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Revision 0

Upland Vegetation of the Central Hanford Site

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

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P.O. Box 650
Richland, Washington 99352

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Upland Vegetation of the Central Hanford Site

1 INTRODUCTION

The Hanford Site has some of the most extensive shrub steppe vegetation remaining in Washington State and is increasingly important to the conservation of both plants and animals in the state and region (e.g., DOE 2017, Hallock et al. 2007, TNC 1999). This report and the associated maps are intended to contribute to understanding the dynamics of the vegetation on the portion of the Hanford Site managed by the U.S. Department of Energy (DOE) (Figure 1-1). In this report, this area is referred to as Central Hanford or the study area.

1.1 Purpose

Accurate vegetation maps constitute an extremely useful tool for making effective management decisions. On Central Hanford, the map greatly assists compliance with the *Hanford Site Biological Resources Management Plan* (DOE 2017), which requires accurate identification of high quality habitats (e.g., Element Occurrences). In addition, an accurate vegetation map establishes invaluable baseline data for proper understanding and management of regionally and nationally important shrub-steppe habitat.

Accurate vegetation maps have been shown to be one of best available tools for determining habitat preference of shrub-steppe obligate species (both currently listed candidates or future potential candidates for the Endangered Species List or listing within Washington State). A recent extensive study on bird habitat and density on the adjacent Hanford Reach National Monument found that the labor intensive, expensive vegetation plots that were established specifically to support that study provided limited information and were much inferior to the vegetation map in predicting bird distribution (Earnst and Holmes 2012).

In addition, vegetation patterns on the landscape can inform fire protection and management actions of the Hanford Site. A study done by the United States Forest Service Rocky Mountain Research Station that was based on a comprehensive review of the literature on the effect of fire on vegetation concluded that:

> *Possibly the three most important ecological site characteristics that influence a site's resilience (ability of the ecological site to recover from disturbance) and resistance to invasive species are soil temperature/moisture regimes and the <u>composition and structure of vegetation</u> on the ecological site just prior to the disturbance event.* (Miller et al. 2013).

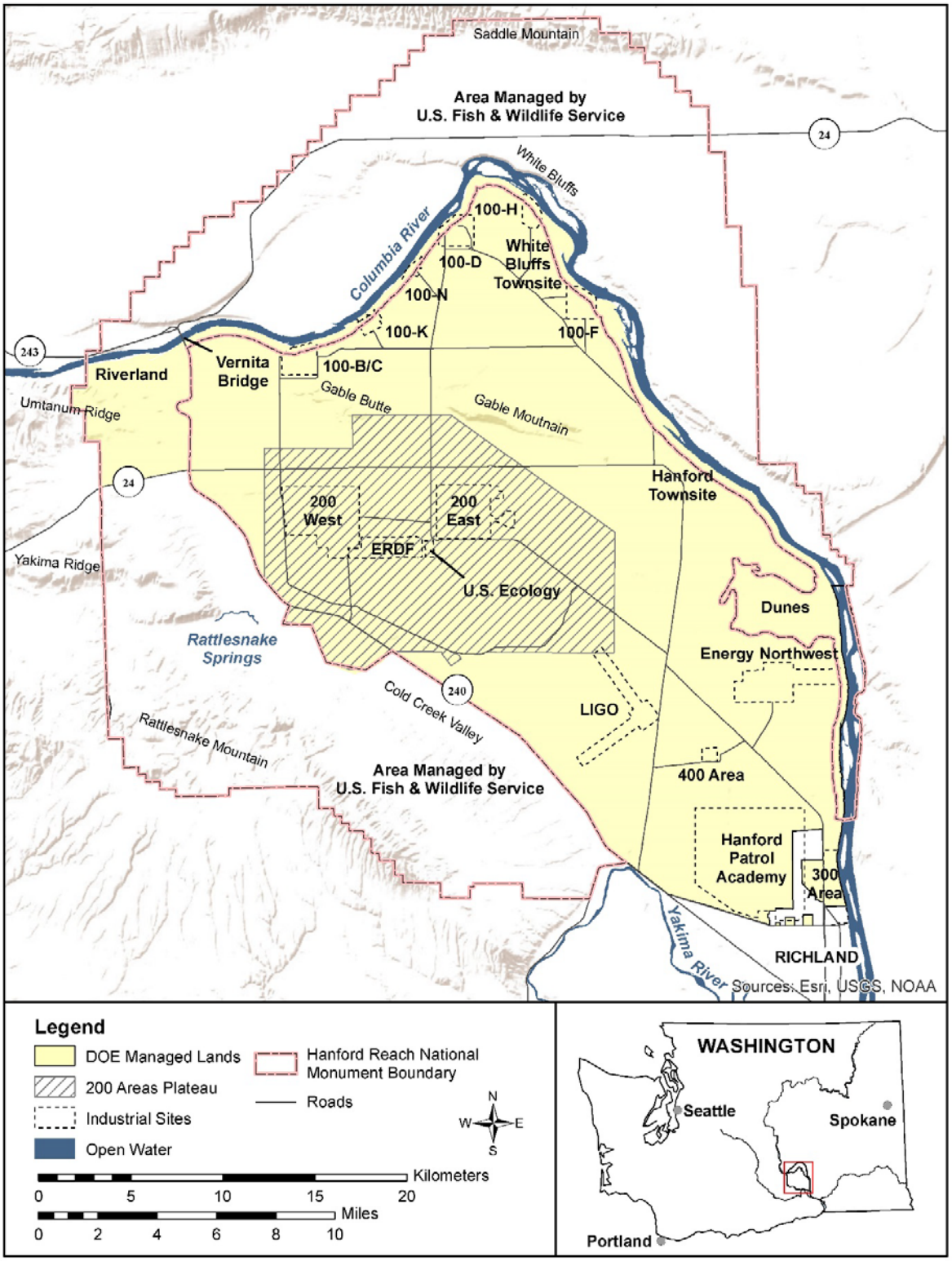

Figure 1-1. Map and General Features of the Hanford Site (DOE 2017)

1.2 Need

When the current mapping activity was initiated, the existing vegetation map for Central Hanford had some deficiencies and was outdated, which limited its utility to identify and represent the vegetation and significant Element Occurrences on the Hanford Site accurately. Its limitations stem from several factors, including being based on coarse-scale aerial imagery from the early 1990s, the poor resolution of which, together with limited fieldwork, resulted in shrub species being incorrectly mapped or misidentified in some areas. In addition, the transfer of the map from aerial imagery to U.S. Geological Survey topographic map quadrangles and then to digital Geographic Information System (GIS) resulted in significant registry errors.

Previous vegetation maps for the Hanford Site were developed in the mid-1990s, and since then, multiple wildfires have burned through significant areas of the site. The recovery of the shrub layer and response of the grass layer in the burned areas differs from one area to another, with some areas exhibiting a plastic response to the fire with a rapid recovery of the shrub layer and/or expanded cover of bunchgrasses. The differential response/recovery depends on several factors, not least of which is geomorphology and historic use of the site. As the 1990s map was updated following large wildfires, burned areas were identified as lacking a shrub layer. Some of those burned areas have had significant reestablishment of shrubs. In addition, fires over the past 20 plus years have left patches of unburned shrubs in some areas, which serve as local refugia and seedbanks. These occurrences are important to depict on the map to help predict future trajectories of vegetation in these areas. The combination of survival and post fire reestablishment also provides significant wildlife habitat.

Finally, the previous vegetation map did not capture significant areas (mostly in the northern sections) where mature big sagebrush have suffered from a die-off since the original map was made, resulting in some areas misidentified as having a good cover of sagebrush.

As the role of climate change within semi-desert landscapes becomes more apparent, accurate maps of current vegetation cover will be invaluable, both to better understand and plan within the shrub-steppe biome in general and to manage the vegetation component that secures the very soils that stabilize the dune-dominated landscape of Hanford and its legacy of contamination.

1.3 Approach

The approach used to develop the updated vegetation information and map for the Hanford Site documented in this report consisted of data gathered by a combination of field observations, onsite photos, and best available aerial imagery. Based upon the data collected, a digital GIS map layer was created with polygons depicting the distribution of several species. These basis mapping units were then clustered into increasingly generalized groups for use in developing maps depicting vegetation at fine to coarse (landscape) levels.

The study area for this effort was the DOE-managed land shown in Figure 1-1 (depicted with yellow shading). This vegetation study focused on upland vegetation only; riparian areas found directly along the shoreline of the Columbia River were not considered during this effort.

1.4 Report Scope

The remaining sections of this report cover the following topics:

- **Section 2** provides the pertinent background for this vegetation study, including a description of Hanford Site climate, geology, and soils; land-use history; and current management.

- **Section 3** discusses the methods used to collect vegetation data for the Hanford Site and to evaluate and develop the final vegetation maps.

- **Section 4** presents the results of the vegetation mapping effort and includes a landscape level map of the study area.

- **Section 5** discusses the Ecological Systems identified and their distribution on the Hanford Site.

- **Section 6** presents species-specific observations for the key shrubs and grasses used for the mapping effort.

- **Section 7** lists the literature cited throughout the report.

2 BACKGROUND

The Hanford Site lies in the heart of the Pasco Basin, a large structural and topographic basin in the Columbia Plateau. The study area (referred to as Central Hanford in this document) is the area managed by DOE in the center of the Hanford Site (Figure 1-1); the other portions of the Hanford Site are managed by the U.S. Fish and Wildlife Service (USFWS) as the Hanford Reach National Monument. Elevations on the Central Hanford study area range from the high areas on Umtanum Ridge (550 m [1,804.5 ft]) and Gable Mountain (330 m [1,082.7]) to along the Columbia River (110 m [361 ft]); most of the study area lies between 150 to 230 m (492 to 754.6 ft).

2.1 Hanford Site Description

The Hanford Site is located within the Columbia Basin Ecoregion, an area that historically included over 6 million ha (14.8 million ac) of steppe and shrub-steppe vegetation across most of central and southeastern Washington State (Franklin and Dyrness 1973) as well as portions of north-central Oregon. The current Hanford Site occupies about 1,516 km^2 (586 mi^2) at the approximate center of the ecoregion (Figure 2.1) and represents one of the largest tracts of native shrub-steppe habitat remaining in Washington State.

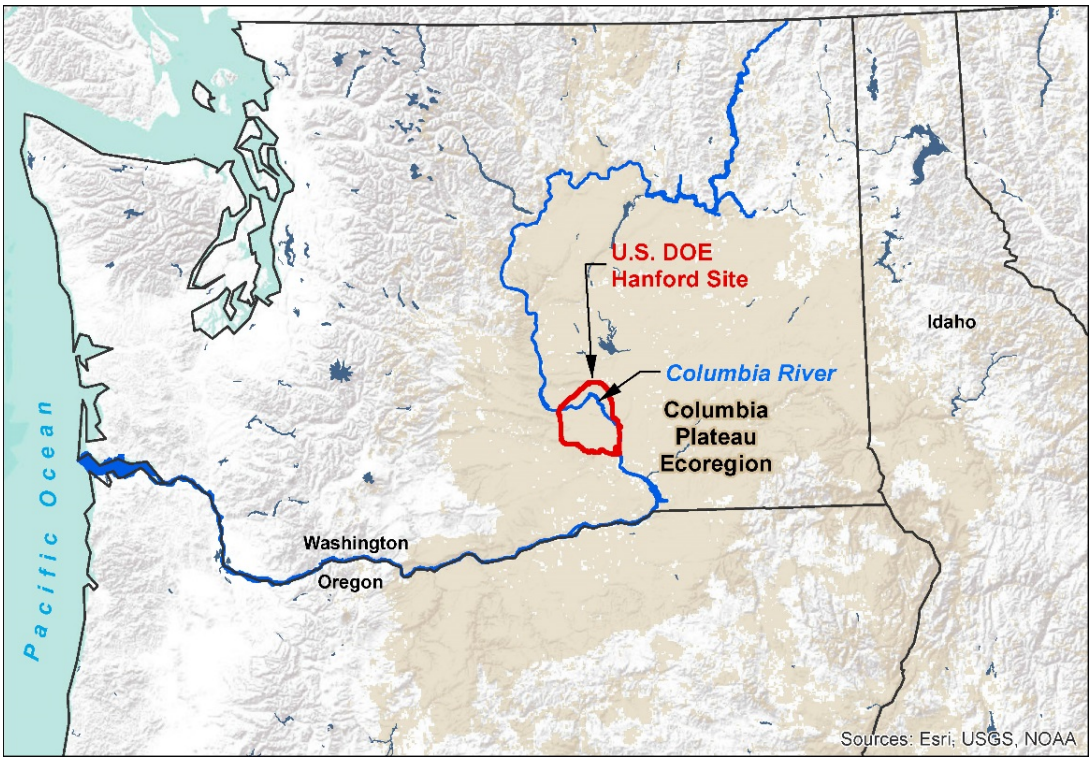

Figure 2-1. The Hanford Site within the Columbia Plateau Ecoregion

A wide variety of habitat types and associated plant communities can be found on the entire Hanford Site, ranging from habitats on talus slopes, unstabilized sand dunes, and high-elevation basalt outcrops to vast expanses of sagebrush/bunchgrass communities. In addition to shrub-steppe habitats, Hanford also includes valuable swale, riparian, wetland, and aquatic resources. A free-flowing stretch of the Columbia River, referred to as the Hanford Reach, bisects the Hanford Site and provides the north and east boundaries of the Central Hanford study area.

2.1.1 Climate

The climate at Hanford is semi-arid with hot, dry summers and cold, wet winters. Based on data collected from 1945 through 2015 (http://www.hanford.gov/hms), the average monthly temperatures at the Hanford Meteorological Station ranged from a low of -0.4 °C (31.3 °F) in January to a high of 24.9 °C (76.9 °F) in July. Average annual precipitation at the Hanford Meteorological Station during this period was 17 cm (6.8 in.). Most precipitation is received between October and April.

Although the Hanford Site's biological resources are characteristic of the Columbia Plateau Ecoregion, the site is unique in that it is located within the driest and hottest portion of the ecoregion (Franklin and Dyrness 1973). These climatic conditions result in somewhat unusual species assemblages relative to the rest of the ecoregion. These same conditions also may result in Hanford shrub-steppe communities being less resilient to disturbance, making restoration and rehabilitation after large-scale disturbance more difficult than other areas that are cooler and receive more precipitation.

2.1.2 Geology

The entire region is underlain by thousands of feet of basalt (Miocene Columbia River Basalt Group) (Reidel et al. 1989). Regional deformation of the basalt has created a series of anticlinal ridges and synclinal troughs (the Yakima Fold Belt), some of which describe the basin.

Basalt exposure within the study area is limited to few areas, most notably Umtanum Ridge, which is an east-west trending anticline that is asymmetrical with a relatively gentle south slope and a steep, intensely folded and faulted north-slope. The ridge plunges to the east and is then prominently exposed in the central portion of the basin as the Gable Butte and Gable Mountain complex. Basalt is also subtly exposed at or near the surface at a small hill in the southwest portion of the study area (near the horn of the Yakima River).

Elsewhere in the study area, the basalt is deeply cloaked beneath two different sedimentary formations. The ancient Ringold Formation (late Miocene to Pliocene) is comprised mostly of sand, silt, and clay that were deposited by lakes and rivers (including the Columbia, Clearwater/Salmon and Yakima Rivers) as they flowed into the basin between 8.5 and 3.4 million years ago. The ongoing regional deformation of the underlying basalt and the formation of the Yakima Fold Belt detained the rivers in the basin and caused large lakes to form, which dropped sediments that filled the basin to around 300-m (984.3-ft) elevation (Fecht et al. 1987, Fecht et al. 2004). Some of the upper layers of the Ringold are cemented by calcium carbonate (Lindsey 1996).

Subsequently, between 3.4 and 2.0 million years ago, the rivers found alternate routes out of the basin that twice caused the base level of the rivers to drop. This caused regional down-cutting (Baker et al. 1991) and partial erosion of the Ringold-era sediments, leaving remnant terraces. The principal remnant

terrace of the Ringold Formation landform within the study area is cloaked under subsequent sediments at the 200 Area Plateau in the central portion of the site, as well as a small exposure on the south slope of Gable Mountain (above West Lake).

More recently, during the Pleistocene, cataclysmic glacial outburst floods repeatedly surged into the Pasco Basin from Sentinel Gap to the northwest and from numerous coulees to the northeast and east. These sediment-laden floodwaters were slowed by a hydraulic dam that formed downstream at Wallula Gap, and temporary lakes formed repeatedly in the basin. As floodwaters slowed, immense quantities of gravel- and sand-dominated sediments were deposited. The stratigraphy of late-Pleistocene cataclysmic flood sediments are "complex over a range of scales due to extremely rapid deposition and dynamic deposition processes during flooding"; as a result, rapid vertical and lateral changes may occur within a few meters (Bjornstad et al. 1994). Bjornstad and Fecht (2002) describe the typical stratigraphy:

> *At the base of the flow, along the sediment-water interface, traction currents carried everything from gigantic boulders that bounced and rolled along the bottom, to finer-grained particles (gravel to clay) in suspension. Higher in the water column, floodwaters were limited to transporting sand, silt, and clay-sized particles. As a result, deposition of the coarsest flood material (cobbles and boulders), as well as entrained finer-grained sediment, was concentrated to lower elevations along the bases of flood channels towards the center of the basin. At higher elevations adjacent to the flood channels, floodwaters were starved of coarser material and, thus, yielded principally horizontally-laminated sands. Around the margins of the basin and in back-flooded valleys often only rhythmically bedded slackwater sand and silt were deposited*.

The initial flooding and subsequent short-lived lake impoundment, followed by drainage of the floodwaters, resulted in a sequence of gravel-dominated facies in main flood channelways, sand-dominated facies adjacent to main channelways, and interbedded sand and silt facies away from main channels along the basin margins and back-flooded environments in tributary valleys (Fecht and Marceau 2006).

In the lee of Umtanum Ridge, the huge Cold Creek Expansion Bar was deposited as the floodwaters spread and slowed into backwater areas of the Pasco Basin. The 200 Area Plateau (with its underlying remnant Ringold terrace) was cloaked with sand- and gravel-dominated sediments, and the expansion bar extends south-southeast across the site.[1] The massive amount of sand-dominated material that accumulated south (in the lee) of the 200 Area Plateau provided the source material for the major dune complexes that subsequently formed downwind.

During each flood event, the final material that was deposited was silt that fell out of suspension during the short period during which the floodwater was ponded (slackwater fines). Exposures of remnant slackwater fines persist in areas subjected to limited subsequent erosion or deposition, such as backwater areas, and occur extensively on the south slope of Umtanum Ridge.

[1] The Cold Creek Expansion Bar includes the 200 Area and extends to the Laser Interferometer Gravitational-Wave Observatory, 400 Area and Wye Barricade facilities.

Towards the end of the late Pleistocene, the outburst floods tended to decrease in size (Fecht et al. 2004).

Additional features of the Pleistocene glacial outburst floods in the study area include flood-rafted icebergs loaded with debris that became stranded below 350-m (1,148.3-ft) elevation on the south slope of Umtanum Ridge, leaving unsorted bergmounds when they melted there (Goff 1981). Other local features include clastic dikes associated with layers of slackwater fines (such as those near Cold Creek drainage) and giant ripples in the north-central portion of the site, a remnant of the immense volume and flow of the largest cataclysmic floods.

Since the end of the Pleistocene cataclysmic floods, the Columbia River has formed numerous channels as it migrated through and around the Gable complex and eastward to incise the Ringold Formation and create the White Bluffs (Baker et al. 1991). The abandoned channels have created a complicated set of fluvial landforms within a series of flood terraces (Fecht et al. 2004). Some of the abandoned channels have a boulder and cobble lag[2] with a silt "plug" (less than 0.6 m [1.2 ft]) sequence of compact silty fine sand deposited when the channels were abandoned (Fecht et al. 2004).

Abandoned channels of the river include one south and west of Gable Mountain, which had a cataract (falls) that plunged into West Lake that was abandoned about 12,000 years ago (Fecht, personal communication) as the river shifted northward. During this shift, the ancient channel bifurcated near the 100-N Area with the "southern" channelway bounded on either side by Pleistocene glaciofluvial bars with chaotic, giant current ripples (Fecht et al. 2004). North of Gable Mountain, overbank deposition from the ancient river contributed sandy material to the Pleistocene glaciofluvial flood bar there.

A series of abandoned river terrace steps occur to the east and southeast of the 100-D Area. These terraces stretch inland up to about 5.6 km (3.5 mi) from the current river channel and contain numerous gravel-dominated overbank levee/slough landforms (Fecht et al. 2004). The higher landforms in this terrace series are a progression of broad benches with narrow channelways; lower in the profile are large river bar bedforms (Fecht et al. 2004). Sandbeds in that area are interpreted by Fecht et al. (2004) as "fluvial deposits from high stage flow in a low energy environment of an ancient Columbia River." Basalt-rich sand may be dunes that have migrated across the gravel bars from the black sands area north of Gable Mountain. Elsewhere in this area, sand sheets apparently accumulated in vegetation or on the lee sides of terrace bars (Fecht et al. 2004). In the southern portion of the study area, the westward extent of the post-glacial river channel was controlled by the Cold Creek Expansion Bar (Fecht et al. 2004).

In areas exposed to strong wind, the upper strata of sand and silt deposits from Pleistocene floods have been partially mobilized, creating dunes and/or sand sheets of varying thickness overlying the Missoula flood deposits and river bedforms. Active dune colonies occur at sites that have a continuing sand source and generally form where the winds are slowed, such as by a rise in elevation. The large, active barchan dune colony in the center eastern portion of the study area is downwind from the sand-rich, wind-exposed southern margin of the 200 Area Plateau, with longitudinal dunes stretching between

[2] Lag -- Residual accumulation of coarse, unconsolidated rock and mineral debris left behind by the winnowing of finer material.

these two sites. Longitudinal dunes also occur downwind from sand-rich sources at the Yakima River, the Cold Creek Expansion Bar, and the black sands area north of Gable Mountain. Local topography around longitudinal dunes is rolling, while sand sheets and interdune areas are relatively planer.

Sand sheets and other sand-dominated substrates are typically stabilized to some extent by vegetation, except locally along dune tops and in blowouts. The effectiveness of vegetation to stabilize sandy sites likely fluctuates over time in response to precipitation patterns, fire, physical disturbance, herbivory, presence and spread of invasive species, and other changes in species dominance.[3]

In the lower flood terraces east of the Cold Creek Bar, slackwater fine sediments occur within the main flood channelways of the cataclysmic floods. These slackwater fines are capped by discontinuous eolean sand sheets, which in turn are capped by a dune colony (Fecht et al. 2004) with a repeating longitudinal pattern trending to the northwest. The dunes are stabilized by vegetation except for limited blowouts.

The riparian area of the relatively free-flowing Hanford Reach of the Columbia River provides the north and east margins of the study site. Otherwise, surface water is limited to small expressions at West Lake (the remnant plunge pool of a channelway of the ancient Columbia River) and Juniper Springs (which occurs on the steep north slope of Umtanum Ridge at an exposure of water-bearing strata between basalt layers). In addition, during extended periods of higher than normal rainfall, surface water is seasonally present in several vernal pools and swales on the basalt. The flow of groundwater is influenced by aquatards created by hidden subsurface topography of the underlying basalt (where near the surface), the cemented cap on the Ringold Formation (where present), cobble-armored ancient channels of the Columbia River, and slackwater fines. A layer of volcanic ash from an eruption of Mount Mazama approximately 7600 years before present may be locally important in forming an aquatard in an area with swales in the southern portion of the site (e.g., east of the Hammer Training Complex; Salstrom and Easterly 2013).

2.1.3 Soils

The 200 Area plateau rises up to a few hundred feet above most of the study area in the central portion of the Hanford Site, with Gable Butte, Gable Mountain, and Umtanum Ridge rising fairly steeply to 238 m (782 ft), 331 m (1,085 ft), and 550 m (1,806 ft), respectively. Soils range from silt loams and stony silt loams on the slopes of Rattlesnake Mountain, Gable Mountain, Gable Butte, and Umtanum Ridge, to sandy loams, loamy sands, and dune sands on the Columbia River Plain (Figure 2.2) (Rickard et al. 1988, Hajek 1966). There are also areas of talus and basalt scree on all major ridges. Variation in soils, elevation, and precipitation from the river to the top of Rattlesnake Mountain allow a variety of shrub-steppe plant species and habitats to exist across the site.

[3] The volume of active sand in the Hanford Dunes decreased by 27% between 1954 and 1994 (Gaylord and Stetler 1994).

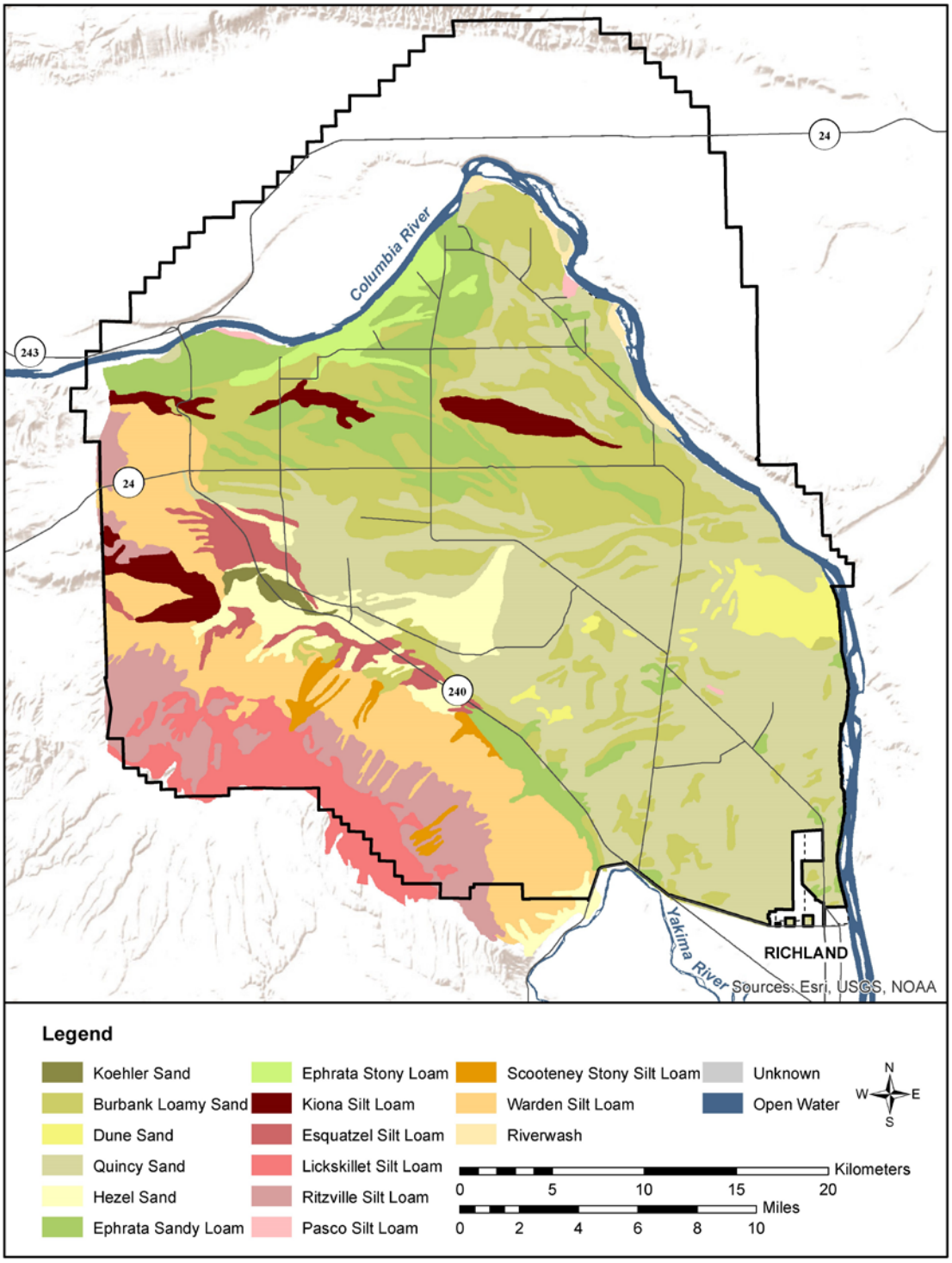

Figure 2-2. Soils of Central Hanford and the Fitzner/Eberhardt Arid Lands Ecology Unit (DOE 2017)

2.2 Land-Use History

The Hanford Site has a rich and varied cultural and management history (DOE 1986, Cushing 1994). Several Native American village sites were located along the Hanford Reach (Cushing 1994, Relander 1956) and regional indications are that they probably used fire to shape the vegetation. Horses used by Native Americans in the region began sometime after 1730 (Hunn 1990) and European settlement began during the 1850s. Since then, the area has experienced several waves of activities, including open-range cattle ranching beginning in the 1850s (Parker 1979) and sheep ranching beginning in the 1880s (McGregor 1982). Overgrazing by livestock occurred in the general area as early as 1880 to1881 (Parker 1979, Richardson 1881), as regional livestock was overwintered at lower elevations such as the Pasco Basin. Between the 1860s and 1900, towns were established along the Columbia River, including Hanford, Wahluke, and White Bluffs (Parker 1979). Farming had begun along the river by the 1890s and several irrigation projects were undertaken on the relatively planer areas (most of which were along the Columbia River), some of which were later abandoned but not before attempts at cultivation had been made.

In 1943, the federal government commandeered the property for the Hanford Engineering Works for the production of nuclear weapons. At that time settlers were evicted and most preexisting structures were razed (Cushing 1994). These properties include numerous farms and orchards, as well as the town sites of Hanford and White Bluffs.

Hanford nuclear production facilities were in the study area. Intense activity occurred for a time, including at Camp Hanford where more than 30,000 people were housed during the start of construction efforts. In the early 1950s, army facilities, including Anti-Aircraft Artillery sites, were established on the Hanford Site around Hanford's nuclear production facilities. Three of the sites were converted to NIKE missile sites and additional support facilities were added, including more roads and buried powerlines. By the 1960s these facilities were decommissioned and demolished, but associated pads, roads and some shade trees remain.

Management of adjacent land includes the unconverted landscape within units of the Hanford Reach National Monument (USFWS) and other public agencies and irrigated agricultural fields.

2.3 Current Management

Management outside the major facilities and localized operational impacts and clean-up activities on Central Hanford include several activities including recent and continuing construction and maintenance of numerous wells to monitor groundwater and their associated access roads throughout the site. Other uses include multiple powerline rights-of-way, several of which have been added or realigned during recent years, and many of which access roads have been hardened with gravel. Overall, there is a network of paved roadways and secondary access and maintenance roads throughout much of the site. Many of these secondary roads are maintained by regular grading and/or kept vegetation free with herbicide. Localized impacts also include quarries and excavation activities associated with Hanford clean-up.

Overall, current land management includes weed control and maintaining roadside firebreaks (disking along major highways and herbicide treatments onsite), wildfire suppression, and in some cases subsequent vegetation rehabilitation treatments, primarily planting shrubs and perennial grasses.

The primary noxious weeds in the upland study area are rush skeletonweed (*Chondrilla juncea*), diffuse knapweed (*Centaurea diffusa*), and yellow starthistle (*Centaurea solstitialis*). Russian knapweed (*Acroptilon repens*) was important in some low-lying areas, particularly along the river in areas mostly not included in the study area. (Common names and their associated scientific name can be found in Appendix A.)

Away from roadways, the principal herbicide is Tordon®, which was initially used to control a yellow starthistle infestation in and around the Hanford Townsite where it had high potential for spread throughout the site (Roos, personal communication; personal observation). Aerial application of Tordon® was made in the study area between 1998 and 2007 (MSA 2008); some areas with dead sagebrush appear to be related to those treatments. Additional use of herbicides in the study area includes the persistent bare ground herbicide Sahara® along roads and to create firebreaks (Roos, personal communication). The network of roads maintained with Sahara® includes along the extensive network of recently established roads associated with well sites.

Boundaries of wildfires that occurred within the study area between 1974 and 2016 are shown in Figure 2-3.

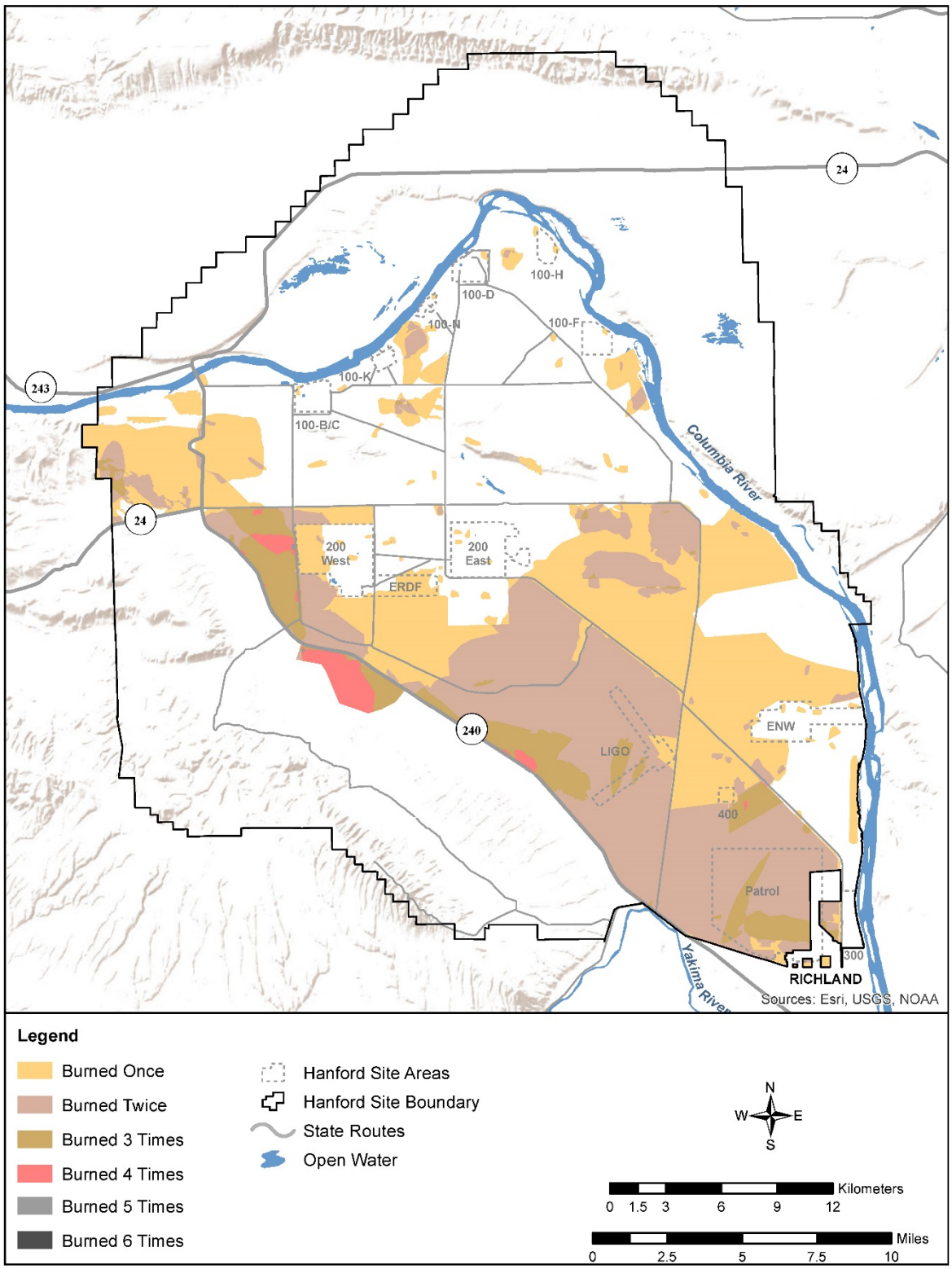

Figure 2-3. Boundaries of Fires on the Central Hanford Study Area from 1978 to 2016 (DOE 2017)

3 VEGETATION MAPPING METHODS

Using a combination of field observations, onsite photos, and best available aerial imagery, a GIS map layer was created with polygons depicting the distribution of several dominant or indicator species. Then, the mapping units were provisionally assigned to an Ecological System, (a classification unit defined in the National Vegetation Classification System) known in Washington (Rocchio and Crawford 2015), to the degree practicable.

3.1 Determining the Vegetation Present

Plant species whose distributions were used to delineate polygon boundaries are listed in Table 3-1. The distributions of high-priority species (and to a lesser degree medium-priority species) were used to draw polygon boundaries. Polygon boundaries were drawn to depict the distributions of medium-priority species where possible and practicable.

Table 3-1. Species Used to Define Polygon Boundaries and Generate Mapping-Unit Names.

Common Name	Scientific Name	Priority for mapping polygon boundary
Shrubs		
Stiff sagebrush	*Artemisia rigida*	High
Big sagebrush	*Artemisia tridentata*	High
Rubber and yellow rabbitbrushes	*Ericameria nauseosa* and *Chrysothamnus viscidiflorus*	Low
Slender buckwheat	*Eriogonum microthecum*	Low
Snow buckwheat	*Eriogonum niveum*	Medium
Rock buckwheat	*Eriogonum sphaerocephalum*	Medium
Winterfat	*Eurotia lanata* (=*Krascheninnikovia lanata*)	High
Spiny hopsage	*Grayia spinosa*	High
Antelope bitterbrush	*Purshia tridentata*	High
Grayball sage	*Salvia dorrii*	Medium
Greasewood	*Sarcobatus vermiculatus*	Medium
Grass		
Indian ricegrass	*Achnatherum hymenoides*	Medium
Crested wheatgrass	*Agropyron cristatum/desortorium*	Medium
Cheatgrass	*Bromus tectorum*	Low

Table 3-1. Species Used to Define Polygon Boundaries and Generate Mapping-Unit Names.

Common Name	Scientific Name	Priority for mapping polygon boundary
Needle-and-thread grass	*Hesperostipa comata*	High
Sandberg bluegrass	*Poa secunda*	Low
Bluebunch wheatgrass	*Pseudoroegnaria spicata*	High
Sand dropseed	*Sporobolus cryptandrus*	Low

Mapping criteria for each species depended on the species' dominance, use in classifying vegetation communities, importance for wildlife species, predictability of habitat, and visibility from a distance. Polygon boundaries were drawn to depict changes in cover of high-priority species and medium-priority species, when discernable (Table 3-1). As much as possible, the boundaries were drawn to reflect the sinuosity of vegetation boundaries to aid future understanding of fire behavior and recovery, wildlife use patterns, and the edge-effect.

Fieldwork in support of the map consisted of traveling extensively throughout the site (both on foot and along roads) and noting the composition of the vegetation and distribution of individual species. In addition, more than 1,000 photo points[4] have been established on Central Hanford at both representative and complex sites, as well as at local vantage points. Many of those points were revisited throughout the vegetation study.

For most of the study area, the best available aerial imagery was high-resolution photos taken during 2008. The area covered by these aerial photos is shown in Figure 3-1. While the aerial imagery was of excellent quality, photo interpretation was still necessary as the color signatures for shrub species varied over the extent of the set. This was due to both some variability of the image clarity and differing reflectivity from the ground surface due to changing aspects, cloud cover, vegetation cover, time of day, etc.

[4] Photo points consisted of marking the site with a global positioning system point and methodically taking approximately 14 overlapping landscape photos (with the horizon at the top of the photo) covering 360 degrees, a series of photos of the ground surface, and plant portraits of the common species in the area to aid correctly identifying plants in the photos. In addition, at some vantage points an additional series of 32 photos were taken with a telephoto lens. The camera was a Leica Digilux 1; photographer was 6 ft 4 in. tall.

Figure 3-1. Area of Central Hanford Covered by 2008 High-Resolution Aerial Photos (shaded)

In spite of this, on the high-resolution imagery mature individuals of sagebrush, antelope bitterbrush, and rabbitbrush, and to a lesser extent spiny hopsage, frequently could be distinguished from one another. However, younger plants, such as those occurring in recently burned areas, could rarely be separated from one another, nor could the other shrub species that were tracked.[5] In these situations, observations and photos from field visits were consulted and used to extrapolate and estimate patterns of re-establishment and distribution of those species. The overall distribution of tall bunchgrasses could be generally recognized on the high-resolution imagery, although individual species could not be distinguished without confirmation from field observations and photos.

Where the high-resolution imagery was unavailable, the much coarser-resolution imagery from the 2011-2013 National Agriculture Imagery Program was used, which resulted in a reduced level of detail and accuracy of the map in those areas. The National Agriculture Imagery Program photos were also consulted throughout the site to detect fire and other changes that occurred since the 2008 imagery was produced.

Field observations were required to distinguish needle-and-thread grass and Indian ricegrass from one another. However, differences in habitat preferences between the two species could be used in some instances, with needle-and-thread grass occurring most predictably in areas with a combination of sand and silt. Both species tended to occur in areas with dune habitats; in those settings both species were generally included in the mapping unit name, except where field observations indicated otherwise. Areas dominated by needle-and-thread grass frequently had small amounts of Indian ricegrass that

[5] Snow buckwheat (*Eriogonum niveum*) often could be discerned where that species occurred at high densities, although lower concentrations could not be distinguished and its signature on the imagery could be confused with other vegetation on the ground.

occurred at too small a scale to be included in the map. In addition, areas along the river with needle-and-thread grass and sand dropseed mixed together were mapped (relatively coarsely) based on field observations only, since the signature of those species on the aerial photos was unclear.

For each polygon, all high and medium priority species that occurred, or were projected to occur, in the polygon were listed in the mapping-unit name. Low-priority species were also included in the mapping-unit name; however, precision of their cover on the map was lower and their distributions were not typically used to draw polygon boundaries.

To capture information about ecological conditions, mosaics, ecotones, and possible recovery potential of individual species, cover of high- and medium-priority species (Table 3-1) in each polygon were indicated at three levels.

1. Low cover (present to approximately 3%) was shown with parentheses (...).

2. Irregular or patchy distribution within a polygon was indicated with brackets [...]. The scale at which the patches occurred varied; no attempt was made to indicate the scale or pattern of clumps, and this designation intergrades with full cover (below) and to a lesser extent with low cover. This designation was also used when species were co-dominant.

3. Moderate to dense cover and a relatively even distribution at finer scales was indicated with no modifier to the species' name.

In addition, the mapping unit name was split into its component species and maps were produced that depict the distribution patterns of each species.

3.2 Creation of Vegetation Maps for the Hanford Site

More than 11,000 polygons and 1,000 mapping units were created to describe the distribution of vegetation in the study area. In addition to depicting the distribution of individual species, and in order to depict the overall vegetation at different levels of complexity and detail, mapping unit names were clustered into three tiers of increasingly generalized groups. Each of the three tiers is described as follows; the decision tree and key developed to cluster the mapping units into tiers is depicted in Appendix B.

- Prior to initiating the clustering process, the three shrub species that occur in similar habitats and have limited occurrence in the study area were combined into the half-shrub category; these were rock buckwheat, slender buckwheat, and grayball sage.

- **Tier 1** clustering was based on minimizing the importance of low focus grasses and shrubs, removing medium and low focus shrubs that occurred at low cover, and lumping high value grasses that occurred at lower cover.

- **Tier 2** clustering further lumped grasses (except for Sandberg bluegrass and cheatgrass) occurring at higher cover or in patches into a more generic bunchgrasses group. In addition, the importance of mid- and low-focus shrubs was reduced in this tier.

- **Tier 3** was developed using the decision tree presented in Appendix B. This decision tree resulted in the identification of 31 vegetation mapping units. The Tier 3 vegetation map is presented and discussed further in Section 4.

Next, the vegetation of the study area was aligned to the degree possible with ecological systems of the National Vegetation Classification known from Washington (Roccio and Crawford 2015). Designation of the ecological system was predicated, in part, on the consideration of site potential for recovery and/or remediation and the potential of the species present to increase (or decrease) in the future. The distribution and types of ecological systems found on the Hanford Site are described in Section 5.

It should be recognized, however, that much of the study area is unique to the Pasco Basin and is outside of the norm for the state; therefore, there is some ambiguity in how to apply ecological systems as they are currently defined. Similar sites have been described from other areas, but types are sensitive to different climates and landscape settings. The descriptions of some of the ecological systems do not completely align with on-the-ground conditions and vegetation found on Central Hanford and should be considered provisional. Collaboration with vegetation ecologists within the Washington State Natural Heritage Program will be initiated to further align these provisional ecological system designations with the National Vegetation Classification System (Roccio and Crawford 2015).

Finally, the distribution of each of the species used to define mapping units for this effort (Table 3-1), along with field observations for each species, are provided in Section 5.

4 VEGETATION MAPPING RESULTS

As described above in Section 3.2, polygons representing over 1,000 vegetation mapping units were combined for use in landscape scale depictions. Tier 3 represents the greatest amount of consolidation of vegetation data; in this tier mapping units were combined into 31 groups. Table 4-1 lists the Tier 3 mapping units along with the total number of polygons included, the acreage covered, and the relative percentage of area on the Central Hanford study area occupied by each type. All mapping units that cover more than 5% of the total area within the study are highlighted in this table. The vegetation map of the Hanford Site depicting Tier 3 data is presented in Figure 4-1.

Earlier vegetation maps for the Hanford Site (e.g., Sackschewsky and Downs 2001) are not directly comparable to this updated map due to different methods and the improved technologies that were used to create and name the map units, as well as the scale at which the mapping was done, partially due to the limited access to and quality of aerial photos. For this GIS-based map, polygons were drawn as precisely as possible for high-priority species and the use of mosaic was applied in a more limited way. However, trends of vegetation change over time can be observed, and some qualitative comparisons of the dominant species are offered in Section 6.

Changes in the cover of vegetation since the mid-1990s varied across the site, with the following primary drivers of change:

- Wildfire and subsequent differential recovery of between individual species and between geomorphic settings
- Continued successional development from both historic and more recent disturbances
- Sagebrush shrub die-off, including in the northern portion of the site during the mid-1990s from undocumented causes, first described by Cardenas et al. (1997)
- Recruitment that has resulted from natural seedling establishment (and planting in limited areas) after wildfire.

Table 4-1. Tier 3 Vegetation Units Used for Landscape Level Mapping of the Hanford Site. Types Covering More than Five Percent of the Study Area are Shaded.

Tier 3 Vegetation Mapping Units	Count of Polygons	Sum of Area (Acres)	Percentage of Total Area
(Bitterbrush)/Bunchgrasses	724	23357	11.64%
(Bitterbrush)/Sandberg bluegrass-Cheatgrass	612	14377	7.16%
(Bitterbrush)[Snow buckwheat]/Bunchgrasses	331	6175	3.08%
(Bitterbrush)[Snow buckwheat]/Sandberg bluegrass-Cheatgrass	287	4261	2.12%
(Half-shrubs)/Bunchgrasses	55	278	0.14%
(Half-shrubs)/Sandberg bluegrass-Cheatgrass	80	614	0.31%
[Snow buckwheat]/Bunchgrasses	116	974	0.49%
[Snow buckwheat]/Sandberg bluegrass-Cheatgrass	165	2030	1.01%
[Stiff sagebrush](Half-shrubs)/Bunchgrasses	43	190	0.09%
Big sagebrush(Bitterbrush)/Bunchgrasses	183	1001	0.50%
Big sagebrush(Bitterbrush)/Sandberg bluegrass-Cheatgrass	373	7258	3.62%
Big sagebrush(Bitterbrush)[Snow buckwheat]/Bunchgrasses	107	406	0.20%
Big sagebrush(Half-shrubs)/Bunchgrasses	69	919	0.46%
Big sagebrush(Half-shrubs)/Sandberg bluegrass-Cheatgrass	117	1242	0.62%
Big sagebrush/Bunchgrasses	228	1436	0.72%
Big sagebrush/Sandberg bluegrass-Cheatgrass	2763	24400	12.16%
Big sagebrush[Snow buckwheat]/Sandberg bluegrass-Cheatgrass	40	69	0.03%
Big sagebrush[Spiny hopsage]/Bunchgrasses	16	171	0.09%
Big sagebrush[Spiny hopsage]/Sandberg bluegrass-Cheatgrass	36	1291	0.64%
Big sagebrush[Stiff sagebrush](Half-shrubs)/Bunchgrasses	18	208	0.10%
Big sagebrush-Bitterbrush/Sandberg bluegrass-Cheatgrass	495	1895	0.94%
Big sagebrush-Bitterbrush[Snow buckwheat]/Bunchgrasses	208	506	0.25%
Big sagebrush-Bitterbrush[Snow buckwheat]/Sandberg bluegrass-Cheatgrass	126	759	0.38%
Bitterbrush/Bunchgrasses	447	4714	2.35%
Bitterbrush/Sandberg bluegrass-Cheatgrass	594	1531	0.76%
Bunchgrasses	712	14119	7.03%
Rabbitbrush/Bunchgrasses	173	1991	0.99%
Rabbitbrush/Sandberg bluegrass-Cheatgrass	562	5237	2.61%
Sandberg bluegrass-Cheatgrass	1872	66877	33.32%
Non vegetated	176	12390	6.17%
Other	9	21	0.01%
Grand Total	**11737**	**200697**	**100.00%**

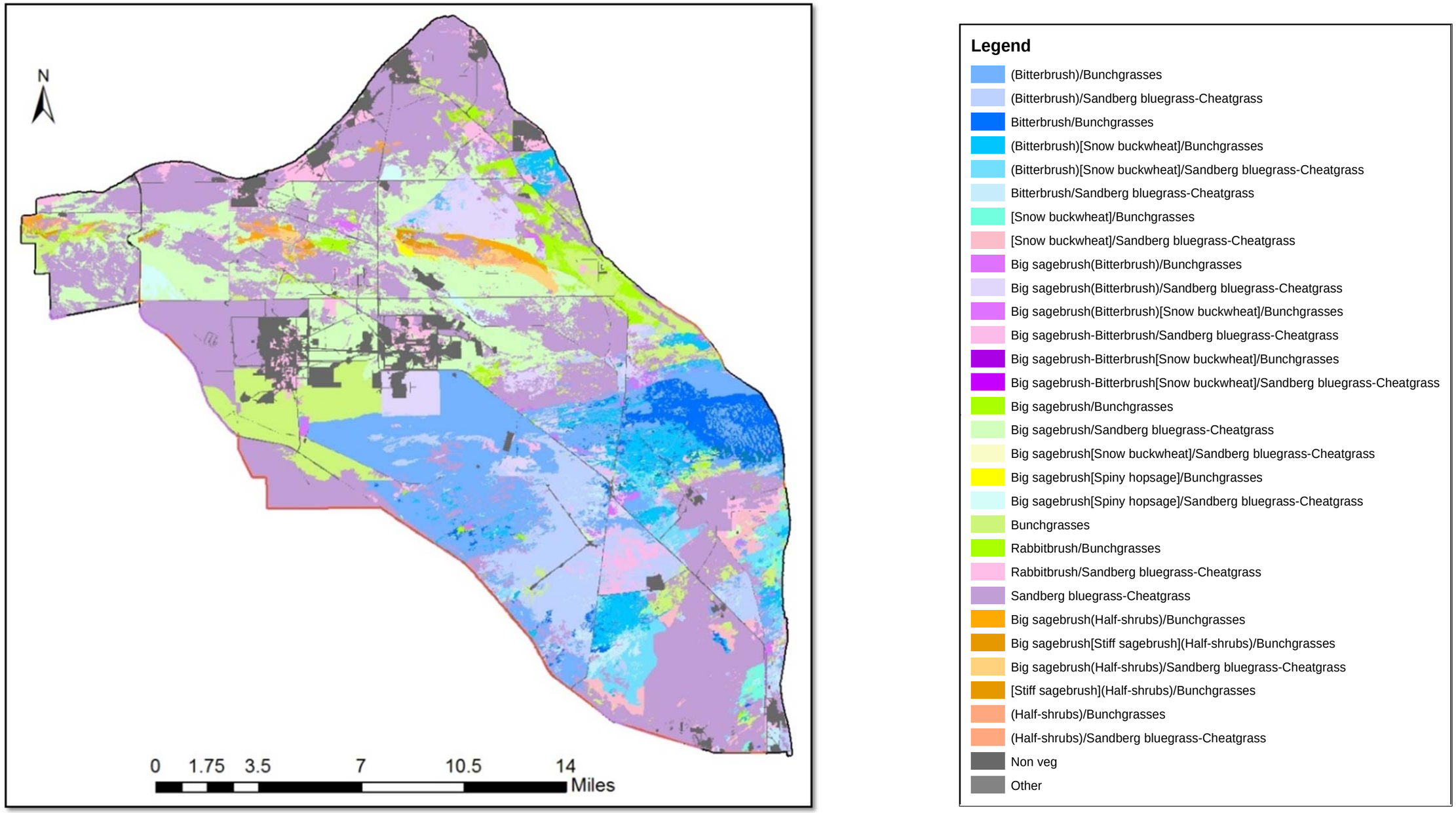

Figure 4-1. Tier 3 Upland Vegetation

5 ECOLOGICAL SYSTEMS ON THE CENTRAL HANFORD STUDY SITE

To align with vegetation types known elsewhere in Washington State and throughout the shrub-steppe ecoregion, the mapping units discussed in Section 4 were correlated with ecological systems of the National Vegetation Classification System in Washington (Roccio and Crawford 2015). Ecological systems are "groups of terrestrial plant communities that are found in similar climatic and physical environments and are influenced by similar dynamic ecological processes, such as fire or flooding, share similar substrates, and/or environmental gradients" (Roccio and Crawford 2015). Ecological systems include natural to semi-natural vegetation and persist for more than 50 years (Roccio and Crawford 2015).

However, the unique vegetation patterns on the Central Hanford have been only marginally incorporated into the National Vegetation Classification, and the disposition of some cases the described ecological systems do not fit perfectly with the pattern present on the site, particularly the distinction between Semi-Desert and Big Sagebrush Shrub Steppe. This is likely at least partially due to access difficulty for ecologists and partially because the site is unique in many respects relative to other areas in Washington.

The upland vegetation on the Central Hanford Site was provisionally placed into 10 ecological systems, which are listed in Table 5-1. These ecological systems were assigned based on first placing mapping units into associations. Each association has a distinctive faithful species and a group of co-occurring species that are present with that species with a high degree of consistency. The plant associations were then placed within one of the ecological systems defined below. The relative percentage of area on the Hanford Site in each of these ecological systems is shown in Figure 5-1 and their relative distribution on Central Hanford shown in Figure 5-2. Some pertinent factors of the Ecological systems are excerpted from the *Ecological Systems of Washington State: A Guide to Identification* (Roccio and Crawford 2015a); more detailed descriptions can be found in that reference.

Each of these ecological systems has been assigned an overall Conservation Status Rank by the Washington Natural Heritage Program based on total range within Washington, the number of occurrences, severity of threats, and resilience. (Rocchio and Crawford 2015b). The ranks assigned to the systems have the following meaning:

- **S1 = Critically Imperiled.** At very high risk of extirpation in Washington State due to very restricted range, very few occurrences, very steep declines, severe threats, or other factors.

- **S2 = Imperiled.** At high risk of extirpation in Washington State due to restricted range, few occurrences, steep declines, severe threats or other factors.

- **S3 = Vulnerable.** At moderate risk of extirpation in Washington State due to fairly restricted range and or/many occurrences, recent and widespread declines, threats, or other factors.

- **S4 = Apparently Secure.** At a fairly low risk of extirpation in Washington State due to an extensive range and/or many occurrences but with possible cause for some concern as a result of local recent declines, threats, or other factors.

- **S5 = Secure.** At very low or no risk of extirpation in Washington State due to a very extensive range, abundant occurrences, with little to no concern from declines or threats.

Table 5-1. Ecological Systems within the Central Hanford Study Area.

Ecological System ; *Association* ; Mapping Unit	Area (ha)	Percentage of Total Study Area	Number of Polygons
Columbia Plateau Scabland Shrubland			
(Artemisia tridentata) Eriogonum microthecum / Poa secunda [Provisional]			
(Half-shrubs)/Bunchgrasses	10.09	0.01%	25
(Half-shrubs)/Sandberg bluegrass-Cheatgrass	207.44	0.26%	62
Big sagebrush(Half-shrubs)/Bunchgrasses	39.24	0.05%	17
Big sagebrush(Half-shrubs)/Sandberg bluegrass-Cheatgrass	215.59	0.27%	57
Total	***472.36***	***0.58%***	***161***
(Artemisia tridentata) Eriogonum microthecum / Pseudoroegneria spicata [Provisional]			
(Half-shrubs)/Bunchgrasses	30.95	0.04%	16
Big sagebrush(Half-shrubs)/Bunchgrasses	7.62	0.01%	17
Total	***38.57***	***0.05%***	***33***
(Artemisia tridentata) Eriogonum sphaerocephalum / Poa secunda [Provisional]			
(Half-shrubs)/Bunchgrasses	11.13	0.01%	2
(Half-shrubs)/Sandberg bluegrass-Cheatgrass	7.37	0.01%	8
Big sagebrush(Half-shrubs)/Sandberg bluegrass-Cheatgrass	259.27	0.32%	51
Total	***277.77***	***0.34%***	***61***
(Artemisia tridentata)Eriogonum sphaerocephalum / Pseudoroegneria spicata [Provisional]			
(Half-shrubs)/Bunchgrasses	4.69	0.01%	3
Big sagebrush(Half-shrubs)/Bunchgrasses	0.26	0.00%	1
Total	***4.95***	***0.01%***	***4***
Artemisia rigida/Poa secunda Shrub Grassland			
(Stiff sage)(Half-shrubs)/Sandberg bluegrass-Cheatgrass	13.16	0.02%	2
(Stiff sage)/Bunchgrasses	0.92	0.00%	5
[Stiff sagebrush](Half-shrubs)/Bunchgrasses	70.01	0.09%	38
Big sagebrush[Stiff sagebrush](Half-shrubs)/Bunchgrasses	83.98	0.10%	18
Big sagebrush[Stiff sagebrush]/Sandberg bluegrass-Cheatgrass	2.37	0.00%	3
Total	***170.44***	***0.21%***	***66***
Artemisia tridentata (Eriogonum sphaerocepahlum) /Hesperostipa comata			
Big sagebrush(Half-shrubs)/Bunchgrasses	93.51	0.12%	25
Total	***93.51***	***0.12%***	***25***
Columbia Plateau Scabland Shrubland Total	**1057.6**	**1.30%**	**350**

Table 5-1. Ecological Systems within the Central Hanford Study Area.			
Ecological System ; *Association* ; Mapping Unit	**Area (ha)**	**Percentage of Total Study Area**	**Number of Polygons**
Columbia Plateau Scabland Shrubland : Inter-Mountain Basins Cliff and Canyon			
(Artemisia tridentata)Eriogonum microthecum / Poa secunda [Provisional]			
(Half-shrubs)/Sandberg bluegrass-Cheatgrass	2.47	0.00%	1
Big sagebrush(Half-shrubs)/Sandberg bluegrass-Cheatgrass	15.14	0.02%	2
Total	***17.61***	***0.02%***	***3***
(Artemisia tridentata)Eriogonum microthecum / Pseudoroegneria spicata [Provisional]			
(Half-shrubs)/Bunchgrasses	5.08	0.01%	1
Total	***5.08***	***0.01%***	***1***
(Artemisia tridentata)Eriogonum sphaerocephalum / Poa secunda (Provisional)			
(Half-shrubs)/Sandberg bluegrass-Cheatgrass	10.8	0.01%	3
Big sagebrush(Half-shrubs)/Sandberg bluegrass-Cheatgrass	9.92	0.01%	4
Total	***20.72***	***0.03%***	***7***
(Artemisia tridentata)Eriogonum sphaerocephalum / Pseudoroegneria spicata [Provisional]			
(Half-shrubs)/Bunchgrasses	37.54	0.05%	4
Big sagebrush(Half-shrubs)/Bunchgrasses	30.01	0.04%	4
Total	***67.55***	***0.08%***	***8***
Artemisia rigida/Poa secunda Shrub Grassland			
[Stiff sagebrush](Half-shrubs)/Bunchgrasses	5.32	0.01%	4
Total	***5.32***	***0.01%***	***4***
Artemisia tridentata (Eriogonum sphaerocepahlum) /Hesperostipa comata			
Big sagebrush(Half-shrubs)/Bunchgrasses	3.06	0.00%	2
Total	***3.06***	***0.00%***	***2***
Columbia Plateau Scabland Shrubland : Inter-Mountain Basins Cliff and Canyon Total	**119.34**	**0.15%**	**25**
Columbia Plateau Vernal Pool			
Poa secunda - cheatgrass (Provisional)			
Vernal Pool	1.51	0.00%	3
Total	***1.51***	***0.00%***	***3***
Columbia Plateau Vernal Pool Total	**1.51**	**0.00%**	**3**
Inter-Mountain Basins Active and Stabilized Dune			
Ericameria nauseosa / Bromus tectorum Ruderal Shrubland (SemiDesert)			
Rabbitbrush/Sandberg bluegrass-Cheatgrass	0.76	0.00%	2
Sandberg bluegrass-Cheatgrass	20.78	0.03%	46
Total	***21.54***	***0.03%***	***48***

Table 5-1. Ecological Systems within the Central Hanford Study Area.			
Ecological System ; *Association* ; Mapping Unit	**Area (ha)**	**Percentage of Total Study Area**	**Number of Polygons**
Purshia tridentata / Achnatherum hymenoides Dune Complex			
(Bitterbrush)/Bunchgrasses	7765.11	9.56%	437
(Bitterbrush)/Sandberg bluegrass-Cheatgrass	5126.8	6.31%	412
(Bitterbrush)[Snow buckwheat]/Bunchgrasses	2498.72	3.08%	331
(Bitterbrush)[Snow buckwheat]/Sandberg bluegrass-Cheatgrass	1724.29	2.12%	287
(Snow Buckwheat)/Bunchgrasses	668.98	0.82%	79
(Snow buckwheat)/Sandberg bluegrass-Cheatgrass	4377.85	5.39%	234
(Snow Buckwheat)Rabbitbrush/Bunchgrasses	186.53	0.23%	39
(Snow Buckwheat)Rabbitbrush/Sandberg bluegrass-Cheatgrass	82.31	0.10%	53
[Snow buckwheat]/Bunchgrasses	394.11	0.49%	116
[Snow buckwheat]/Sandberg bluegrass-Cheatgrass	821.63	1.01%	165
Big sagebrush(Bitterbrush)/Bunchgrasses	1.26	0.00%	1
Big sagebrush(Bitterbrush)/Sandberg bluegrass-Cheatgrass	1193.88	1.47%	3
Big sagebrush(Bitterbrush)[Snow buckwheat]/Bunchgrasses	164.49	0.20%	107
Big sagebrush-Bitterbrush/Sandberg bluegrass-Cheatgrass	600.19	0.74%	214
Big sagebrush-Bitterbrush[Snow buckwheat]/Bunchgrasses	188.99	0.23%	174
Big sagebrush-Bitterbrush[Snow buckwheat]/Sandberg bluegrass-Cheatgrass	299.47	0.37%	125
Big sagebrush-Snow buckwheat/Sandberg bluegrass-Cheatgrass	29.67	0.04%	42
Bitterbrush/Bunchgrasses	1877.96	2.31%	409
Bitterbrush/Sandberg bluegrass-Cheatgrass	543.76	0.67%	449
Bitterbrush[Snow buckwheat]/Sandberg bluegrass-Cheatgrass	7.88	0.01%	1
Bunchgrasses	2382.37	2.93%	60
Sandberg bluegrass-Cheatgrass	150.65	0.19%	22
Total	***31086.9***	***38.28%***	***3760***
Inter-Mountain Basins Active and Stabilized Dune Total	**31108.44**	**38.30%**	**3808**
Inter-Mountain Basins Active and Stabilized Dune : Inter-Mountain Basins Cliff and Canyon			
Purshia tridentata / Achnatherum hymenoides Dune Complex			
Bitterbrush/Sandberg bluegrass-Cheatgrass	17.87	0.02%	1
Total	***17.87***	***0.02%***	***1***
Inter-Mountain Basins Active and Stabilized Dune : Inter-Mountain Basins Cliff and Canyon Total	**17.87**	**0.02%**	**1**

Table 5-1. Ecological Systems within the Central Hanford Study Area.			
Ecological System ; *Association* ; Mapping Unit	**Area (ha)**	**Percentage of Total Study Area**	**Number of Polygons**
Inter-Mountain Basins Big Sagebrush Steppe			
Artemisia tridentata (Ericameria nauseosa)/Poa secunda			
Rabbitbrush/Sandberg bluegrass-Cheatgrass	2.5	0.00%	2
Sandberg bluegrass-Cheatgrass	58.91	0.07%	21
Total	***61.41***	***0.08%***	***23***
Artemisia tridentata / Hesperostipa comata			
(Bitterbrush)/Bunchgrasses	1674.42	2.06%	280
Big sagebrush(Bitterbrush)/Bunchgrasses	400.61	0.49%	181
Big sagebrush/Bunchgrasses	517.13	0.64%	211
Big sagebrush-Bitterbrush/Bunchgrasses	15.9	0.02%	34
Bitterbrush/Bunchgrasses	29.54	0.04%	38
Bunchgrasses	2402.34	2.96%	540
Rabbitbrush/Bunchgrasses	616.07	0.76%	132
Total	***5656.01***	***6.96%***	***1416***
Artemisia tridentata / Hesperostipa comata : Sarcobatus vermiculatus / Distichlis spicatum			
Bunchgrasses	4.98	0.01%	1
Total	***4.98***	***0.01%***	***1***
Artemisia tridentata / Poa secunda			
(Bitterbrush)/Bunchgrasses	12.88	0.02%	7
(Bitterbrush)/Sandberg bluegrass-Cheatgrass	692.85	0.85%	196
Big sagebrush(Bitterbrush)/Sandberg bluegrass-Cheatgrass	1737.97	2.14%	369
Big sagebrush/Bunchgrasses	8.46	0.01%	4
Big sagebrush/Sandberg bluegrass-Cheatgrass	9536.13	11.74%	2751
Big sagebrush-Bitterbrush/Sandberg bluegrass-Cheatgrass	166.57	0.21%	281
Bitterbrush/Sandberg bluegrass-Cheatgrass	57.99	0.07%	143
Bunchgrasses	39.74	0.05%	4
Rabbitbrush/Bunchgrasses	3.09	0.00%	2
Rabbitbrush/Sandberg bluegrass-Cheatgrass	1855.84	2.29%	481
Sandberg bluegrass-Cheatgrass	3655.83	4.50%	423
Total	***17767.35***	***21.88%***	***4661***
Artemisia tridentata / Pseudoroegneria spicata			
Big sagebrush/Bunchgrasses	17.63	0.02%	4
Total	***17.63***	***0.02%***	***4***

Table 5-1. Ecological Systems within the Central Hanford Study Area.			
Ecological System ; *Association* ; Mapping Unit	**Area (ha)**	**Percentage of Total Study Area**	**Number of Polygons**
Ericameria nauseosa / Bromus tectorum Ruderal Shrubland (SemiDesert)			
(Bitterbrush)/Sandberg bluegrass-Cheatgrass	1.42	0.00%	4
Rabbitbrush/Sandberg bluegrass-Cheatgrass	31.32	0.04%	11
Sandberg bluegrass-Cheatgrass	7247.27	8.92%	732
Total	***7280.01***	***8.96%***	***747***
Poa secunda – Bromus tectorum (Provisional)			
Sandberg bluegrass-Cheatgrass	35.99	0.04%	7
Total	***35.99***	***0.04%***	***7***
Pseudoroegneria spicata - Poa secunda Grassland			
Bunchgrasses	17.05	0.02%	9
Total	***17.05***	***0.02%***	***9***
Inter-Mountain Basins Big Sagebrush Steppe Total	**30840.43**	**37.97%**	**6868**
Inter-Mountain Basins Big Sagebrush Steppe : Inter-Mountain Basins Cliff and Canyon			
Artemisia tridentata (Eriogonum sphaerocepahlum) /Hesperostipa comata			
Big sagebrush(Half-shrubs)/Bunchgrasses	197.6	0.24%	1
Total	***197.6***	***0.24%***	***1***
Artemisia tridentata / Hesperostipa comata			
Bunchgrasses	19.11	0.02%	2
Total	***19.11***	***0.02%***	***2***
Pseudoroegneria spicata - Poa secunda Grassland			
Bunchgrasses	9.9	0.01%	2
Total	***9.9***	***0.01%***	***2***
Inter-Mountain Basins Big Sagebrush Steppe : Inter-Mountain Basins Cliff and Canyon Total	**226.61**	**0.28%**	**5**
Inter-Mountain Basins Big Sagebrush Steppe : Inter-Mountain Basins Greasewood Flat			
Artemisia tridentata / Poa secunda			
Big sagebrush/Sandberg bluegrass-Cheatgrass	13.5	0.02%	1
Total	***13.5***	***0.02%***	***1***
Artemisia tridentata / Poa secunda : Sarcobatus vermiculatus / Distichlis spicata			
Big sagebrush/Sandberg bluegrass-Cheatgrass	2.57	0.00%	1
Total	***2.57***	***0.00%***	***1***
Inter-Mountain Basins Big Sagebrush Steppe : Inter-Mountain Basins Greasewood Flat Total	**16.07**	**0.02%**	**2**

Table 5-1. Ecological Systems within the Central Hanford Study Area.			
Ecological System ; *Association* ; Mapping Unit	**Area (ha)**	**Percentage of Total Study Area**	**Number of Polygons**
Inter-Mountain Basins Cliff and Canyon			
(Artemisia tridentata)Eriogonum microthecum / Poa secunda [Provisional]			
(Half-shrubs)/Sandberg bluegrass-Cheatgrass	1.11	0.00%	2
Big sagebrush(Half-shrubs)/Sandberg bluegrass-Cheatgrass	0.31	0.00%	2
Total	***1.42***	***0.00%***	***4***
(Artemisia tridentata)Eriogonum microthecum / Pseudoroegneria spicata [Provisional]			
Big sagebrush(Half-shrubs)/Bunchgrasses	0.44	0.00%	1
Total	***0.44***	***0.00%***	***1***
(Artemisia tridentata)Eriogonum sphaerocephalum / Poa secunda (Provisional)			
(Half-shrubs)/Sandberg bluegrass-Cheatgrass	5.76	0.01%	1
Total	***5.76***	***0.01%***	***1***
(Artemisia tridentata)Eriogonum sphaerocephalum / Pseudoroegneria spicata [Provisional]			
(Half-shrubs)/Bunchgrasses	13.13	0.02%	3
Total	***13.13***	***0.02%***	***3***
Artemisia rigida/Poa secunda Shrub Grassland			
[Stiff sagebrush](Half-shrubs)/Bunchgrasses	1.57	0.00%	1
Total	***1.57***	***0.00%***	***1***
Artemisia tridentata (Ericameria nauseosa)/Sandberg bluegrass			
(Half-shrubs)/Sandberg bluegrass-Cheatgrass	0.23	0.00%	1
Big sagebrush(Half-shrubs)/Sandberg bluegrass-Cheatgrass	2.6	0.00%	1
Sandberg bluegrass-Cheatgrass	2	0.00%	1
Total	***4.83***	***0.01%***	***3***
Artemisia tridentata / Hesperostipa comata			
Bunchgrasses	2.7	0.00%	2
Total	***2.7***	***0.00%***	***2***
Ericameria nauseosa / Bromus tectorum Ruderal Shrubland (Semi-Desert)			
Sandberg bluegrass-Cheatgrass	21.59	0.03%	4
Total	***21.59***	***0.03%***	***4***
Inter-Mountain Basins Cliff and Canyon Total	**51.44**	**0.06%**	**19**

Table 5-1. Ecological Systems within the Central Hanford Study Area.			
Ecological System ; *Association* ; Mapping Unit	**Area (ha)**	**Percentage of Total Study Area**	**Number of Polygons**
Inter-Mountain Basins Semi-Desert Shrub Steppe			
Artemisia tridentata / Poa secunda			
(Bitterbrush)/Sandberg bluegrass-Cheatgrass	2.43	0.00%	1
Big sagebrush/Sandberg bluegrass-Cheatgrass	316.06	0.39%	1
Rabbitbrush/Sandberg bluegrass-Cheatgrass	0.4	0.00%	1
Sandberg bluegrass-Cheatgrass	6.09	0.01%	4
Total	***324.98***	***0.40%***	***7***
Ericameria nauseosa / Bromus tectorum Ruderal Shrubland (Semi-Desert)			
Rabbitbrush/Sandberg bluegrass-Cheatgrass	71.21	0.09%	5
Sandberg bluegrass-Cheatgrass	11301.13	13.91%	345
Total	***11372.34***	***14.00%***	***350***
Grayia spinosa / Poa secunda			
(Bitterbrush)/Bunchgrasses	2.54	0.00%	1
Big sagebrush[Spiny hopsage]/Bunchgrasses	69.33	0.09%	16
Big sagebrush[Spiny hopsage]/Sandberg bluegrass-Cheatgrass	522.5	0.64%	36
Total	***594.37***	***0.73%***	***53***
Krascheneninnikovia lanata / Hesperostipa comata Dwarf Shrubland			
Big sagebrush/Bunchgrasses	37.91	0.05%	9
Big sagebrush/Sandberg bluegrass-Cheatgrass	1.04	0.00%	2
Bunchgrasses	165.67	0.20%	8
Sandberg bluegrass-Cheatgrass	41.78	0.05%	7
Total	***246.4***	***0.30%***	***26***
Sporobolus cryptandrus -Poa secunda Grassland			
Rabbitbrush/Sandberg bluegrass-Cheatgrass	30.41	0.04%	6
Sandberg bluegrass-Cheatgrass	76.09	0.09%	7
Total	***106.5***	***0.13%***	***13***
Inter-Mountain Basins Semi-Desert Shrub Steppe Total	**12644.59**	**15.57%**	**449**
Invasive Perennial Grassland and Forbland			
Agropyron cristatum Western Ruderal Perennial Grassland			
Big sagebrush/Sandberg bluegrass-Cheatgrass	0.25	0.00%	2
Rabbitbrush/Sandberg bluegrass-Cheatgrass	44.51	0.05%	1
Sandberg bluegrass-Cheatgrass	62.73	0.08%	17
Total	***107.49***	***0.13%***	***20***
Invasive Perennial Grassland and Forbland Total	**107.49**	**0.13%**	**20**

Table 5-1. Ecological Systems within the Central Hanford Study Area.			
Ecological System ; *Association* ; Mapping Unit	**Area (ha)**	**Percentage of Total Study Area**	**Number of Polygons**
Non Vegetated			
Non veg	5014	6.17%	176
Total	**5014**	**6.17%**	**176**
Non Vegetated Total	**5014**	**6.17%**	**176**
Other			
Other	6.84	0.01%	6
Sandberg bluegrass-Cheatgrass	4.84	0.01%	1
Total	**11.68**	**0.01%**	**7**
Other Total	**11.68**	**0.01%**	**7**
Grand Total	**81217.07**	**100.00%**	**11733**

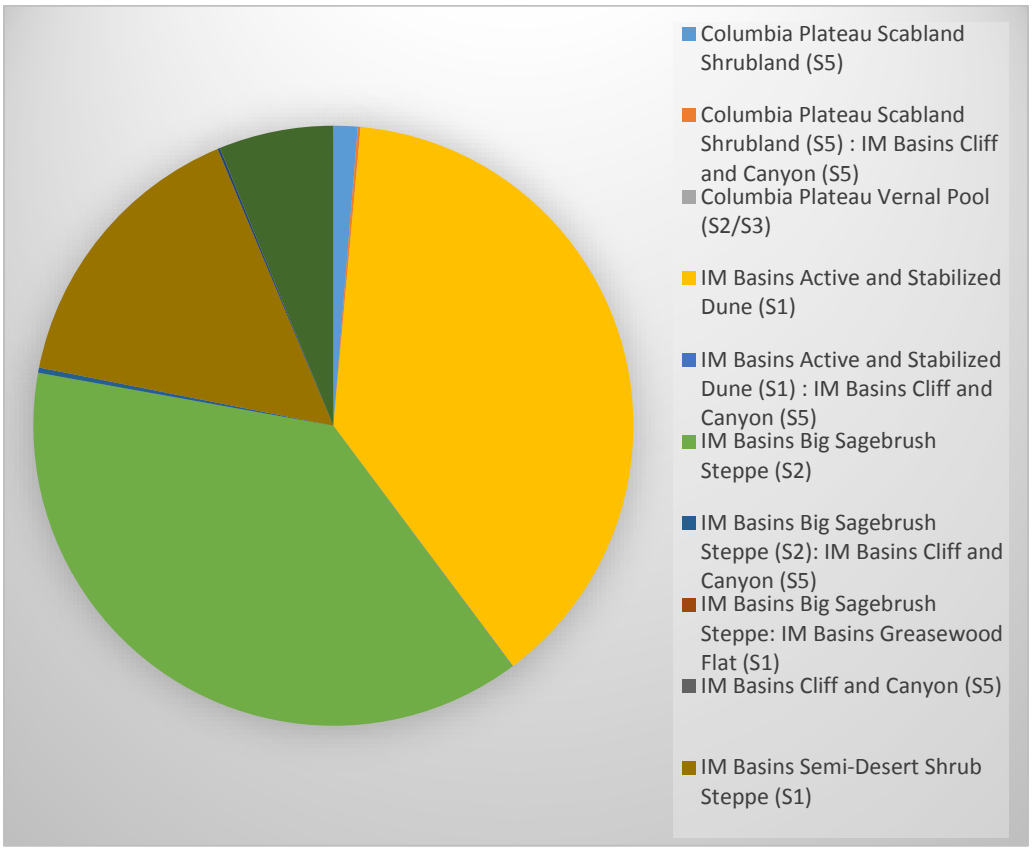

Figure 5-1. Relative Percentage of Area Covered by the Ecological Systems Found on the Central Hanford Study Area

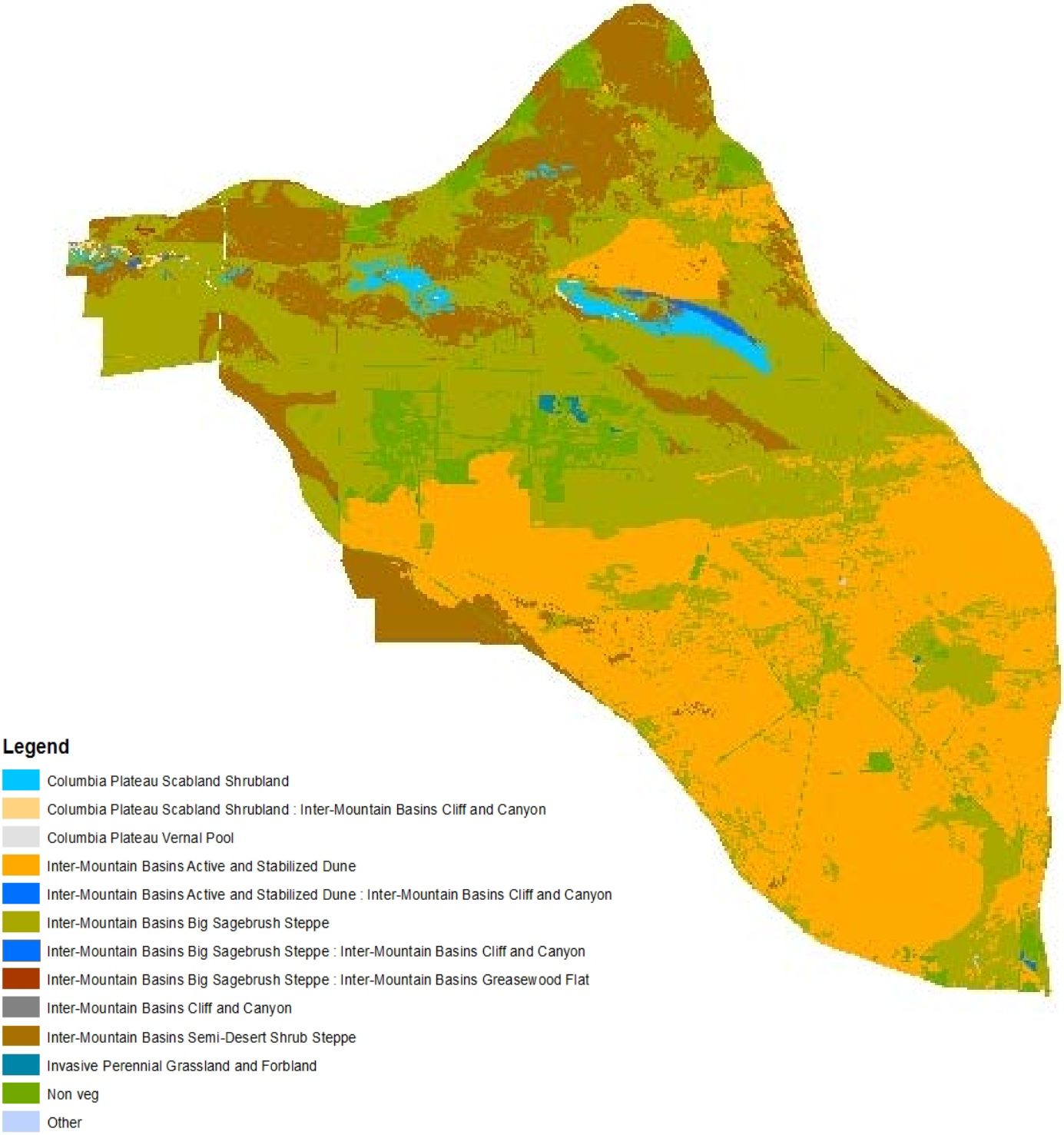

Figure 5-2. Ecological Systems Occurring on the Central Hanford Study Area

5.1 Columbia Plateau Scabland Shrubland

This ecological system is characteristicaly associated with flats, plateaus, and gentle to steep slopes with rock. Occurring on site with little soil development and areas of exposed rock, gravel, or compacted soil, these shrublands are extremely xeric and the vegetation is low (less than 0.5 m [1.6 ft]) with an open canopy. On Central Hanford, this ecological system is found primarily on Gable Mountain, Gable Butte, and Umtanum Ridge. Figure 5-3 shows an occurrence of this ecological system in the study area.

Scabland shrublands are generally dominated by stiff sagebrush (*Artemisia rigida*) along with or only by other dwarf-shrub species particularly buckwheat (*Erigonum*) species (e.g., slender buckwheat [*E. microthecum*], rock buckwheat [*E. sphaerocephalum*], strict buckwheat [*E. strictum*], and thymeleaf buckwheat [*E. thymoides*]). Some sites can be dominated by grasses and semi-woody forbs. Low cover of perennial short bunchgrasses, primarily Sandberg bluegrass, with scattered forbs, including species of onion (*Allium* sp.), pussy-toes (*Antennaria* sp.), balsamroot (*Balsamorhiza* sp.), desertparsley (*Lomatium* sp.), and phlox (*Phlox* sp.).

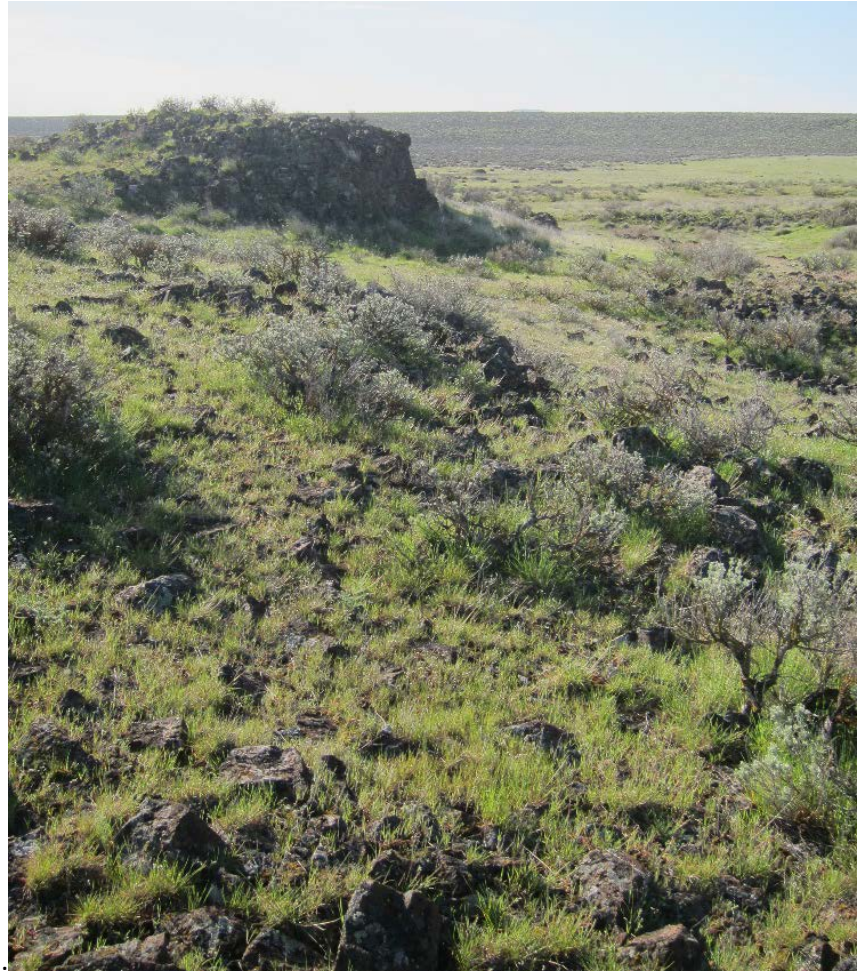

Figure 5-3. Columbia Plateau Scabland Shrubland with Rigid Sagebrush and Sandberg Bluegrass

Land uses in this system are few due to the rocky soils. The primary stressor on the Hanford Site is the introduction of invasive plant species and fire. Because this system provides little forage it is used little by livestock and the conservation status of the Columbia Plateau Scabland Shrubland ecological system is considered Secure (S5) in Washington State (Roccio and Crawford 2015). On the study site, this system frequently forms a complex matrix with the Inter-Mountain Basins Big Sagebrush Steppe or the Inter-Mountain Basins Semi-Desert Shrub-Steppe ecological systems.

5.2 Columbia Plateau Vernal Pool

Shallow ephemeral wetlands, known as vernal pools, occur in depressions throughout the exposed, volcanic scablands of the Columbia Plateau. They are characterized by freshwater inundation for much of the late winter and early spring, often drying out by late spring and summer. These pools generally result from direct precipitation and vary in size from year to year. On Central Hanford, located in the driest area of the Columbia Plateau, vernal pools may not have standing water every year. Figure 5-5 shows an occurrence of this ecological system on Central Hanford during a wet spring.

Vernal pools on the Central Hanford vary with regard to size, species composition, and presence of rare and invasive plant species. Vegetation is dominated by annual forbs and grasses, and some pools have a high cover of moss. Vernal pools occur on Central Hanford: at the east end of Umtanum Ridge, in the central part of Gable Butte, and at the eastern end of Gable Mountain (TNC 1998). Vernal pools are geographically limited but can be locally common in Washington State. This ecological system is considered Imperiled (S2/S3) within the state.

Figure 5-4. One of the Larger Vernal Pools on Gable Butte

5.3 Inter-Mountain Basins Active and Stabilized Dune

Inland active or stabilized dunes and sandsheets with patchy or sparse vegetation occur across the Columbia Basin. In general, the vegetation cover is related to the amount of annual rainfall and rate of evapotranspiration. Species occupying the dune environment are often adapted to shifting, coarse-textured sunbstrates and form patchy or open grasslands, shrublands, or steppe. Vegetation cover ranges from sparse (less than 20%) to moderate (greater than 60%) and species composition is related to the degree of sand stabilization/vegetation cover and position on the dune.

Scurf pea (*Psoralidium lanceolatum*) and Indian ricegrass typically dominate the initial stages of stabilization and are also commonly found on dunes with varying stages of stabilization. Prior to stabilization, shrubs are spare and thickspike wheatgrass (*Elymus lanceolatus*), a rhizomatous grass, and herbs such as winged dock (*Rumex venosus*) and whiteleaf scorpionweed (*Phacelia hastata*) are common. With increased sand stabilization shrubs such as rubber and yellow rabbitbrush, bitterbrush, snow buckwheat, and big sagebrush are often dominant. Forbs such as pale evening-primrose (*Oenothera pallida*), sand beardtongue (*Penstemon acuminatus*), whiteleaf scorpionweed, terpentine springparsley (*Pterixia terebintha*), Columbia cutleaf (*Hymenopappus filifolius*), thread leaf scorpianweed (*Phacelia linearis*), Carey's balsamroot (*Balsamorhiza careyana*), terpentine springparsley (*Pterixia terebinthua*), Columbia cutleaf (*Hymenopappus filifolius*), threadleaf fleabane (*Erigeron filifolius*), and prairie junegrass (*Koeleria macrantha*) are common but contribute little to the total vegetation cover. Non-native weedy species cheatgrass, Russian thistle (*Salsola tragus*), and tumblemustard (*Sisymbrium altissimum*) are common and sometimes abundant. Where dunes have overridden or partially covered other soil types, Sandberg bluegrass or other shrub steppe species are often present. Figure 5-6 shows two examples of this ecological system on Central Hanford.

The inland dune ecological system has always been relatively rare in Washington State, and the total extent of this system has declined approximately 76% since the early 1970s due primarily to agricultural conversion, reservoir flooding, and dune stabilization. Inter-Mountain Basins Active and Stabilized Dune systems are ranked as Critically Imperiled (S1) in Washington State.

The Washington State Natural Heritage Program has issued the *Conservation Strategy for Washington State Inland Sand Dunes* (Hallock et al. 2007) that identifies management strategies for the conservation of these systems. Two areas on the Central Hanford Site are identified in this strategy document as having significant conservation value.

Figure 5-5. Stabilized Dune with Turpentine Spring Parsley (top) and Winged Dock and Scurf Pea on Unstable Dune Face with Adjacent More Stabilized Area Dominated by Rabitbrush and Cheatgrass (bottom)

5.4 Inter-Mountain Basins Big Sagebrush Steppe

The Inter-Mountain Big Sagebrush Steppe system is dominated by sagebrush (*Artemisia* spp.) and/or bitterbrush (*Purshia tridentata*) in an open to moderately dense (5 to 40% cover) shrub layer with at least 25% total perennial herbaceous cover. Depending on the site, associated grasses can include bluebunch wheatgrass (*Pseudoregnaria spicata*), Sandberg bluegrass (*Poa secunda*), Cusick's bluegrass (*Poa cusickii*), prairie junegrass (*Koeleria macrantha*), needle-and-thread grass (*Hesperostipa comata*), and Thurber's needlegrass (*Achnatherum thurberianum*). The natural fire regime of this ecological system maintains a patchy distribution of shrubs, so the general aspect is that of a grassland.

Landforms that support shrub steppe are a mosaic of patch types or plant associations that reflect differences in site (soils/precipitation zone) and fire effects. Soils can be deep (greater than 15 cm [6 in.]) to shallow and non-saline. The space between vascular plants often supports a biological crust that can cover up to 90% or more if there is no disturbance on the site. Biological crust cover generally decreases with increasing vascular plant cover, elevation, and soil disturbance.

This ecological system has a wide distribution, but large areas are in poor to fair condition. Good to excellent condition areas are rare in communities where bluebunch wheatgrass and needle-and-thread grass are the dominant grasses (such as the Hanford Site) because of weed invasion. Conversion to agriculture is a serious threat in other sites within the Columbia Basin. The Inter-Mountain Basins Big Sagebrush Steppe is considered Imperiled (S2) within Washington State. Figure 5-7 shows two occurrences of this ecological system in the study area. The top photograph depicts the more common situation in which Sandberg bluegrass and cheatgrass (reddish grasses shown in photo) are very common in the understory (also note the large swath of needle-and-thread grass in the background). The bottom photo depicts a less disturbed occurrence of this ecological system.

Figure 5-6. Two Occurrences of Inter-Mountain Basins Big Sagebrush Steppe on Central Hanford

5.5 Inter-Mountain Basins Semi-Desert Shrub Steppe

This ecological system occurs in large to small patches in the hottest , driest (less than 20 cm [8 in.] per year) areas within the Columbia Basin, and is characterized by an open shrub to moderately dense woody layer and a strong grass layer. The woody layer is often a mixture of shrubs and dwarf shrubs, but it can be dominated by a single shrub species. Characteristic shrubs in this system include spiny hopsage or winterfat with rubber rabbitbrush. Big sagebrush can also be present, and grayball sage can be found in stonier sites. Characteristic grasses include Indian ricegrass, Thurber's needlegrass (*Achnatherum thurberiana*), squirreltail bottlebrush (*Elymus elymoides*), Sandberg bluegrass, and needle-and-thread grass. Annual grasses, especially cheatgrass, can be present to abundant in semi-desert shrub-steppe systems. Figure 5-8 shows an occurrence of this ecological system in the study area.

Within Washington State, the Inter-Mountain Basins Semi-Desert Shrub Steppe is uncommon and has a limited range, thus the conservation status of this ecological system is Critically Imperiled (S1) within the State. Following fire or site disturbance, annual species tend to replace perennials; there is a high potential of invasion of cheatgrass. In much of this system's likely historical range, it has been replaced by irrigated agriculture.

Figure 5-7. Inter-Mountain Basins Semi-Desert Shrub Steppe with a Spiny Hopsage Shrub Layer and an Understory Dominated by Neede-and-Thread Grass and Cheatgrass

5.6 Inter-Mountain Basins Greasewood Flat (Provisional Assignment)

This ecological system typically occurs on saline soils with a shallow water table and intermittent floods but remains dry for most of the growing seasons. While it typically occurs on flats, it may also occur in uplands, such as around springs/seeps. The system usually occurs as a mosaic of multiple communities with open to moderately dense shrublands dominated or co-dominated by greasewood (*Sarcobatus vermiculatus*). Other shrubs that might be present include big sagebrush and winterfat. Grasses may include basin wildrye (*Leymus cinereus*).

The primary ecological processes maintaining the greasewood flat system is an elevated groundwater table. Greasewood is intolerant of waterlogged saline soils and typically increases with water drawdown. An obligate phreatophyte, greasewood is able to tap into groundwater at great depth (greater than 10 m [32.8 ft]). Figure 5-9 shows an occurrence of this ecological system in the study area.

Within Washington State, the Inter-Mountain Basins Greasewood Flat is uncommon and is never very abundant where it occurs. Due to threats from nonnative species and continual grazing, as well as the fact that most extant occurrences are small and fragmented, this ecological system is considered to be Critically Imperiled (S1) within the state.

Figure 5-8. Greasewood on North Slope of Umtanum Ridge

5.7 Inter-Mountain Basins Cliff and Canyon

This ecological system is typically comprised of the barren and sparsely vegetated landscape of steep cliff faces, narrow canyons, and smaller rock outcrops (in our area primarily basalt) and includes vegetation of unstable scree and talus slopes. It may include widely scattered shrubs common in the adjacent plant communities, including big sagebrush and bitterbrush. Figure 5-10 shows an occurrence of this ecological system in the study area.

Woody plants and small patches of grassland are often restricted to shelves, cracks, crevices, and other areas where soil accumulates; vegetation usually covers less than 10% of the total area. Due to the sparse nature of the vegetation in cliff areas, fire is rarely a large factor in this system. Similarly, this system usually occurs in difficult to reach locations and is, therefore, often protected from human disturbance. The conservation status of the Inter-Mountain Cliff and Canyon ecological system is Secure (S5) in Washington State.

Figure 5-9. Inter-Mountain Cliff and Canyon Ecological System Occurrence on Umatanum Ridge

5.8 Invasive Perennial Grassland and Forbland

About 0.1% of the total area on the Hanford Site is characterized by vegetation that is comprised primarily of non-native perennial grasses and invasive forbs. This ecological system is found in areas that have been significantly altered by past disturbance and natural vegetation types are no longer recognizable. This ecological system was not included in the most recent International Vegetation Classification system (NatureServe 2017) and is considered to be a "provisional" designation here.

Perennial grasses found in this provisional system on the Hanford Site can include bulbous bluegrass (*Poa bulbosa*) and crested wheatgrass (*Agropyron cristatum*), a non-native invasive grass that has been planted during past remediation efforts. Common co-occurring forbs include knapweed species (*Centaurea spp.*), fiddleneck species (*Amsinckia* spp), jagged chickweed (*Holosteum umbellatum*), spring whitlowgrass (*Draba verna*), and globemallow (*Sphaeralcea munroana*). Figure 5-11 shows an occurrence of this ecological system in the study area.

Figure 5-10. Crested Wheatgrass in a Revegetation Site on Central Hanford

5.9 Other Areas

Seven out of 11,737 polygons could not be placed in one of the ecological systems discussed above. These seven polygons cover roughly 11.7 ha (29 ac), which is less than 0.1% of the total area on Central Hanford. These areas represented one of two uncommon vegetation types: swales and a small abandoned channel found along the River Corridor.

Three swales occur in the southern portion of the study area and appear to be unique on Central Hanford. Species that occur there include some that are not known to occur elsewhere on site (Sackschewsky and Downs 2001, personal observation) (i.e., beardless wildrye [*Leymus triticoides*] and the non-native hairy crabgrass [*Digitaria sanguinalis*]). In addition, two species considered to be "facultative wetland" species that do not generally occur outside of riparian area on Hanford were present (i.e., coyote willow [*Salix exigua*] and "mountain rush" [*Juncus arcticus* var. *littoralis*]). Other unusual species occurring in and around the swales include Douglas' sedge (*Carex douglasii*), and yellow beeplant (*Cleome lutea*), neither of which are typically found on Central Hanford (Sackschewsky and Downs 2001, personal observation). In addition, salt heliotrope (*Heliotropum curassavicum*) is common there, otherwise known only in and around vernal pools on Central Hanford.

Together, these species suggest that the local area has increased seasonally available moisture releative to other places on site. Likely related to this, immediately to the south a thick layer of Mazama ash[6] is exposed where an old irrigation ditch bisected the dune and created a blowout. It seems probable that the ash underlies at least the low areas below the eolian sand, creating an aquatard and causing water to accumulate at some depth.

Figure 5-11 shows one of the swales occurring in the southern portion of the Hanford Site. Salt heliotrope can be seen in the foreground of this photo, mountain rush (brown, erect stems) in the middle of the photo, and a sward of beardless wildrye (deep green) in the background. One of the authors can be seen holding a large carcass of a previous year's yellow beeplant.

[6] Mazama ash was derived from the volcanic eruption that created Crater Lake, Oregon, about 7000 years ago.

Figure 5-11. Swale Area in the Southern Portion of the Study Area

6 SPECIES-SPECIFIC OBSERVATIONS

The following section contains distribution maps and field observations for the key shrubs and grasses used in mapping the vegetation on Central Hanford. On the maps in this section, species are depicted at three levels of cover: low (…), patchy […], and moderate to dense.

6.1 Big Sagebrush

Figure 6-1 shows the distribution of big sagebrush on Central Hanford. The highest cover of big sagebrush shrubs are in areas that haven't burned since at least the 1970s, which are generally located in the northern portion of the study area. These unburned areas often have both big sagebrush and smaller amounts of spiny hopsage, which together can form relatively closed canopies in some areas; shrubs in these areas are typically mature to decadent.

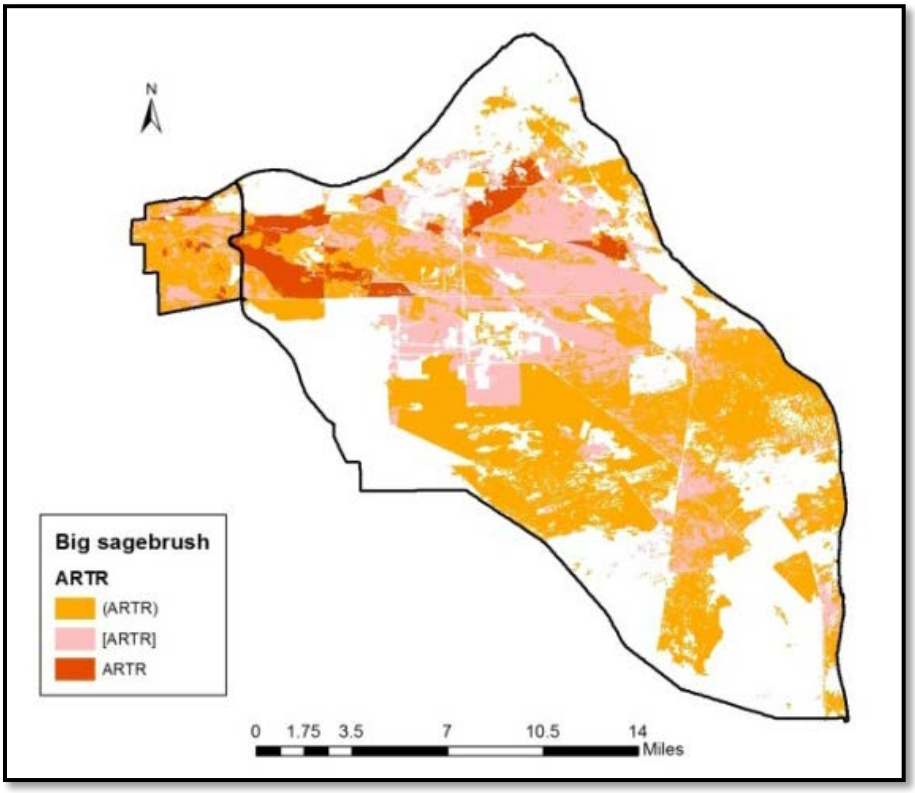

Figure 6-1. Big Sagebrush Distribution on the Central Hanford Site

6.1.1 Big Sagebrush and Wildfire

After fire, reestablishment by big sagebrush varied across the site and appears to be loosely correlated to landscape geomorphology. The species has reestablished most successfully on finer sands and silt facies of the cataclysmic floods (such as on the south slope of Umtanum Ridge and between the Wye Barricade, Laser Interferometer Gravitational-Wave Observatory, and Fast Flux Test Facility sites) and on

loess (such as east of the 200 Area Plateau). In some of these areas, recruitment has been robust (Figures 6-2 and 6-3).[7] Post-fire establishment of big sagebrush on loess may be enhanced by seeds being buried before the fire, enhancing their chance of surviving the fire and providing a good seedbed after the fire.

Figure 6-2. Sagebrush Plants Established in 2010 in an Area Burned in 2009 (south slope of Umtanum Ridge)

[7] In portions of the site, a large cohort of sagebrush plants became established in 2010, a high rainfall year (26 cm [10.19 in.], HMS 2015).

Figure 6-3. Juvenile Big Sagebrush Established in 2010 (East of 200 Area)

Big sagebrush was generally slow to recover on the sorted sands of dunes. Sagebrush was also less likely to recover from disturbance on coarser soils of the mainstream glacial outwash channels and the abandoned channels of the ancient Columbia River, such as the channel south of Gable Mountain. There, the vegetation currently appears to be frozen in a cheatgrass-dominated monoculture (Figure 6-4).

Figure 6-4. Abandoned Channel of the Post-Pleistocene Columbia River Dominated by Cheatgrass.

Big sagebrush was also slow to become reestablished in areas that burned multiple times, although some shrubs are occasionally present (Figure 6-5). In contrast, antelope bitterbrush frequently reestablished after the fire on the stabilized dunes (Section 6.3).

Figure 6-5. Big Sagebrush Shrub in an Area Burned in Both the 1984 and 2000 Wildfires

6.1.2 Big Sagebrush Die-off

The cover of sagebrush shrubs has decreased in a part of the northern portion of the study area (Figure 6-1). There, sagebrush die-off was first observed by Pacific Northwest National Laboratory in the spring of 1993 (Cardenas et al. 1998; Figure 6-6). The die-off from that time period is still evident and sagebrush has not come back into the hardest-hit sites (Figure 6-7). The distribution of shrubs affected in that event was within coarse-textured deposits of the ancestral Columbia River channels and giant ripples created during the glacial outburst floods.

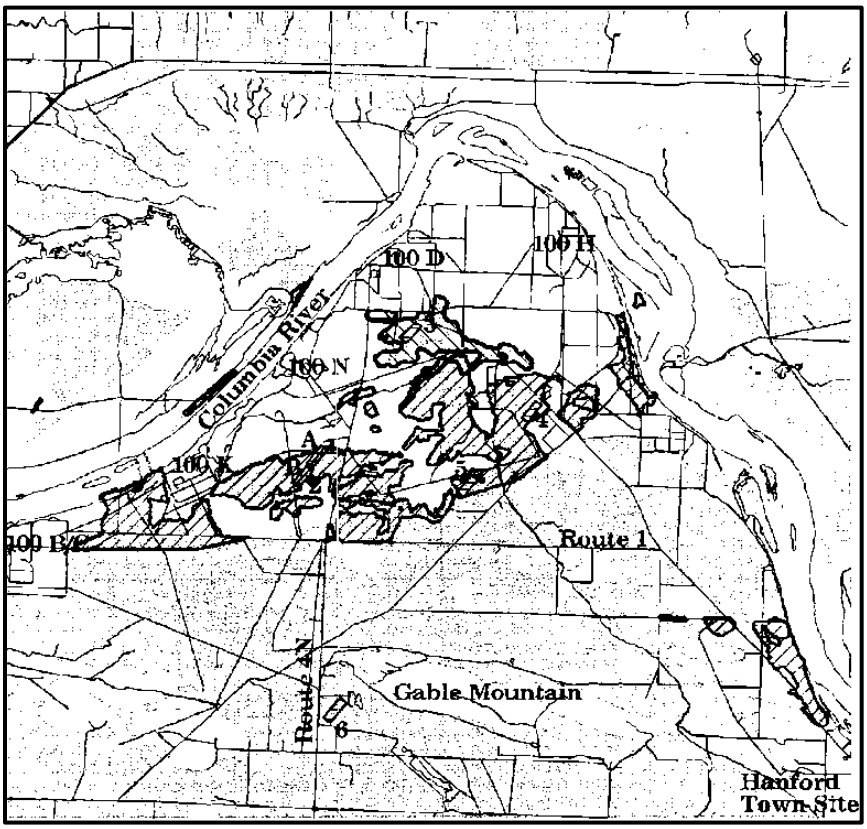

Figure 6-6. Distribution of Big Sagebrush Die-off, First Observed in 1993 (Cardenas et al. 1997)

The cause of the die-off is not known, but hypotheses regarding similar shrub die-off in the Great Basin (which involved several species) included overgrazing, drought, winter injury, insects, and plant pathogens (Cardenas et al. 1997). Additional reasons may include anoxia if the die-off occurred during a period of particularly high precipitation (Wallace and Nelson 1990). On Central Hanford, the die-off occurred in what may be characterized as poor quality habitat due to the coarse-textured deposits that remain within the ancestral Columbia River channels and zone with giant ripples from the Pleistocene floods. In addition, the sagebrush shrubs in that area generally had a decadent appearance (with dead branches). It is likely that there was a cohort of sagebrush that became established following a cycle of drought and grazing pressures during the 1930s, which likely would have shifted the balance towards woody species with big sagebrush being especially favored due to its unpalatable nature. This was followed by an abrupt change of management for the Hanford Project in 1943, when the system was released from livestock grazing. A cohort of shrubs established around that time would be about 60 to 70 years old. While the maximum lifespan of big sagebrush may exceed 150 years (Ferguson 1964), it likely varies widely; specific studies in undisturbed Wyoming big sagebrush communities have found the maximum age to be 57 years in southern Wyoming (Sturges 1977) and 50 years in New Mexico (Vincent 1992).

Added to the age of the plants, another factor that may have enhanced the tipping point may be related to a significant wet period with 5-cm (2-in.) equivalent (68 cm [26.8 in.] of snow) during the winter of 1992 to 1993, with 26 of 29 days with measurable precipitation (Hoitink 2004). The impermeability of

the underlying cobble substrate may have created anoxic conditions that weakened the shrubs and contributed to their demise.

Seedling sagebrush plants are not present in most of the area in which the big sagebrush die-off occurred. There is some rabbitbrush and a small amount of spiny hopsage; the grass layer is typically dominated by cheatgrass, with small amounts of Sandberg bluegrass.

Figure 6-7. Dead Big Sagebrush in Die-off Zone Described by Cardenas et al. (1997)

6.2 Spiny Hopsage

Figure 6-8 shows the distribution of spiny hopsage on Central Hanford. Spiny hopsage generally occurs together with sagebrush, usually without significant cover from tall bunchgrasses. Typical sites include areas with finer-textured soils on the surface (including slackwater fines and loess); the species also occurs in areas of the mainstream facies of the cataclysmic floods with a gravel/cobble substrate and relatively lower proportions of sand, such as north of the 200 Area. Small coppice dunes can form under spiny hopsage shrubs, which have dense, low-growing limbs that trap wind-blown sediments. The finer surface soils observed may have accumulated after the spiny hopsage became established (perhaps sometimes over a gravel rich substrate).

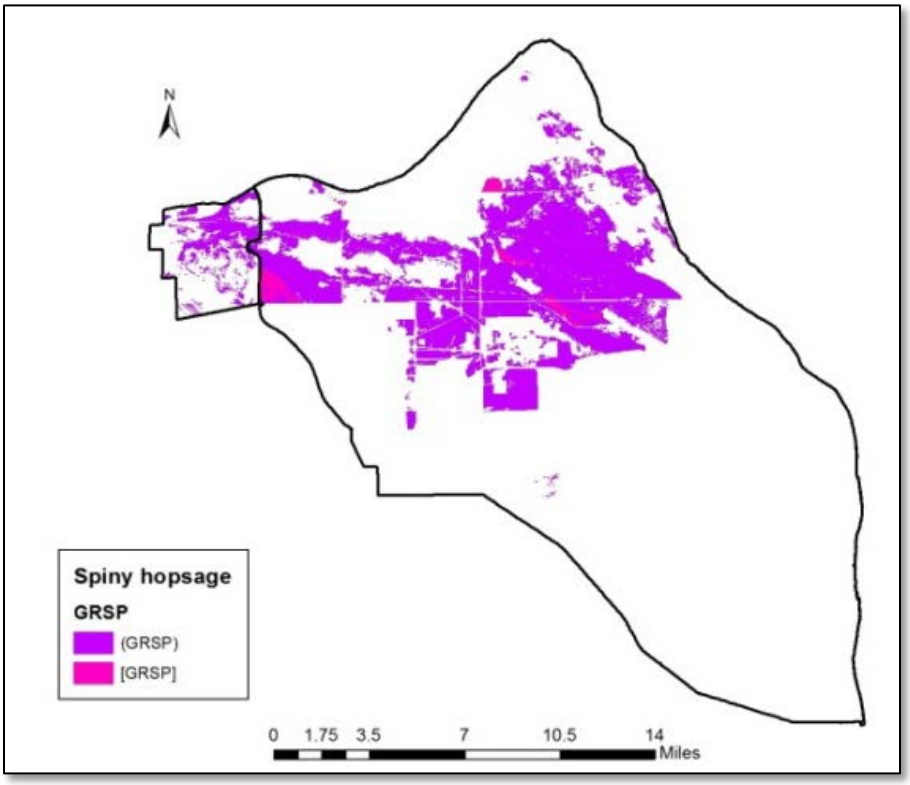

Figure 6-8. Spiny Hopsage Distribution on the Central Hanford Site

With notable exceptions, spiny hopsage plants on Central Hanford are not present in areas that have burned recently, although widely-scattered individuals occur as surviving individuals within burned areas (Figure 2-3).[8] Areas that have burned where the species occurs include north of the Yakima Barricade (east of Highway 240), portions of which are mapped as having burned in either 1977 or 1984; on the south slope of Umtanum Ridge west of Highway 24, which is mapped as having burned multiple times; and a small area east of the 200 Area Plateau that is mapped as having burned in 1977 and 1984. While the species often sprouts after fire elsewhere in its range (Tirmenstein 1999a), in Washington State the species is usually killed by fire, at least in recent decades (e.g., Rickard and McShane 1984, personal

[8] Widely scattered individual spiny hopsage shrubs, too infrequent to predict or map, occur south of what was depicted on the map.

observation). This is likely due to hotter fires caused by cheatgrass near the root crown (Shaw, personal communication). While it is possible that some plants became established from seed after fire, it is more likely the scattered extant plants were in unburned patches or sprouted after being burned.

In the northeast portion of the study area, patches of spiny hopsage occur as islands within a portion of the farming landscape that apparently wasn't converted for agriculture. The sites are frequently on sandy soil that was an overbank deposition from the post-Pleistocene ancestral Columbia River, which probably mantles a gravel/cobble substrate. These sites appear to be remnants in an area that was otherwise under cultivation before acquisition by DOE in 1943.

In addition, spiny hopsage seedlings have generally not been observed during recent decades on Central Hanford (Rickard, personal communication, personal observation), on the nearby Hanford Reach National Monument, or on the Yakima Training Center (personal observation). This may be another indication that spiny hopsage currently has a tenuous presence in the region. During this study, a single spiny hopsage seedling was found growing in a crack in old asphalt on the lower slope south of Umtanum Ridge (Figure 6-9). The only other plants recently established from seed that we have observed in the past 20 years were on the cut-slope of Highway 240 at Umtanum Ridge. This suggests that establishment occurs in a very harsh environment with little or no competition, and possibly enhanced moisture within the gravel/cobble (which was mimicked by the asphalt at the seedling site).

Figure 6-9. Spiny Hopsage Seedling on Old Roadbed on Lower Slope of Umtanum Ridge

6.3 Antelope Bitterbrush

Figure 6-10 shows the distribution of antelope bitterbrush on Central Hanford. On eolean sand of stabilized dunes, antelope bitterbrush responded with some plasticity to the fires that burned across a large portion of the site in both 1984 and 2000, such as south and east of Laser Interferometer Gravitational-Wave Observatory and south of the 400 Area (along both sides Route 10). In some areas within those sites, many new seedlings have become established and are fast gaining stature (Figure 6-11). In the stabilized dunes, scattered shrubs occasionally survived the fire(s), likely due to the influence of varied topography and open sand on fire behavior (Figure 6-12). Clumps of seedlings, presumably from scatterhoards of heteromyid rodents, were regularly observed during 2015 (Figure 6-13). Bitterbrush rarely sprouts after fire in our area, although it is known to sprout elsewhere.

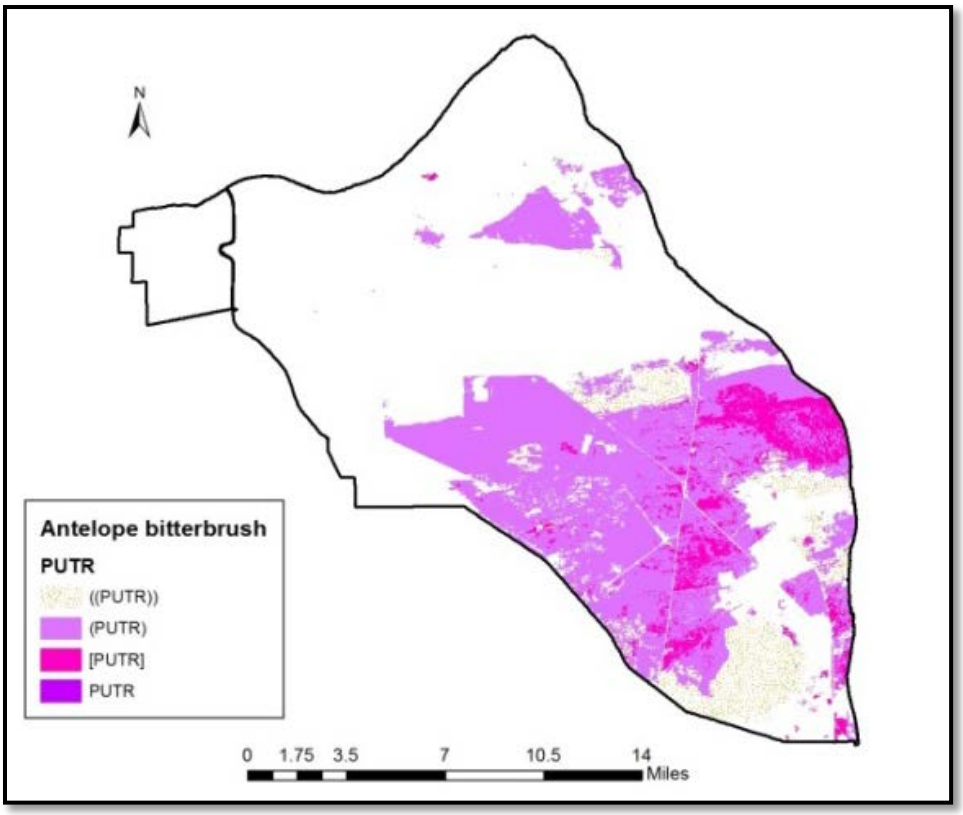

Figure 6-10. Antelope Bitterbrush Distribution on the Central Hanford Site

Antelope bitterbrush occurred with big sagebrush in most portions of the area that burned and where shrub reestablishment is occurring, and is generally regaining cover more quickly than the latter species. Reasons for the disparate response may include being released from competition, differences in seed dispersal (animals vs. wind), and seed survival (pre-fire burial by rodents versus lying on the surface or passive burial by substrate accumulation). Weather conditions after the fire and differing germination requirements may also be responsible.

Figure 6-11. Reproduction of Antelope Bitterbrush, and Bitterbrush and Big Sagebrush Individuals, within an Area that Burned in both 1984 and 2000

Figure 6-12. Antelope Bitterbrush on Stabilizing Dunes

Figure 6-13. Clumps of Antelope Bitterbrush Seedlings and Juveniles, likely Germinated from Scatterhoards Stashed by Heteromyid Rodents

In parts of the central part of the study area, particularly around Route 4S, are areas in which bitterbrush shrubs that established after the 1984 or 2000 fires have been killed (or have suffered die-back from the top) from an unknown cause (Figure 6-14). The shrubs appear to have been growing quickly, with robust growth and an even stature, often having reached 1.5 to2 m (4.9 to 6.5 ft) or more tall, before being affected. The dead/stunted shrubs are usually, but not always, located within an irregular area, with the highest concentrations of afflicted individuals closer to a road, suggesting possible drift from roadside herbicide treatments. Young, vigorous bitterbrush shrubs (less than a meter tall) are frequently present at these sites, suggesting that the mature shrubs were impacted several years ago and that the cause(s) is not currently active. Co-occurring big sagebrush shrubs were not affected.

Figure 6-14. Die-off of Antelope Bitterbrush along Route 4S, with Unaffected Big Sagebrush

6.4 Snow Buckwheat

Figure 6-15 shows the distribution of snow buckwheat on Central Hanford. Like antelope bitterbrush, snow buckwheat also thrives in and around dune and stabilizing dune habitats (Figure 6-13); however, the species also occurs with lower cover in areas with silt and sand-sheets left by the cataclysmic floods that have not been re-sorted by wind.

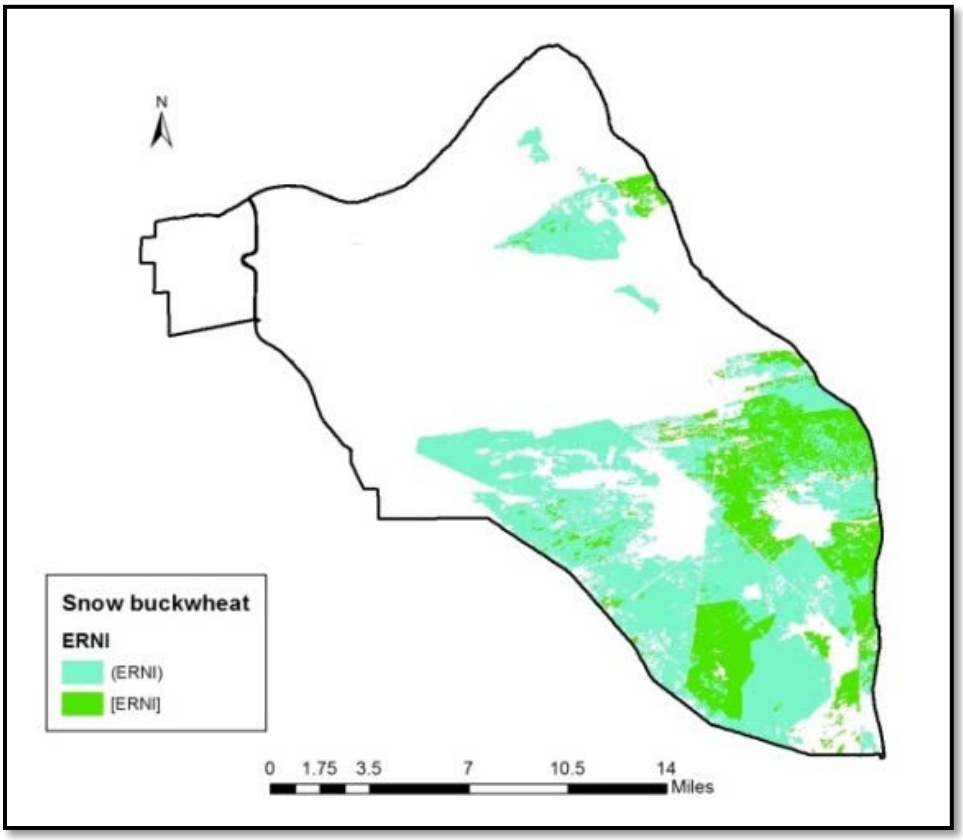

Figure 6-15. Snow Buckwheat Distribution on the Central Hanford Site

6.5 Winterfat, Stiff Sagebrush, and Rock Buckwheat

Figure 6-16 shows the distribution of winterfat, stiff sagebrush, and rock buckwheat on Central Hanford. In the Pasco and Yakima Basins, winterfat primarily occurs of slackwater fines deposited by the Pleistocene cataclysmic floods (personal observation). Within the study area, the species on Umtanum Ridge, generally in a small basin to the south of Umtanum Ridge, with smaller amount found above the basin on the ridge itself (Figure 6-17). Recent fires in the area have eliminated most of winterfat plants from burned areas. This suggests that the fires were relatively hot there, since the species can survive low-severity fires (Pellant and Reichert 1984). Stiff sagebrush and rock buckwheat occur in the limited areas of shallow soils within the study area (Figure 6-18).

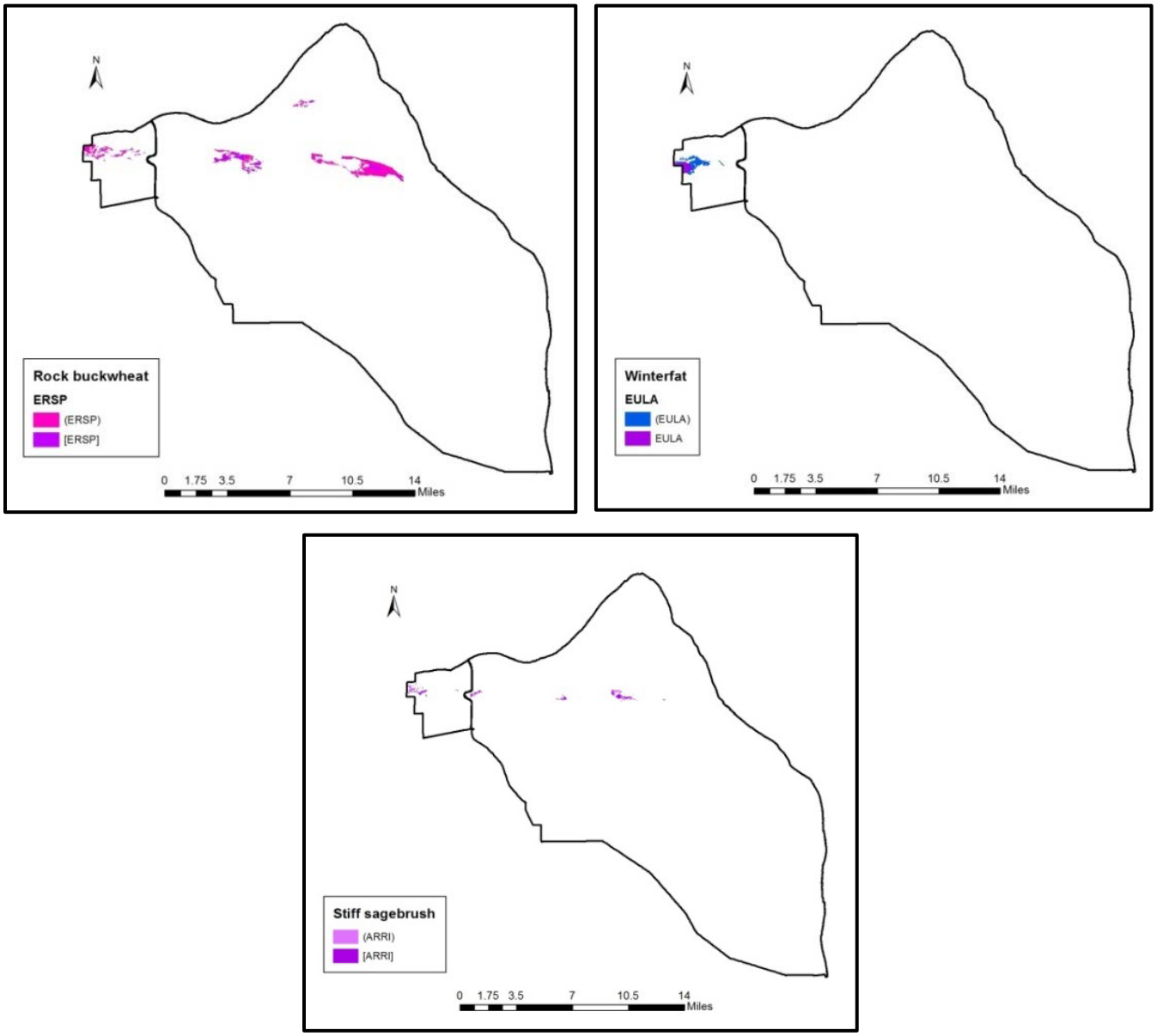

Figure 6-16. Distributions of Rock Buckwheat, Winterfat, and Stiff Sagebrush on the Central Hanford Site

Figure 6-17. Winterfat on Umtanum Ridge

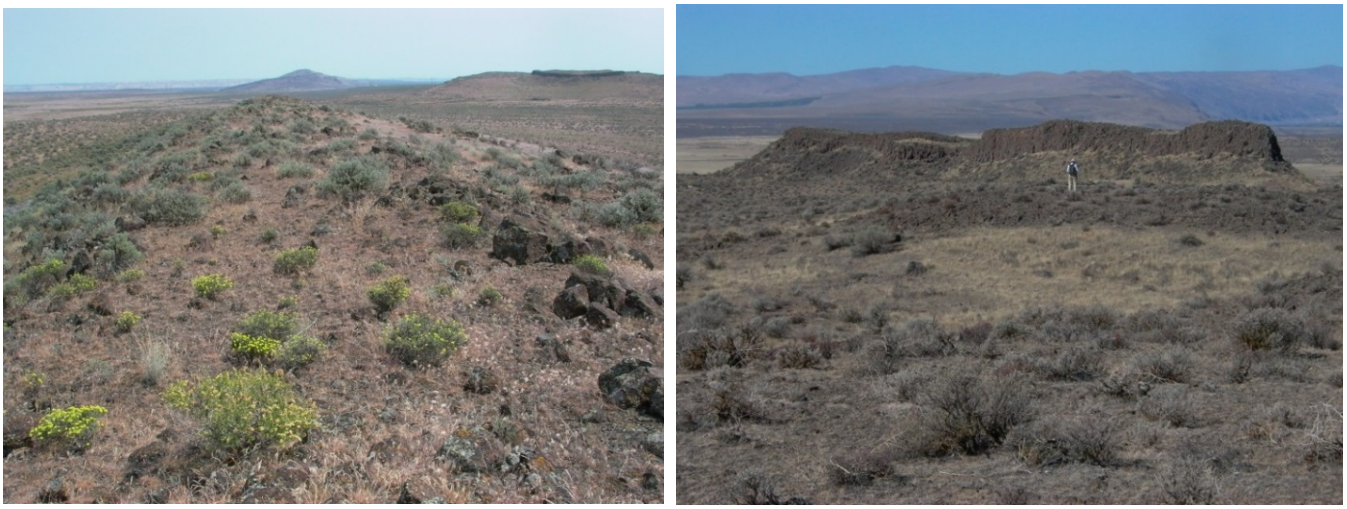

Figure 6-18. Lithosols with Rock Buckwheat and Stiff Sagebrush

6.6 Rabbitbrushes

Rubber and yellow rabbitbrushes occur throughout Central Hanford, with the latter species more common in active dune systems. Rubber rabbitbrush is generally considered to be early- to mid-seral species that declines in later succession and is excellent for soil stabilization and erosion control (Tirmenstein 1999a). While that taxon is not considered important for large mammals, yellow rabbitbrush is considered important browse and both provide cover for several species of nesting birds and shade and litter that may enhance habitat for other species (Tirmenstein 1999a, b). In addition, both rabbitbrush taxa provide potentially important floral resources in the fall, and attract a wide variety of insects. Rabbitbrushes are host plants for “unusually large numbers” of gall-inducing insects

(Russo 2006), which likely increase complexity of the ecological sites. They also provide shade and litter that may provide habitat for additional species to germinate and grow.

6.7 Needle-and-Thread Grass

Figure 6-19 shows the distribution of needle-and-thread grass on Central Hanford. The cover of needle-and-thread grass has increased substantially after fire in some of areas since at least 1995,[9] as we have previously observed in the Pasco Basin (e.g., Easterly and Salstrom 2002, 2004; Salstrom and Easterly 2011). This response is particularly evident where the cover of shrubs is high and there was at least some needle-and-thread grass present before the fire. This species generally occurs in areas with sand and silt facies of the cataclysmic floods, as well as dune and especially inter-dune areas. It typically occurs on planer surfaces on and around dunes on finer sand, sand/silt, and slackwater fines. The species typically forms swards, with a dense, fibrous root system that is negatively associated with several species, including cheatgrass, but also may suppress forbs (Figure 6-20).

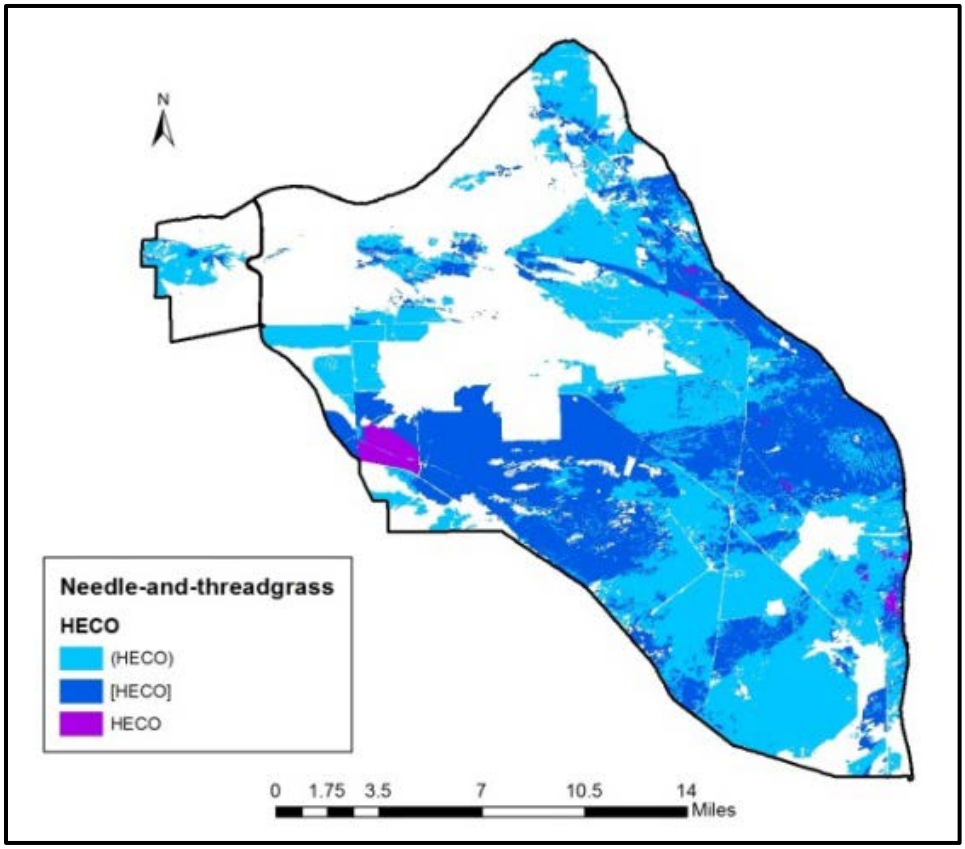

Figure 6-19. Needle-and-Thread Grass Distribution on the Central Hanford Site

[9] In some areas, the cover of the species has even increased significantly from that observed on the 2008 high-resolution aerial photos.

Figure 6-20. Needle-and-Thread Grass

In contrast, dead needle-and-thread grass plants occurred on some shallow soils, such as on Umtanum Ridge. There, the dead plants appeared to be a younger cohort that established during more productive years in marginal habitat and has since died, likely in response to drought during recent years.

6.8 Indian Ricegrass

While needle-and-thread grass frequently occurs with small amounts of Indian ricegrass (which may not always be included in the mapping-unit name), the latter species typically prefers sorted, mobile sand and thus occurs more commonly in dune habitats. Figure 6-21 shows the distribution of Indian ricegrass on Central Hanford.

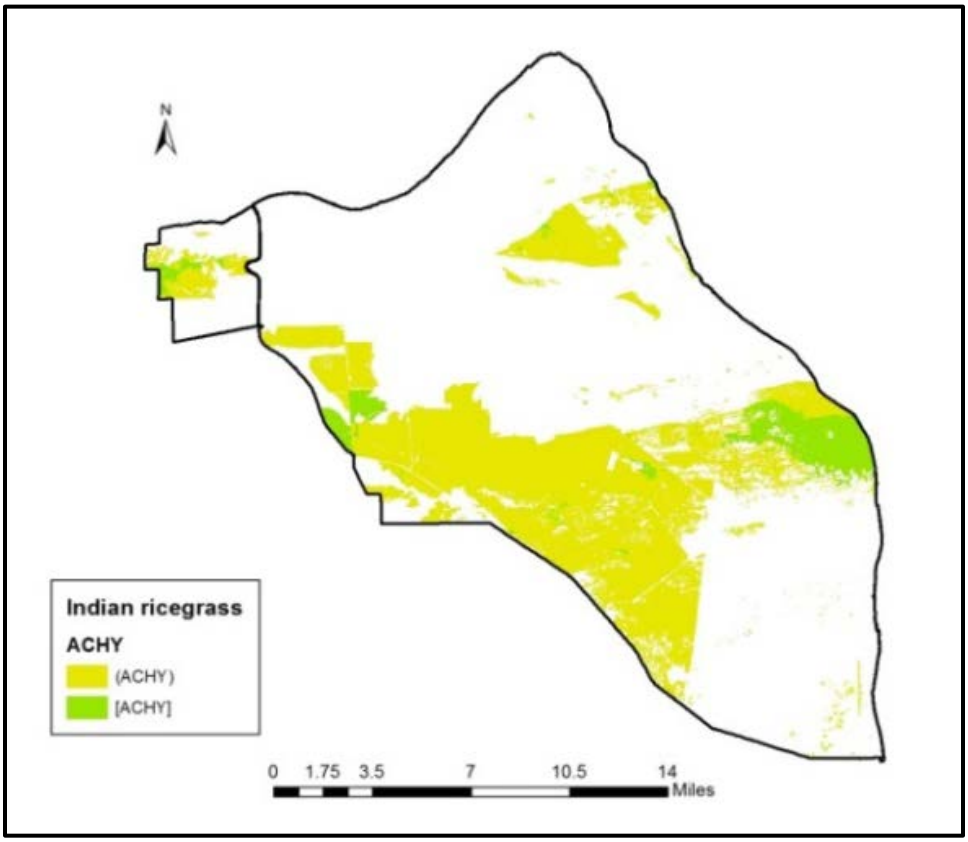

Figure 6-21. Indian Ricegrass Distribution on the Central Hanford Site

6.9 Bluebunch Wheatgrass

Figure 6-22 shows the distribution of bluebunch wheatgrass on Central Hanford. Within the study area, bluebunch wheatgrass occurs primarily on and near basalt, especially on north aspects, on Umtanum Ridge (Figure 6-23) and the Gable complex, and less abundantly where basalt is near the surface near the horn of the Yakima River in the southwest of the study area.

Elsewhere, the species occurs in very limited areas as widely-spaced to scattered individuals on cobble-rich or other coarse substrates, mostly north of the Gable complex, with some plants in and around the 300 Area. The plants located on the central portion of the Site are often quite large.

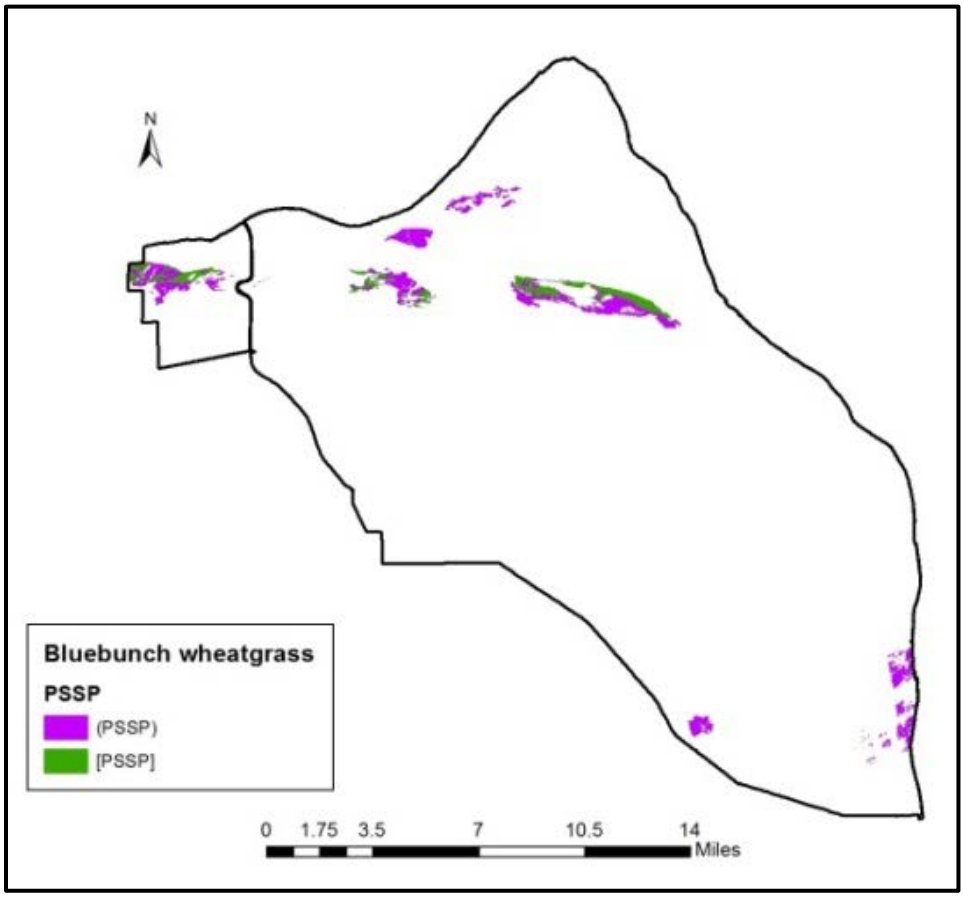

Figure 6-22. Bluebunch Wheatgrass Distribution on the Central Hanford Site

Figure 6-23. Bluebunch Wheatgrass on the North Slope of Umtanum Ridge

6.10 Sand Dropseed

Figure 6-24 shows the approximate distribution of sand dropseed on Central Hanford. Since the mid-1990s, the cover and frequency of sand dropseed has increased greatly, particularly on lower elevations in the northern portion of the study area. While previously observed primarily along roads, now it is seen widely scattered throughout much of the site as individuals and groups of plants. While considered native in some communities, it may become weedy or invasive in some regions or habitats and may displace more desirable vegetation if not properly managed (Simonin 2000). This species is a prolific seed and produces and spreads naturally from seed once established (Plummer et al. 1955), increasing on depleted rangelands and wastelands (Welsh et al., 2003). Sand dropseed produces a dense sand binding network of roots that can spread up to 0.6 m (2 ft) laterally and over 2.4 m (8 ft) deep (Coupland and Johnson 1965).

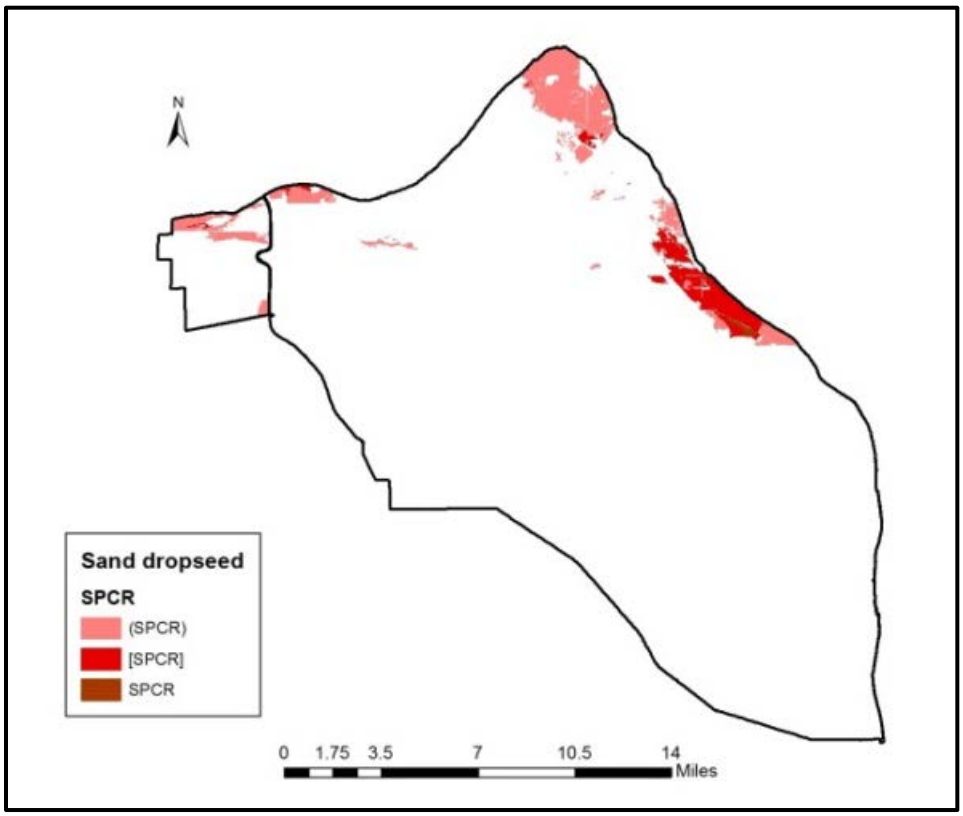

Figure 6-24. Sand Dropseed Distribution on the Central Hanford Site

6.11 Sandberg Bluegrass and Cheatgrass

Areas without shrubs (other than rabbitbrush) or tall bunchgrasses are generally occupied by cheatgrass and Sandberg bluegrass. These sites typically occur in low-lying, planer areas, including zones of cobble and/or gravel near the river (frequently in mainstream facies of the cataclysmic floods) and in channelways of the ancient Columbia River that didn't receive subsequent sand deposition (either from overbank river deposits or dune migrations).

In addition, some areas without shrubs (other than rabbitbrush) or tall bunchgrasses are well-packed fine silt, including some abandoned channels of the ancient Columbia River and in some areas south of the 200 Area where slackwater fines are exposed on the surface. These are areas where shrubs are not well supported, didn't reinvade after fire, or had been intensely disturbed (such as from historic farming). Grasses in these areas are usually comprised of a combination of cheatgrass, with varying amounts of Sandberg bluegrass.

Aspect and topography are the greatest predictors of predominate species, with Sandberg bluegrass usually dominant on even slight north aspects and often in small topographic basins. However, cover of Sandberg bluegrass appears to have decreased in many areas since the mid-1990s. It is likely that some of the patterns established at that time were in response to greater than average precipitation during that time. Areas with silt and slackwater fines have very little Sandberg bluegrass present, with cheatgrass now being the dominant at those sites.

Figure 6-25. Invasive Annual Grassland Dominated by Cheatgrass

6.11.1 Co-occurring Invasive Species

The invasive species bulbous bluegrass increasingly occurs on shallow soils, often over cobble. In addition, jagged chickweed (*Holosteum umbellatum*) and spring whitlowgrass (*Draba verna*) contribute copious cover in some areas. Species of annual fescue (*Vulpia* spp.) contributed significant cover in some areas; species present are both native (*V. microstachys* and *V. octoflora)* and introduced (*V. bromoides*).

6.11.2 Cheatgrass Die-off Circles

Cheatgrass appears to be increasingly subjected to the circular die-off that was previously described in the Pasco Basin (e.g., Salstrom and Easterly 2013; Easterly and Salstrom 1998, 2004, 2007). Cheatgrass crop circles are a phenomenon that causes clearly-demarked holes in the fabric of dense cover of cheatgrass in several areas within the Pasco Basin, as on Central Hanford and the Wahluke Slope. The circles are typically 1 to 4 m (3.28 to 13.1 ft) in diameter, but have been observed up to 7 m (23 ft), and appear to get progressively fuzzy-edged with time. These circles appear to be nurse areas or cheatgrass-free zones for at least a few years in which a wide assortment of species, some of which are native grasses and forbs, occur (Figure 6-25). While each footprint's clear pattern of opportunity fades, this transition towards higher diversity appears to allow for establishment of mid- and later-seral species. The circles likely occur because of a soil fungus (Dr. Ann Kennedy, WSU, personal communication).

In addition, a similar pattern was observed in early May 2015, in which distinct, usually circular patches of blond cheatgrass plants that were surrounded by plants in the red phase. The blond plants were generally shorter than surrounding plants, densely packed, and usually had caryopses that were aborted. Where observed, this was a landscape-wide pattern, generally with no apparent ground disturbances or surface irregularities (Figure 6-26). The circles usually occurred on flat to south aspects. It was unclear whether these 2015 circles were due to a different mechanism, such as a particular cycle of precipitation and drought, or possibly the same mechanism at an earlier state of infestation.

Figure 6-26. Cheatgrass Crop Circles in which the Density of Cheatgrass is Low[10]

[10] Low density of cheatgrass in these crop circles provides a place where other species can become established. The species in the circles typically include fiddlenecks (*Amsinckia* sp.), tumblemustard (*Sisymbrium altissimum*), and needle-and-thread grass.

Figure 6-27. Blond Cheatgrass Circles, 2015

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APPENDIX A. COMMON AND SCIENTIFIC NAMES

antelope bitterbrush	*Purshia tridentata*
balsamroot	*Balsamorhiza* sp.
basin wildrye	*Leymus cinereus*
beardless wildrye	[*Leymus triticoides*
big sagebrush	*Artemisia tridentata*
bitterbrush	*Purshia tridentata*
bluebunch wheatgrass	*Pseudoroegnaria spicata*
buckwheat	*Erigonum*
bulbous bluegrass	*Poa bulbosa*
Carey's balsamroot	*Balsamorhiza careyana*
cheatgrass	*Bromus tectorum*
Columbia cutleaf	*Hymenopappus filifolius*
coyote willow	*Salix exigua*
crested wheatgrass	*Agropyron cristatum/desortorium*
Cusick's bluegrass	*Poa cusickii*
desertparsley	*Lomatium* sp.
diffuse knapweed	*Centaurea diffusa*
Douglas' sedge	*Carex douglasii*
fescue	*Vulpia* spp.
fiddleneck species	*Amsinckia* spp
globemallow	*Sphaeralcea munroana*
grayball sage	*Salvia dorrii*
greasewood	*Sarcobatus vermiculatus*
hairy crabgrass	*Digitaria sanguinalis*
Indian ricegrass	*Achnatherum hymenoides*
jagged chickweed	*Holosteum umbellatum*
knapweed species	*Centaurea spp.*
mountain rush	*Juncus arcticus* var. *littoralis*]
needle-and-thread grass	*Hesperostipa comata*
onion	*Allium* sp.

pale evening-primrose	*Oenothera pallida*
phlox	*Phlox* sp.
prairie junegrass	*Koeleria macrantha*
pussy-toes	*Antennaria* sp.
rubber rabbitbrush	*Ericameria nauseosa*
rock buckwheat	*Eriogonum sphaerocephalum*
rush skeletonweed	*Chondrilla juncea*
Russian knapweed	*Acroptilon repens*
Russian thistle	*Salsola tragus*
sagebrush	*Artemisia* spp.
salt heliotrope	*Heliotropum curassavicum*
sand beardtongue	*Penstemon acuminatus*
sand dropseed	*Sporobolus cryptandrus*
Sandberg bluegrass	*Poa secunda*
scurf pea	*Psoralidium lanceolatum*
slender buckwheat	*Eriogonum microthecum*
snow buckwheat	*Eriogonum niveum*
spiny hopsage	*Grayia spinosa*
spring whitlowgrass	*Draba verna*
squirreltail bottlebrush	*Elymus elymoides*
stiff sagebrush	*Artemisia rigida*
strict buckwheat	*E. strictum*
terpentine springparsley	*Pterixia terebintha*
thickspike wheatgrass	*Elymus lanceolatus*
thread leaf scorpianweed	*Phacelia linearis*
threadleaf fleabane	*Erigeron filifolius*
Thurber's needlegrass	*Achnatherum thurberianum*
thymeleaf buckwheat	*E. thymoides*
tumblemustard	*Sisymbrium altissimum*
whiteleaf scorpionweed	*Phacelia hastata*
winged dock	*Rumex venosus*)
wppeinterfat	*Eurotia lanata*

yellow beeplant	*Cleome lutea*
yellow rabbitbrush	*Chrysothamnus viscidiflorus*
yellow starthistle	*Centaurea solstitialis*

APPENDIX B. DECISION TREE AND KEY TO MAPPING UNITS

Definitions used in winnowing polygon names (Mapping Units) into more generalized categories (tiers 1-3)	
0	Not present
1	Parentheses
2	Brackets
3	Full
AGCR	*Agropyron cristatum*
ARRI	*Artemisia rigida*
ARTR	*Artemisia tridentata*
Bunchgrasses	From Tier 2: Combination of *Achnatherum hymenoides, Hesperostipa comata,* and/or *Pseudoroegneria spicatum.* Does not include other bunchgrasses. From Tier 1: 'Bunchgrasses' refers only to *Achnatherum hymenoides* and *Hesperostipa comata*.
CHNA-VI	Rabbitbrush (either or both *Ericameria nauseosa* and *Chrysothamnus viscidiflorus*)
ERNI	*Eriogonum niveum*
EULA	*Eurotia lanata* (=*Krascheninnikovia lanata*)
GRSP	*Grayia spinosa*
Half-shrubs	From Tier 2: any combination of *Eriogonum sphaerocephalum, E. microthecum* and/or *Salvia dorrii.*
PUTR	*Purshia tridentata*
SPCR	*Sporobolus cryptandrus*

Tier 1
Removed POSE-BRTE when other grasses present EXCEPT removed when (SPCR) the only other grass and left POSE = 1 (POSE); remaining POSE and BRTE went to 2.
HECO and/or ACHY at 1 went to (Bunchgrass); named HECO and ACHY separately if at 2 or 3.
HECO and PSSP at 2 went to 3.
ARTR and PUTR at 2 went to 3.
Removed (ERNI).
Removed (CHNA-VI).
SPCR at 3 went to [SPCR].
Removed all double parentheses.

Tier 2 Methods (Built on Tier 1)
'Bunchgrasses' at 2 moved to 3.
PSSP, ACHY and HECO at 2 and 3 went to 'Bunchgrasses' at 3
PSSP at 1 went to 'Bunchgrasses' at 1.
Remove AGCR at 1.
Removed SPCR at 1.
Remove SPCR if 'Bunchgrasses' present.
Remove POSE at 1.
All EULA went to 2.
Combine any level of ERMI, ERSP and/or SADO into 'Half-shrubs' at 1.
If 'Bunchgrasses' not present, insert POSE and BRTE at 2.
CHNA-VI removed IF other shrubs present at 2 or 3 BUT left in if only ERNI present.

Key to Tier 3 (Built on Tier 2)	
1.a Half-shrubs (*Eriogonum sphaerocephalum, E. microstachys, Salvia dorrii)* present	
2.a ARRI present	
3.a ARTR 2 or 3	**Big sagebrush[Stiff sagebrush](Half-shrubs)/Bunchgrasses**
3.b ARTR absent or 1	**[Stiff sagebrush](Half-shrubs)/Bunchgrasses**
2.b ARRI absent	
4.a ARTR 2 or 3	
5.a Bunchgrass 2 or 3	**Big sagebrush[Half-shrubs]/Bunchgrasses**
5.b Bunchgrass absent or 1	**Big sagebrush[Half-shrubs]/Sandberg bluegrass-Cheatgrass**
4.b ARTR absent or 1	
6.a Bunchgrass 2 or 3	**[Half-shrubs]/Bunchgrasses**
6.b Bunchgrass absent or 1	**[Half-shrubs]/Sandberg bluegrass-Cheatgrass**
1.b Half-shrubs absent	
7.a PUTR present	
8.a PUTR 1	
9.a ARTR 2 or 3	
10.a ERNI 2	
12.a Bunchgrass 2 or 3	**Big sagebrush(Bitterbrush)[Snow buckwheat]/Bunchgrasses**

			12.b Bunchgrass absent or 1	**Big sagebrush(Bitterbrush)[Snow buckwheat]/ Sandberg bluegrass-Cheatgrass**
		10.b ERNI 0 or 1		
			13.a Bunchgrass 2 or 3	**Big sagebrush(Bitterbrush)/Bunchgrasses**
			13.b Bunchgrass absent or 1	**Big sagebrush(Bitterbrush)/Sandberg bluegrass-Cheatgrass**
	9.b ARTR absent or 1			
		14.a ERNI 2		
			15.a Bunchgrass 2 or 3	**Big sagebrush(Bitterbrush)[Snow buckwheat]/Bunchgrasses**
			15.b Bunchgrass absent or 1	**(Bitterbrush)[Snow buckwheat]/ Sandberg bluegrass-Cheatgrass**
		14.b ERNI 0 or 1		
			16.a Bunchgrass 2 or 3	**(Bitterbrush)/Bunchgrasses**
			16.b Bunchgrass absent or 1	**(Bitterbrush)/Sandberg bluegrass-Cheatgrass**
8.b PUTR 2 or 3				
	17.a ARTR 2 or 3			
		18.a ERNI 2		
			19.a Bunchgrass 2 or 3	**Big sagebrush-Bitterbrush[Snow buckwheat]/Bunchgrasses**
			19.b Bunchgrass absent or 1	**Big sagebrush-Bitterbrush[Snow buckwheat]/Sandberg bluegrass-Cheatgrass**

			18.b	ERNI 0 or 1	**Big sagebrush-Bitterbrush/Sandberg bluegrass-Cheatgrass**
		17.b	ARTR absent or 1		
			20.a	Bunchgrass 2 or 3	**Bitterbrush/Bunchgrasses**
			20.b	Bunchgrass absent or 1	**Bitterbrush/Sandberg bluegrass-Cheatgrass**
7.b	PUTR absent				
		21.a	GRSP 2 or 3		
			22.a	Bunchgrass 2 or 3	**Big sagebrush[Spiny hopsage]/Bunchgrasses**
			22.b	Bunchgrass absent or 1	**Big sagebrush[Spiny hopsage]/Sandberg bluegrass-Cheatgrass**
		21.b	GRSP 0 or 1		
			23.a	ARTR 2 or 3	
				24.a Bunchgrass 2 or 3	**Big sagebrush/Bunchgrasses**
				24.b Bunchgrass absent or 1	**Big sagebrush/Sandberg bluegrass-Cheatgrass**
			23.b	ARTR 0 or 1	
				25.a ERNI 2	
				26.a Bunchgrass 2 or 3	**[Snow buckwheat]/Bunchgrasses**
				26.b Bunchgrass absent or 1	**[Snow buckwheat]/Sandberg bluegrass-Cheatgrass**
				25.b ERNI 0 or 1	

27.a	CHNA-VI present		
	28.a	Bunchgrass 2 or 3	**Rabbitbrush/Bunchgrasses**
	28.b	Bunchgrass absent or 1	**Rabbitbrush/Sandberg bluegrass-Cheatgrass**
27.b	CHNA-VI not present		
	29.a	Bunchgrass 2 or 3	**Bunchgrasses**
	29.b	Bunchgrass absent or 1	**Sandberg bluegrass-Cheatgrass**