sources listed in Figure 6.

Knapweeds – Russian, Diffuse, and Spotted. Russian knapweed *(Acroptilon repens)* is a rhizomatous, perennial forb that reproduces by both seed and vegetative growth. In the lower Columbia Basin, Russian knapweed occurs primarily on sub-irrigated sites with additional moisture; at higher elevations it occurs on both upland and lowland sites. Diffuse knapweed (*Centaurea diffusa*) and spotted knapweed (*Centaurea stoebe*) are annuals or biennials, capable of reproducing by seed or root fragments. Spotted and diffuse knapweed are both common in disturbed rangeland and abandoned agricultural fields.

Figure 7. Blooming whitetop patches around barn and homestead, Wenatchee, Washington.

Effective control of knapweeds can be obtained with tillage, herbicide application of either Milestone or Transline, or a combination of tillage and herbicides. See **Table 2** for specific recommendations, including herbicide application rates. At least two successive years of treatment will be necessary to control large populations. Treatment should therefore begin during the first year of the typical site preparation sequence, or a year in advance, if possible.

Forb and shrub plantings should be postponed until residues of Milestone or Transline have degraded (see previous section for details). Alternatively, forb and shrub planting can be targeted to areas that were not treated for knapweed. Over time, established plants may serve as a seed source for areas not planted.

Dalmatian toadflax *(Linaria dalmatica)* is a perennial, weakly rhizomatous forb common along roadsides, gravel pits, in disturbed rangeland, and in CRP fields, particularly in Douglas County. Limited seed dispersal distance, in combination with rhizomes, result in rather patchy distribution of this species. Once it is well established, Dalmatian toadflax is challenging to control, as seed may remain viable in the soil for 10 years or longer.

Control of Dalmatian toadflax can be achieved through a combination of tillage and herbicides. An effective herbicide application includes Escort and Banvel applied in the early growth stage (rosette to early bud growth). This can be followed by either tillage or spot-spraying to treat new seedlings. See Table 2 for application rates based on timing and application method.

Figure 6. Bio-control contacts

Gary Piper, WSU Entomologist
509-335-1947 Email: glpiper@wsu.edu

Larry Skillestad, USDA-APHIS
(509) 353-2950 Email: larry.d.skillestad@usda.gov

Paul Brusven, Nez Perce Biocontrol Project (208) 843-9374

Ideally, treatment should begin at least one year before commencing typical site preparation sequence. Two to three successive years of treatment will be necessary to eliminate the population, followed by vigilant monitoring each year for at least 5 years to find and treat emerging seedlings.

Whitetop *(Cardaria draba)*, also known as hoary cress, is a rhizomatous, perennial forb common along roadsides, in abandoned agricultural fields, and in rangeland, particularly in areas with historical livestock congregation (Figure 7). Reproduction is primarily vegetative, resulting in dense but often scattered stands. Due to the extensive underground root system, whitetop control typically requires multiple treatments within a year, over a several year period.

Whitetop treatment should begin in the first year of site preparation, ideally with a mix of Escort and Dicamba applied during the early flowering stage. Subsequent regrowth should be treated in the same manner as the summer progresses. One year of treatment will greatly reduce the size and density of large populations, but continued monitoring and treatment over the next one to two years is necessary for lasting control.

Rush skeletonweed *(Chondrilla juncea)* is a perennial, tap-rooted forb common along roadsides and disturbed rangelands. Reproduction occurs primarily through wind-dispersed seed, and occasionally from root fragments.

Rush skeletonweed control typically involves tillage such as disking or rod-weeding for two or more years, or ideally, release of bio-controls before beginning restoration process. Several bio-controls are available for this species, and are very effective. Chemical control can also be achieved with Tordon, particularly when applied in early growth stages (rosette through early flowering). Application of Tordon should be avoided if possible, however, due to the long-term residual effect on native broadleaves.

Field bindweed *(Convolvulus arvensis)*, also known as morning glory, is a perennial forb common in irrigated pasture and abandoned agricultural fields. Reproduction occurs through both seed and rhizomes. Once bindweed is established, however, growth of a population is primarily vegetative. Seed viability in the soil reportedly ranges from 20 to 50 years, making long-term monitoring and control efforts essential.

The most effective control strategy for field bindweed is treatment with Paramount in the fall or mid-summer during flowering. At least two successive years of control is generally required to control the population, followed by long-term monitoring and control of new seedlings. Until populations are fully controlled, rod-weeding and cultivation should be avoided, due to the ability of bindweed to spread via rhizome fragments.

Canada Thistle, Musk Thistle, and Scotch Thistle. Canada thistle (*Cirsium arvense*) is a perennial, rhizomatous species found in moist or sub-irrigated sites in the central Columbia Basin, and in moist sites and swales at higher elevations. Musk thistle (*Carduus nutans*) and Scotch thistle (*Onopardum acanthium*) are primarily biennials, and are found commonly along roadsides and in degraded rangeland across eastern Washington. Musk thistle has also been known to invade abandoned agricultural fields, primarily at higher elevations in Okanogan County.

Excellent control of the thistles can be achieved through application of Transline or Milestone at younger growth stages (rosette through early flowering, or fall regrowth). Scotch thistle should be sprayed in the rosette or early bolt stage, for best control with Transline and Milestone. Tordon can be used at more mature growth stages, but is not recommended due to residual length. See **Table 2** for application rates.

Jointed goatgrass (*Aegilops cylindrica*) is a winter annual grass commonly found in wheat fields, CRP, and along roadsides. Seed longevity in the soil ranges from 3 to 5 years, depending on annual precipitation (Donald and Zimdahl, 1987).

Jointed goatgrass control can be achieved through cultural or chemical methods, or a combination of both. Good control can be obtained in one year if a moldboard plow is used to bury seed. Otherwise site preparation should include a 2-year process of spring Roundup applications, followed by light tillage to stimulate additional germination.

Table 2. Herbicide recommendations for selected weeds during site preparation.

Species Name	Timing	Herbicide Mix (per acre)	Timing	Herbicide Mix (per acre)	Adjuvants (per acre)
Russian knapweed	Actively growing to early flowering	7 oz Milestone	Fall regrowth	7 oz Milestone	1 oz NIS[1]
Diffuse/Spotted knapweed	Rosette to early flowering	5 oz Milestone 7 oz Transline	Fall regrowth	5 oz Milestone 7 oz Transline	1 oz NIS
Dalmatian toadflax	Actively growing through Bud	1 oz Escort; 8 oz Dicamba			1 oz NIS
Whitetop	Up until full Flower; early flowering is ideal	0.75-1 oz Escort; 8 oz Dicamba			4 oz AMS[2]; 1 oz NIS
Canada/Musk Thistles	Actively growing	7 oz Milestone 7 oz Transline	Fall regrowth	7 oz Milestone 7 oz Transline	1 oz NIS
Scotch Thistle	Rosette to early bolt	7 oz Milestone 7 oz Transline	Late flowering	32 oz Tordon	1 oz NIS
Rush skeletonweed	32 oz Tordon	Rosette to early flowering			1 oz NIS
Field Bindweed	Flower	10 oz Paramount	Fall regrowth	10 oz Paramount	24 oz MSO[3]
Jointed goatgrass	Seedhead emergence or earlier	32 oz Roundup			16 oz AMS; 1 oz NIS

[1]NIS = Non-ionic surfactant – Example trade name “R-11”

[2]AMS = Ammonium sulfate – Water conditioner – Example trade name “Bronc Max”

[3]MSO = Methylated seed oil – Surfactant

2.8 Resource Assessment

2.8.1 Introduction

All projects require labor, materials, equipment and time. The purpose of this section is to help project planners adequately identify resource needs.

Labor. Restoration work often requires intense labor in specific, yet brief, periods of time. Planning must consider periods of peak labor needs at critical steps like planting and weed control. As critical time periods can be somewhat unpredictable, planning for flexibility is essential.

Plant materials. Plant material availability can affect the degree of restoration that is possible, project costs, and the length of time to complete a project. Some plant material is readily available, some must be collected or grown under contract, and some is simply not available due to poor increase or collection potential. Planning must consider not only what types of materials will be needed (which species, seed or plugs), but also when and what quantities are needed. Most native seed providers are listed on the **Native Seed Network**. Instructions for developing seed mixes are provided in **Section 3.1** Seed Mix Development, Seed Acquisition and Seed Propagation

Time. Project duration and activity timing varies with the weed species that must be controlled, the species that are to be planted, climate and other variables. **Section 3.2.7** Scenario-based site preparation processes includes project timeline tables for common restoration scenarios based on invasive species that must be controlled. For projects requiring native seed propagation, **Figure 22.** Seed increase development timeline. The timeline is generic and details must be worked out with individual seed providers.

Equipment. Identify equipment needs. It is important to identify the right equipment to successfully complete a project. The section identifies what equipment is needed or optimal for a variety of actions in a variety of situations.

2.8.2 Equipment selection guide

The following section describes the functions of key pieces of equipment used in restoration work, and includes specifications that can be used to purchase, rent, or contract for this equipment. An exhaustive list of implements that may be used in shrub-steppe restoration is beyond the scope of this document; focus is placed on key implements commonly used and available to WDFW managers. For ease of use, equipment is broken into four categories: power units, site preparation equipment, spraying equipment, and seeding equipment.

2.8.2.1 Power units

In the context of restoration, power units are used to pull spray equipment, tillage implements, seeders, and implements used to prepare the seedbed. The most commonly used and utilitarian power unit is a tractor, but ATVs and crawlers have specific applications as well. The most critical aspect for selecting the appropriate power unit is to match the size and power with desired restoration implements. The following section describes general requirements for power units; more specific requirements are included with each implement.

ATVs

ATVs can be used to pull sprayers, small packers or harrows, and seed broadcasters. ATVs are available in sizes ranging from 200 to 650 cc (cubic centimeters of piston displacement); in order to pull commonly used restoration equipment, 300 to 450 cc is typically adequate. Additional specifications that may improve performance and efficiency include four-wheel drive, power steering, and foam or slime-filled tires (when operating in brushy or rocky areas). Training is required prior to operating ATVs, but is typically minimal.

Tractors

Tractors can be used to pull sprayers, seeders, packers, harrows and tillage equipment. Sizes range from 15 to 650 hp (horsepower), but most managers utilize tractors that range from 90 to 150 hp (Figure 8). Prior to purchasing or renting a tractor, consult with the vendor on proper size and power for desired implements and site terrain. One of the most common mistakes made by new restoration practitioners is purchasing a tractor that is not powerful enough to pull necessary implements. Additional specifications that may increase performance and efficiency include enclosed cabs, mechanical front wheel drive, and wider tires for less ground disturbance. Tractors can also be outfitted with dual rear tires to improve traction and power on steeper hillsides. Operator training is essential for safe tractor operation, particularly when operating on moderate to steep hillsides.

Figure 8. Tractor and folded rotary-blade mower

Crawler Bulldozers

Crawlers are rarely owned by WDFW, but can be rented for specific projects that require additional pulling power or traction, and where minimizing ground disturbance is not an issue. The most common application is pulling utility drills on steep hillsides (greater than 35% slopes), or pulling a sheeps-foot roller, which is too heavy for most tractors. A D-5 or D-6 is usually sufficient, and should have steel tracks if operating on rocky or brushy sites. Extensive operator training is typically required for safe operation of crawler bulldozers.

2.8.2.2 Site preparation equipment

Rotary-Blade Mowers

Rotary-blade mowers are used during site preparation to cut existing vegetation, including grasses and brush. A heavy-duty type is also available for dense grasses and brush, as well as small-diameter trees. Rotary-blade mowers are capable of cutting vegetation to a 4 to 6 inch stubble height, depending on the evenness of the field.

Rotary-blade mowers are PTO (power take-off) driven, and available in 6 to 26 feet widths; wider mowers use a hydraulic system to fold, allowing for easier road transport. Depending on size, mowers are either 3-pt or pull-type.

Appropriate mower width depends on field size and terrain. For a relatively flat field 50 acres or less, a smaller, 3-pt hitch mower should be adequate. A wider, pull-type mower may be needed for larger fields, or for hilly fields that require a slower operating speed. Tractor horsepower necessary to pull rotary mowers varies with width and terrain, but in general ranges from 45-150 hp. A 10-15 foot wide mower requires 90-125 hp; a 26-ft mower requires 125-150.

Rotary-blade mowers are good all-around mowers, and are less expensive than flail mowers. In general, rotary mowers are more flexible in larger widths than flail mowers, and therefore cause less ground disturbance when operating in uneven terrain. Rotary mowers require less power to operate than flail mowers, and need less maintenance.

Unlike flail mowers, rotary-blade mowers cannot efficiently mow woody vegetation, in particular sagebrush that is larger than two inches in diameter. Multiple passes are typically needed to mow and grind up larger diameter sagebrush.

Flail Mowers

Flail mowers can be used to mow dense grasses, brush, and small diameter trees such as Russian olives. They are capable of grinding vegetation into smaller pieces than rotary mowers, and are much more efficient to operate in dense brush. Flail mowers are most useful for grinding up woody plants, as well as large Russian thistle and kochia plants, on relatively flat fields.

Flail mowers are PTO driven, and available in 6 to 20 feet widths. Depending on width, mowers are either 3-pt or pull-type. Some models have hydraulically controlled wheels mounted on the back of the mower to control depth. Unlike rotary mowers, wider models do not fold for transportation on roads, which complicates moving from site to site.

As with rotary-blade mowers, appropriate mower size depends on field size and terrain. Tractor horsepower required to pull flail mowers ranges from 45 to 175 hp, depending on the width of the mower. For a 20-ft mower, a 125 hp tractor is required for flat ground, and at least a 150 hp tractor is required for hilly terrain.

Light Spring-Tine Harrow

Light spring-tine harrows are used during site preparation for smoothing a rough seed bed and breaking up soil crust, or incorporating broadcasted seed or soil amendments. Functional tillage depth ranges from one-half to three inches, depending on the angle of the tines and soil firmness. Light spring-tine harrows are useful primarily on prepared seedbeds, and cause minimal disturbance when used in a no-till seedbed.

Spring-tine harrows are available in widths ranging from 4 to 60 feet. Smaller harrows (4 to 5 ft) can be pulled behind an ATV; larger harrows are pulled by tractors, either as a 3-pt hitch or pull-type. Ideal harrow width depends on field size and topography, but functional widths for most WDFW projects range from 15 to 40 feet.

In order to pull a 4 to 5 foot harrow on uneven or hilly terrain, ATVs should be 200 cc or larger. For a 15 to 40 foot harrow, a tractor from 75 to 125 hp will be necessary, depending on topography.

Heavy Spring-Tine Harrow

Heavy spring-tine harrows (Figure 9)are used during no-till site preparation to reduce standing dead vegetation, and to incorporate litter and weed seed. Functional tillage depth ranges from 2 to 5 inches, depending on the angle of the tines and depth adjustments. Incorporating weed seed stimulates germination, and therefore depletion of the weed seed bank. This process occasionally tears out grass crowns, but generally leaves existing perennial vegetation intact.

Figure 9. Heavy spring-tine harrow (40-ft)

Heavy spring-tine harrows are available in 20 to 60 foot widths, and are primarily pull-types. A functional harrow width for most WDFW restoration projects ranges from 20 to 45 feet. Depth and angle of tines is adjusted hydraulically; wider harrows can also be folded for road transport.

Relatively powerful tractors are needed to pull heavy spring-tine harrows, as there is no weight on the tractor. Required horsepower ranges from 100-250 hp; a 175 hp tractor with dual rear tires is needed to pull a 45 foot wide harrow in the hilly terrain depicted in Figure 9.

Shallow tillage with a spring-tine harrow has several distinct advantages over disking or plowing. Harrows are not as affected by rocks, and harrowing leaves deep root structure, crowns, and surface residue, which helps prevent erosion.

Spike Tooth Harrow

Spike tooth harrows are generally used on prepared seed beds, either to level and smooth the seedbed, break up clods, or incorporate broadcasted seed or soil amendments. As with light spring-tine harrow, tillage depth ranges from one-half to three inches, depending on soil firmness and adjustment of tooth angle.

Spike tooth harrows are available in 4 foot sections, and are primarily pull-types. A four foot section can be towed behind an ATV; any other sizes should be pulled with a tractor with a minimum of 15 hp. As these harrows cannot be lifted, a trailer or pick-up is required for transport from site to site.

Ring Cultipacker

Cultipackers are used in prepared seed beds to firm soils, break up clods, and press broadcasted seeds into the soil (figure 10). Packers are often pulled behind disks, to compact and firm the seedbed. A firm seedbed is particularly important when using a conventional grain drill without depth bands, as an uneven seedbed results in irregular planting depths. Cultipackers should not be used on very dry soils, as they will pulverize the soil and create a fine powder, which increases the risk of erosion.

Figure 10. Ring cultipacker pulled behind a roto-vator and a rolling basket packer.

Ring cultipackers are available in 4 to 30 foot widths, and are generally sized to be slightly wider than the implement that they are pulled behind. Cultipackers require minimal horsepower to tow. Small sections can be towed behind an ATV, or wider sections behind a tractor.

It should be noted that wide cultipackers are challenging to transport on roads, as they do not fold. In addition, units without transport wheels require trailers to move from site to site.

Offset Disks

Offset disks are used for chopping, cutting, and incorporating surface litter and vegetation, as well as loosening the soil and breaking up shallow compaction layers. Offset disks are used primarily in abandoned agricultural fields to control annual weeds and loosen the soil for subsequent rod-weeding or culti-weeding. Disking is also useful for breaking up and incorporating dense sod and litter, but should not be used in rocky soils. Offset disks are commonly used in many different types of agriculture, and are therefore readily available in most areas.

Offset disks are available in sizes ranging from 5 to 25 feet. Smaller sizes are 3-pt, while larger sizes are pull-types. A functional width for most restoration work is 12 to 14 feet for a large tractor, or 5 feet for a smaller tractor. Most offset disks have an adjustable depth range, based on disk size, angle, and depth control from hydraulically controlled wheels. Depending on width, tractor horsepower needed to pull offset disks ranges from 45-300 hp. For a 12 to 14 foot disk, 100 to 150 hp is appropriate, depending on terrain.

Sweep Chisel Plow

Sweep chisel plows are used to cut bunchgrass crowns or sod at the roots, typically at a depth of 4 to 6 inches (Figure 11). Separating the crown from the roots increases control of tough perennial grasses, including crested wheatgrass, big bluegrass, and intermediate wheatgrass. Sweep chisels work below the soil surface, and therefore retain substantial residue which decreases erosion, as compared to disking. As with disking, sweep chisels do not operate well in rocky soils.

Figure 11. Sweep Chisel (Courtesy Binghman Brothers Inc.)

Sweep chisel plows are available in 12 to 30 foot widths, but a 14 to 15 foot width is commonly used for the field sizes encountered by WDFW managers. For broad use, a sweep with 34 inches of vertical clearance and 12 to 18 inches of lateral clearance is desirable. Tractor horsepower necessary to pull sweep chisels ranges from 120 to 200 hp. For a 14 foot plow, 125 hp is appropriate for flat fields, or 150 hp for hillsides.

Moldboard Plow

Moldboard plows are used to turn under dense sod, primarily in fine-textured soils above 15 inches of annual precipitation where smooth brome, intermediate wheatgrass, or other rhizomatous grasses are dominant (Figure 12). When used in combination with herbicides, moldboard plows can provide complete control of rhizomatous grasses, by covering surface vegetation, and exposing deep rhizomes to the air to dry out.

Moldboard plow sizes are described in terms of the number of bottoms (i.e. blades), rather than width; sizes range from 2 to 12 bottoms, but 3 to 5 bottoms are more typically used. Multiple cut sizes are available, from 12 to 18 inches, but 18 inches is the most common. Smaller plows (2 to 7 bottoms) are typically 3-pt hitches, while larger plows (8 to 10 bottoms) are pull-types.

Moldboard plows require substantial power; required tractor horsepower ranges from 65 to 200 hp, with 125 to 175 needed for a 3 to 5 bottom plow. Plowing is considerably slower than disking, and cannot be conducted in rocky soils. Maintenance is also more time consuming than for disks or sweep chisels.

Figure 12. Four-bottom moldboard plow, with a ring cultipacker

Sheeps-foot Roller

Sheeps-foot rollers are used to break up dense brush, and to punch through thick duff and litter to expose soil, creating shallow pockets. Broadcast seeding following rolling deposits seed into these pockets, and allows for good seed-soil contact. Application of this type of roller within shrub-steppe is limited; currently, use is primarily for seeding through the thick leaf and duff layer left behind following Russian olive removal or tree thinning.

Figure 13. Sheeps-foot roller pulled by D-6 bulldozer

Sheeps-foot rollers are comprised of large steel drums filled with water or diesel for added weight; these drums are covered by 100 or so, 4 to 6 inch tall by 2 to 3 inch wide knobs (see Figure 13). They are available in 5 foot increments; the roller in Figure 13 is comprised of two 5 foot sections. Sheeps-foot rollers require substantial power and traction to pull, therefore, a crawler is typically necessary (D-5 or greater). Operating a sheeps-foot roller is slow, due the weight and limited maneuverability.

Rod-weeder

Rod-weeders are used to control taprooted annual weeds in prepared seedbeds, typically fallow dryland wheat fields (Figure 14). Rod-weeders are comprised of a rotating bar that is pulled through the soil at a depth of 3 to 4 inches; bar rotation is in the opposite direction of movement through the soil. Rod weeders may or may have sweeps. Soil must be loosened prior to rod-weeding, typically by disking.

Rod-weeders are available in widths ranging from 10 to 36 feet. Minimal horsepower is required to pull a rod-weeder, depending on width, a 60 to 130 hp tractor should be sufficient. Rod-weeders are relatively simple implements, require little maintenance, and can last for decades.

Rod-weeders are used primarily in abandoned agricultural fields, where weed control involves annual weeds such as Russian thistle and mustards. Rod-weeding is not as effective on cheatgrass, and is therefore used in combination with herbicide applications when cheatgrass is present. On a per acre basis, rod-weeding is less expensive than herbicide application, and has the added benefit of sealing the soil to retain moisture during fallow cycles.

Figure 14. Rod weeder (Courtesy Bingham Brothers Inc.)

Rod-weeding and other types of tillage that involve pulling implements through the soil should be avoided when rhizomatous weeds, such as Canada thistle or Russian knapweed, are present. Rhizome fragments can be spread throughout the field easily during rod-weeding, and can greatly complicate weed control.

Culti-weeder

Culti-weeders and rod-weeders perform similar functions, i.e., annual weed control in previously cultivated fields. Culti-weeders have a cultivator, comprised of spring shanks and sweeps, which precedes a rod-weeder, and therefore provides greater control of fibrous rooted annuals than rod-weeders alone. Culti-weeders work best in finer texture soils, e.g. silt loams. Depending on soil firmness, culti-weeders can be used alone, or following disking to loosen the soil.

Available sizes range from 24 to 60 feet wide. Tractor horsepower required to pull these sizes ranges from 100 to 150 hp. Culti-weeding is more expensive than rod-weeding alone, but still significantly less expensive than herbicide applications. Culti-weeding can also be used as a substitute for herbicide applications, when dusty leaves could preclude good herbicide contact. As with rod-weeding, culti-weeding should not be used when rhizomatous weeds are present.

2.8.2.3 Spraying equipment

ATV Sprayers

Sprayers ranging from 3 to 16 feet in width can either be directly mounted onto, or pulled behind, an ATV (Figure 15). A common width for ATV-operated spray equipment is 12 feet. ATV sprayers are more maneuverable than tractor sprayers, have a minimal footprint, and are easier to operate on moderate to steep hillsides. Fields 100 acres or less can be efficiently sprayed with an ATV sprayer.

Figure 15. ATV sprayer with a 12-ft boom, spraying fire lines in Yakima County

Spray tanks ranging from 20 to 35 gallons are appropriate for use with an ATV, meaning that between 2 and 3.5 acres can be sprayed with one tank load. For effective spraying, ATVs should be between 250 and 650 cc; 450 cc is a commonly used size. Ideally, ATVs should also be equipped with four-wheel drive, power steering, and a dyed foam marker system for even coverage.

Sprayers are calibrated based on the rate of nozzle spray and ATV speed. Boom systems purchased from agricultural supply typically come with nozzles that spray at a rate appropriate for travel across agricultural fields. These nozzles will need to be replaced for use on rocky or uneven rangeland, where significantly lower rates of travel are required.

Tractor Sprayers

Sprayers ranging from 10 to 40 feet in width can either be attached with a 3-pt hitch or pulled behind a tractor; commonly used boom widths range from 16 to 25 feet. Sprayers can be attached by either a 3-pt or pull-type hitch, and are either PTO or hydraulically driven. Tractor sprayers are less maneuverable than ATV sprayers, have a greater impact on soils, and are more challenging to operate on moderate to steep hillsides. Fields 100 acres or greater, or smaller, flat fields can be efficiently sprayed with a tractor pulled sprayer.

Spray tanks ranging from 140 to 300 gallons are appropriate for use with a tractor sprayer, meaning that over 14 acres can be sprayed with one tank load. Tractor horsepower ranges from 45 to 150 hp, depending on tank size and terrain. Ideally, tractors should have mechanical front wheel drive and wider tires for traction.

Aerial Sprayers

Another option for large-scale herbicide applications is to contract for an aerial sprayer. Aerial herbicide application is also useful in marshy areas, on steep hillsides, or on sites with limited ground access. Aerial sprayers are able to cover the same acreage much faster than ground based equipment, but can be limited in their ability to operate due to herbicide label restrictions associated with wind speed, as application occurs at a greater height and drift becomes a factor. In addition, selectively treating specific plants, or discrete areas can be challenging with aerial sprayers, although techniques/equipment are being introduced regularly to improve selectivity.

Figure 16. Herbicide application with a fixed-wing airplane

Herbicides can be applied aerially by either fixed wing airplane or helicopter, depending on the site and application rate (Figure 16). Helicopter systems can apply at higher rates than fixed wing, as helicopter speed is significantly slower and more adjustable than fixed wing speed. Boom width for most aerial sprayers ranges from 30 to 60 feet wide.

Weed Wiping

Weed wipers are used to treat vegetation at a specific height, and can be used to target taller weeds in shorter stands of newly planted seedlings. The most common application is the treatment of cereal rye in young plantings (Figure 17). Cereal rye quickly reaches 3 to 4 feet heights, and can therefore be targeted with little or no impact to underlying vegetation.

Wipers can be handheld, pushed in front of an ATV or pulled behind an ATV. Wiper widths range from 4 to 30 feet, and can be pulled with minimal horsepower. Wipers are comprised of a horizontal tube made of sponge, carpet or other liquid holding material mounted to a steel bar. When the wiper contacts vegetation, a concentrated herbicide mixture is applied directly to the target plant. Wipers can be shop built, but manufactured brands such as Smucker are highly recommended for proper application rates.

Figure 17. Weed wiper treatment of headed out cereal rye in Benton County

Wiping provides optimal control of herbicide application, as drift is non-existent. Dripping, however, is a potential problem as dripped herbicide can kill shorter non-target plants. Front mounted wipers have a general disadvantage of the ATV wheels running over the recently wiped grasses, potentially applying herbicide to non-target plants. As wiping only treats the tallest layer of vegetation lower growing weeds may be missed. Wider weed wipers become less maneuverable, particularly when navigating around sagebrush.

2.8.2.4 Seeding equipment

A discussion of the appropriate situations to use various seeding methods is included in **Section 3.3** Planting Methods The following discussion focuses on the specifications of different types of seeding equipment, as well as specifications of the power units used to operate this equipment.

Drills

Drills are tractor-pulled implements that open furrows with a set of disks, then place seed in the furrows at a specified rate. Depending on the type of drill, furrows may be closed with press wheels or allowed to drop naturally over the seed. Seeding depth can be controlled using depth bands that attach to disc and control furrow depth, by adjusting the 3-pt hitch, and/or by the firmness of the seedbed. Drills with depth bands are capable of seeding through plant residue, while other drills should be used only in prepared seed beds.

Drills range from 4 to 12 feet in width. Drills can be either 3-pt or pull types, depending on size and desired use. The most commonly used drills are 12 foot pull-types; these drills should be pulled with a 90 to 150 horsepower tractor, depending on traction and terrain.

Figure 18. Multiple drill set-up being used to seed a 600 acre no-till field

Most drills are ground-driven (turning of wheels propels internal components), with hydraulic lift for transport between sites. Multiple drills can be hitched together (Figure 18) to reduce time needed to seed s field using either shop-built or manufactured hitches. **Table 3** includes a comparison of attributes for the drills currently used by WDFW. It is important to confirm that drills apply seed at the correct rate. The **Seed Drill Calibration Tool** can be used to ensure that drills apply seed at the desired rate.

Air Seeders

Air seeders are used primarily to seed large dryland wheat fields, but can be used in shrub-steppe restoration if properly adjusted. An air seeder is comprised of a large seed cart, which meters seed using an air system to the implement cart. The implement cart is pulled behind the air cart and has spring shanks that create furrows for the seed, followed by coil packers to firm the soil and create seed-soil contact. For shrub-steppe restoration, these shanks are adjusted to only scratch the soil surface, rather than to create a deep furrow. A spring-tine harrow or coil packer is often mounted on the back of the implement cart. Seeding depth is dependent on the use of one of these implements, as well as the seedbed firmness.

A minimum of 100 hp is needed to pull a large air seeder. More horsepower will be needed for hilly fields or when pulling coil packers on the implement cart. Air seeders are easy to calibrate, and the forced air systems provide good control over seed flow. See **Table 3** for a comparison of attributes for the air seeders commonly used by WDFW.

Broadcasters

There are numerous brands and models of seed broadcasters available. ATV-mounted broadcasters with picker wheels are desirable for seeding the fluffy native grass and forb seed used for shrub-steppe restoration. Hand held broadcasters should be continuously agitated during use to keep a constant flow of seed. Seeding width for broadcasters depends on model and adjustments, but typically ranges from 2 to 10 feet.

It is notoriously difficult to attain a precise seeding rate when using broadcasters. ATV-mounted broadcasters have few factory built adjustments, and are calibrated based on ATV speed and dilution with fillers. In addition, seeding rate is greatly increased when the ATV bounces over uneven or rocky sites.

Figure 19. Truax seed slinger mounted on the front of an ATV, with a spring-tine harrow pulled behind

Seeding rate can be double-checked using the following method. Measure out a small area, and using the defined seeding rate, calculate the number of pounds of seed needed for that area. That seed amount should be placed in the hopper, broadcasting should proceed until the seed runs out. The difference between the acreage seeded and target acreage can be used to calculate the actual seeding rate.

Another method that can be used to double-check seeding rates involves calculating seeds per square foot of the desired seed mix, proceeding with seeding as planned, and then counting the seeds per square foot in several representative frames. This sort of visual assessment works best if some sort of "catchment" (piece of cloth or other substance) is laid down and the sown seeds counted on that surface. This method can also be used to obtain a visual estimate of desired seeding rate for smaller, hand broadcasting projects.

Manufacturer	Truax Inc	Tye	Valmar	Bee-line[1]	John Deere	Case IH
Design type	Heavy double disk drill	Double disk drill	Broadcast air drill	Broadcast air drill	Conventional grain drill	Conventional grain drill
Model/Description	Flex-II	8 ft Grain Drill		Custom built	450, 455, 8000 Series	5000 Series
Planting depth control	Depth Bands – Good	Good on firm seed bed	Based on seedbed firm and harrow position	Poor, depth based on soil looseness.	Good on firm seed bed	Good on firm seed bed
Seed boxes	Separate boxes for large and small seed	Separate boxes for large and small seed	One box	Separate boxes for large and small seed	One box	One box
Seed segregation or bridging concerns	Low - has agitators	Low – Grass box has picker wheel	Yes - no agitators	Medium - agitator in grass seed box	Yes - no agitators	Yes - no agitators
Seed carrier recommendations Note: Carriers not always needed.	Rice hulls work best; other fillers flow too fast Rate: 10-15%	Rice hulls work best; other fillers flow too fast; filler ratio is crucial because of the limited sprocket adjustments Rate depends on seeding rate: 50% is common	Carriers generally not needed; If dilution is necessary, use rice, which works well and is easy to obtain	Carriers generally not needed; If dilution is necessary, use rice, which works well and is easy to obtain	Rice works best for models without picker wheels Rate depends on seeding rate: 50% is common	Rice works best for models without picker wheels Rate depends on seeding rate: 50% is common
Site preparation prerequisites	Can be used in no-till or tilled soils.	Can be used in no-till or tilled soils.	Requires tilled, loose seedbed.	Requires tilled, loose seedbed.	Works best in smooth, tilled seed bed	Works best in smooth, tilled seed bed

Table 3. Current WDFW drills and air seeders, including capabilities and special considerations

[1]Special note: The Swanson Lakes Bee-line was custom built for WDFW with a picker finger inside the grass box.

2.9 Restoration Goals and Objectives

This section is largely based on the Society for Ecological Restoration International's **Developing and Managing Ecological Restoration projects, 2nd Edition**.

2.9.1 Setting goals

Goals are the ideal states and conditions that an ecological restoration project attempts to achieve. Written expressions of goals provide the basis for all restoration activities and the basis for project evaluation. It is extremely important to express each and every project goal with a succinct and carefully crafted statement.

Statements of ecological goals should candidly express the degree to which recovery can be anticipated to a former state, a desired state or a trajectory. Some ecosystems can be faithfully restored to a probable historical condition, whereas others may not ever approximate a reference system because of contemporary constraints or conditions. It is critical that restoration goals be realistic, both in terms of ecological feasibility and resource constraints.

All ecological restoration projects share a common suite of ecological goals related to ecosystem integrity, health, and the potential for long-term sustainability. A project may also have additional ecological goals, such as to provide habitat for particular species of concern or group of species. Consider developing goals for each of the following ecological attributes as applicable.

To varying degrees restored sites:

- Will contain a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure
- Consist of indigenous species to the greatest practicable extent
- Include functional groups necessary for continued development and/or stability
- Are capable of self sustaining, reproducing populations
- Are appropriately integrated into a larger ecological matrix or landscape, in which potential threats (e.g., weed infestations, excessive grazing) have been eliminated or reduced as much as possible
- Are sufficiently resilient to endure normal periodic stress events in the local environment (e.g., fire, drought, etc.)

Examples

- The restored ecosystem will be dominated by a mix of native bunchgrasses that are similar in composition and abundance to the reference site
- Functional group restoration
    - Dominant native bunchgrasses will be restored (by seeding)
    - Nitrogen-fixing lupines will be restored (by seeding)
    - Shrubs will provide structural diversity (via natural reinvasion)
- Invasive weeds will be eliminated or reduced as much as possible
- Provide winter habitat for sharp tailed grouse
- The restored ecosystem will be drought resistant and fire resilient

It is important to identify what is not included in the goals so that restoration efforts are in proper context. Such clarifications may include:

- Many forbs will not be restored due to lack of available seed. It is likely that a limited number of forb species will spontaneously re-invade the site.
- Due to repeated fires that start on nearby lands and the inability to eliminate that threat, fire-intolerant shrubs will not be restored.

Defining a reference ecosystem or reference. is an important tool for identifying meaningful, realistic goals. The reference represents the future condition or target on which the restoration is designed and serves as a basis for project evaluation (see Section ***3.5 Effectiveness Monitoring of Vegetation Restoration***). The reference can consist of the pre-alteration condition if it is known, one or more reference sites with the same type of ecosystem, descriptions of such sites, or other sources. The reference must be sufficiently broad to accommodate the amplitude of potential endpoints that could reasonably be expected from restoration.

Instruction on how to best estimate historical condition to be used as the reference is provided in Section ***2.1 Historical Conditions Research***. The degree to which the reference can serve as a model for a restoration project can vary widely among projects. In some projects, the reference can serve almost as a template. In others, it can only hint at the direction of development. Using methods described in Section ***2.1 Historical Conditions Research*** identify reference species composition as per **Table 4**.

Table 4. Historical conditions species composition - example

Soils (see map in soils reports)	% of site	Ecological site name or reference	Presumed species composition
Cashmere fine sandy loam, 0 15 percent slopes	60	R008XY101WA	Bluebunch wheatgrass 72% Sandberg Bluegrass 10% Cusick's bluegrass 7% Thurber needlegrass 7% Needle and thread 2% Lupines 2%
Quincy complex, 3 to 15 percent	40	Ecological site info not available, species and their relative abundances estimated based on nearby reference site	Indian ricegrass 70% Needle and thread 10% Sandberg bluegrass 7% Bluebunch wheatgrass 5% Lupines 2% Bitterbrush 5% Sagebrush 5%

2.9.2 Setting objectives

In order to achieve restoration goals, explicit actions are undertaken to attain specific end results. Each end result is called an objective. Objectives are selected with the anticipation that their completion will allow the fulfillment of project goals. Thus, objectives are used as indicators of goal attainment.

Objectives should be explicit and in terms that can be readily measured. They are used as the basis for success criteria to be evaluated via monitoring. Objectives generally include a time component that specifies when they are to be achieved. This helps to link them to the restoration monitoring, and allows systematic, sequential evaluation of short, medium, and longer-term objectives.

To the degree that reaching the reference species composition is a restoration goal, objectives can be tied to reference conditions or actions needed to achieve them. While it may be unrealistic to set precise species-by-species cover objectives matching reference site conditions, objectives should relate to those reference features considered most important (for example, species diversity, bunchgrass density, or shrub cover).

As precise reference system data are usually not available and variable due to site-specific conditions, disturbances and successional states, general abundance categories can be used to set meaningful objectives. Attainment of the following general abundance level categories can also be verified with limited monitoring resources.

1 = Rare (only a few plants encountered)
2 = Occasional (Widely scattered individuals, or only a few patches that locally can include many individuals)
3 = Frequent (Widely distributed, or more than a few patches)
4 = Common (Well distributed in most areas, or many patches)
5 = Abundant (Large numbers of plants across entire unit, and often many patches as well)

The following example objectives could be useful for a project if the goal is to restore dominant species identified in the historical condition. If the goal is to restore habitat for a particular species like sage grouse, recovery plans or species experts may be able identify vegetation objectives that can be used as indicators of habitat quality.

Examples:

- Within 3 years, establish native bunchgrasses as the dominant component
    - abundance level 5 for at least 2 species
    - abundance level >2 for at least 5 species
- Within 3 years, establish lupines at an abundance level ≥2.
- Within 10 years, shrubs are present at an abundance level of ≥3 on Quincy soils

Other objectives may not be related to the reference system but are critical to achieving the conditions associated with it.

Examples

- Within 3 years after planting no weed species will have an abundance level of ≥3
- Fence constructed to exclude cattle

3.0 Project Implementation

3.1 Seed Mix Development, Seed Acquisition and Seed Propagation

Unique seed mixes are often developed for restoration projects, based on the desire to match site-specific conditions, or achieve wildlife-specific habitat management goals. The design process typically begins with selecting a desired plant species composition, based on reference sites and habitat goals. Then desired species are cross referenced with commercially available species and seed sources, and the most appropriate sources are chosen based on project location and climate. Species substitutions may be required due to limited availability, or seed increase contracts can be developed to produce large quantities of project-specific seed.

The following sections will provide guidance to managers on the following: 1) the development of seed mixes, 2) the selection of appropriate seed sources, and if necessary, 3) the development of local seed sources.

3.1.1 Species composition

Seed mix composition is typically based on reference sites, Ecological Sites, wildlife habitat goals, and/or expert opinion. Seed mix development can start remotely by an examination of soils and Ecological Site Descriptions (ESDs), and be refined through the establishment of reference sites. As seed mixes may not feasibly contain all of the species that occur on references and ESDs, wildlife habitat goals can be used to select certain species from the overall list. Expert opinion can be obtained, as needed, for sites that have no published ecological sites or easy to locate references.

The **Seed Mix Calculator** included in this manual is based on seed composition by numbers rather than by weight. This type of calculator allows designers to visualize the percent composition of seedlings in the first year, and design mixes accordingly. Mix composition by weight is calculated from seed composition, as this is the common method for purchasing seed from seed vendors.

3.1.2 Ecological site descriptions

The Natural Resources Conservation Service (NRCS) has developed descriptions of possible plant communities that could be present at a site called Ecological Sites. Maps are based on county-wide soil surveys, and classify plant communities based on soils, aspect, and precipitation zone. Ecological site maps can be downloaded from the **Web Soil Survey** for most low elevation areas in eastern Washington. Fields that have been farmed for a number of years often do not have assigned Ecological Sites, as these are rangeland designations, but adjacent, unfarmed areas with similar soils can be used to identify the correct site. Once the Ecological Site has been identified, Ecological Site Descriptions (ESDs) can be downloaded. The following steps can be used to retrieve Ecological site descriptions.

1. Access the NRCS' **Web Soil Survey**
2. Define an Area of Interest using the interactive map
3. Select the Soil Data Explorer tab. There are several sub-tabs within this page with information about site soils. A site-specific soil report can be printed or downloaded.
4. Select the Soils Report tab. The report will include Ecological Site names and numbers.
5. Select the Ecological Site Assessment tab

6. View, print or download the Ecological Site Map and Ecological Sites by Map Unit Component Table to see how Ecological Sites are thought to have covered the land.
7. Select each of the Ecological Site tabs on the lower left portion of the page (Example site number and name: R007XY401WA – Alkali Bottom 6-9 PZ)
8. Print or download reports directly from the site if available
9. If the reports are not available go to NRCS **Field Office Technical Guide** web site.
10. Select your state and county of interest on the Locator Map
11. Select Section II from the drop down menu in the first folder under FOTG
12. Open the Ecological Site Descriptions folder (bottom one)
13. Select the Major Land Resource Area (MLRA) with numbers corresponding to the first three numbers in the Ecological Site. (For example MRLA B007 will contain the Ecological Site Description for R007XY401WA)
14. Download applicable Ecological Site Descriptions

ESDs contain a detailed list of plant species, including grasses, forbs, and shrubs, grouped by functional type. They were created by averaging the species found in similar relict sites across the region (Major Land Resource Area in NRCS parlance), and therefore local forb species lists may not be accurate at a site-specific scale, or forbs are identified only to genus. Percent composition listed in ESDs is based on forage production rather than more common ecological metrics like canopy coverage, as ESDs are used as a planning tool for grazing management. These percentages provide a general idea of species dominance and diversity for populating the following list.

- Dominant Grass Species: (list species with greater than 20% composition)
- Common Grass Species: (list species with a less than 20% but more than 5% composition)

These data can then be used to identify appropriate reference sites.

Table 5 contains an excerpt from the Stony 9-15 PZ ESD, from which the common and dominant grasses can be identified.

Historical Climax Plant Community			
Plant Group Type			
Perennial Cool Season Mid-Grass Decreasers		*pound*	
Count Each Listed Species up to the listed pounds for the Species			
PSSP6	bluebunch wheatgrass	405	68%
FEID	Idaho fescue	30	5%
ACNED	Nelson needlegrass	6	1%
POCU3	Cusick's bluegrass	6	1%
Perennial Cool Season Mid-Grass Increasers		*pound*	
Count Each Listed Species up to the listed pounds for the Species			
POSE	Sandberg bluegrass	68	11%
ACTH7	Thurber needlegrass	30	5%
HECOC	needleandthread	8	1%
KOMA	prairie Junegrass	6	1%
ELEL5	bottlebrush squirreltail	6	1%
Perennial Cool Season Tall-Grass		*pound*	
Count Each Listed Species up to the listed pounds for the Species			
LECI4	basin wildrye	6	1%

Table 5. Excerpt from Stony 9-15 PZ Ecological Site Description

3.1.3 Literature and historical records review

There are numerous publications and databases that describe vegetation or wildlife habitats along with the ecological processes that maintain them. Examples include:

- ***The Washington Natural Heritage Program's* Draft Field Guide to Washington's Ecological Systems**

- ***Wildlife–Habitat Relationships in Oregon and Washington (D.H. Johnson T. A. O'Neil. 2001)*** Select chapters including **Chapter 2**, which describes wildlife habitats and **Habitat maps** for the entire Columbia River Basin can be viewed on line.
- ***NatureServe Explorer***

Local historical records including survey records, journals and old photographs can also provide valuable insights into the historical conditions. Local historical societies are a good means to identifying local experts. Universities often house historic records as well. The **Washington State University Library Image Collection** includes photos showing what many areas looked like more than a century ago. **Government Land Office Survey Records** from the late 1800's often provide the earliest written descriptions of vegetation. While descriptions are not very detailed like "bunchgrasses and lupines" or "bunchgrasses, juniper and some sagebrush", they can help practitioners compare reference sites to historical conditions. Caution is advised when using journals and other historical records as authors were not usually trained in recording quantitative objective observations.

3.1.4 Reference sites

While pristine reference sites may no longer exist, close approximations of the potential plant community can be found in a number of places. Areas less likely to be affected by anthropic disturbance can be found within livestock exclosures, areas naturally isolated from livestock access such as steep hillsides, protected areas such as parks, and isolated areas without livestock water access (Shinneman et al. 2008). For former agricultural fields, adjacent areas that have not been tilled and are fenced to exclude livestock may provide good references. ESDs should be used to determine dominant and common grass species, which can then be used to help locate appropriate reference sites. It is important to recognize, however, that relatively undisturbed-looking sites may have been substantially altered by past grazing, modified fire regimes, hydrological alterations or other processes. At a minimum, however, such sites indicate what native plants successfully compete under current conditions.

The following information should be collected from reference sites:

- Percent composition for dominant grasses
- Percent composition for common grasses
- Percent composition for common shrub species
- Percent composition of common forb species

Percent composition of all species should add up to 100%. The following table provides an example of what this data would look like for a site with an assigned ecological site of Stony 9-15 PZ (USDA-NRCS, 2005).

Grasses	Forbs and Shrubs	
50% Bluebunch wheatgrass	2% Sagebrush	1% Antelope bitterbrush
20% Sandberg's bluegrass	5% Carey's balsamroot	1% Parsnipflower buckwheat
5% Cusick's bluegrass	5% Tailcup lupine	1% Mariposa lily
1% Six weeks fescue	3% Slender hawksbeard	1% Thompson's paintbrush
1% Great Basin wildrye	3% Nineleaf desertparsley	1% Basalt milkvetch

Table 6. Reference site species composition example

For managers who have not previously performed vegetation monitoring, estimating composition may seem like a daunting task. It may be helpful to bring along a vegetation monitoring quadrat, and practice estimating composition within a smaller, defined area, before extrapolating to the site level.

3.1.5 Wildlife habitat goals

Once ESDs and reference sites have been examined, specific forb and shrub species can be chosen from the overall species list based on habitat goals. In cases where the restoration goal is to simply improve ecological integrity, the seed mix should be developed to approximate the reference community to the greatest degree practical.

If goals involve habitat restoration for specific species such as sage grouse or mule deer, the seed mix can be developed with an emphasis on meeting the needs of those species. These goals are generally derived from habitat or diet studies in the scientific literature, or from guidance documents like recovery plans, produced by state or federal wildlife agencies.

Following the above example on a Stony 9-15 PZ ecological site, the manager could choose to plant bitterbrush, balsamroot, lupine, and buckwheat, in order to provide winter forage for mule deer (Burrell 1982). If the goal for the same site is management for sage-grouse brood rearing habitat, the mix could include sagebrush, while increasing forb cover to 25% using as many forb species as possible (Stinson et al. 2004).

3.1.6 Expert opinion

Another potential source for designing restoration seed mixes is expert opinion, generally from local ecologists and botanists. WDFW's land managers, private lands biologists, and other Lands Division employees have considerable botanical knowledge. In addition, other agencies (DNR's Program, private vegetation consultants, and BLM botanists) or **Native Plant Society** botanists could be consulted on native species composition in challenging situations. Private organizations and firms can also provide guidance on seed mix development. For a directory of people who might be able to assist see Section 6.1.1 Contacts.

3.1.7 Example grass seed mixes and seed use considerations

Table 7 has been provided for illustrative purposes to show how seed composition by percent, weight and pure live seed/acre vary in typical grass seed mixes due to differences in seed weight. The differences can be even greater with shrubs and forbs whose seeds can vary dramatically in size. A common mistake is to plant too many seeds of the smaller-seeded species like yarrow, sagebrush and Sandberg's bluegrass. The Seed Mix Calculator can help one avoid such mistakes.

Table 7. Example of a grass and forb/shrub seed mixes on a loamy soil site in the Columbia Plateau

Grass Species	**Seed Composition**	**Seeds Per Square Foot**	**Weight Composition**	**PLS Lbs/Acre**
Bluebunch wheatgrass	40%	17	75%	5.3
Sandberg's bluegrass	35%	14.9	10%	0.7
Idaho fescue	25%	10.3	15%	1.0
Total	100%	42.2	100%	**7**
Forb/Shrub Species	**Seed Composition**	**Seeds Per Square Foot**	**Weight Composition**	**Lbs/Acre**
Yarrow	20%	2.4	1%	0.04
Silky lupine*	2%	0.2	26%	0.79
Big Sagebrush	20%	2.4	1%	0.04
Shaggy fleabane daisy	15%	1.8	1%	0.04
Prairie flax	13%	1.5	5%	0.16
Arrowleaf balsamroot	15%	1.8	47%	1.41
Parsnipflower buckwheat	15%	1.8	17%	0.52
Total	**100%**	**11.8**	**100%**	**3**

Table 8 lists species that have been planted in restoration projects as seed. The list gives a general idea as to how easy or difficult it is to collect, propagate and establish different species from seed based on WDFW experience through 2011. Many important native species are not included solely due to lack of experience with them in restoration. The absence of such species is not intended to imply that they would not make good candidate to use as seed. The table will be expanded over time to reflect as practitioners gain experience with more species.

Table 8. Species ease of use by seed*

Grasses	Starter seed collection	Seed increase	Plant establishment	Overall Rating
Bluebunch wheatgrass	Moderate	Easy	Easy	Easy
Bottlebrush squirreltail	Moderate	Challenging	Moderate	Moderate
Great Basin wildrye	Easy	Two years to seed production	Easy	Easy
Idaho fescue	Easy	Two years to seed production	Moderate	Moderate
Indian Ricegrass	Moderate	Easy	Easy	Easy
Inland saltgrass	Difficult	Difficult	Difficult	Difficult
Needle and thread	Difficult	Two years to seed production	Moderate	Difficult
Prairie junegrass	Moderate	Two years to seed production	Moderate	Moderate
Sand dropseed	Moderate	Easy	Moderate	Moderate
Sandberg's bluegrass	Moderate	Easy	Moderate	Easy
Thickspike wheatgrass	Moderate	Easy	Moderate	Moderate
Thurber's needlegrass	Difficult	Difficult	Moderate	Difficult
Shrubs	Starter seed collection	Seed increase	Plant establishment	Overall Rating
Big sagebrush	Easy	Not applicable*	Easy	Easy
Greasewood	Difficult	Not applicable*	Difficult	Difficult
Yellow rabbitbrush	Moderate	Not applicable*	Easy	Easy
Rubber rabbitbrush	Moderate	Not applicable*	Easy	Easy
Winterfat	Moderate	Not applicable*	Easy	Easy
Forbs (harder in general)	Starter seed collection	Seed increase	Plant establishment	Overall Rating
Balsamroot spp.	Easy	Moderate	Difficult	Difficult
Blanket flower	Moderate	Moderate	Moderate	Moderate
Blue mountain penstemons	Moderate	Difficult	Moderate	Moderate
Buckwheat, parsnipflower	Moderate	Not applicable*	Moderate	Moderate
Buckwheat, snow	Easy	Not applicable*	Easy	Moderate
Common sunflower	Moderate	Moderate	Moderate	Moderate
Dusty Maiden	Moderate	Moderate	Moderate	Moderate
Lewis's flax	Moderate	Easy	Easy	Easy
Lupine, silky	Moderate	Not applicable*	Moderate	Moderate
Lupine, velvet	Moderate	Not applicable*	Moderate	Moderate
Shaggy Daisy	Easy	Moderate	Easy	Easy
Slender Hawksbeard	Moderate	Difficult	Moderate	Moderate
Yarrow	Easy	Not applicable*	Easy	Easy

*Easier to wild-collect than grow.

3.1.7 Seed classes

A number of different classes of seeds are commercially available, from cultivated varieties that have undergone years of testing and manipulation, to source identified varieties that originate directly from wild populations. Figure 20 is reprinted from the AOSCA (Association of Seed Certifying Agencies) publication Native Plant Connection. At the top of this flow chart, wild collected seed (aka *germplasm accessions*) can proceed down two different pathways, a "manipulated track" or a "natural track". Moving the seed collection down the manipulated track indicates that purposeful genetic manipulation has occurred to select for or create specific traits, commonly high forage productivity, quick establishment, and plant uniformity for seed production. Seed collections that proceed down the natural track do not have purposeful genetic manipulation (AOSCA, 2003). A description of the origin and development of commonly used cultivars and releases can be found on-line at the Native Seed Network Releases web page or in the USFS publication Grass cultivars: Their origins, development, and use on national forests and grasslands in the Pacific Northwest (Aubry et al. 2005).

3.1.7.1 Natural track

The top box along the natural track is the "Source Identified Class", which indicates that no testing or selection of the accession has occurred. This seed is either collected directly from wild populations, or wild collections were sent directly to production fields without any intermediate steps. This class of seed most closely resembles the genetics of the native population of origin (AOSCA, 2003).

If species are purchased individually, the seed tag will be yellow, indicating that this seed is certified as Source Identified. Seed mixes do not generally indicate the seed class of each species within the mix, but the seed vendor should be able to provide this information, upon request.

As germplasm accessions proceed down the natural track, accessions are selected for specific traits (Selected Class), and tested for heritability of those traits (Tested Class). No intentional genetic manipulation within accessions occurs during this process. This evaluation process takes multiple years, and is typically performed by federal agencies, seed companies, college extension programs, or native seed partnerships.

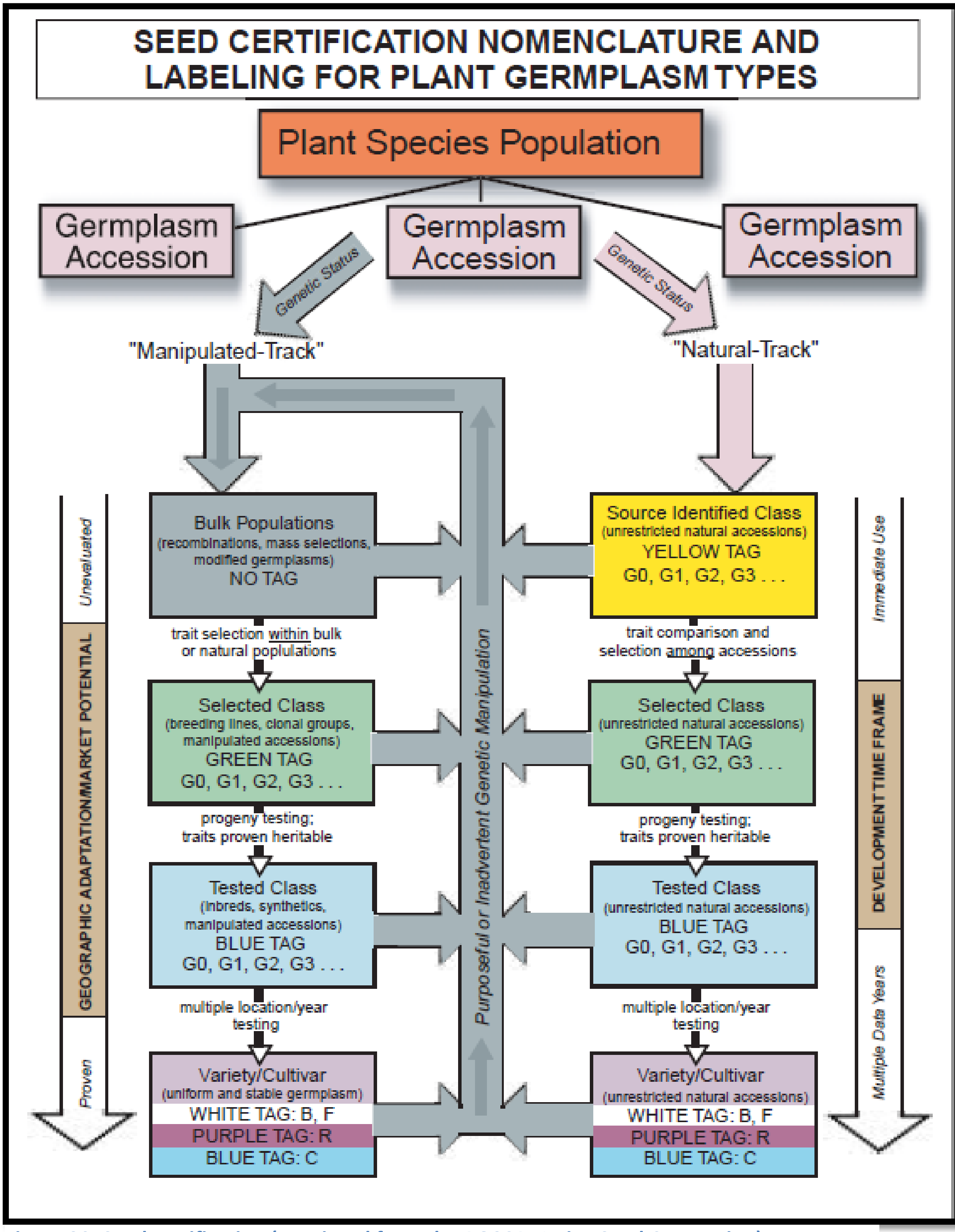


Figure 20. Seed certification (Reprinted from the AOSCA Native Seed Connection)

It should also be noted that some Natural Track Selected Class germplasms include multiple native populations, specifically combined to increase genetic diversity and adaptability. "Reliable" Sandberg's bluegrass is an example of a multiple collection site germplasm. While pooling collections in this manner increases genetic diversity, it also decreases the genetic resemblance to any particular site.

An example of a Natural Track Selected Class release is "Anatone" bluebunch wheatgrass, which originates from southeastern Washington, and was selected from other accessions for rapid establishment and drought tolerance. If sold as individual species, Selected Class releases have a green tag, and Tested Class releases have a blue tag. If sold as a mix, the purchaser should ask the vendor for seed certification and class information.

The final box along the Natural Track represents formally released cultivars. The term cultivar is a concatenation of cultivated variety, and is used to designate specific releases that have gone through selection for specific traits, testing of trait inheritance, and multi-year testing over a broad geographic range.

3.1.7.2 Manipulated track

Unlike natural track accessions, manipulated track accessions are subject to either selection within the population for specific traits, or hybridization between populations to create specific traits. As a result, manipulated track germplasms no longer closely resemble native populations on a genetic level.

As with the natural track procession, as an accession moves down the manipulated track line, additional testing and selection occurs for specific traits, until a formal cultivar release is made. Cultivars are tested for adaptability to broad geographic ranges, over multiple years. This process takes many years, and may be performed by federal agencies, seed companies, college extension programs, or native seed partnerships.

An example of a manipulated track cultivar is "P-7" bluebunch wheatgrass. P-7 was created by crossing 23 bluebunch wheatgrass collections from six western states and British Columbia with the bluebunch wheatgrass cultivars "Goldar" and "Whitmar" (Jones et al. 2002). The Agricultural Research Service (ARS) developed P-7 to provide a genetically diverse bluebunch wheatgrass cultivar for use in revegetation work across a wide geographic area.

Manipulated Track-Selected Class seed is sold with a green tag, and Manipulated Track-Tested Class seed is sold with a blue tag. Seed mixes to not typically indicate the class of each species, but this information should be available from the vendor, by request.

3.1.7.3 Selecting the Class of Seed

The class of seed chosen for a given project depends on general goals, i.e. restoration, revegetation, or reclamation, as well as site constraints, timing, cost and availability (Jones and Monaco, 2007). Several excellent frameworks have been developed to guide practitioners through the seed selection process, namely, Lesica and Allendorf (1999), Aubry et al. (2005), and Jones and Monaco (2007). In general, preferred seed for restoration projects is native, locally adapted, and genetically diverse, as such seed is most likely to produce long-term sustainable native plant communities. This includes source-identified seed or other natural track releases collected from an ecologically similar site (Aubry et al. 2005). Manipulated class cultivars may be appropriate for projects where site reclamation or re-vegetation are primary goals, or for highly disturbed sites (e.g. mine tailings) where competitive traits developed in cultivars may be necessary for establishment.

For an in-depth discussion of genetic choices and consequences, readers are referred to the previously mentioned references, as well as the USFS publication Genetically Appropriate Choices for Plant Materials to Maintain Biological Diversity (Rogers and Montalvo, 2004). The following section provides guidance on determining appropriate transfer zones for seed sources.

3.1.8 Seed selection

Selection of appropriate seed sources can be one of the most critical aspects for the long-term sustainability of restoration plantings. US Forest Service geneticists are in the process of developing seed transfer zones for several commonly seeded species, based on empirical common garden studies. To date, seed zone maps relevant to eastern Washington shrub-steppe are being developed for the following species: prairie junegrass, bluebunch wheatgrass, Indian ricegrass, tapertip onion, and Sandberg's bluegrass. As these studies are completed and maps are published, link will be established to empirical seed zone maps.

In the meantime, and for species not included in empirical studies, a provisional seed map has been developed, based on climate and Level III eco-regions (Bower et al. 2010). This map can be used to verify that selected seed ecotypes are from climatically similar areas, and therefore will have a reasonable expectation of success on the project site. ArcGIS shapefiles or Google Earth KML files containing this map can be downloaded from the USFS **Western Wildland Threat Assessment Center**.

Figure 21 depicts the provisional seed zone map for grasses and forbs. The USFS provisional seed zone map does not take into account soils or other microsite information. Should multiple choices for ecotypes occur within the same seed zone, ecotypes from similar soils and sites should be selected for the project seed mix.

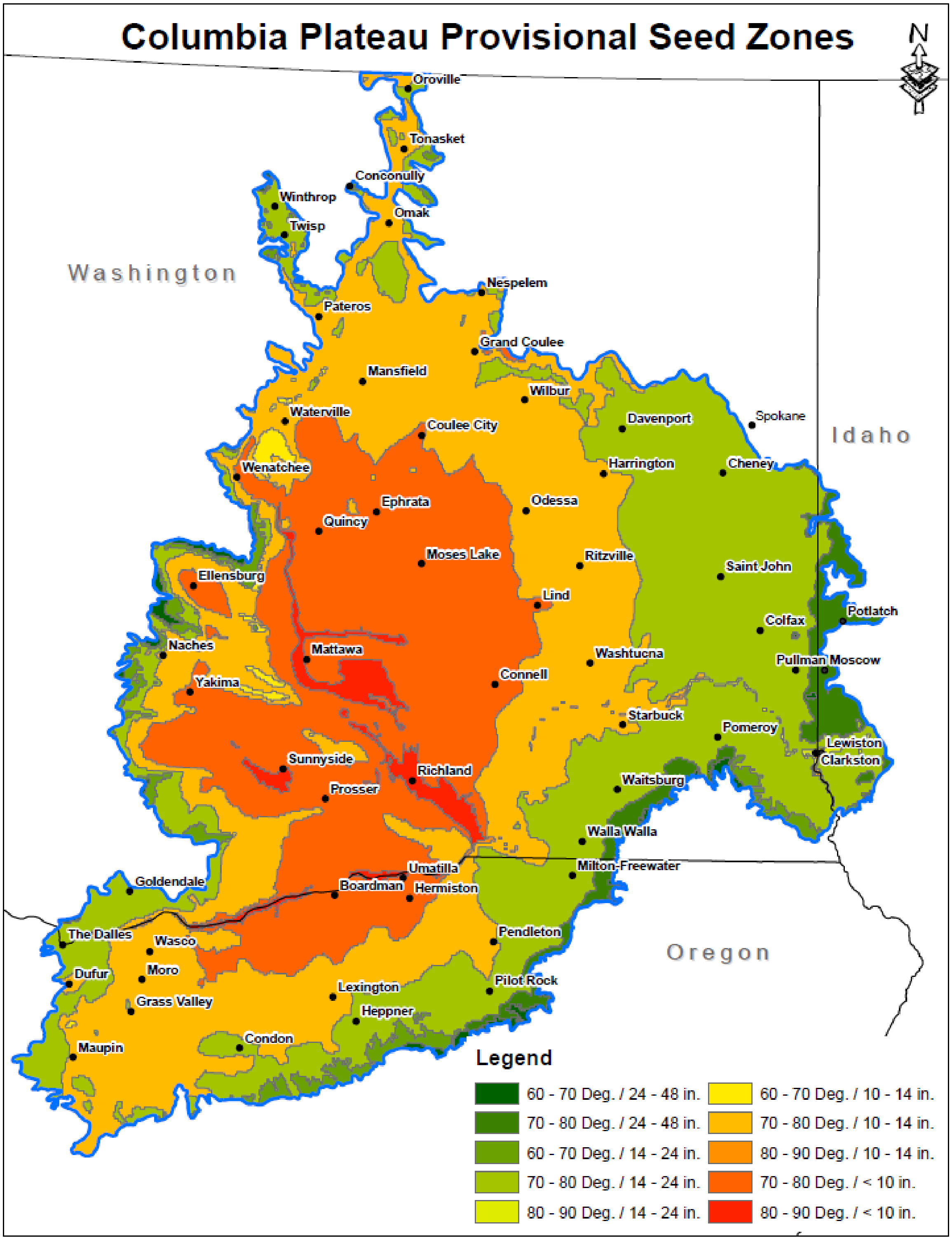


Figure 21. Columbia Plateau Provisional Seed Zones

3.1.9. Pure live seed vs. bulk seed.

Seed may be purchased on either a bulk seed (actual weight) basis, or Pure Live Seed (PLS) basis. Pure live seed is calculated by multiplying the purity of a seed lot (percent of weight that is seed of the desired species, as opposed seed of other species, chaff, and stems) by the germination rate of the seed lot (percent of seed that germinates in a lab test). Most agencies have moved to purchasing seed on a PLS basis, and this approach works well for large seed lots. However for smaller seed lots, many of which

PLS = Purity **x** Germination

are wild collections, PLS testing is not performed, as it would add anywhere from $25 to $200 per pound to the cost of seed, therefore making small seed lots difficult to market. Managers should be aware that rarer, wild collected forbs, grasses and shrubs may not be available for purchase on a PLS basis.

3.1.10 Seed increase

Seed increase contracts can be developed with either public or private production facilities to develop locally native seed sources for a specific project or region. It is becoming increasingly popular for several organizations or agencies to join together for this purpose, creating native seed banks or partnerships. Figure 22 illustrates the timeline needed for the seed increase process.

Figure 22. Seed increase development timeline

Timeline	Year 1												Year 2											
	Winter			Spring			Summer			Fall			Winter			Spring			Summer			Fall		
Task	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Wild Collection																								
Increasing																								
Grass																			1					
Forb																				2				
Outplanting – Grass																								
Outplanting – Forb																								

Timeline cont'd	Year 3												Year 4											
	Winter			Spring			Summer			Fall			Winter			Spring			Summer			Fall		
Task	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Wild Collection																								
Increasing																								
Grass																								
Forb								3																
Outplanting – Grass												X												
Outplanting – Forb																								X

[1]Harvest of most grass species begins, excluding those with an extended juvenile phase (Idaho fescue).
[2]Harvest of fast growing forb species begins, including yarrow, lupines, fleabane daisies, and others
[3]Harvest of slower growing forb species begins, including buckwheats and penstemons.

As a first step, foundation seed (wild collected seed to be used for propagation) should be collected for desired species. This seed may be collected from relict areas adjacent to project site, or from similar sites within the same seed zone. Care should be taken to select sites that have not been previously planted to cultivars of the same species, or species that have the potential to cross with the desired species (particularly important for *Elymus* species). In general, collection sites should be located at least 100 feet from roads or other planted sites.

Collection sites should also be selected to avoid contamination with weed species, particularly if weed seeds have a similar size and weight as target seeds, and are mature during the collection period. It is particularly important to avoid contamination of cheatgrass, North Africa grass (Ventenata), and rattail fescue seed with the following grasses: blue wildrye, bluebunch wheatgrass, Great Basin wildrye, Idaho fescue, and bottlebrush squirreltail.

The protocol for wild collection of native seeds includes the following steps: 1) select at least 5 populations a minimum of 1 mile apart (BLM 2011), 2) clip heads from mature plants into an open tub with garden pruners or sharp heavy scissors, 3) spread the material on a tarp to achieve a thin layer, and 4) dry seed in a covered area with good ventilation. Box fans should be used to enhance ventilation. Seeds with explosive dehiscence (e.g. lupines) or light, fluffy seeds (e.g. hawksbeards), should be placed in an enclosed container, covered with a heavy screen, and ventilated with box fans.

A good rule of thumb for seed collection is the 3:1 rule; collect three pounds of raw material for every one pound of cleaned seed desired. For USDA or Department of Interior (DOI) agencies, wild-collected seed can be cleaned at the USFS Bend Extractory in Bend, Oregon. For other agencies or private organizations, seed can be cleaned by private milling facilities, such as those available from native seed vendors.

In general, 1-2 PLS pounds of grass seed can be used to establish a 1-acre production field. Smaller seeded species such as Sandberg's bluegrass and prairie junegrass only require 1 PLS pound of foundation seed per acre, while larger seeded species such as bluebunch wheatgrass and blue wildrye may require 2 PLS pounds. Yield of seed increase fields varies greatly depending on grower, year, and ecotype. Specific information on expected seed yield per acre should be obtained from contracted seed producers.

3.2 Site Preparation

3.2.1 General principles

In general, four objectives should be achieved through the site preparation process: 1) reduction of the weed seed bank; 2) reduction of plant residue; 3) removal of existing vegetation; and 4) preparation of seed bed. The following section discusses each of the objectives in general, and introduces several possible methods for addressing these objectives.

3.2.2 Reduction of weed seed bank

Reduction of the weed seed bank is critical, as young native seedlings compete poorly with dense stands of cheatgrass and other annual weeds (Harris and Wilson 1970). Therefore, a significant reduction in the weed seed bank must occur prior to seeding for the seeding to have a reasonable expectation of success.

Seedbank reduction can be achieved over a shorter time period by shallow tillage with a heavy spring-tine harrow, which places the seed in contact with the soil and stimulates germination, followed by spraying. Alternatively, seed banks can be depleted over an extended time by repeatedly controlling weed flushes with either herbicides or mechanical weeding (i.e. rod-weeding or culti-weeding). Harrowing is effective in uncultivated and rocky soils, where rod-weeders cannot operate.

3.2.3 Reduction of plant residue

Plant residue provides erosion control, but excessive litter and standing dead vegetation can decrease herbicide efficacy and reduce planting success. Plant tissue decomposition occurs at relatively slow rates in semi-arid eastern Washington, leaving several years of standing dead vegetation growing amongst live stems and leaves. Herbicide application over the top of intertwined live and dead stems is intercepted by dead stems, reducing coverage and herbicide efficacy (Ghadiri et al. 1984, Wolf et al. 2000).

Plant residue can be reduced with a minimum till process involving mowing and harrowing, or by full tillage with disks or plows. The intensity of tillage typically depends on available equipment, soil types, and initial levels of residue present on a site. More intensive tillage, i.e. moldboard plowing or heavy disking, can bury plant residue and weed seed with one step, but should be avoided if possible due to the increased risk of erosion (Shipitalo and Edward 1998).

Prescribed burning is also an effective and efficient way to reduce plant residue. However, the logistics of prescribed burning on WDFW land have curtailed its use in shrub-steppe restoration, and therefore insufficient experience has been obtained to warrant inclusion in this manual at this time.

3.2.4 Removal of existing vegetation

Prior to seeding desired species, the majority of existing vegetation should be eliminated, along with weed seed that is likely to compete with young seedlings. This involves controlling weed seed production, cheatgrass in particular, and killing perennial grasses. A field-wide application of glyphosate timed to coincide with at least 6-8 inches of perennial grass growth, but prior to cheatgrass flowering, is the most critical step. Taprooted annuals such as mustards and Russian thistle can be removed with mechanical weeders, such as culti-weeders, and rod-weeders.

Heavy tillage may also be necessary to remove tall wheatgrass, dense crested wheatgrass, or rhizomatous grasses that create a dense sod or thatch layer that cannot be drilled through. In this situation, a sweep chisel plow or heavy disks can be used to break dense bunchgrass crowns, or a moldboard plow can be used to turn under thick sod.

3.2.5 Preparation of the seed bed

An ideal seed bed is firm enough to allow accurate planting and seed-soil contact, yet is loose enough to allow seedling emergence and root growth. Ideal firmness varies based on planting equipment, but as a rule of thumb, when walking across the surface, a person should sink no more than 2 inches deep. Minimum or no-till site preparation typically results in a firm seed bed, without additional steps. Harrowing or packing can be used following heavy tillage, as necessary, to smooth and firm the seed bed.

3.2.6 Site conditions

Site preparation processes vary based on site-specific conditions, the most important of which are existing vegetation, soil type, accessibility, and site variability. Existing vegetation is the primary determinant of site preparation length and number of steps. Perennial rhizomatous grasses require more tillage, and therefore a more intensive removal process than either perennial bunchgrasses, or annuals such as cheatgrass. Broadleaf weeds, if present, generally need to be addressed as a separate process, as specific treatments are required. Soil type and accessibility primarily affect the type of equipment and tillage that can be utilized on a site.

In order to begin developing a site preparation plan, the following questions should be answered:

1. What is the existing vegetation?
    a. Are annual grasses common or dominant?
    b. Are perennial grasses present? If so, what species?
    c. Are rhizomatous grasses present?
    d. Is dense or large diameter brush present?
2. What is the soil type? Are there rocks in the soil profile?
3. Is the site accessible by heavy equipment, ie tractors? Is the slope less than 30%?
4. Is the field fairly uniform, or will different processes be required in different areas?
5. Are any unique site challenges present, i.e. soil compaction, excess nutrients, high alkalinity, residual herbicides, and large weeds populations? If so, see ***Section 2.7 Site Challenges*** section before proceeding.

Once these questions have been researched, site preparation planning can proceed. The following sections will help guide managers through the development of a site preparation plan, based on responses to the above questions, and the restoration scenarios presented in the following sections.

3.2.7 Scenario-based site preparation processes

The following sections describe site preparation processes for three of the scenarios most likely to be encountered by WDFW managers, i.e., bunchgrass fields, rhizomatous grass fields, and abandoned agricultural fields. At the end of each section, sample site preparation timelines are presented for each of these scenarios.

No matter how well planned the site preparation process may be, unexpected events, i.e. late summer rainfall or weed flushes, often occur requiring adaptive management. Close monitoring of the project site, as well as flexible funding and staffing to respond to unexpected events, is critical to project success.

All herbicide mixes that include Roundup (glyphosate) assume the use of 4 pound active ingredient formulations, i.e. Roundup and Roundup Pro. Mixes should be adjusted if using different Roundup formulations, such as Roundup Concentrate (5.5 pound active ingredient formulation).

3.2.7.1 Bunchgrass fields

Crested Wheatgrass Fields

For stands of perennial bunchgrasses such as crested wheatgrass, the first site preparation step is typically a field wide mowing. Mowing should be timed such that weed and grass seed is mature, so that all annual seed production is cut and placed on the ground and so that plants have minimal time to produce new foliage in that growing season. This typically coincides with mid-summer, but can occur any time after seed maturity through early fall. Ideally, stands should be mowed to a 4-6 inch stubble height. A rotary-blade mower can be used to mow grasses and small-diameter brush (<2 inches); if the field is comprised of large patches of brush with greater than 2 inch trunks, a flail mower should be considered.

Figure 23. Crested wheatrass in the spring following mowing and harrowing

Mowing serves two purposes. First, mowing shatters seedheads and can help ensure that a greater percent of the seed bank will be killed as seedlings with subsequent herbicide applications. Second, mowing reduces the amount of standing dead vegetation, which exposes greater green leaf tissue for herbicide uptake the following spring, therefore increasing herbicide efficacy. The second step for crested wheatgrass stands is a field-wide harrowing, typically using a heavy, spring-tine harrow. This step follows mowing, and should be deferred until fall rains have increased soil moisture, thereby reducing the amount of dust released into the air during harrowing.

Harrowing works weed seed into the soil, providing seed-soil contact for optimal germination of weed seeds. Harrowing also incorporates litter into the soil and further reduces standing dead vegetation, both of which result in greater leaf area and herbicide uptake. Figure 23 illustrates a crested wheatgrass field in the spring following both mowing and harrowing. This stand is vigorously growing, with plenty of leaf area for herbicide uptake.

The following spring, once grasses have achieved 6 to 8 inches of new growth, and prior to cheatgrass seedhead emergence, the field is then sprayed with a heavy Roundup application. Table 9 provides specific rates and adjuvants for the recommended herbicide mixture.

Table 9. Herbicide mix and rates for initial control of crested wheatgrass during site preparation

Species	Herbicide Mixtures and Rates
Crested wheatgrass	96 oz/acre Roundup, 16 oz/acre AMS[1], 1 oz/acre NIS[2]

[1]Ammonium sulfate, common trade name is Bronc Max

[2]Non-ionic surfactant, common trade name is R-11

Vigorous stands of crested wheatgrass may need additional tillage or herbicide applications to treat regrowth, particularly in high precipitation years. Sweep-chisel plowing can be used on sites where crested wheatgrass crowns are dense enough that poor seed-soil contact will be achieved through seeding. On sites without dense crested wheatgrass sod, a Roundup-Banvel herbicide mixture (see **Table 11**) can be used to treat crested wheatgrass regrowth along with summer annual broadleaf weeds.

Figure 24. Crested wheatgrass field on sandy site, several weeks after first Roundup application

Sweep chisel plowing separates bunchgrass roots from crowns 3 to 4 inches below the soil surface. This provides greater bunchgrass control, while breaking up sod and crowns, thereby reducing the residue that will be seeded through. Sweep chisel plowing should be followed by harrowing with a light spring-tine harrow, or packing with a ring cultipacker, to smooth and firm the seed bed.

Follow-up crested wheatgrass treatment is typically necessary only on sites with finer texture soils and good moisture holding capacity (e.g. Figure 23), as sandy and rocky soils do not typically support vigorous stands of crested wheatgrass in the Columbia Basin. Figure 24 depicts a crested wheatgrass stand growing on sandy soils in northern Grant County, in late August following the heavy Roundup application. Only one Roundup application was necessary to control crested wheatgrass on this site.

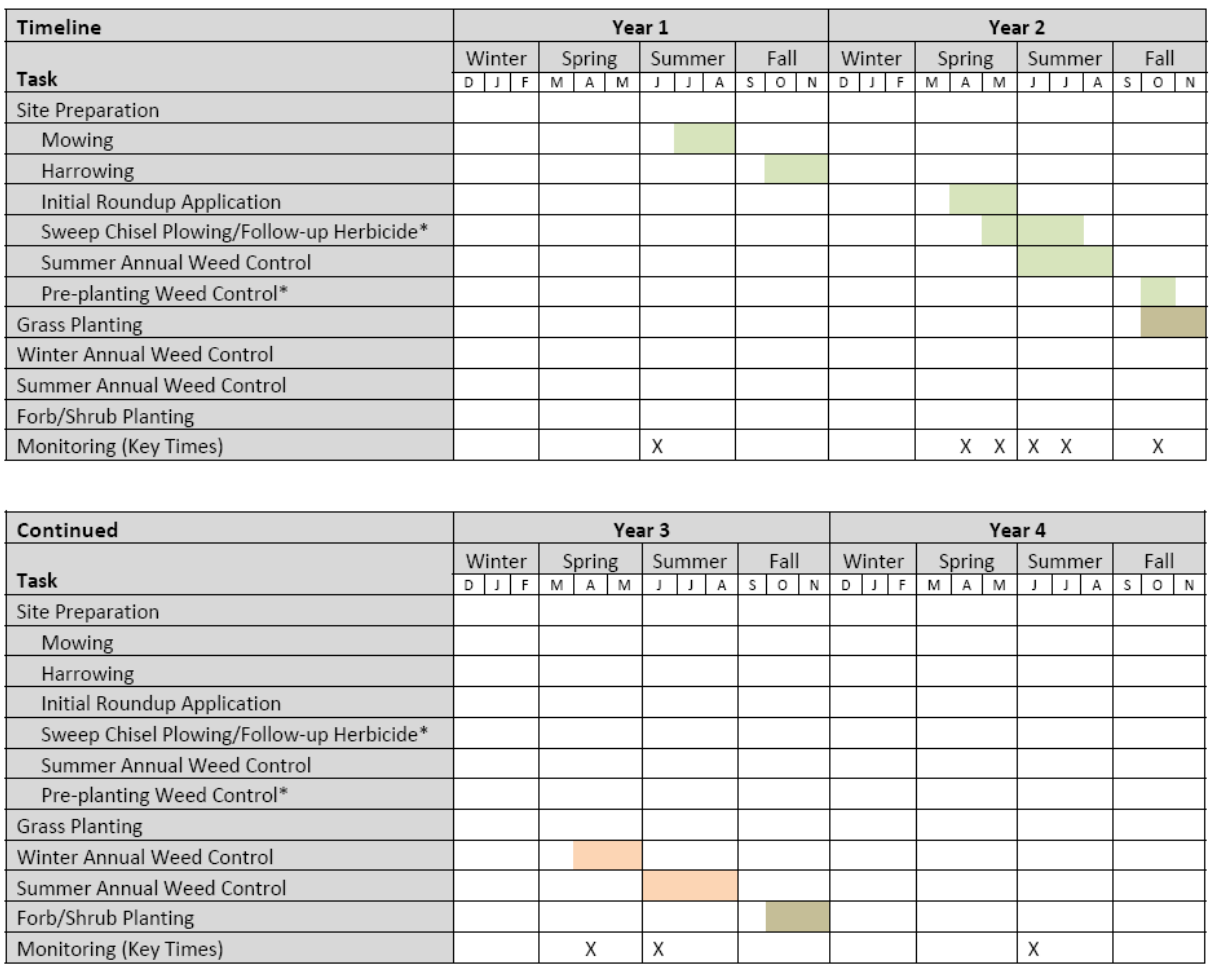
The final step in the site preparation process is annual weed control through the summer and fall. Broadleaf summer annuals such as prickly lettuce and Russian thistle can either be sprayed with the herbicide mixes included in Table 10, or mowed during the flowering stage to minimize seed production. Herbicide applications should be timed to occur when seedlings are either in the rosette stage, or at most 4 inches tall. In some years, several weed flushes will occur throughout the summer, depending on the timing of mid-summer rains.

Flushes of cheatgrass brought on by fall rains should also be controlled prior to seeding (see Table 10). On sites with substantial cheatgrass seed banks, an additional fall harrowing to stimulate cheatgrass emergence is also highly recommended. Cheatgrass control in the fall, or in late winter/early spring prior to seeded species emergence (**Section 3.4.2** Immediately following planting), will be one of the most critical factors determining success on these sites. Figure 25 shows the entire timeline for restoring crested wheatgrass fields

Table 10. Recommended herbicide mixes for the summer and fall prior to seeding crested wheatgrass fields.

Targeted Weeds	Herbicide Mixes and Rates
Crested wheatgrass regrowth, and summer annual broadleaf control	64 oz/ac Roundup, 3 oz/acre Banvel, 16 oz/acre AMS, 1 oz/ac NIS
Summer annual broadleaf control	12-16 oz/acre 2,4-D, 3 oz/acre Banvel, 1 oz/acre NIS
Fall cheatgrass control	12 oz/acre Roundup, 1 oz/acre NIS, 10 oz/acre AMS

Figure 25. Timeline for restoring created wheatgrass field



- As needed

Tall Wheatgrass or Sheep Fescue Fields

Removal of tall wheatgrass requires additional tillage as compared to crested wheatgrass, in order to break-up large crowns and incorporate substantial amounts of biomass. An additional fallow year is also typically required for full control and residue decomposition.

The first step for tall wheatgrass control is a field-wide mowing, timed to occur in late summer or fall of Year 1. The following spring, when tall wheatgrass has achieved at least 8 inches of new growth (but prior to seedhead emergence), a heavy Roundup application is applied using the rates and adjuvants listed in Table 11. Then 1 to 2 weeks later, waiting for a flush of annual broadleaves, the field should be disked to break up root crowns and control weeds.

Throughout the summer of Year 2, the field should be harrowed several (2-3) times to further break up crowns and incorporate litter and biomass into the soil. In spring of Year 3, another field-wide application of Roundup should occur using the same rates, adjuvants, and timing as in Year 2. After another flush of annual broadleaves occurs, the field should be plowed or disked with a heavy disk to incorporate any remaining residue or root crowns. A ring culti-packer can be pulled behind the disk or plow to firm and pack the field in preparation for planting, or packing can occur in a separate step.

Table 11. Herbicide mix and rate for site preparation on tall wheatgrass and sheep fescue fields

Species	Herbicide Mixtures and Rates
Tall wheatgrass, Sheep fescue	96 oz/acre Roundup, 16 oz/acre AMS, 1 oz/acre NIS

Sheep fescue is more resistant to Roundup and other herbicides than other reclamation bunchgrasses meaning that control of this species requires more tillage, and typically 1 more year of fallow. The site preparation process follows the same steps as with tall wheatgrass control, except for the following: 1) a sweep chisel should be used instead of a disk in Year 2; 2) harrowing is only necessary once during the summer of Year 2; and 3) plowing or disking in the summer of Year 3 is not necessary.

Spring Roundup applications should use the rates and adjuvants listed in Table 11, and should be timed to coincide with 6 inches of new sheep fescue growth (but prior to seedhead emergence). Additional broadleaf weed control should occur as necessary during the summer of Year 3, using the rates and adjuvants listed in **Table 10**. Packing with a ring culti-packer may be required prior to seeding, depending on fall rainfall.

Occasionally, retention of some of the existing vegetation is desirable, typically where native species such as big sagebrush have invaded the field and provide a unique seed source or habitat value (Figure 26). Islands of big sagebrush can be avoided during mowing or harrowing, and subsequent Roundup applications have little or no effect on big sagebrush. Broadleaf-selective herbicide applications should not be applied over sagebrush however, as dicamba will likely cause some damage.

Figure 26. Sagebrush islands and strips are avoided during site preparation to serve as seed sources (background).

In summary, the site preparation process for bunchgrass fields takes from 2 to 3 years, and requires a combination of mechanical and cultural methods.

Figures 27 and 28 provide summaries of the timelines for site preparation for tall wheatgrass and sheep fescue, along with key times for monitoring.

Figure 27. Tall wheatgrass field restoration timeline

Timeline	Year 1												Year 2											
	Winter			Spring			Summer			Fall			Winter			Spring			Summer			Fall		
Task	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Site Preparation																								
Mowing																								
Initial Roundup Application																								
Sweep chisel plowing																								
Harrowing																								
Second Roundup Application																								
Plowing/Disking and Packing																								
Summer Annual Weed Control																								
Pre-planting Weed Control*																								
Grass Planting																								
Winter Annual Weed Control																								
Summer Annual Weed Control																								
Forb/Shrub Planting																								
Monitoring (Key Times)																		X	X	X				

Continued	Year 3												Year 4											
	Winter			Spring			Summer			Fall			Winter			Spring			Summer			Fall		
Task	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Site Preparation																								
Mowing																								
Initial Roundup Application																								
Sweep chisel plowing																								
Harrowing																								
Second Roundup Application																								
Plowing/Disking and Packing																								
Summer Annual Weed Control																								
Pre-planting Weed Control*																								
Grass Planting																								
Winter Annual Weed Control																								
Summer Annual Weed Control																								
Forb/Shrub Planting																								
Monitoring (Key Times)						X	X	X			X						X	X	X	X				

- As needed

Figure 28. Timeline for restoring sheep fescue fields

Timeline	Year 1												Year 2											
	Winter			Spring			Summer			Fall			Winter			Spring			Summer			Fall		
Task	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Site Preparation																								
Mowing																								
Initial Roundup Application																								
Sweep chisel plowing																								
Harrowing																								
Second Roundup Application																								
Summer Annual Weed Control																								
Pre-planting Weed Control*																								
Grass Planting																								
Winter Annual Weed Control																								
Summer Annual Weed Control																								
Forb/Shrub Planting																								
Monitoring (Key Times)																		X	X	X				

Continued	Year 3												Year 4											
	Winter			Spring			Summer			Fall			Winter			Spring			Summer			Fall		
Task	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Site Preparation																								
Mowing																								
Initial Roundup Application																								
Sweep chisel plowing																								
Harrowing																								
Second Roundup Application																								
Summer Annual Weed Control																								
Pre-planting Weed Control*																								
Grass Planting																								
Winter Annual Weed Control																								
Summer Annual Weed Control																								
Forb/Shrub Planting																								
Monitoring (Key Times)						X	X	X			X						X	X	X	X				

- As needed

3.2.7.2 Rhizomatous Grass Fields

The site preparation process for rhizomatous grass fields (Figure 29) mirrors that of bunchgrass fields for the first 3 steps, namely, mowing, harrowing, and the heavy Roundup application. Roundup application rates for the rhizomatous grasses commonly encountered by WDFW managers are included in Table 12.

Table 12. Herbicide mix and rates for common rhizomatous grasses

Rhizomatous grass Species	Herbicide Mixtures and Rates
Intermediate wheatgrass, smooth brome	96 oz/acre Roundup, 16 oz/acre AMS[1], 1 oz/acre NIS[2]

[1]Ammonium sulfate, common trade name is Bronc Max

[2]Non-ionic surfactant, common trade name is R-11

Seven days following herbicide application (delay allows for full herbicide translocation), the field should be plowed with a moldboard plow. Deep plowing with a moldboard turns dense sod under the surface, and exposes rhizomes to the air to desiccate. Moldboards are generally followed by a ring culti-packer to smooth and firm plowed soil. Should rocky soils prohibit using a moldboard plow, a sweep-chisel plow can be substituted. Following the sweep plow, sites should be harrowed with a heavy spring-tine harrow to help break up dense sod and then packed with a ring culti-packer.

Follow-up applications of the Roundup mixture listed in **Table 12** will likely be needed throughout the summer to target rhizomatous grass regrowth. Moist areas such as swales should be closely monitored, as these are the areas were regrowth is most likely. Annual broadleaf control should also continue through the summer. Mowing timed to coincide with weed flowering can be used to reduce weed seed production, or the broadleaf-selective herbicide mix listed in **Table 10** can be used to target plants in the rosette stage.

The decision to continue fallow for another year, or to proceed with planting in Year 2, is based on the level of control achieved on rhizomatous grasses. An additional year of chemical fallow will result in higher control of rhizomatous grasses, but managers have often noted that control is increased only marginally. If the decision is made to continue chemical fallow, herbicide mixes should be applied at the previously discussed rates and times, and planting can proceed in the fall of Year 3.

In summary the site preparation process for rhizomatous grass fields takes from 2 to 3 years, and requires a combination of mechanical and cultural methods. **Figure 29** provides the timeline for site preparation, along with key times for monitoring.

Figure 29. Rhizomatous grass field restoration timeline

Timeline	Year 1												Year 2											
	Winter			Spring			Summer			Fall			Winter			Spring			Summer			Fall		
Task	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Site Preparation																								
Mowing																								
Harrowing																								
Initial Herbicide Application																								
Moldboard Plowing/Packing																								
Summer Annual Weed Control																								
Follow-up grass control*																								
Pre-planting Weed Control*																								
Grass Planting																								
Winter Annual Weed Control																								
Summer Annual Weed Control																								
Forb/Shrub Planting																								
Monitoring (Key Times)							X										X		X	X	X		X	

Continued	Year 3												Year 4											
	Winter			Spring			Summer			Fall			Winter			Spring			Summer			Fall		
Task	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Site Preparation																								
Mowing																								
Harrowing																								
Initial Herbicide Application																								
Moldboard Plowing/Packing																								
Summer Annual Weed Control																								
Follow-up grass control*																								
Pre-planting Weed Control*																								
Grass Planting																								
Winter Annual Weed Control																								
Summer Annual Weed Control																								
Forb/Shrub Planting																								
Monitoring (Key Times)					X		X												X					

*As needed

3.2.7.3 Abandoned Cropland

In the Columbia River Basin, abandoned cropland is typically colonized by Russian thistle and other annual broadleaves for the first few years following abandonment, and quickly succeeds to a cheatgrass and tumble mustard plant association that is stable for years or even decades (Rickard and Sauer 1982). Other sub-dominant species that occur commonly in abandoned cropland include diffuse and spotted knapweed, Dalmatian toadflax, jointed goatgrass, and beginning more recently, cereal rye.

The site preparation process for abandoned cropland may occur within one growing season if weeds are limited to cheatgrass and mustards. However, the presence of difficult-to-control weeds such as jointed goatgrass, knapweeds, Dalmatian toadflax, or cereal rye require a longer, typically 2-year process, in order to achieve full control of weed populations. Should rhizomatous weeds such as field bindweed or Russian knapweed be present, weed control should begin one year in advance of this site preparation process, following the methods presented in **Section 2.7** Site Challenges

The first step in the site preparation process is a field-wide application of Roundup, using the rates and adjuvants listed in Table 13, at the seedhead emergence stage of cheatgrass and/or jointed goatgrass (whichever comes first). Then approximately 2 weeks following this herbicide application, following the next flush of weeds, the field should be disked with an offset disk to loosen soils and control weeds. Subsequent summer annual flushes, along with spotted knapweed, diffuse knapweed, and Dalmatian toadflax seedlings, can then be controlled with a rod-weeder, which cuts off taproots approximately 3 inches below the soil surface.

Table 13. Herbicide mixes and rates for annual grass control during site preparation

Bunchgrass Species	Herbicide Mixtures and Rates
Cheatgrass and jointed goatgrass control at the seedhead emergence stage	32 oz/acre Roundup, 16 oz/acre AMS, 1 oz/acre NIS
Cheatgrass and jointed goatgrass seedlings	12 oz/ac Roundup, 10 oz/acre AMS, 1 oz/acre NIS

Additional annual grass flushes should be sprayed with the Roundup mix listed in Table 13 (rate depends on maturity), or controlled with a culti-weeder. Rod-weeders are relatively ineffective on fibrous-rooted species like cheatgrass, as fibrous root systems have more root surface area in the top three inches of soil to recover from rod-weeding.

If no jointed goatgrass, diffuse/spotted knapweed, Dalmatian toadflax, or cereal rye are present, planting may proceed in the fall of Year 1. Prior to planting, the field may need to be packed with a ring culti-packer, depending on the degree to which summer and fall rains have firmed up the seed bed. Additional cheatgrass control may also be required following fall precipitation, prior to planting. If one or more of the weeds listed above are present, site preparation should continue for an additional year, following the same process outlined for Year 1. Disking should be used as necessary to loosen up the ground for culti-weeding or rod-weeding. Planting can then proceed in the Fall of Year 2, following packing with a ring culti-packer, as needed.

The timeline for site preparation and restoration of abandoned cropland is summarized in Figure 30.

Timeline	Year 1												Year 2												Year 3											
Task	Winter			Spring			Sum.			Fall			Winter			Spring			Sum.			Fall			Winter			Spring			Sum.			Fall		
	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Site Preparation																																				
Initial Herbicide Application																																				
Disking																																				
Rod-weeding/Culti-weeding																																				
Pre-planting Weed Control*																																				
Grass Planting																																				
Winter Annual Weed Control																																				
Summer Annual Weed Control																																				
Forb/Shrub Planting																																				
Monitoring (Key Times)					X	X	X	X	X		X						X		X												X					

*As needed

Figure 30. Abandoned crop land restoration timeline

3.3 Planting Methods

3.3.1 Introduction

Over the last several decades, WDFW managers have developed successful planting methods for the restoration of shrub-steppe habitat. The following sections describe these methods, and discuss situations where alternative processes may be desired. The goal of this chapter is to help managers select the most effective planting technique for their project, and to provide guidance on the most critical components, i.e. timing, seeding depth, and seeding method and rate.

3.3.2 Timing

3.3.2.1 Grasses

Optimal seeding time varies from year to year, based on winter weather conditions and the timing and amount of rainfall in the fall and spring. In general however, late fall seeding, just before the soil freezes, is the most consistently successful in the eastern Washington shrub-steppe region. Soil temperatures at this time are typically low enough to prevent germination, or if germination occurs, seedlings do not emerge from the soil. This provides some protection from exposure to winter conditions, as well as desiccation.

Most eastern Washington plant species are active during the cool, moist months of the year, i.e. February through June (March through July at higher elevations). A late fall planting positions seed such that emergence and growth can occur immediately after soil temperatures increase, which takes maximum advantage of a relatively condensed growing season.

Late fall seeding is often referred to as a "dormant seeding", as it occurs when the soil is cold enough to prevent seed germination (ideally). This terminology can be confusing for some, however, who assume that dormancy refers to the seed itself. Most grasses have little or no seed dormancy, and can germinate at any time given appropriate soil moisture and temperature. To prevent such misinterpretation, the term dormant seeding will not be used in this manual. Recommended seeding dates based on elevation and precipitation are included in Figure 35.

When it is feasible, planting during the late winter works just as well, if not better, than late fall plantings. Planting may occur during warm spells in January or early February, in mild winters at moderate elevations, or typical winters at low elevations. Seeding during this time period minimizes the time that germinated seed is

Seeding Window - Grasses

Low elevations (<10" precipitation):
November 1 – February 15

Middle elevations (10-14" precipitation):
October 15 – March 1

Higher elevations (14-24" precipitation):
October 15 – December 1

Seeding Window – Forbs and Shrubs

Low elevations (<10" precipitation):
October 15 – December 1

Middle elevations (10-14" precipitation):
October 1 – December 1

Higher elevations (14-24" precipitation):
October 1 – November 20

Figure 31. Seeding Windows

exposed to frozen soils, and may increase seedling survival. Planning for such a warm spell is typically difficult however, as predicting future weather patterns in notoriously unreliable. The safest bet is to plan for a late fall seeding, and use winter warming periods as a back-up for planting, as needed.

In many years, adequate moisture is present to allow early spring seeding, particularly at high elevations. The factor limiting such seeding is typically soil texture; finer texture soils common in this region are inaccessible by seeding equipment for most of the spring. Therefore, in higher elevation areas with silt or clay soils, the safest time for seeding is still the late fall.

3.3.2.2 Forbs and Shrubs

Unlike grasses, many forb and shrub seeds have physical or physiological dormancy, and have unique stratification and/or scarification requirements that must be met in order to germinate. *Stratification* refers to the exposure of seed to cold, moist conditions, typically for several weeks or months. Many forb and shrub seeds have underdeveloped embryos and require several months of stratification for the embryo to develop, before germination can proceed. *Scarification* refers to a process which physically damages a hard seed coat, allowing the seed to imbibe moisture, and either germinate, or begin the stratification process.

In order for stratification requirements to be met, forbs should be planted in the fall or early winter. This will allow ample exposure to cold, moist conditions, even for species such as arrowleaf balsamroot, which requires a 90-day stratification (Young and Evans 1979). Spring plantings are not recommended, unless species with no stratification needs will be planted, such as yarrow, longleaf phlox, and blanketflower.

Without scarification, germination of hard-seeded species occurs over an extended time period, as natural processes such as weathering or animal digestion erode thick seed coats and allow water uptake. Research on manual scarification techniques is ongoing for many hard-seeded species, such as prairie clovers, lupines, and globe mallows (e.g. Dunn 2011). Currently, hot water or physical abrasion treatments show promise for large-scale application, but techniques have not been adopted by either agencies or seed vendors. Such seed priming techniques may ultimately increase the success of forb seedings, as germination will occur over a shorter time frame, before seeded grasses dominate the site. Without seed priming, managers should not expect immediate germination of species with thick, hard seed coats.

3.3.2.3 Post-fire seeding

The optimal time to broadcast or aerial seed following a wildfire is as soon as possible after the fire is controlled. Broadcasted seed sinks easily through the dry, powdery ash layer, or is pushed through by fall rains, placing the seed in contact with the soil. If seeding is postponed until after rains have occurred, the ash is often hardened and does not allow the seed to contact the soil surface.

3.3.3 Seeding depth

Seedling emergence and survival depends on selecting the appropriate seeding depth, which for most shrub-steppe species is just below the soil surface. Table 14 lists optimal seeding depths for commonly seeded species, by various soil types. In general, seeding depths should be slightly deeper in coarser texture soils than finer texture soils. This ensures that seeds have adequate moisture to germinate in well drained, coarse-textured soils.

With the exception of bitterbrush, most species germinate and emerge well from 1/4 to 3/8 inch planting depths in fine to medium texture soils, or 1/4 to 1/2 inch depths in coarse texture soils. This applies to smaller-seeded species such as big sagebrush, as well as large-seeded species such as Great Basin wildrye. Bitterbrush appears to be more sensitive to seeding depth than most species, and should be seeded at depths ranging from 1/2 to 1 inch deep, depending on soil type.

Seeding depth is regulated by the type of equipment used for seeding. Depth can be controlled using depth bands or other devices on seed drills and air seeders, or by following broadcast or aerial seedings with harrowing or packing. See the following section on seeding methods for descriptions and limitations.

Table 14. Optimal seeding depths for commonly planted species.

Species	**Drilling Depths (inches) by Soil Texture**	
	Fine/Medium	*Coarse*
Bluebunch wheatgrass	1/4 to 3/8	1/2
Sandberg's bluegrass	1/4	1/3
Idaho fescue	1/4 to 3/8	N/A
Great Basin wildrye	1/4 to 3/8	1/2
Indian ricegrass	1/4 to 1/2	1/2
Bitterbrush	1/2 to 1	1
Snow buckwheat	1/4	1/4
Parsnip-flowered buckwheat	1/4	1/4
Big sagebrush	1/4 to 3/8	1/4 to 3/8

3.3.4 Seeding methods

3.3.4.1 Drill seeding and air seeding

Drill seeding is the preferred method for restoration, as it provides the best seed-soil contact and the most accurate seed placement of all planting techniques. Drilling also requires lower seeding rates, and typically results in better seedling establishment than broadcast seeders, air seeders, or hydro-seeders.

Air seeders can seed up to 70 feet in one pass, and are therefore cost-effective for large seeding projects. They are used primarily in prepared seedbeds, as control over seeding depth declines with increasing residue. An even, firm seed bed is required in order to achieve uniform and shallow planting depths.

Optimal seeding rates for drill seeding can vary depending on the presence of depth bands, the quality of seedbed preparation, soil texture and annual precipitation. The **Seed Mix Calculator** provides a range of rates, based on these factors. It should be noted, however, that seeding rate selection is generally not one of the main determinants of project success; experience has shown that a large range of rates can result in a successful stand, depending on the above-listed factors, and of course, precipitation following seeding.

WDFW managers have historically drill seeded grasses at around 9 pounds of pure live seed (PLS) per acre, and the majority of these seeding projects have been successful. This seeding rate may be reduced by 25% on well prepared seed bed, if competition from weeds is greatly reduced, or if using a drill with depth bands. Seeding rates for air seeders should be increased by at least 25%, as seed placement is less accurate than with drills. The seeding rate box at the end of the seeding methods sections contains a summary of recommended rates by site and method.

Seed drilling rates for forbs and shrubs typically depend on project funding and availability, rather than the rates most appropriate for the site. In the past several years, WDFW projects have typically seeded from 1-3 PLS pounds of forb and shrub seed per acre. As many forbs have millions of seeds per pound, it is also important to calculate number of seeds per square foot, in order to avoid planting excessive amounts of species such as western yarrow or big sagebrush.

3.3.4.2 Broadcast and aerial seeding

Broadcast and aerial seeding is typically reserved for areas and sites where drilling is not feasible, due to accessibility, rocky soils, steep hillsides, or size. For small-scale projects, generally less than 0.5 acres in size, seeds can be broadcast with a hand-held broadcaster, and lightly raked to cover the seed. ATV-mounted broadcasters can be used for projects ranging from 0.5 acres to 100 acres, and are particularly effective if a spring-tine, spike-tooth, or blanket (aka pasture) harrow is pulled behind the ATV to cover the seed (Figure 31). Safe operation of ATVs generally limits their use to areas with 40% or less slope.

Figure 32. Spring-tine harrow with seed broadcaster mounted to frame.

Steep hillsides or inaccessible areas are often seeded aerially, either by helicopter or fixed-wing airplane. This type of seeding generally only follows wildfires, as no other site preparation is feasible in these areas. Helicopters are often used for sagebrush seeding following wildfires that kill sagebrush, but do not burn hot enough to damage the perennial bunchgrass and forb community. Helicopter seeding typically involves a bucket equipped with agitators to prevent the clumping of fluffy sagebrush seed. Fixed wing airplanes are typically used to seed heavier-seeded species, such as grass mixes.

As broadcast seeding does not result in optimal seed placement, seeding rates are usually doubled, as compared to drill seeding rates. Raking or harrowing following seeding greatly increases seedling establishment, particularly for larger-seeded species.

3.3.4.3 Hydro-seeding

Hydro-seeding is used primarily on steep hillsides along roads to provide short-term soil stabilization through the application of mulch, and long-term stabilization through plant establishment. Hydro-seeding has historically occurred as a 1 stage process, whereby seed is applied in a mixture with hydraulic mulch and water. This process results in most of the seed being suspended within the mulch, therefore creating poor seed-soil contact and limited seeding success.

More recently, hydro-seeding has moved to a 2-stage process, whereby seed is hydraulically applied with enough mulch to act as a tracer, then the majority of the mulch is applied over the top in a second layer. This process has improved stand establishment, but overall success is still poor relative to drill seeding or broadcasting/harrowing, where seeds are actually incorporated into the soil. Several thousand gallons of water are used to apply seed and mulch over one acre, making hydro-seeding the most expensive seeding method available. Mulching type and application rates vary based on slopes, annual precipitation, and desired length of soil stabilization. An in-depth discussion of mulch types and rates is included in Steinfeld et al. 2007, and will not be covered again here due to limited applicability for WDFW managers.

Table 15. Base seeding rates for grasses and seeding method multipliers

Base Seeding Rates for Grasses

Conventional Drill (no depth bands)

Site	Precipitation (inches)	PLS lbs / acre
Loamy Soils	<14"	8.5 - 10
Gravelly/Sandy Soils	<14"	6.5 - 8
Loamy Soils	>14"	10
Gravelly/Sandy Soils	>14"	8

Base Seeding Rates for Forbs and Shrubs

Common seeding rates for combined forbs and shrubs range from **1 - 3 PLS pounds per acre**, or 10 to 30 seeds per square feet, depending on project funding and availability.

Seeding Method Multipliers

Method	Multiplier
Conventional Drill-No Depth Bands	1
Drill-Depth Bands	0.75
Air Seeder – Low residue	1.25
Air Seeder – High residue	1.75
Broadcast	2
Aerial	2
Hydro 1-Stage	3
Hydro 2-Stage	2

3.3.5 Seeding and planting strategies

3.3.5.1 Staged planting

In recent years, the majority of restoration projects that included forb or shrub seeding have utilized a “staged planting” approach, whereby grasses and forbs are planted in successive years. This approach allows one year of weed control with broadleaf-selective herbicides after grasses have been seeded. There are pros and cons to this approach, but on balance, it seems to be the most effective technique currently available.

Figure 33. Dense grass growth limits forbs in the second growing season at Reardan Lakes.

The old agricultural or CRP-type fields that WDFW work has primarily focused on have substantial banks of weed seeds, including purple mustard, tumble mustard, henbit, and many other species. A one to two year site preparation process that successfully controls existing vegetation opens a niche for such species, and dense flushes of weeds in the first spring following grass seeding are typical. If left uncontrolled, these dense weed flushes can out-compete young grass seedlings, resulting in full or partial stand failure.

However, in years with lots of spring moisture (e.g. 2010 and 2011), grass growth during the first and second growing seasons is so vigorous that dense stands limits forb and shrub establishment (Figure 33). It is therefore a trade-off between successful grass and forb establishment, but on balance, staged plantings are currently the best available process for weed-prone agricultural fields.

3.3.5.2 Forb Islands

Currently, the expensive nature of forb and shrub seed often limits the amount that can be used in a restoration project. One approach to balance costs with habitat objectives is to seed only a portion of the field, depending on project funding and seed availability.

Using this approach, forb and shrub seed is planted in strips in a random or systematic pattern, while providing the maximum opportunity for seed movement across the field after source plants have become established. Provided conditions remain suitable for seedling establishment, the speed of forb and shrub movement into unseeded areas may be relatively fast for wind dispersed species such as yarrow, fleabane daisy, and sagebrush, but significantly slower for species with limited seed dispersal such as penstemons and balsamroot. However, if sown grasses establish well on a site, subsequent spread of forbs and shrubs into this competitive matrix may be extremely limited, at least over the short term. Additional long-term monitoring is needed to fully assess the efficacy of this approach in establishing a diversity of native forbs.

3.3.5.3 Planting plugs

Growing seedlings in the greenhouse and out-planting into the field is commonly used in several different restoration scenarios. Seedlings are often planted in areas where soils are too rocky for traditional site preparation, or to accelerate wildlife habitat development (Newsome 2011). Seedlings can also be used to augment plant communities that are somewhat degraded, but still have some components of the native plant community that managers wish to retain. In instances where seed is limited, for example with rare plant species, planting seedlings can also make the most efficient use of limited seed. Outplanting of plugs may also be used with species that establish poorly in the field from seed.

Site preparation for plug plantings is typically nominal, and involves either 1) scalping a 1-2 foot diameter circle with a shovel, or 2) spraying a 2-3 foot diameter circle with a 0.5-2% Round-up solution prior to planting. Scalping or a 0.5% Roundup solution works best for planting through annual weeds such as cheatgrass, while spraying with a 2% Roundup solution is ideal for planting through more vigorous perennial species, such as quackgrass.

Commonly used planting containers range from 4 to 10 in^3 (e.g. Page and Bork 2005). To increase planting efficiency, custom-welded planting bars can be made to create holes the exact size and shape of containers.

Out-planting can occur in the fall before the soil freezes or in the spring, once the soil thaws and the sites become accessible. Planting density is driven by project funding and objectives. A density of 50-200 plants per acre may be used to augment diversity or habitat value, but a density of 0.5 plants per square foot may be required for site stabilization.

If properly grown and planted, a survival rate of 70 – 90% is common for many grass species, including Great Basin wildrye and bluebunch wheatgrass (Page and Bork 2005, Link and Bradney 2009). Survival rates for forb and shrub seedlings vary, but are generally lower than grass seedling survival rates. Johnson and Okuila (2006) found 60-70% survival of bitterbrush seedlings after the first growing season in south-central Oregon, while Newsome (2011) found 10-50% sagebrush seedling survival after 3 years, depending on type of stock and planting year conditions. Wirth and Pyke found that survival of 2 common forb transplants, woolypod milkvetch and hawksbeard, ranged from 10-50% after 2 years.

3.4 Post Planting Weed Control

3.4.1 Introduction

Weed control following planting is critical to the long-term success of a restoration project. Site preparation reduces the weed seed bank, but weed seed depletion rarely occurs without multiple years of fallowing, and this type of intensive site preparation is neither cost effective nor practical for most wildlife area managers.

The type of post-planting weed control utilized depends on the following factors: 1) age and phenology of seeded species, 2) density of weed population, 3) phenology of weed population, and 4) presence of seeded broadleaves. A variety of mechanical and chemical options are available, depending on these factors. The following sections outline general strategies for weed control during the first two years following planting, as well as for long-term control. For easy reference, ***Table 16*** at the end of this section contains specific weed control recommendations; these recommendations are based on the cumulative experiences of wildlife area managers and other WDFW staff.

All herbicide mixes that include Roundup (glyphosate) herbicides assume the use of 4 pound active ingredient formulations, i.e. Roundup and Roundup Pro. Mixes should be adjusted if using different Roundup formulations, such as Roundup Concentrate (5.5 pound active ingredient formulation).

3.4.2 Immediately following planting

There is a limited time window immediately following seeding when cheatgrass and other weeds can be controlled with no impact to seeded species. The length of this window depends on soil moisture and temperature; germination and emergence of many native grasses will occur within 7 – 10 days with good soil moisture and soil temperatures at or above 45°F. If soil temperatures are between 32°F and 45°F, seeded species will emerge slowly, taking 2 – 3 weeks.

Cheatgrass control is critical in the fall and early winter; fall-emerged cheatgrass is very competitive with young grass seedlings, as cheatgrass root systems develop at a faster rate than native roots (Harris 1977). Cheatgrass roots may already be established and depleting soil moisture by the time seeded species germinate and emerge (Hironaka 1961). Prior to seeded species emergence, cheatgrass and other weeds can be controlled with herbicides such as Roundup that have no soil activity. The rate of Roundup used for cheatgrass control depends on the growth stage of cheatgrass and seeded grasses. As the likelihood of planted species emergence increases, Roundup application rates should decline to minimize impacts to seeded species.

Seeding with a seed drill or air seeder/harrow typically results in dust deposition on cheatgrass leaves, which may preclude cheatgrass control by reducing herbicide absorption through the leaf (Zou and Messersmith 2005). Dusty leaves are normally only an issue for several days after seeding; rain, wind, or several nights of dew or frost is sufficient to clean dust off of leaves. Should herbicide application occur within several days of seeding, cheatgrass leaves should be examined for dust, and application postponed as needed (no more than a few days) to achieve good herbicide contact.

3.4.3 Immediately following seedling emergence

Newly emerged native grass seedlings have very little surface area to take up herbicides, so a light Roundup application can be used to target cheatgrass at this growth stage. Cheatgrass should be no older than 2-3 leaves in order for a light Roundup application to provide good control. Cheatgrass with more than 2-3 leaves has likely been emerged for several weeks, and could have been targeted prior to seeded species emergence. Correct timing of this application is critical; seeded species should be no larger than an inch or two, with only one leaf. Rates and adjuvants for this Roundup application are included in **Table 16**.

Figure 34. Tansy mustards over-shadowing grass seedlings in the spring following planting.

3.4.4 Spring following seeding

The primary weeds encountered in the spring following seeding include winter annuals, such as tumble mustard, tansy mustard (Figure 33) and purple mustard, as well as cheatgrass, particularly if no fall Roundup application was made. Restoration fields should be monitoring weekly during the spring after seeding, in order to determine if weed presence poses a significant problem for seeded species.

Figure 35. Mowing a dense cheatgrass stand to allow native seedlings to compete for moisture and light

Often, annual broadleaves are common, but occur at low enough densities that native grass seedlings are not significantly affected. Tumble mustard and tansy mustard are two species that are not particularly competitive with seeded species, provided that they do not dominate the field. In this situation, mustards can be mowed with a large rotary mower during the flowering stage; this process will significantly curtail seed production. Purple mustard however, can easily out-compete seeded grasses, and should be controlled early in the spring, preferably during the rosette stage.

Several broadleaf-selective herbicides can be utilized to control mustards, provided that no native forbs were included in the seed mix. If native forbs were planted, mowing during the flowering stage is the most effective way to control weeds while minimizing damage to seeded species. Another option for broadleaf weed control if native forbs have been planted, but have not emerged, is to apply a broadleaf-selective herbicide with no residual activity, such as Buctril or MCPA. Native forb and shrub emergence often occurs later in the spring (April to May), leaving a short window for winter annual control.

Mowing can also be used to suppress cheatgrass (Figure 34). Mowing cheatgrass just after seedhead emergence will temporarily reduce competition with seeded species for soil moisture and light, as well as reducing seed production. Rainfall following mowing will typically allow cheatgrass to send out an additional tiller and produce seed. If cheatgrass re-growth continues to out-compete seeded natives for moisture and light, an additional mowing may be necessary.

Winter annual broadleaves such as tansy mustard and tumble mustard are relatively easy to control with a combination of MCPA, Buctril, and Banvel, see **Table 16** for rates and adjuvants. This application should be applied when at least 50% of mustard rosettes are 2-3 inches in diameter. This will ensure that the majority of mustard seeds have germinated and emerged, and will limit the need for re-application later in the spring.

Purple mustard is highly competitive with native grasses, and should be controlled when large populations occur in the spring following seeding. The herbicide Express should be added to the above MCPA mixture for effective control of purple mustard.

Cereal rye populations appear to be expanding exponentially in the Columbia Basin, and have become increasingly common in abandoned agricultural fields and CRP plantings. Multiple years of cereal rye control will likely be needed following plant establishment, due to relatively long (10+ years) seed longevity. Fortunately, cereal is easily treated with a wick application of concentrated Roundup. Wick applications can target vegetation at specific heights, and can therefore treat cereal rye at the seedhead emergence stage, as seeded native species are substantially shorter. Wick application rates and adjuvants are included ***Table 16***.

3.4.5 Summer following seeding

The primary target of summer weed control is summer annuals, i.e. prickly lettuce, Russian thistle and kochia. All of these species are relatively easy to control, provided that application occurs early on, when seedlings are only a few inches tall. See **Table 16** for recommended herbicide mixes and rates. Follow-up applications may be needed if early summer rains promote additional weed flushes. Monitoring should continue throughout the summer in order to catch and treat such weed flushes. Russian thistle can be controlled by mowing later on in the summer; this will not completely eliminate seed production, but will reduce production to a benign level.

3.4.6 Spot spraying weeds

Difficult-to-control perennial weeds should be controlled prior to planting native species, as the herbicides used to control these species can damage young seedlings (e.g. Milestone, Escort, etc.). Spot-spraying of weeds should continue throughout early stand establishment, provided that care is taken to minimize effects to young seedlings.

Ideally, application should occur in the early summer, during the bud to early flower stage. This growth stage coincides with the maximum amount of leaf area herbicide uptake, while preventing seed production and dissemination across the field. Areas spot-sprayed with Milestone or Transline should not be seeded to native forbs for several years, in order to allow herbicide residuals to decay. **Section** 2.7 Site Challengesprovides more specific information on herbicide residual effects.

Smooth brome in particular should be vigilantly monitored, and re-growth should be spot-sprayed with a heavy Roundup solution (**Table 16** for rates). Smooth brome has the ability to invade and quickly dominate young grass stands; therefore control is critical during the first few years of stand establishment. Roundup will also control young native grass seedlings at this rate; therefore, spot-sprayed areas will likely need to be re-seeded.

3.4.7 Second growing season following seeding

Broadleaf weed control during the second season following seeding, assuming that native broadleaves are included in the seed mix, is limited to mechanical control options, i.e., mowing, the introduction of bio-controls, and broadleaf-selective herbicide application prior to native broadleaf emergence. Mowing should be timed to coincide with weed flowering, in order to curtail weed seed production. If native forbs have been planted, but have not emerged, there is a short window to apply broadleaf-selective herbicides with no soil activity, such as Buctril or MCPA.

If necessary, cheatgrass can be controlled in the second and third growing season with mowing, timed to coincide with the seedhead emergence stage. As an alternative, a light application of the grass-selective herbicide Select can be used to selectively control annuals such as cheatgrass. Timing of spraying should occur at the boot stage through early seedhead emergence stage. Non-target impacts to Sandberg's bluegrass may also occur with Select application.

Table 16. Post planting weed control options by season and species.

Weed Species	First Growing Season (Grasses only)	Second Growing Season (Grasses, Forbs, and Shrubs)	Long-term Control
Annual Species			
Cereal rye	Cereal rye at seedhead emergence stage: Wick application of following herbicide mix: 33% - 50% Roundup solution; 1% NIS[1]; 1% AMS[2]	Cereal rye at seedhead emergence stage: Wick application of following herbicide mix: 33% - 50% Roundup solution; 1% NIS; 1% AMS	Multiple years of control necessary. Cereal rye at seedhead emergence stage: Wick application of following herbicide mix: 33% - 50% Roundup solution; 1% NIS; 1% AMS
Cheatgrass (and other annual bromes)	Prior to seeded grass emergence: Spray with following herbicide mix (per acre): 12 oz Round-Up, 8 oz AMS, 1 oz NIS	Cheatgrass will fade out over time once natives are well established. Control is typically not needed after the first growing season.	Cheatgrass will fade out over time once natives are well established. Control is typically not needed after the first growing season.
	Seeded grass at 1-leaf stage, cheatgrass 3-leaf stage or younger (1 tiller only): Spray with 3.5 oz/acre Roundup	Cheatgrass seedhead emergence stage: Mow to lowest height possible.	Cheatgrass seedhead emergence stage: Mow to lowest height possible.
	Seeded grass 2-leaf stage and beyond; cheatgrass seedhead emergence stage: Mow to lowest height possible.	Cheatgrass boot stage through seedhead emergence stage: Spray with following herbicide mix: 6-8 oz/acre Select, 16 oz/acre COC[3].	Cheatgrass boot stage through seedhead emergence stage: Spray with following herbicide mix: 6-8 oz/acre Select, 16 oz/acre COC.
Jointed goatgrass	Late October of first growing season: Apply 3 pints/acre Prowl. Oil formulation works better than water formulation.	Late October of second growing season: Apply 3 pints/acre Prowl.	Late October of third growing season: Apply 3 pints/acre Prowl. 2-3 years of control may be needed for large populations.
Kochia	Kochia control in the first year is critical. 12 oz/acre Starane/Vista, 3 oz/acre Banvel, 1 oz/acre NIS; also controls Russian thistle; treat early (less than 6 inches tall).	1.5 pints Buctril, 12 oz Starane/Vista; works well on taller kochia, very easy on grasses	Kochia will fade out over time once natives are well established.

[1]Non-ionic surfactant, [2]Ammonium sulfate, [3]Crop oil concentrate

Table 16 continued

Weed Species	**First Growing Season (Grasses only)**	**Second Growing Season (Grasses, Forbs, and Shrubs)**	**Long-term Control**
Annual Species Continued			
Purple mustard	Add 0.2 oz/ac Express to tumble mustard MCPA herbicide mix	Purple mustard will fade out over time once natives are well established.	Purple mustard will fade out over time once natives are well established.
Tumble mustard and other winter annuals (henbit, shield peppergrass, poverty weed, common groundsel)	Type of control depends on whether or not density is high enough to crowd out seeded species during the spring. High density populations should be sprayed with the following herbicide mix: 10 oz/acre MCPA, 8 oz/acre Buctril, 1 oz/acre NIS	Mow during flowering to curtail seed production.	Tumble mustard and other winter annuals will fade out over time once natives become well established.
	Low density populations can be mowed in the early summer, when flowering, to curtail seed production.	Apply 12 oz/acre Buctril and 1 oz/acre NIS on broadleaf rosettes no larger than 2 inches in diameter, provided that native forbs have not emerged.	
Prickly lettuce	Germinates later than winter annuals, but can be treated the same way, just later in the season (late spring/early summer). Use same herbicide mixture as for winter annuals.	Mow during flowering to curtail seed production.	

Table 16 Continued

Weed Species	**First Growing Season (Grasses only)**	**Second Growing Season (Grasses, Forbs, and Shrubs)**	**Long-term Control**
Biennial/Perennial Species			
Diffuse/Spotted/Russian Knapweed	Spot spray with following herbicide mixture at bud to early flowering stage: 0.25% Milestone, 1% NIS. Broadcast applications should be avoided, as damage to grass seedlings is possible, and broadleaves should not be planted in areas broadcast-treated with Milestone for 2-3 years after treatment.	Same as previous year. Milestone and Transline will kill broadleaf seedlings, legumes are particularly susceptible.	Same as previous year. Multiple years of control will be necessary.
	Transline may be substituted for Milestone. Spot spray: 0.25% Transline, 1% NIS. Broadleaves should not be planted in areas treated with Transline for 1-2 years after treatment.		
Introduced Thistles (Canada, Scotch, Musk)	Spot spray with following herbicide mixture at bud to early flowering stage: 0.25% Milestone, 1% NIS. Broadcast applications should be avoided, as damage to grass seedlings is possible, and broadleaves should not be planted in areas broadcast-treated with Milestone for 2-3 years after treatment.	Same as previous year. Milestone and Transline will kill broadleaf seedlings, legumes are particularly susceptible.	Same as previous year. Multiple years of control will be necessary.
	Transline may be substituted for Milestone. Spot spray: 0.25% Transline, 1% NIS. Broadleaves should not be planted in areas treated with Transline for 1-2 years after treatment.		
Smooth Brome, intermediate wheatgrass, and quackgrass	Spot spray with following herbicide mixture: 2% Round-Up, 1% AMS, 1% NIS. Re-seed sprayed areas as necessary. Treatment of smooth brome in the first few years of stand establishment is critical.	Same as previous year. Several years of spot-spraying may be necessary.	
White-top	0.33 oz/acre Harmony, 3 oz/acre Banvel, 1 oz/acre NIS. This mixture should be mixed up in an ATV spray tank, and transferred to a back-pack sprayer for spot-spraying. Spot-spray to wet.	Same as previous year. Several years of spot-spraying may be necessary.	

3.5 Effectiveness Monitoring of Vegetation Restoration

3.5.1 Introduction and Defining Monitoring Levels A and B

Monitoring is a process used to determine and document successes, failures, and unexpected outcomes. Monitoring coupled with project documentation allows us to learn from our efforts and convey what we learn to others, essential components of adaptive management. Monitoring and documentation can help us replicate our successes, understand why some methods did not produce the results we expected, and avoid repeating costly mistakes.

Monitoring associated with restoration efforts can be carried out for a variety of reasons. Objectives can vary from plant diversity (e.g., establish species A, B, and C) and weed control (e.g., eliminate species X, Y, and Z) to system function (e.g., reduce soil erosion) and wildlife habitat (e.g., did an animal return to thrive in the restored area). The possibilities are almost endless, but resources available for monitoring never are. Therefore, in this section we suggest monitoring protocols that focus entirely on evaluating the basic effectiveness of vegetation restoration efforts, based on the assumption that for most managers, information on how the plant community has developed in a restoration project is fundamental to most overall restoration goals. Other monitoring may be added on, but a basic understanding of the vegetation status is usually essential. The protocols are designed to gather two basic types of information: did the restoration meet specific objectives, and what did we learn that will make future restoration more successful?

The monitoring protocols build directly upon the specific vegetation objectives developed for the restoration (see section on setting Goals and Objectives). Generally, these objectives will fall into three main categories: 1) Composition (e.g., what species were established and/or eliminated), 2) Abundance (e.g., how much of a species or group of species is present on a site), and 3) Structure (e.g., do tall shrubs exist on a site). Depending on the overall restoration goals, these objectives may be quantified at various levels of detail (e.g., bunchgrass is common/abundant, percent cover $\geq$25%, at least 12 native species established, >1 shrub/10m^2, etc.).

The Level A and Level B monitoring protocols described here are designed primarily to be used in restoration of agricultural and CRP fields in shrub-steppe systems. They will provide basic status information for a restoration site in each of the three categories, but they are not meant to be either encyclopedic or statistically robust. Rather, they provide a flexible approach that can be tailored to the particular objectives and resources available to each project. Examples of several typical measures are provided, but decisions about which to use, or whether others might be more appropriate based on restoration objectives and available resources, must be made by the manager. To the extent that resources allow, managers are encouraged to supplement Level A measures with additional Level B measures if greater quantitative detail or statistical rigor is needed to determine attainment of specific goals.

Level A –Data are mostly collected in coarser, qualitative or semi-quantitative categories, and are gathered for each parameter that has been selected to relate back to specific restoration objectives. Data are based on a summary obtained while doing a general walk through each unit being evaluated. Level A measures are supplemented by digital photos, which also relate to specific restoration objectives.

Level B –Data are collected to provide more quantitative detail on particular species or groups of species than for Level A, and are gathered for each parameter based on defined areas (quadrats, plots, belt-transects) within each unit being evaluated. Abundance data are usually collected using one of three main approaches – percent cover, frequency, or density (total number/area) - depending on the restoration objectives and the nature of the species being monitored.

It may be helpful to divide each site into several "units" that are drawn on a map of the site, and are based on differences in treatment or physical characteristics. For example, if several treatments (preparation methods, seed mixes, etc.) were carried out within a restoration site, each can be considered a different unit (such as "A", "B", etc.). Similarly, a site could be divided into multiple units defined by major soil types, or slopes of different steepness or aspect, *if* they appear to correspond to observable differences in results on the ground. In these cases, each unit within the site should be assessed separately.

Several important attributes of healthy shrub-steppe may take years to develop, such as development of a microbiotic crust, or growth of a tall shrub layer. The monitoring protocols described here do not include these longer-term components, although they can be easily included as additional measures over time.

Restoration is a process that takes time. Short-term objectives are likely to differ from longer-term objectives. For example, short-term goals may focus on establishing a bunchgrass cover above some specified level, whereas a long-term goal may include a structural shrub objective as well. Because of these changes, the specific parameters being monitored may vary somewhat over time. Each monitoring entry should just focus on those objectives most appropriate to the current stage of the restoration.

Instructions for Level A Monitoring. An example data form is provided after the instructions below. It may be helpful to pre-populate the data form with a list of all planted species, and all weeds that have been previously noted on the site prior to treatment.

In each unit delineated within a site, walk a course that allows a visual assessment of the variability in composition across the unit. Note the distance walked and/or area covered. Compile a list of all species. Many find it easiest to group species into categories suggested on the form (e.g., seeded grasses, seeded forbs, etc.). For each species, record its average abundance throughout the unit in one of the following categories:

1 = Rare (only a few plants encountered)
2 = Occasional (Widely scattered individuals, or only a few patches that locally can include many individuals)
3 = Frequent (Widely distributed, or more than a few patches)
4 = Common (Well distributed in most areas, or many patches)
5 = Abundant (Large numbers of plants across entire unit, and often many patches as well)

It is important to recognize that many additional features may also be useful to assess at Level A, depending on objectives. The sample form should be modified accordingly to allow systematic recording of this additional information. A separate page may be added that includes spaces to note observations regarding evidence of erosion, use by wildlife, patterns of vegetation establishment, success or failure of plantings and weed control, etc. Space should also be provided to record descriptive information in a narrative form as well.

3.5.2 Summarizing Level A data

Many measures useful in evaluating restoration success can be obtained from the Level A data. Overall diversity (richness) and abundance objectives may be evaluated for planted species, native species, exotic species, or by life form (e.g., planted bunchgrasses) as a group. Managers also usually find it useful to evaluate the success of individual species, to help in choosing those that perform most reliably. Some examples of these measures, together with how they might be calculated, include:

Native species richness - Total number of observed native species (planted and adventitious)

Planted species richness - Total number of planted species observed. This might also be useful to express as a percent of species planted (e.g., What proportion of the planted species successfully established? Depending on objectives, "success" might be defined as having an abundance rank ≥2).

Planted species abundance – The individual abundance ranks for each planted species may be of greatest interest (e.g., Did the planted lupine become well-established, with an abundance rank ≥3? Which planted species established poorly or not at all, with an abundance rank ≤2?).

Exotic species abundance – The individual abundance ranks for each weed may be of greatest interest (e.g., Was cheatgrass abundance ≤2?). Or, overall weed control may be key (e.g., Were all weeds adequately controlled, with a collective abundance rank ≤2?)

Shrub species abundance – Over the short-term (first few years), successful establishment of shrub species may be of greatest interest. (e.g., big sagebrush has an abundance rank ≥3).

An example of a completed form is shown in Figure 36. Readers can download a blank, editable **Level A Field Data Form**.

Figure 36. Level A – Field Data Form (Example with fictional goals and data)

Site Name	Example
Wildlife area unit	Headquarters
Date:	6/12/11
Recorded by	Your name
Survey Distance or Area	5 acres
Time since planted	3 years

Abundance rating

1=Rare
2=Occasional
3=Frequent
4=Common
5=Abundant

Table 1: Vegetation Monitoring Conclusions and observations

Objective	Met?	Observations/conclusions
1. Within 3 years, establish two or more native bunchgrasses at abundance level 5	Yes	Dominants match reference dominants
2. Within 3 years, establish at least 5 more native bunchgrasses at abundance level ≥2	Yes	Invasion of basin wildrye helped us meet objective.
3. Within 3 years, establish lupines at an abundance level ≥2.	No	Not met, seeded species doing poorly. Another lupine is invading. Goal may still be met in time
4. Within 5 years, bitterbrush and sagebrush at abundance level ≥ 2 on Quincy soils	No	Bitterbrush not at target level yet. No action needed, objective will likely be met in few years.
5. Within 3 years after planting no weed species has an abundance level of ≥3.	Yes	Decreasing.

Table 2: Vegetation Observations

Species	**Observed Abundance**	Objective and associated success criteria.				
		1	2	3	4	5
Seeded grasses						
Bluebunch wheatgrass	*5*	*At least*	*At least*			
Indian ricegrass	*5*	*two*	*Five*			
Needle and thread	*3*	*species*	*species*			
Sandberg bluegrass	*4*	*with a*	*with a*			
Cusick's Bluegrass	*0*	*rank*	*rank*			
Thickspike wheatgrass	*1*	*of 5*	*of 2*			
Seeded forbs						
Velvet lupine	*0*			*2*		
Shrubs						
Antelope bitterbrush	*1*				*2*	
Big sagebrush	*2*				*2*	
Non-seeded native species						
Silky lupine	*1*			*Bonus*		
Great basin wildrye	*2*		*Bonus*			
Exotic species						
Russian knapweed	*2*					*<3*
Jointed goatgrass	*1*					*<3*
Canada thistle	*2*					*<3*

Observations: Soil stabilized. Sharp tail grouse observed.

3.5.3 Photomonitoring Instructions

Photos are taken to provide visual documentation of the particular characters of interest (such as bunchgrass density, patterns of weed establishment, etc.), and which augment the abundance estimates and narrative descriptions of conditions. In many cases, it may be useful to establish permanent photopoints to provide a slightly more rigorous way of assessing change on the site over time. Helpful guidance on photomonitoring, how to make photopoints permanent, sample data forms for recording information, etc., are available Online. The USDA Forest Service's **Remote Sensing Applications Center** includes a quick overview of salient points to consider when setting up photomonitoring sites on their mapping and monitoring web site. The **Photo Point Monitoring Handbook** (Hall, 2002) provides a much more comprehensive description of photomonitoring.

*www.fs.fed.us/eng/rsac/invasivespecies/.../**Photopoint**_monitoring.pd...*

An example of a photomonitoring data form is included below as Figure 37. People can also download an editable version of the **Photo Point Monitoring Form.**

Figure 37. Photo point monitoring form

Photo Point Monitoring Form

Photo point name or number:		
Date:		
Observer:		
Restoration Site/Unit:		
Camera Location (GPS Coordinates):		
Compass bearing;	Distance:	
Slope:	Slope position:	Aspect:
Notes:		
Inset photo here		

4.0 Maintenance and Enhancement

4.1 General Principles

The intensive, initial steps in a restoration project start a site along a trajectory to reach a desired range of states. Long term maintenance and enhancement are usually required to keep a site progressing on this trajectory because 1) the full complement of species, structure, and ecological processes are not fully established during the initial restoration work, 2) native species often are not capable of fully excluding invasive species, and 3) natural processes needed to create or perpetuate the historical condition usually have been modified to the extent that they must be actively controlled, induced, or simulated.

The main difference between intensive restoration projects and maintenance is that restoration projects often attempt to wipe the slate clean and start over. Maintenance and enhancement efforts, however, usually involve promoting the continued existence or furthering the development of existing, desirable vegetation much like second-year post-planting weed control (**Section 3.4.7** Second growing season following seeding). Therefore, recommendations that proved effective in the post-planting restoration setting, such as mowing and applying herbicide to control weeds, may be of great value if continued into the long term maintenance setting. Manual Sections that may prove especially helpful in the maintenance context include

- **2.8.2.3 Spraying equipment**
- **3.4.6 Spot spraying weeds**
- **3.4.7 Second growing season following seeding**
- **3.5 Effectiveness Monitoring of Vegetation Restoration**
- **3.5.3 Photomonitoring Instructions**
- **6.1 Overview and Hyperlink Directory**
- **6.2 Local Expertise Directory**
- **6.3 Herbicide and Adjuvant Descriptor and Use Tables**

4.2 Managing Ecological Processes

Ecological processes that often shaped the historical conditions in shrub-steppe and grassland communities of the Columbia River Basin include fire, floods, herbivory, and drought. While in many cases, protecting a site from unnatural disturbances is an essential maintenance strategy, natural ecological processes often involve disturbing vegetation and soils. Such disturbances can be very beneficial when similar to natural historical events. While little can be done to control droughts and flooding, the other processes can often be affected or partially simulated via maintenance. Restoring or simulating natural processes may involve actions and strategies that were not included in a restoration project.

In general, the frequency and intensity of fire is an ecological process that has been altered greatly due to fire suppression, man-made ignitions, and the modification of community flammability via introduced species and altered fire return intervals. In most shrub-steppe systems in Washington, the current fire return interval is now too frequent to allow for the development and maintenance of historic vegetation. Therefore, fire suppression and fire breaks may be needed if the goal is to establish vegetation that is not compatible with the current fire regime.

Herbivory can strongly influence the species composition and structure of a plant community. In cases where there are substantial numbers of grazing or browsing ungulates, their use of a site may serve to sustain or degrade a plant community depending on the intensity of use. Effective vegetation maintenance may require ungulate management.

5.0 Documentation

5.1 Documentation and Case History Library

Documenting and sharing project information is a powerful means of accelerating the science and art of restoration. Interviews with pioneering restoration specialists indicate that many lessons were independently learned via the slow, expensive, frustrating process of trial and error. The Restoration Project Documentation Form (**Figure 38)** has been created so that managers can conveniently and uniformly record planning and implementation activities as they occur and then share details about projects. The form provides for narratives, summary tables, monitoring data, photographs, and attaching of ancillary documents to create a comprehensive case history that can be shared with others who might be assigned in mid-project, colleagues, funding institutions, and other interested parties. While the template asks for standard information to allow for meaningful comparisons of projects, there is no limit on what information can go into case histories.

It is important to note that case histories need not be fully completed to be of value. Partially completed case histories can also serve as the basis for initial funding requests, progress reports and applications for continuing financial support. In fact, case histories are never really done. The section evaluating current conditions can be repeatedly completed at different post-project time intervals to track the trajectory of a site.

WDFW has started to build a **Case History Library** containing case histories for projects of different ages representing a variety of restoration project scenarios. Going forward, project managers should be able to produce more detailed case histories with little extra effort. A Restoration Project Documentation Form template with built instructions is provided below as **Figure 38**. Editable, electronic versions of the form can be downloaded **with** and **without** instructions. All of the intermediate work products that this manual suggests be created(e.g., seed list, monitoring report form) can be directly inserted into the Restoration Project Documentation Form to gradually create a complete case history.

The form should be used as the project progresses, starting with the earliest phases of planning. Instructions within the form should be deleted after they are no longer needed. When documentation proceeds as the project progresses, it is easy to include details that are otherwise soon forgotten or later require more effort to retrieve.

Going forward, WDFW, BLM, and others can add to an expanding case history library. Project proponents are encouraged to submit case histories to Richard.Tveten@dfw.wa.gov. If all future projects contributed to a shared case history library, project proponents could quickly gain insights learned from recent, similar projects and apply them to their projects. Likewise, the information could be used to prioritize research and update this manual.

Figure 38. Restoration Project Documentation Form

Restoration Project Documentation Form

Delete instructions (red-font) as form is completed

Recorded By:
Contact Information:
Date Recorded:
Location and Site Attributes:

Project name		
County		
Location	T R S	Lat. Long. -
Wildlife area and Unit		
Restored area size		
Ownership		
Elevation	Useful link http://www.earthtools.org/	
Aspect		
Slope		
Annual Precipitation	Useful link http://prismmap.nacse.org/nn/index.phtml	

Soils: *(Brief description of the major soil types on the site. May include populating attached Table 1)*

Adjacent land use and condition: *(Describe uses that may impact project site (native species present, weed infestations, fire risk, herbicide use, grazing, and farmland)*

Site History: *Former land use (CRP, grazing other, dates), pre-restoration dominant species composition*

Project Goals: *Explain what you hoped to achieve (short and long term). Include cover and composition goals if they were defined. (Table 1 may be helpful when setting vegetation goals)*

Site Preparation: *Summarize specific site preparation measures, and the sequence in which they were carried out, in Table 2. Include any overall site preparation comments here. (see Table 2, attached)*

Seed Mix: *Species used, copy of the tag, (see Table 3, attached)*

Planting: *(Provide details of planting methods in Table 4, attached)*

Post-planting weed control and other management actions: *(see Table 5, attached)*

Evaluation of Current Conditions

(As restoration site conditions vary over time, it is advisable to periodically assess site status. New copies of this section can be completed and attached each time a new assessment is made.)

Date of status assessment: ________________

Current Status: *(Describe current status of planted species and weeds. Summarize weed control effectiveness)*

Goals realization: *(How close are you to what you intended to restore? Relate original goals to current status)*

Special circumstances affecting outcomes: *(Note post-restoration events such as extreme weather, fires, disease problems, etc. as well as good things like native species re-invasion)*

Keys to present level of success: *(Special actions or circumstance that may have improved project outcomes, lessons learned. What would you have done differently?)*

Project site future: *What do you plan (or would like) to do to make further improvements.*

Table 1: Soils, ecological sites or reference sites, and presumed dominant species

Information can be summarized in the following table. Sample data often may be derived from two websites. The Websoilsurvey link listed above also can be used to provide site-specific information on potential vegetation. Use the Ecological Site Numbers identified in the Ecological Site Assessment tab, or in the custom soils report, to download Ecological site descriptions at a separate website: http://efotg.sc.egov.usda.gov/efotg_locator.aspx?map=WA

To download Ecological Site Description, select the county of interest, select section II in the drop down box on left side of the screen and then open the Ecological Site Descriptions folder at the bottom of the folder list. Attach the reports as attachments B1,B2,…Bn) for those who may wish to study them further or compare goals to pre-degradation conditions.

While Ecological Site Descriptions are often a convenient way to learn about historical conditions, such descriptions are not always available or may contradict other available sources. As an alternative, , or in addition to the above, information on potential native plant species may be compiled by examining less-disturbed nearby sites, if they exist, or other references.

Soils	% of site	Ecological site name or reference site description	Presumed dominant species composition in healthy condition

Table 2: Site preparation: *Add rows as necessary*

Date	Action	Objective(s)	Observations/Notes (chemicals, equipment used, and special issues).

Table 3: Seed Mix: *(May attach seed mix from labels if available as Attachment xx). List the species included in the seed mix in Table 3. Include any special notes here regarding why species were chosen*

Species	Percent	Seeds/s.f.	Pure live seeds lbs/acre

Table 4: Planting:

Date	
Methods(s) and planting equipment	
Planting depths	
Seeding Rate (lbs/acre, or seeds /foot)	
Special actions taken	
Fertilizers/soil amendments	

Table 5: Post Planting Actions and Observations. *Summarize specific measures taken, why they were taken, and any observations regarding their success, in Table 4. Also, include inspections, monitoring and observations of events that could affect project outcomes like extreme weather or wildfires. Add rows as necessary.*

Date	Action	Observations/Notes (Weed control chemicals and equipment used, effectiveness, inspection observations, any special issues).

Attachments

Site map: *Provide a map or aerial image delineating the restoration site. The following website is a useful tool for producing site maps and getting detailed soils information (see Table 1): http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx*
Site specific information on soil types, together with an aerial image, can be obtained using the Area of Interest tab to delineate the site. The Soil Map tab will show the soil types, together with descriptions of each. You may be able to download all this information in a custom soils report using the "shopping cart" feature, depending on your operating system. Mozilla Firefox seems to work better than Internet Explorer. You will need to disable "Popup Blockers" to download information (see FAQ's and "Known Problem Workarounds"). Other sources of soil maps and information may be local NRCS offices.

Google Earth is another useful tool for delineating site locations on aerial imagery, getting precise elevations, and Adjacent Land Use information. Oftentimes, this site has imagery from multiple dates, which can be useful for getting a historical perspective.

Pre-project images: *Include pre-project photograph(s) and/or reference site photograph(s) as Attachment*

Post-project images: *Include post-project photograph(s) as Attachment.*

Post project characterization data: *(Attach any monitoring data, if any, as Attachment)*

6.0 Technical Resources

6.1 Overview and Hyperlink Directory

This section provides or identifies resources and tools to help project managers find information, plan actions or document activities. All of the resources identified or provided within this manual can viewed within this section or reached via internal hyperlink to other parts of this document (bold) or download sites (Bold and underlined). Some of the associated tools go to the headings of sections containing the resources or tools rather than the item itself so that the reader is also directed to the brief text that describes the tool and puts it in context. Table and figure numbers for internal resources and web site addresses are provided hard copy users.

6.1.1 Contacts

- **Section 6.2 Local Expertise Directory**
- **Figure 6. Bio-control contacts**

6.1.2 General restoration

- ***Developing and Managing Ecological Restoration projects, 2nd Edition.*** http://www.ser.org/content/guidelines_ecological_restoration.asp.
- ***Ecological Restoration Primer, Society for Ecological Restoration (SER International Science and Policy Working Group 2004).*** http://www.ser.org/content/ecological_restoration_primer.asp

6.1.3 Monitoring and documentation

- **Restoration project documentation form with embedded instructions** http://wdfw.wa.gov/publications/01330/RestorationProjectDocumentationForm_with_instr.doc
- **Restoration project documentation form without embedded instructions** http://wdfw.wa.gov/publications/01330/RestorationProjectDocumentationForm_without_instr.doc
- **Level A field data monitoring form** http://wdfw.wa.gov/publications/01330/LevelAFieldDataForm.doc
- **Photo point monitoring form** http://wdfw.wa.gov/publications/01330/PhotoPointMonitoringForm.doc
- **Remote Sensing Applications Center (Photo Point monitoring guidance)** http://www.fs.fed.us/eng/rsac/invasivespecies/mapping_main.htm
- **Photo Point Monitoring Handbook** http://www.fs.fed.us/pnw/pubs/gtr526/

6.1.4 Permitting and environmental compliance

- **BPA environmental Compliance web site.** http://efw.bpa.gov/contractors/work_categories/work_elements/we002.aspx

6.1.5 Plant identification

- **Seedling Identification Guide**
  http://wdfw.wa.gov/publications/01330/Seedling_ID_Guide_092711.pdf

6.1.6 Seed mix development and planting recommendations

- **Figure 21. Seed certification (Reprinted from the AOSCA Native Seed Connection)**
- **Figure 22. Columbia Plateau Provisional Seed Zones**
- **Table 1. Alkaline tolerant grass seed mix**
- **Table 15. Base seeding rates for grasses and seeding method multipliers**
- **Table 14. Optimal seeding depths for commonly planted species.**
- **Seed Drill Calibration Tool**
  http://wdfw.wa.gov/publications/01330/SeedDrillCalibrationTool.xls
- **Native Seed Network.** http://www.nativeseednetwork.org/home/index.php .
- **Western Wildland Threat Assessment Center**
- http://www.fs.fed.us/wwetac/threat_map/SeedZones_Intro.html
- **Native plant Connection** http://www.aosca.org/native%20plant%20restoration.htm
- **Native Seed Network Releases web page** http://www.nativeseednetwork.org/releases

6.1.7 Site research

- **Web Soil Survey** http://websoilsurvey.nrcs.usda.gov/app/
- **Western Region Climate Center**. http://www.wrcc.dri.edu/summary/climsmwa.html
- **Government Land Office Survey Records**
  http://www.blm.gov/or/landrecords/survey/ySrvy1.php
- ***NatureServe Explorer*** http://www.natureserve.org/explorer/index.htm
- ***Draft Guide to Ecological Systems***.
  www1.dnr.wa.gov/nhp/refdesk/pubs/wa_ecological_systems.pdf
- ***Wildlife–Habitat Relationships in Oregon and Washington***.
  - **Chapter 2**, http://www.nwhi.org/index/publications.
  - **Habitat maps** http://www.nwhi.org/index/ecoprovinces.
- **Washington State University Library Image Collections** http://content.wsulibs.wsu.edu/
- **Field Office Technical Guide** .http://www.nrcs.usda.gov/technical/efotg/
- **Natural Heritage Program**
  http://www.dnr.wa.gov/researchscience/topics/naturalheritage/pages/amp_nh.aspx
- **Native Plant Society** http://www.wnps.org/chapters.html
- **2.7.2 Excess nutrients - testing labs and recommended tests**
- **Figure 5. Soil bioassay method**

6.1.8 Timelines and activity timing

- **Figure 22. Seed increase development timeline**
- **Figure 25. Timeline for restoring created wheatgrass field**
- **Figure 27. Tall wheatgrass field restoration timeline**

- **Figure 28. Timeline for restoring sheep fescue fields**
- **Figure 29. Rhizomatous grass field restoration timeline**
- **Figure 30. Abandoned crop land restoration timeline**

6.1.9 Weed control

- **Table 18. Restoration site herbicides**
- **Table 19. Restoration project adjuvants spreadsheet**
- **Table 16. Post planting weed control options by season and species.**
- **Table 9. Herbicide mix and rates for initial control of crested wheatgrass during site preparation**
- **Table 10. Recommended herbicide mixes for the summer and fall prior to seeding crested wheatgrass fields.**
- **Table 11. Herbicide mix and rate for site preparation on tall wheatgrass and sheep fescue fields**
- **Table 12. Herbicide mix and rates for common rhizomatous grasses**
- **Table 13. Herbicide mixes and rates for annual grass control during site preparation**
- **Pacific Northwest Weed Management Handbook**. http://pnwhandbooks.org/weed/

6.2 Local Expertise Directory

The following is not an exhaustive directory. Rather, it reflects people who, during the development of this manual, indicated that they were willing to share their contact information in the event that others wished to contact them about restoration and they are available. Inclusion of commercial entities in no way constitutes an endorsement or preference for them over other entities. Other persons can be added to an online version of the directory as they are identified. Please submit requests to add, remove or revise such information to Richard.Tveten@DFW.wa.gov.

Table 17. Local expertise directory

Name	Affiliation	Phone Number	Experience
Asher, Melissa	BFI Native Seeds	509-793-5476 asherm@bfinativeseeds.com	Taxonomy, monitoring, plant propagation, weed control
Benson, Jerry	BFI Native Seeds	509.765.6348 jbenson@bfinativeseeds.com	Restoring shrub-steppe and grasslands. Commercial propagation, weed control.
Bracken, Ed	WDFW	509-925-1014	Range science, monitoring
Brusven, Paul	Nez-Perce	208-843-9374	Bio-control
Camp, Pam	Formerly BLM	509-663-5491 pacamp@nwi.net,	Managed restoration projects in Douglas and Grant counties. Forb establishment.
Cindi Confer	WDFW	509-697-4503 Cindi.Confer@dfw.wa.gov	Restoration in Kittitas and Yakima counties.
Cotton, John	WDFW	509-754-4624ex35 John.Cotton@dfw.wa.gov	Optimizing habitat in highly altered areas like circle corners.
Dunwiddie, Peter	UW	206-729-1851 pdunwidd@u.washington.edu	Monitoring
Easterly, Richard	SEE Botanical	360-481-1786 seebotanical@comcast.net	Vegetation mapping, Landscape Interpretation, Ecology, Rare Plants
Finch, Mike	WDFW	509-636-2344 Mike.Finch@dfw.wa.gov	Restoration experience in Lincoln and Spokane counties.
Fleenor, Richard	NRCS	509-389-1021. richard.fleenor@wa.usda.gov	Plant materials
Goldie, Kevin	USFWS	509-546-8300 Kevin_Goldie@fws.gov	Post-fire Restoration of shrub-steppe and riparian areas, weed control.
Hallet, Marc	WDFW	509-686-4305 Hallemh@dfw.wa.gov	Restoration in Douglas, Chelan and Okanogan counties
Hays, David	WDFW	360-902-2366 David.hays@dfw.wa.go	Endangered species conservation
Dave Heimer	WDFW	253-759-7165 David.heimer@dfw.wa.gov	Weed control
Larsen, Don	WDFW	509-329-2967 Donald.Larsen@dfw.wa.gov	Restoration on private lands
Lopushinsky, Pete	WDFW	509-663-6260	Restoration in Kittitas and Grant

		lopuspl@dfw.wa.gov	counties
Mader, Eric	Xerces Society	503-232-6639 eric@xerces.org	Pollinator restoration, pollinator/forb relationships
McKoy, Tom	WDFW	509-996-2559 Thomas.McCoy@dfw.wa.gov	Restoration in Okanogan County, range science
Merg, Kurt	WDFW	509-648-3680 Kurt.Merg@dfw.wa.gov	Restoration on private lands
Newsome, Heidi	USFWS	509-546-8300 Heidi_Newsome@fws.gov	Post-fire restoration of shrub-steppe uplands and grasslands
Olds, Rich	XID Services	1-800-872-2943 509-332-2989 info@xidservices.com	Taxonomy, weed control
Olson, Jim	WDFW	509-826-4430 James.Olson@dfw.wa.gov	Restoration in Okanogan County,
Peterson, Dan	WDFW	509-686-4305 Dan.Peterson@dfw.wa.gov	Restoration in Douglas, Chelan and Okanogan counties
Piper, Gary	WSU	509-335-1947 glpiper@wsu.edu	Bio-control
Ross, Rocky	WDFW semi-retired	509-539-1136	Restoration in Yakima and Benton Counties, post-fire restoration and alkali soils.
Sak, Robby	WDFW	509-840-2877 Robert.Sas@dfw.wa.gov	Restoration in Yakima and Benton Counties, post-fire restoration and alkali soils.
Salstrom, Debra	SEE Botanical	360-481-1786 seebotanical@comcast.net	Rare plants, plant ecology and botany, vegetation mapping
Schroeder, Mike	WDFW	509-686-2692 Michael.Schroader@dfw.wa.gov	Research with sharptail and sage grouse
Sheridan, Chris	BLM	509-665-2118 csherida@blm.gov	Ecology and ecological methods, restoration
Sillstead, Larry	USDA-APHIS	(509) 353-2950 Email: larry.d.skillestad@usda.gov	Bio-control
Swedberg, Dale	WDFW	509-223-3358 swedbdas@dfw.wa.gov	Restoration in Okanogan county via tree harvest and fire.
Taylor, Jody	WDFW	509-697-4503 Jody.Taylor@dfw.wa.gov	Restoration in Kittitas and Yakima counties.
Tveten, Richard	WDFW	360-902-2367 Richard.Tveten@dfw.wa.gov	Taxonomy, Fire ecology, can help identify experts

6.3 Herbicide and Adjuvant Descriptor and Use Tables

As weed control using herbicides spans all phases of project restoration, this section includes tables describing chemicals that are recommended. **Table 18. Restoration site herbicides** provides the chemical names, trade names, modes of action and uses for numerous, commonly used herbicides. **Table 19. Restoration project adjuvants** provides chemical names trade names, application rates and uses for adjuvants.

Table 18. Restoration site herbicides

Chemical Name	Mode of Action[1]	Chemical Family[1]	Used to Control[2]	Description[3 and 4]	Trade Names Commonly Available in Eastern Washington
Fluazifop	ACCCase Inhibitors	Aryloxyphenoxy propionate	Suppress grasses to enhance forbs	Grass selective; non-residual	Fusilade; Fluazifop
Clethodim	ACCCase Inhibitors	Cyclohexanedione	Suppress grasses to enhance forbs	Grass selective; non-residual	Select; Volunteer; Arrow
Sethoxydim	ACCCase Inhibitors	Cyclohexanedione	Suppress grasses to enhance forbs	Grass selective; non-residual	Poast
Imazamox	ALS Inhibitor	Imadazolinone	Cheatgrass and general broadleaves; seedling establishment of alfalfa fields	Non-selective; Residual ranges from short to long-term[4], depending on rate and species sensitivity	Raptor; Clearcast (aquatic formulation)
Imazapic	ALS Inhibitor	Imadazolinone	Cheatgrass; general broadleaves	Non-selective; residual	Plateau
Imazapyr	ALS Inhibitor	Imadazolinone	Woody plant control; sagebrush	Non-selective; long-term residual	Arsenal; Habitat (aquatic formulation)
Chlorsulfuron	ALS Inhibitor	Sulfonylurea	Annual broadleaves, toadflax, whitetop	Broadleaf selective; long-term residual	Telar; Gleen
Metsulfuron-methyl	ALS Inhibitor	Sulfonylurea	Annual broadleaves, toadflax, whitetop	Broadleaf selective; short-term residual	Escort; Ally
Tribenuron-methyl	ALS Inhibitor	Sulfonylurea	Whitetop; establishment of natives within whitetop; annual broadleaves	Broadleaf selective; short-term residual	Express; Harmony
Bromoxynil + 2-4 D	Combination	Combination	Annual broadleaves	Broadleaf selective; non-residual	Maestro D

Restoration project herbicides - continued

Chemical Name	**Mode of Action**[1]	**Chemical Family**[1]	**Used to Control**[2]	**Description**[3 and 4]	**Trade Names Commonly Available in Eastern Washington**
Bromoxynil + MCPA	Combination	Combination	Annual broadleaves	Broadleaf selective; non-residual	Maestro (Advanced and MA); Bronate; Brox-M
Glyphosate + Imazapic	Combination	Combination	Cheatgrass	Non-selective; mid to long-term residual	Journey
Glyphosate	EPSP Synthase Inhibitors	Organophosphorus	Cheatgrass, perennial grasses; specialized applications in desired grass stands	Non-selective; non-residual; systemic	Round-Up Pro; Bucaneer; Glystar; Credit; Rodeo (aquatic formulation)
Pendimethalin	Mitosis Inhibitors	Dinitroaniline	Jointed goatgrass in young grass stands	Mostly grass-selective, with a few susceptible broadleaves; mid-term residual	Prowl
Paraquat	Photosystem I Inhibitor	Bipyridinium	Burn down	Non-selective; short-term residual; contact	Gramoxone
Bromoxynil	Photosystem II Inhibitor	Benzonitrile	Small, annual broadleaves; just after planting (no germ)	Broadleaf selective; non-residual	Buctril; Maestro (2EC and 4EC); Brox 2EC
Tebuthiron	Photosystem II Inhibitor	Substituted urea	Sagebrush; woody species	Broadleaf selective at lower rates; non-selective at higher rates; long-term residual	Spike
Simazine	Photosystem II Inhibitor	Triazine	Cheatgrass control in well established grasses; hard on forbs	Non-selective; residual	Simtrol; Princep

Restoration project herbicides - continued

Chemical Name	Mode of Action[1]	Chemical Family[1]	Used to Control[2]	Description[3 and 4]	Trade Names Commonly Available in Eastern Washington
Dicamba	Synthetic auxin	Benzoic acid	Annual broadleaves; perennials in combo with express/harmony	Broadleaf selective; short-term residual at 8-12 oz/acre; non-residual at lower rates	Banvel; Vanquish; Clarity
2-4 D + Dicamba	Synthetic auxin	Combination	annual broad	Broadleaf selective; non-residual	Trimec; Weedmaster; dozens of others
Clopyralid + 2-4 D	Synthetic auxin	Combination	Annual and perennial broadleaves; Perennial Composites	Broadleaf selective; long-term residual	Curtail
Triclopyr + Picloram	Synthetic auxin	Combination	Sagebrush; rabbitbrush	Broadleaf selective; long-term residual	Brushmaster
2-4 D	Synthetic auxin	Phenoxy	Annual broadleaves	Broadleaf selective; non-residual	Water Formulation: 2,4-D Amine; Hidep; Basecamp; Amine-4; LV6 Oil Formulation: Weedar 64; Formula 40
MCPA	Synthetic auxin	Phenoxy	Annual broadleaves	Broadleaf selective; non-residual	MCPA; Bromine; Chiptox; Thistrol
Aminopyralid	Synthetic auxin	Picolinic Acid	Perennial weeds, particularly Composites	Broadleaf selective; long-term residual	Milestone

Restoration project herbicides - continued

Chemical Name	Mode of Action[1]	Chemical Family[1]	Used to Control[2]	Description[3 and 4]	Trade Names Commonly Available in Eastern Washington
Clopyralid	Synthetic auxin	Picolinic Acid	Perennial weeds, particularly Composites	Broadleaf selective; long-term residual	Transline; Stinger
Picloram	Synthetic auxin	Picolinic Acid	Perennial weeds, particularly Composites	Broadleaf selective; long-term residual	Tordon 22K; Grazon; Access
Fluoxypyr	Synthetic auxin	Pyridine	Kochia; bedstraw	Broadleaf selective; non-residual	Starane; Vista; Starane Ultra
Triclopyr	Synthetic auxin	Pyridine	Sagebrush; woody species	Broadleaf selective; non-residual	Remedy; Garlon; Garlon 3A
Quinclorac	Synthetic auxin	Quinoline carboxylic acid	Field bindweed	Controls annual grasses and certain broadleaves; mid to long term residual	Paramount

[1]Source: Herbicide handbook, Weed Science Society of America, Ninth Edition, 2007

[2]Common uses for WDFW managers during restoration work

[3]Source: WDFW managers and staff practical experiences

[4]Short-term residual activity is defined in this manual as lasting less than 2 months; mid-term lasts for 2 months to a year; long-term lasts for more than one year.

Table 19. Restoration project adjuvants

Name	Use	Used With[1]	Description	Amount Used	Trade Names Commonly Available in Eastern Washington
Ammonium sulfate (AMS)	Water Conditioning Agent	Roundup	Increases rate of weed control	2% solution, 8-16 oz/ac	Bronc Max
Non-ionic surfactants	Herbicide absorption aid	Most herbicide mixes	Increases absorption of herbicide	1% solution or 1-2 oz/ac	R-11, Super-Spreader 90, Spreader 90
Crop oil concentrate (COC)	Herbicide absorption aid	Grass-selective herbicides	Increases absorption of herbicide	16-64 oz/ac	Mor-Act, ROC
Methylated seed oil (MSO)	Herbicide absorption aid	Paramount	Increases absorption of herbicide	8-64 oz/ac	Hasten, Competitor, Renegade, Super Spread MSO

[1]Commonly used by WDFW managers during restoration work

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