DOE/RL-2019-70
Revision 0

STUDY PLAN TO CHARACTERIZE ROOT DEPTH AND MASS OF FOCAL SHRUB-STEPPE VEGETATION SPECIES ON THE HANFORD CENTRAL PLATEAU

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

U.S. DEPARTMENT OF ENERGY | Richland Operations Office

P.O. Box 550
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

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Title: *Study Plan to Characterize Root Depth and Biomass of Focal Shrub-Steppe Vegetation Species on the Hanford Site Central Plateau*

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Contents

1 Introduction 1-1

1.1 Study Scope and Need 1-1
1.2 Background 1-3
1.2.1 Central Plateau Habitat and Land Uses 1-3
1.2.2 Biomobilization at the Hanford Site Central Plateau 1-4
1.2.3 Conceptual Exposure Model 1-7
1.3 Data Quality Objective Summary 1-7
1.3.1 Problem Statement and Definition 1-8
1.3.2 Principal Study Questions 1-8
1.4 Project Schedule 1-10

2 Quality Assurance Project Plan 2-1

2.1 Project Management 2-1
2.1.1 Project or Task Organization 2-1
2.1.2 Special Training and Certification 2-6
2.2 Documents and Records 2-6
2.3 Data Generation and Acquisition 2-8
2.3.1 Study Equipment 2-8
2.3.2 Nondirect Measurements 2-9
2.3.3 Data Management 2-9
2.3.4 Assessment and Oversight 2-10
2.4 Data Review and Usability 2-10
2.4.1 Data Review and Verification 2-10
2.4.2 Reconciliation with User Requirements 2-11

3 Field Sampling Plan 3-1

3.1 Sampling Objective 3-1
3.2 Target Plant Species for Root Excavation and Core Drilling 3-1
3.3 Study Design 3-2
3.4 Key Activities Prior to Root Study Implementation 3-5
3.4.1 Study Location Selection 3-5
3.4.2 Conduct Mock Field Trial of Root Characterization Study 3-6
3.4.3 Field Mobilization Planning Activities 3-7
3.5 Plant Root Excavation Methodology 3-7
3.6 Soil-Root Core Drilling Methodology 3-11
3.6.1 Soil Root Core Numbers, Type, Placement, and Depth 3-11
3.6.2 Soil-Root Core Drilling Methods 3-12

3.7 Sample Preparation Laboratory Activities 3-15
3.7.1 Laboratory General Requirements 3-15
3.7.2 Plant Tissue, Root Tissue, and Soil Core Sample Preparation and Processing 3-16
3.8 Aboveground Plant Tissue, Root, and Soil Sample Analyses 3-22
3.8.1 Aboveground Plant Tissue Fresh and Dry Weight Analyses from Total Root Excavation and Soil-Root Coring 3-22
3.8.2 Root Tissue Fresh and Dry Weight Analyses from Total Root Excavation and Soil Coring 3-24
3.8.3 Soil Moisture Analysis for Root Excavation and Soil Core Composite Samples 3-24
3.8.4 Soil Type and Soil Grain Size Profile Analyses for Root Excavation and Coring Soil Samples 3-24
3.9 Data Analysis 3-25
3.9.1 Hypotheses Testing 3-25
3.9.2 Statistical Design 3-27
3.10 Documentation of Field and Laboratory Activities 3-29
3.11 Corrective Actions and Deviations for Sampling Activities 3-29
3.12 Calibration of Field and Sample Preparation Laboratory Equipment 3-30
3.13 Sample Handling 3-30
3.13.1 Sample Preservation 3-31
3.13.2 Containers 3-31
3.13.3 Container Labeling 3-31
3.13.4 Sample Custody 3-31
3.13.5 Sample Transportation 3-32
4 Management of Investigation-Derived Waste 4-1
5 Health and Safety 5-1
6 References 6-1

Appendix

A Systematic Planning Record ..... A-i

Figures

Figure 1-1. Hanford Site Central Plateau 1-2
Figure 1-2. Conceptual Site Model for Outdoor Worker Exposure to Soil Radiological Contaminants Biomobilized by Deep-Rooted Vegetation 1-7
Figure 2-1. Project Organization 2-2
Figure 3-1. Root Characterization Study Design 3-4
Figure 3-2. Map of Potential Study Locations 3-6
Figure 3-3. Schematic of Plant Excavation 3-8
Figure 3-4. Continuous Core Placement Over Center Mainstem (Taproot) and Around Plant Specimen Dripline Perimeter 3-12
Figure 3-5. Depth Interval-Specific Sample Compositing Scheme for Root Tissue and Soil 3-19

Tables

Table 1-1. Frequency of Observations of Contamination in Media from the Hanford Site Central Plateau 1-5
Table 1-2. Study Activities and General Completion Timeframes 1-10
Table 2-1. Soil and Vegetation Tissue Holding Time Guidelines for Laboratory Analysis 2-5
Table 2-2. Change Control Procedures for the Root Excavation Study Plan 2-7
Table 3-1. Example of Plant Specimen Data Recorded During Field Scouting Activities 3-6
Table 3-2. Number and Type of Collocated Soil Cores Collected 3-14
Table 3-3. Requirements for Soil and Vegetation Sample Analysis 3-15
Table 3-4. Number and Type of Sample Analysis per Excavation Interval for Total Root Excavation and Soil Core Drilling 3-23
Table 3-5. Descriptive Statistics Overview 3-27
Table 3-6. Simple Linear Regression Analyses – Aboveground Plant and Soil Characteristics Relationship to Root Depth and Root Biomass 3-27
Table 3-7. Statistical Test to Compare Methodologies 3-28

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Terms

ANOVA	analysis of variance
BT	biomobilization team
BTL	biomobilization technical lead
BTR	buyer's technical representative
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy, Richland Operations Office
DOT	U.S. Department of Transportation
DQA	data quality assessment
DQI	data quality indicator
DQO	data quality objective
ECO	environmental compliance officer
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FS	feasibility study
FSO	field sample operations
FSP	field sampling plan
FWS	field work supervisor
GPR	ground-penetrating radar
GPS	global positioning system
HASQARD	*Hanford Analytical Services Quality Assurance Requirements Document*
HEIS	Hanford Environmental Information System
IATA	International Air Transportation Association
IDW	investigation-derived waste
LOE	line of evidence
MSW	miscellaneous solid waste
MTCA	Model Toxics Control Act
NCO	Nuclear Chemical Operator
OU	operable unit
PRC	Plateau Remediation Contractor
PSQ	principal study question
QA	quality assurance

QAPjP	quality assurance project plan
QC	quality control
RCO	Radiological Control Organization
SME	subject matter expert
SMR	sample management and reporting
SP	study plan
UTM	universal transverse mercator

1 Introduction

Plant roots play an essential role in overall plant health and longevity. Roots are critical to plant mineral nutrition, regulation of various plant-soil interactions, and influencing plant-microbial relationships. Overall, plant roots have the unique ability to manipulate their immediate surroundings to meet the plant's biological needs. Roots penetrate and move through the soil in search of water and minerals that are required for plant growth, development, and reproduction. Roots are essential to plant life by providing uptake and absorption of nutrients. However, the same mechanisms (e.g., uptake, absorption) that sustain plant life can be used within radiologically contaminated soil environments to biomobilize soil radionuclides aboveground vertically, thereby creating a potential pathway of exposure to external radiation. To understand vertical biomobilization[1] of radionuclides by Hanford Site plant species, there is a need for characterizing systems of deep-rooted shrub-steppe Central Plateau species. The methods and procedures presented in this study plan (SP) will inform Hanford Site remedial decision making by defining the physical and biological factors (i.e., species-specific root penetration depth, depth-specific root mass, soil physical characteristics) that influence root intrusion and vertical radionuclide biomobilization within the shallow (0-4.9 m [0-16 ft]) vadose zone of the Hanford Site Central Plateau (Figure 1-1).

This study is the second of a complimentary line of evidence (LOE) approach that evaluates root characteristics influencing vertical biomobilization of soil radionuclides by key deep-rooted vegetation on the Hanford Site Central Plateau. The first LOE study conducted as part of the Central Plateau Biomobilization Program is detailed in DOE/RL-2017-14, *Study Plan to Evaluate Radionuclide Biomobilization in Opportunistically Identified Contaminated Deep-Rooted Vegetation in the Hanford Site Central Plateau*. Additional biomobilization LOE studies necessary to support remedial decision making will be documented in future SPs.

1.1 Study Scope and Need

Understanding vertical biomobilization of radionuclides by Hanford Site plant species requires characterizing the root systems of deep-rooted shrub-steppe Central Plateau species that may be present. This Hanford Site root characterization study will explore root characterization of deep-rooted vegetation species using two methods: root core drilling and complete plant root excavation. Plants identified as target species for root characterization were identified by reviewing available local information and visiting Hanford Site Central Plateau locations of interest where the targeted species were known to occur. Targeted deep-rooted vegetation species on the Central Plateau are the annual forb Russian thistle (*Salsola kali*) and perennials big sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), and gray rabbitbrush (*Ericameria nauseosa*).

Total root excavation and soil core drilling methods for targeted species will be used to determine root penetration depth as well as measure root biomass by depth within the soil column (i.e., down to a maximum depth of 4.9 m [16 ft]). Plant measurements such as plant height, canopy width, plant trunk circumference, root perimeter area, soil type, percent soil and plant moisture, soil and plant dry weight, soil and plant fresh weight, and plant (perennials) age will be determined to explore possible relationships with root penetration and root biomass by depth.

[1] Vertical biomobilization is defined as contaminant movement through the soil column to the soil surface through varying mechanisms such as vegetation uptake and translocation through root systems, animal burrowing, and invertebrate burrowing.

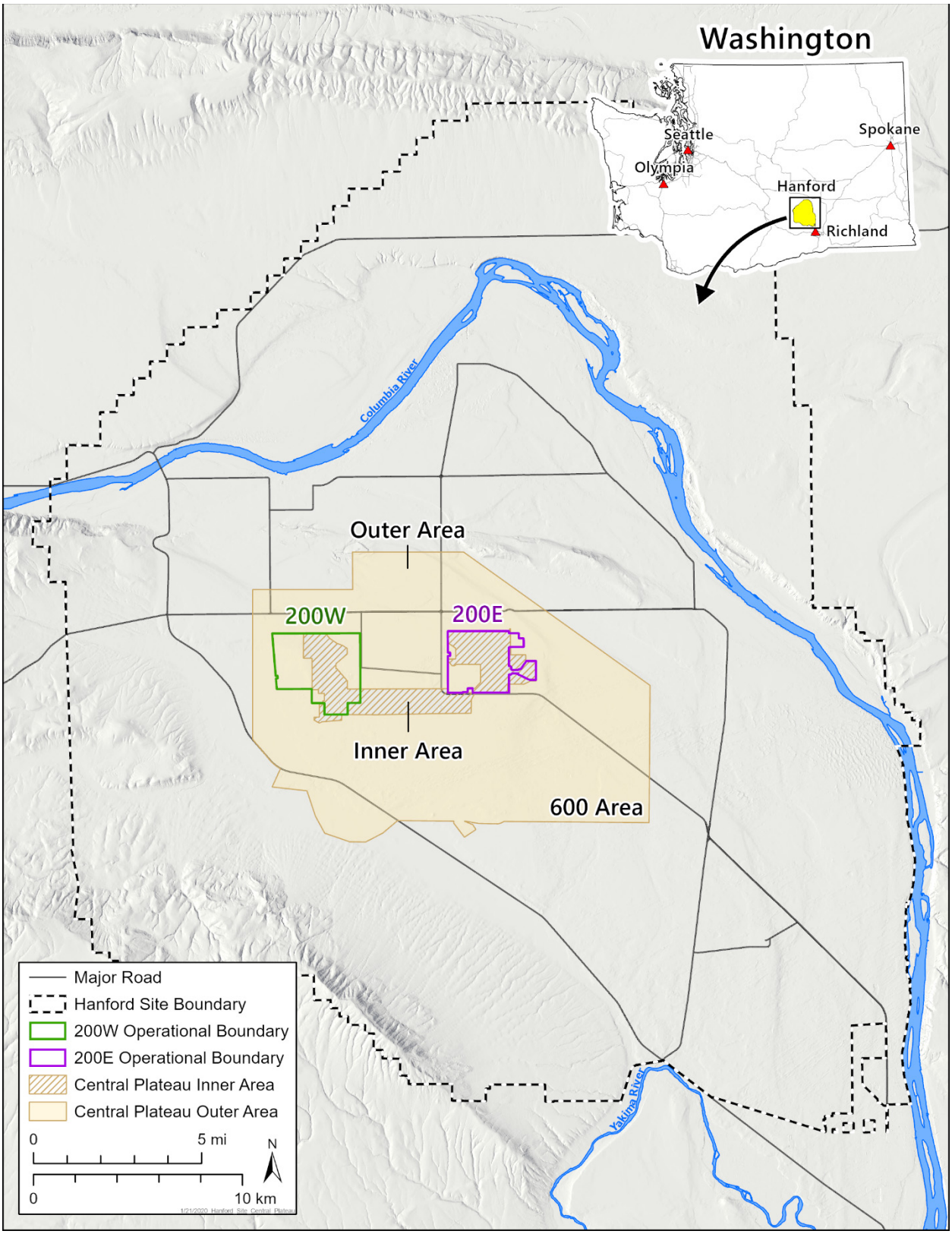

Figure 1-1. Hanford Site Central Plateau

The data and information generated in this root study will inform soil remedial alternative evaluations (specifically, a "leave-in-place" option) in future feasibility studies (FSs). The 3 to 4.6 m (10 to 15 ft) shallow vadose zone is of particular interest because it represents the boundary between a suggested Hanford Site-specific bioactive zone depth (3.05 m [10 ft]) (CHPRC-00651, *Evaluation of Biointrusion at the Hanford Site for Protection of Ecological Receptors*; Sample et al., 2015, "Depth of the Biologically Active Zone in Upland Habitats at the Hanford Site, Washington: Implications for Remediation and Ecological Risk Management") and the standard soil point of compliance depth of 4.6 m (15 ft). This depth range is subject to WAC 173-340 regulations ("Model Toxics Control Act—Cleanup" [MTCA]) for protection of ecological receptors, which allows for the regulated community to petition for a conditional point of compliance soil depth for protection of ecological receptors following specified procedures (e.g., WAC-173-340-7490(4)(a), "Terrestrial Ecological Evaluation Procedures").

This SP was developed using the data quality objective (DQO) process and detailed in Appendix A.

1.2 Background

This section evaluates the significance of the radionuclide biomobilization pathway for waste management areas and operable unit (OUs) within the Central Plateau.

1.2.1 Central Plateau Habitat and Land Uses

The Central Plateau encompasses the 200 1 Area NPL (40 CFR 300, Appendix B) site and includes two principal areas, as shown in Figure 1-1:

- **Inner Area:** Defined as the final footprint area of the Hanford Site, the Inner Area is dedicated to long-term waste management and containment of residual contamination. The Inner Area covers 25.9 km^2 (10 mi^2) and will remain under federal ownership and control as long as potential hazards exist.
- **Outer Area:** The Outer Area portion of the Central Plateau is outside the boundary of the Inner Area. Contaminated soil and debris removed as part of Outer Area cleanup will be placed in the Inner Area for final disposal. Completing cleanup of the approximately 170 km^2 (65 mi^2) Outer Area will shrink the active footprint of the Central Plateau to the Inner Area (DOE/RL-2009-10).

The Central Plateau is located in a semiarid climate with average annual precipitation of 17 cm (6.8 in.). Average monthly temperatures from 1945 through 2015 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 (DOE/RL-96-32, *Hanford Site Biological Resources Management Plan*).

The habitat is predominantly shrub-steppe. The shrub overstories are dominated by sagebrush (*Artemisia* spp.), antelope bitterbrush (*Purshia tridentata*), and gray (*Ericameria nauseosa*) or green rabbitbrush (*Chrysothamnus viscidiflorus*), with perennial bunchgrass understories dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*), Sandberg's bluegrass (*Poa secunda*), Indian ricegrass (*Achnatherum hymenoides*), or needle-and-thread grass (*Hesperostipa comata*) (DOE/RL-96-32). Large range fires in recent years have altered the composition of the habitat, decreasing the extent of mature sagebrush stands and increasing non-native species such as tumbleweed (Russian thistle) and tumble mustard (*Sisymbrium altissimum*) (PNNL-6415, *Hanford Site National Environmental Policy Act [NEPA] Characterization*). Within the Inner Area, which has a higher density of waste sites than the Outer Area, much of the ground surface is intentionally kept barren to support ongoing operations. Invasive species such as Russian thistle and cheatgrass (*Bromus tectorum*) are commonly associated with disturbed soils present over waste sites (PNL-2774, *Characterization of the Hanford 300 Area Burial*

Grounds, Task IV – Biological Transport). In contrast, portions of the shrub-steppe habitat in the Outer Area have been relatively undisturbed for over 70 years.

Dominant soil types within the Central Plateau are Quincy sand, Burbank loamy sand, Hezel sand, and Ephrata sandy loam. The Burbank, Hezel, and Quincy soil types are excessively well drained, coarse-textured soils underlain by gravel, sand, or lacustrine material at a depth of 25.4-101.6 cm (10-40 in.) with shallow slopes, low to moderately high water-holding capacity, moderate to very rapid permeability, slight to moderate water erosion hazard, and severe wind erosion hazard (Rasmussen, 1971, *Soil Survey of Benton County Area, Washington*). Coarse soils foster diffuse recharge (PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*). The Ephrata sandy loam is medium-textured and is underlain by gravelly material that may have a depth of several feet; it is associated with Burbank soil (BNWL-243, *Soil Survey: Hanford Project in Benton County Washington*).

The Columbia River is approximately 4.5 km (2.8 mi) north of the northern boundary of the Central Plateau. Active ponds within the Central Plateau include West Lake (a seasonal, highly saline waterbody, recharged naturally from groundwater) and the 200 Area Treated Effluent Disposal Facility disposal ponds (PNNL-6415). There are no streams located within the Central Plateau. Depth to groundwater within the Central Plateau varies from 54.9 to 93 m (180 to 305 ft) (DOE/RL-2011-50, *Regulatory Basis and Implementation of a Graded Approach to Evaluation of Groundwater Protection*).

1.2.2 Biomobilization at the Hanford Site Central Plateau

More than 80 plant and animal species known to transport radiological contamination on the Hanford Site are listed in WCH-316, *Hanford Site Biological Transport Summary*. The report describes the following terrestrial species as the most significant regarding biological transport throughout the Central Plateau: tumbleweed (*Salsola kali*), mulberry trees (*Morus alba*), other riparian plants such as reed canary grass (*Phalaris arundinacea*) and locust trees (*Robinia pseudo-acacia*), harvester ants (*Pogonomyrmex owyheei*), fruit flies (*Drosophila melanogaster*), mud daubers (wasps) (*Sceliphron caementarium*), waterfowl, pheasants, swallows, rock doves, avian predators and scavengers (e.g., owls, hawks, and magpies), mice, rabbits such as jackrabbits (*Lepus* spp.) and cottontail rabbits (*Sylvilagus nuttallii*), badgers (*Taxidea taxis*), coyotes (*Canis latrans*), and mule deer (*Odocoilus hemionus*).

Vegetation is continually managed at waste sites on the Central Plateau using herbicides and physical removal because measured radionuclide doses are regularly found to exceed Radiological Control Organization (RCO) thresholds (i.e., localized background concentrations). For tumbleweed (Russian thistle or tumble mustard), the entire aboveground portion of the plant becomes mobile at the end of its annual lifecycle. The stem of the plant detaches from its roots and can physically spread contamination (i.e., plant fragments, including seeds and litter) across large areas as the plant is carried by wind, hence the term “tumbleweed.”

Mammals known to burrow to various depths in contaminated soils (CHPRC-00651; Sample et al., 2015) are exposed to and frequently uptake radionuclides and are therefore removed from work areas (Table 1-1). Several species of ant occur on the Hanford Site, with harvester being most common and known to excavate deeper than burrowing small mammal species (CHPRC-00651; Sample et al., 2015).

Table 1-1. Frequency of Observations of Contamination in Media from the Hanford Site Central Plateau

Years	Number (and %) of Observations											Total
	Ants	Birds and Bats	Invertebrates (Other)	Manmade Materials	Mice	Soil and Related Materials	Tumbleweeds	Urine and Feces	Vegetation (Other)	Vertebrates (Smaller)	Vertebrates (Larger)	
1994–1998	16 (3%)	11 (2%)	26 (4%)	1 (<1%)	75 (12%)	264 (44%)	140 (23%)	34 (6%)	21 (3%)	14 (2%)	2 (<1%)	604
1999–2003	4 (1%)	2 (1%)	5 (1%)	1 (<1%)	10 (3%)	91 (26%)	212 (60%)	18 (5%)	8 (2%)	3 (1%)	1 (<1%)	355
2004–2008	4 (1%)	3 (1%)	2 (<1%)	2 (<1%)	19 (4%)	67 (14%)	323 (65%)	59 (12%)	9 (2%)	6 (1%)	0 (0)	494
2009–2013	5 (1%)	25 (6%)	0 (0)	13 (3%)	3 (1%)	86 (20%)	204 (47%)	77 (18%)	16 (4%)	1 (<1%)	0 (0)	430
2014–2016	2 (1%)	22 (7%)	0 (0)	5 (2%)	20 (6%)	55 (17%)	136 (42%)	77 (24%)	3 (1%)	1 (<1%)	0 (0)	321
Totals	**31 (1%)**	**63 (3%)**	**33 (1%)**	**22 (<1%)**	**127 (6%)**	**563 (25%)**	**1,015 (46%)**	**265 (12%)**	**57 (2%)**	**25 (1%)**	**3 (<1%)**	**2,204**

Notes: "Ants" includes the insects themselves, hills, and mounds.
"Birds and bats" includes various species and nests.
"Invertebrates (other)" includes bees and wasps, caterpillars, beetles, flies, and unidentified insects.
"Manmade" includes a concrete floor, caisson, asphalt, foam, boot, riser pipe cap, and a power pole.
"Mice" includes the species themselves, plus nests, carcasses, skeletons, and bait stations.
"Soil and related materials" includes entries for contaminated soil spots, specks, dust, gravel, stone, and rocks.
"Tumbleweeds" include rooted, loose, fragments, soil, seeds, and specks. Species of tumbleweed are not specified but are assumed to include predominantly Russian thistle and some tumble mustard.
"Urine and feces" include urine and feces from birds and mammals.
"Vegetation (other)" includes vegetation other than tumbleweed such as bunch grass, rabbitbrush, sagebrush, crested wheat grass, grass, dried vegetation, bunchgrass, cattail reed or fragments, shrubs, and grass root ball or sod material.
"Vertebrates (smaller)" includes rats, rabbits, snakes, gophers, toads, and lizards.
"Vertebrates (larger)" includes data for coyote, deer, and feral dogs.

Environmental radiological surveys are routinely conducted across the Hanford Site. The frequency of contaminated media observed during these radiological surveys is summarized in Table 1-1. The table summarizes radiologically contaminated media in 5-year increments from a spreadsheet of environmental surveillance data for the years 1994 – 2016 based on the quarterly environmental radiological survey reports. The data are filtered to include only locations within the Central Plateau. The detection frequencies are related, in part, to the frequency and intensity of monitoring, which has varied over the years. In all but the first 5 years, the most frequently reported contaminated media was tumbleweeds, while the second most frequently reported media varied between soil and urine/feces. For the entire reporting period, tumbleweeds accounted for 46% of all observations.

Biota (e.g., plants, harvester ants, and mammals) are not equal in their relative importance to vertical biomobilization of soil radiological contamination on the Central Plateau. Vertical biomobilization by

deep-rooted plants, particularly tumbleweed,[2] is most frequently reported in summary reports prepared quarterly over the past 22 years (Table 1-1). Root intrusion of the targeted vegetation species for this study are at depths as follows: Russian thistle 2.4 m (7.9 ft), tumble mustard <2.4 m (<7.9 ft), sagebrush 2.5 m (8.2 ft), antelope bitterbrush 3 m (9.8 ft), and (gray) rabbitbrush 2.5 m (8.2 ft). These rooting depths extend deeper than the burrowing depths of both ants and mammals (CHPRC-00651; Sample et al., 2015). In addition, plants have greater spatial distribution across the Central Plateau compared to terrestrial invertebrates and vertebrates. Sample et al., 2015 reports that big sagebrush, the dominant shrub over much of the Hanford Site, represents 26% of total land cover, significantly larger than the spatial distribution of terrestrial invertebrates (harvester ants excavate a soil volume of 5440 cm^3 over 19,424 ha) and large mammals (e.g., badger density one animal or 10 dens/260 ha). Small mammals such the Great Basin pocket mouse (*Perognathus parvus*), the most abundant mammal on the Hanford Site, has reported population densities of between 12 and 28 individuals/ha in sagebrush habitats (Sullivan and Sullivan, 2008, "Dynamics of Peripheral Populations of Great Basin Pocket Mice, *Perognathus parvus*, and Western Harvest Mice, *Reithrodontomys megalotis*, in Southern British Columbia"). Deep-rooted vegetation is therefore considered the dominant (but not the only) biota responsible for vertical biomobilization of subsurface radionuclide soil contamination across the Central Plateau.

The bioaccumulation of different radionuclides by plants on the Central Plateau varies widely. Uptake or concentration ratios (plant concentration/soil concentration) were <1 (10^{-2} to 10^{-6}) in Russian thistle for cesium-137 and the transuranics neptunium-237, plutonium-239, americium-241, and curium-244. In contrast, all concentration ratios reported in the same study for strontium-90 and technetium-99 exceeded one, indicating greater concentrations in biota tissues than soil (PNL-2253, *Ecology of the 200 Area Plateau Waste Management Environs: A Status Report*). In a later study also on the Central Plateau, concentration ratios in sagebrush ranged from 0.65 to 13.31 for technetium-99, 0.0 to 12.8 for cesium-137, and 0.02 to 145.5 for strontium-90 (WHC-EP-0771, *Comparison of Radionuclide Levels in Soil, Sagebrush, Plant Litter, Cryptogams, and Small Mammals*). PNL-2253 discusses the limitations to the concept of concentration ratios, emphasizing their location-specific nature. The wide range in concentration factors for the same radionuclide in the same plant species is attributed to differing exposure circumstances (e.g., old contaminated soil versus newly contaminated soil with airborne sources also present), soil type, and underlying soil chemical processes. In addition, research on metals indicates uptake to be a nonlinear process, with greater uptake at lower concentrations and lower uptake at higher concentrations (Efroymson et al., 2001, "Uptake of Inorganic Chemicals from Soil by Plant Leaves: Regressions of Field Data").

In a review of historical records of contaminated biota in the 200 Areas from 1965 to 1994 (WHC-MR-0418, *Historical Records of Radioactive Contamination in Biota at the 200 Areas of the Hanford Site*), tissue concentrations exceeded 10 pCi/g in 42% (1,900 out of approximately 4,500 individual cases) of observations for radionuclide uptake in or transport on biota. The 4,500 observations represented 45 species of wildlife (primarily small mammals including animal urine or feces) and 30 species of vegetation (most commonly Russian thistle). A total of 835 wildlife observations had concentrations >10 pCi/g of the reported analytes (cesium-137, strontium-90, plutonium-239, plutonium-240, and uranium [all isotopes]). The highest concentrations were 3,200,000 pCi/g strontium-90 in a Russian thistle in 1981 at the BC Cribs and 66,000,000,000 pCi/g strontium-90 in 1991 in a house mouse from the BX Tank Farm. The highest concentrations were most frequently from small mammals or animal feces. The report noted that reduced uptake and transport of contaminants was observed at waste areas that had been interim stabilized.

[2] Species of tumbleweed are not specified in radiological monitoring and reporting but are assumed to include predominantly Russian thistle and some tumble mustard.

The frequency of contaminated media observed during routine environmental radiological surveys is an indication of more recent biomobilization patterns on the Central Plateau. Table 1-1 summarizes Central Plateau radiological survey reports from 1994 to 2016. The detection frequencies are related in part to the frequency and intensity of monitoring, which has varied over the years. In all but the first 5 years, the most frequently reported contaminated media was tumbleweeds (species unspecified but assumed to include predominantly Russian thistle with some tumble mustard), while the second most frequently reported media varied between soil, urine, and feces. For the entire reporting period, tumbleweeds accounted for 46% of all observations; additionally, maximum and mean activity levels in vegetation were 9,000,000 and 379,619 dpm/100 cm^2; in ant mounds, >1,000,000 and 295,065 dpm/100 cm^2; and in mammal tissue, urine and feces were 6,000,000 and 282,888 dpm/100 cm^2. (Note that for the averages, some values did not include areal units, and the missing units were assumed to be 100 cm^2). Of the three taxa known to biomobilize contaminants on the Hanford Site, deep-rooted plants appear to be associated with the greatest amount of upward biomobilization.

1.2.3 Conceptual Exposure Model

Intrusion into contaminated soil by the roots of some deep-rooted vegetation species occurring on the Hanford Site may have implications for exposure of human receptors and with the derivation of health protective soil remedial alternatives in future FSs. Historical operations at and waste management of the Central Plateau have resulted in contaminated soils (and structures) at the ground surface and at depth. As shown by Hanford Site data (Table 1-1), deep-rooted vegetation species can extend roots into contaminated soils and translocate radionuclide contamination to the aboveground plant. Once biomobilized to the surface, radionuclides in plant tissue represent a source of radiological contamination with potential risk implications to outdoor workers. The primary human exposure pathway is external gamma exposure from biomobilized gamma-emitting radionuclides in areas where radiologically contaminated vegetation[3] is present (Figure 1-2).

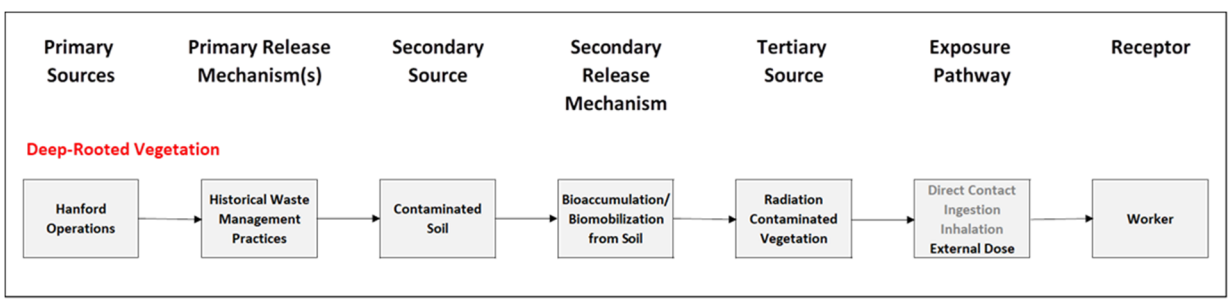

Figure 1-2. Conceptual Site Model for Outdoor Worker Exposure to Soil Radiological Contaminants Biomobilized by Deep-Rooted Vegetation

1.3 Data Quality Objective Summary

The DQO defines data collection criteria as well as ensures the type, quantity, and quality of data are consistent with intended application. Appendix A summarizes the detailed DQO process for this root study.[4]

Empirical data generated during this study will answer the questions "what is the mean root penetration depth, and the mean root biomass by soil depth of mature, well established deep-rooted shrub steppe species at the Hanford Site?" In addition, relationships between aboveground plant and soil characteristics

[3] Worker exposures to radiologically contaminated material vertically biomobilized by other biota (e.g., soil in mounds excavated by burrowing ants) can also occur and may be the subject of future sampling and analysis activities.
[4] Other DQO aspects are presented in Chapter 3, including study design, statistical design, and hypothesis testing.

and how they relate with root depth as well as root biomass by depth will be explored. Finally, differences between two selected root excavation methodologies will be assessed to determine which methodology may be the most efficient and effective for supporting future biomobilization research of deep-rooted plant species on the Hanford Site.

1.3.1 Problem Statement and Definition

Historical operations and waste management on the Hanford Site have resulted in the presence of radiologically contaminated soils at the surface and at depth. Waste management areas with shallow soil radioactive contamination typically have been stabilized by adding clean cover (soil, gravel, etc.) to reduce exposure from radionuclides to workers. Plants within deep-rooted shrub-steppe vegetation are known to extend roots deeply into contaminated soils and translocate (i.e., vertically biomobilize) radionuclide contamination to the surface as documented through routine radiation monitoring and control operations on the Hanford Site. Biomobilization by vegetation species results in a noncontact gamma radiation exposure pathway to onsite workers in areas where biomobilized radiological contamination is present at the surface (i.e., in aboveground vegetative tissues), as illustrated in Figure 1-2. Understanding rooting depths informs whether the mandated MTCA soil cleanup point of compliance protects workers from radionuclide biomobilization by colonizing deep-rooted species post remediation (e.g., in areas with a potential "leave in place" remedial option) or whether an alternative conditional point of compliance would provide adequate protection. The existing data for Hanford Site relevant shrub-steppe vegetation are currently insufficient to ascertain with confidence maximum root penetration depths of shrub-steppe vegetation on the Central Plateau. To address this data need, root penetration and root biomass by soil depth for targeted deep-rooted vegetation species will be measured. Selected specimens of deep-rooted plant species from within the Hanford Site boundary will be identified using scientific judgement and expertise and then sampled by selecting the most efficient, effective, and occupationally safe root characterization methodologies.

1.3.2 Principal Study Questions

This SP includes five principal study questions (PSQs):

PSQ 1: For focal mature shrub-steppe vegetation species[5] on the Central Plateau, what is the deepest observed root penetration depth (i.e., across discrete soil depth intervals) within the study targeted soil depth range (0–4.9 m [0–16 ft])?

PSQ 2: For focal mature shrub-steppe vegetation species[7] on the Central Plateau, what is the distribution of root biomass per unit of soil volume within discrete soil depth intervals of the study targeted soil depth range(0–4.9 m [0–16 ft])?

[5] Focal mature shrub-steppe vegetation specimens are defined as those specifically targeted for root characterization based on their association with the Central Plateau, their estimated plant age and root depth, their reported biomobilization potential, and reported rooting depth in the literature. Targeted species include the annual forb Russian thistle (*Salsola kali*) and the perennials big sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), and gray rabbitbrush (*Ericameria nauseosa*).

PSQ 3: For focal mature shrub-steppe vegetation species[7] on the Central Plateau, do aboveground physical shrub measurements (e.g., aboveground biomass, plant height, canopy width, root perimeter, plant trunk circumference, age, etc.) correlate with belowground root penetration depth or root biomass per soil volume unit within the study targeted soil depth range (0-4.9 m [0-16 ft])?

PSQ 4: For soil within the study targeted soil depth range (0-4.9 m [0-16 ft]) occurring beneath focal, mature shrub-steppe vegetation specimens on the Central Plateau, is there a correlation between soil grain size profile and root penetration depth and belowground biomass per unit of soil volume?

PSQ 5: For focal mature shrub-steppe vegetation specimens on the Central Plateau, does observed shrub root penetration and root biomass by depth per unit of soil volume within the study targeted soil depth range (0–4.9 m [0–16 ft]) differ based on the type of root characterization method (i.e., root excavation versus root coring)?

The data gaps addressed by the PSQs are (1) rooting depth; (2) root biomass by depth; (3) identification of key relationships (if any) between aboveground plant characteristics and rooting depth as well as root biomass; (4) identification of key relationships (if any) between soil grain size profile and rooting depth as well as root biomass; and (5) differences or similarities between root excavation methodologies based on mean root depth and root biomass by soil depth per target vegetation species. Below are the decision statements or estimation statements needed to address the PSQs.

1. The principal estimate to be made for each focal mature vegetation specimen for PSQ 1 is the observable root penetration depth within the study targeted soil depth range (0-4.9 m [0-16 ft]). It is expected that the deepest root penetration will be observed in the most mature (oldest) specimens (soil type and soil grain size profile may also play a role in root penetration depth).

2. The principal estimate to be made for each focal mature vegetation specimen for PSQ 2 is the root mass per unit of soil volume (eight soil depth intervals) within the study targeted soil depth range (0-4.9 m [0-16 ft]). It is expected that the greatest root biomass per soil volume will be observed in the shallowest soil depth intervals.

3. The principal estimate to be made for each focal mature vegetation specimen for PSQ 3 are regression analyses to explore relationships between aboveground shrub specimen measurements (shrub height, canopy width, root perimeter, aboveground biomass, plant trunk circumference, and age via trunk ring counting) as well as both root penetration depth and biomass measurements. There is no a priori expectation regarding potential relationships, which will be determined during this study.

4. The principal estimate to be made for each focal mature vegetation specimen for PSQ 4 are regression analyses between soil grain size profile within the study targeted soil depth range (0–4.9 m [0–16 ft]) and root penetration and root biomass by depth. There is no a priori expectation regarding these potential relationships, which will be determined during this study.

5. The principal estimate to be made for each focal mature vegetation specimen for PSQ 5 is whether statistically significant differences ($p \leq 0.05$) in mean specimen root penetration and mean root biomass by soil depth are evident between the root characterization methods: excavation and coring. There is no a priori expectation on whether there will be a statistically significant difference between methods used to determine mean root penetration or mean biomass.

1.4 Project Schedule

The project will be conducted over 3 years following a "mock field trial" to practice and optimize characterization activities and methods. A brief overview of study activities and generalized timeframes are summarized in Table 1-2.

Table 1-2. Study Activities and General Completion Timeframes

Study Activity	General Description and Completion Timeframe
BTL, BT, and BTR select root study candidate sampling locations	Identify candidate plant sampling location(s) based on type, number, and age of plant species present, access for drilling equipment, physical hazards, clearance review (cultural and ecological) concerns, including required mitigation for habitat destruction. This activity is likely to involve multiple identification efforts across the project cycle.
BTL and BT select specific target species plant specimens for clearance review and root characterization.	As soon as possible following sampling location selection. GPS coordinates of identified specimens are recorded and submitted for clearance review. Approximate completion timeframe following sampling area(s) selection is 1 month.
BTL, BT, and SMR initiate excavation permit and ecological and cultural resources review process	As soon as possible to provide a minimum schedule cushion of 120 days prior to either mock field trial or definitive study. Approximate completion timeframe is 3-6 months.
Preparation of Health and Safety Plans by participating organizations (BTL, DT, ECT, SPL, and HS)	As soon as possible following clearance review. Activity time anticipated to be 2-3 months.
SMR, FWS, BTR, and BTL finalize the DT and ECT field sampling teams	Finalize makeup of field sampling teams to perform excavations and soil core drilling activities. Completed as soon as possible following clearance review.
Setup of all necessary contracts for DT, SPL, and AL by BTR and SMR	As soon as possible following the ecological and cultural clearance review. Approximate completion timeframe is 2-3 months.
FWS, SMR, BTR, FSO, DT, RMS, ECO, ECT, HS, SPL attend mock field trial training workshop organized by BTL/BT	Training workshop(s) to review root study design details, sampling methods, health and safety requirements, DC, ECT, and PL requirements and roles, foreseeable field and laboratory problems requiring immediate procedure modifications (prior to initiating the mock field trial), 1-2 months.
FSO, FWS, DT, BT, ECO, ECT, and HS conduct a mock field trial overseen by BTL and BT	Following training, clearance and contract completion. Approximate completion timeframe is 3-4 months.
FWS, SMR, BTR, FSO, DT, ECO, ECT, HS, and SPL attend mock field trial "lessons learned" workshop organized by BTL and BT to identify required procedure or health and safety modifications (if any)	Within 4-6 weeks of mock field trial completion. DOE-RL will also be briefed on the lessons learned workshop findings.

Table 1-2. Study Activities and General Completion Timeframes

Study Activity	General Description and Completion Timeframe
FSO, FWS, BTL, BT, DT, ECO, ECT, and HS conduct definitive root study at selected locations	Following the finalization of SP incorporating lessons learned from the mock field trial. Study completion timeframe is up to 4 months annually over 3 years.
SMR, FSO, FWS, BTR, ECT, DT, and RMS perform or oversee sample location(s) cleanup (includes cleanup and removal of residual plant material, backfilling pits, removal of rock pads or roads, and conduct of required vegetation mitigation)	Ongoing throughout the study until completed.
BTL initiates data analysis	As soon as possible by BT following completion of fieldwork and receipt of all data from SPL and AL. Approximate timeframe of activity is 4 months annually.
Data report	Prepared at conclusion of a 3-year study. Annual RL briefings on study progress.

Note: These are general schedule guides applicable to the mock field trial and the conduct of the definitive root characterization study. Some schedule activities shown in the table may change following conduct of the mock field trial.

AL = analytical laboratory
BT = biomobilization team
BTL = biomobilization technical lead
BTR = buyers technical representative
DOE-RL = U.S. Department of Energy, Richland Operations Office
DT = drilling team
ECO = environmental compliance office
ECT = excavation team
FSO = field sample operations
FWS = field work supervisor
GPS = global positioning system
HS = health and safety
RMS = revegetation mitigation specialist
SMR = sample management and reporting
SP = study plan
SPL = sample preparation laboratory

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2 Quality Assurance Project Plan

This quality assurance project plan (QAPjP) establishes the quality requirements for environmental data collection and includes planning, implementation, and assessment of sampling tasks, field measurements, laboratory analysis, and data review. This chapter describes the applicable environmental data collection requirements and controls based on the QA elements found in the following documents:

- EPA/240/B-01/003, *EPA Requirements for Quality Assurance Project Plans*
- DOE/RL-96-68, *Hanford Analytical Services Quality Assurance Requirements Document* (HASQARD)
- DoD/DOE, 2019, *Department of Defense (DoD) Department of Energy (DOE) Consolidated Quality Systems Manual (QSM) for Environmental Laboratories*

Tri-Party Agreement quality assurance (QA)/quality control (QC) requirements apply to the data collection planning process and data collection activities to be performed under this SP. In addition, this QAPjP describes requirements and controls based on guidance outlined in Ecology Publication No. 04-03-030, *Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies*, and EPA/240/R-02/009, *Guidance for Quality Assurance Project Plans*. The QAPjP includes the following sections that describe the quality requirements and controls applicable to Hanford OU sampling activities:

- Section 2.1, Project Management
- Section 2.2, Data Generation and Acquisition
- Section 2.3, Assessment and Oversight
- Section 2.4, Data Review and Usability

2.1 Project Management

This section outlines project organization and responsibilities of the personnel associated with the root characterization study.

2.1.1 Project or Task Organization

The U.S. Department of Energy, Richland Operations Office (DOE-RL) is the lead agency for the root characterization study presented in this SP. DOE-RL directs the Plateau Remediation Contractor (PRC) or other contractor(s) responsible for planning, coordinating, collecting,[6] preparing, packaging, and shipping (as applicable) samples to the laboratory(-ies). Sampling activities for the root characterization study are independent of sampling and characterization activities planned for existing Central Plateau OUs through the remedial investigation/feasibility study (RI/FS) process. The project organization is described in the following sections and outlined in Figure 2-1.

[6] Includes soil and root core collection and field excavation root data (root length and biomass data).

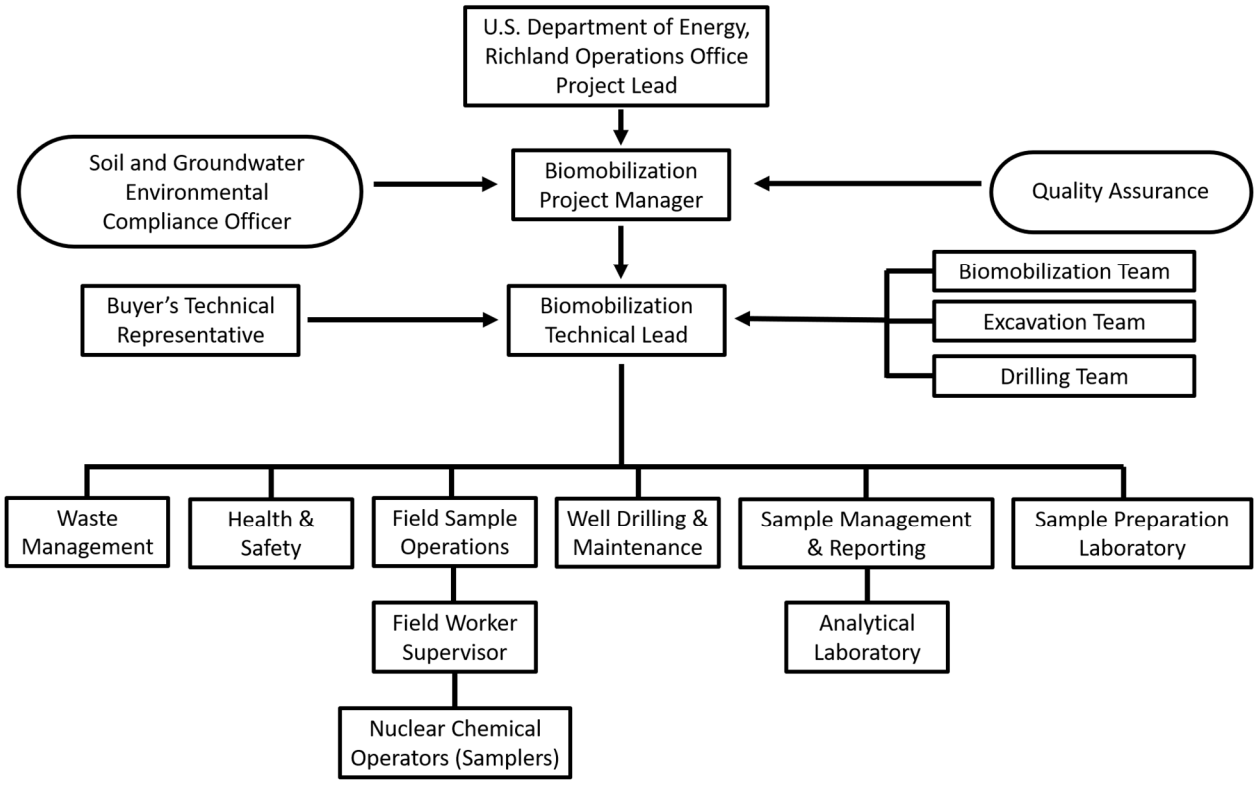

Figure 2-1. Project Organization

2.1.1.1 U.S. Department of Energy, Richland Operations Office Project Lead

The DOE-RL project lead oversees the contractor's performance and works with the contractor and regulatory agencies, as applicable, to resolve issues and provide technical input to DOE-RL management.

2.1.1.2 Biomobilization Project Manager

The PRC biomobilization project manager is responsible and accountable for root characterization study activities, including coordinating with DOE-RL, regulatory agencies, and contractor management to support root characterization study activities and to ensure that work is performed safely and cost effectively. In addition, the biomobilization project manager (or designee) oversees documentation, requirements, field activities, subcontracted tasks, and project files to ensure they are properly followed or maintained.

2.1.1.3 Biomobilization Technical Lead

The biomobilization technical lead (BTL) is the technical authority and subject matter expert (SME) on the root characterization study design and study objectives, and ensures that field and sample preparation activities are conducted in accordance with the SP. The BTL (or designee) coordinates with the buyer's technical representative (BTR), supervises field activities and conducts (or designates) field assessments documenting compliance with all SP technical requirements. The BTL collaborates with the environmental compliance officer (ECO), QA organization, Health and Safety organization, sampling field work supervisor (FWS), and Sample Management and Reporting (SMR) to integrate technical disciplines in the planning and implementation of the root characterization study.

2.1.1.4 Buyer's Technical Representative (BTR)

The BTR represents the PRC's technical position, interfacing with project, technical, and SMEs to ensure that subcontractors adhere to their contracts. The BTR participates in the pre-award acquisition, coordinates contractor's mobilization and logistics, provides technical direction (SP compliant) and guidance to the contractor (within scope of the contract), monitors the contractor's work to ensure successful performance, and thoroughly reviews all invoicing and payment to confirm that the authorized work has been completed and accepted. The BTR is a key point of contact between the BTL's designated biomobilization team representative and other PRC study personnel.

2.1.1.5 Biomobilization Team

The biomobilization team (BT) is comprised of designated biomobilization team representative(s) (selected by the BTL) and an external SME with Hanford Site vegetation, biointrusion, and biomobilization expertise. The biomobilization team serves numerous roles including but not limited to the following responsibilities:

- Coordinating with PRC on initiating or tracking the clearance process for each identified sampling location
- Coordinating with the BTL to determine locations of specific plant specimens for root characterization
- Maintaining a separate (i.e., from the FWS) field notebook for daily oversight activity observations
- Maintaining project files
- Supporting the conduct of the study and performing specific data collection activities in the field
- Overseeing the field compliance assessments as directed by the BTL

2.1.1.6 Drilling and Excavation Teams

The drilling and excavation operation managers work with the BTR, BTL, and BT, and are responsible for the following tasks:

- Planning, coordinating, and executing the root excavation and soil core drilling work to meet the requirements of the SP. The soil coring work will be conducted using a continuous coring method to collect "tight" intact soil cores that can be cut into the eight required core depth intervals.
- Conducting the root excavation work by removing large areas of soil surrounding the plant specimen at 0.61 m (2 ft) intervals until 4.9 m (16 ft) depth is achieved.
- Communication with health and safety regarding implementation of safe work conditions and procedures during drilling and excavation processes.
- Coordinating with the field sample operations (FSO), FWS, and BTL (or designee) regarding field constraints, sampling questions, or any proposed field changes to aspects of the sampling activity that could have a significant effect on sampling design (and study outcomes).

2.1.1.7 Field Sample Operations, Field Worker Supervisor, Nuclear Chemical Operator

The FSO is responsible for planning, designating and coordinating field sampling resources. The FWS identifies and documents any deviation from the field sampling requirements, and communicates immediately any change control requirements to the BTR and BTL. Under FWS supervision, the nuclear chemical operator (NCO) field samplers complete field logbooks, data forms, and chain-of-custody forms (including any shipping paperwork, if required) and coordinate delivery of field samples to the sample preparation laboratory (or analytical laboratory in the case of some root excavation samples). NCOs will be trained to perform their required activities consistent with the requirements of this SP.

Pre-job briefings are conducted by the FSO in accordance with work management and work release requirements to evaluate activities, proper field documentation, and associated job hazards by considering the following factors:

- Objective of the activities
- Individual tasks to be performed
- Field documentation requirements (field logbook maintenance)
- Hazards associated with the planned tasks (and equipment)
- Controls applied to mitigate the hazards
- Environment in which the job will be performed
- Location where the job will be performed
- Equipment and material required

Each participating organization in the root characterization study field work is responsible for attending the pre-job briefing as well as documenting their organization's health and safety briefing requirements.

2.1.1.8 Sample Management and Reporting

The SMR position oversees offsite laboratories (sample preparation and analytical laboratories), coordinates with the laboratory to ensure that laboratories conform to the requirements of this plan, and verifies that laboratories are qualified to perform Hanford Site work. The SMR generates field sampling documents, sample authorization forms (providing information and instruction to the laboratories), and sample labels. The SMR revises field sampling documents to reflect approved changes and is responsible for resolving any sample documentation deficiency or issue associated with FSO or other entities. Receiving data from the laboratories, the SMR ensures that the data are appropriately reviewed, performs data entry into the Hanford Environmental Information System (HEIS) database, and arranges for data validation, data usability, and recordkeeping. SMR is also responsible for informing the BTL (or designee) of any issues reported by the laboratory(s).

2.1.1.9 Environmental Compliance Officer

Reporting to the biomobilization project manager (or BTL), the ECO provides technical oversight, direction, and acceptance of project and subcontracted environmental work and also develops appropriate mitigation measures with the goal of minimizing adverse environmental impacts.

2.1.1.10 Health and Safety

The Health and Safety organization is responsible for coordinating industrial safety and health support within the project as performed through health and safety plans, job hazard analyses, and other pertinent safety documents required by federal regulations or internal primary contractor work requirements.

2.1.1.11 Sample Preparation Laboratory

The contracted sample preparation laboratory processes deep-rooted vegetation (roots and soil from soil cores, aboveground plant tissue) to prepare composite samples and perform other sample characterization activities. The sample preparation laboratory works with SMR to submit prepared composite samples to the contracted analytical laboratory.

2.1.1.12 Analytical Laboratories

The analytical laboratories conducting identified testing (soil grain size profile analysis, soil typing, etc.) will do so in accordance with established procedures and subcontract requirements, and provide necessary data packages containing results for physical measurements and any QC and maintenance records associated with equipment used that affect measurement quality. Laboratories will provide explanations of results to support data review and resolve any issue with testing, QC, or maintenance records. Statements of work flow include quality requirements consistent with HASQARD (DOE/RL-98-68). The laboratories are evaluated under the DOE Consolidated Audit – Accreditation Program (or successor programs) to DoD/DOE (2019) requirements and must be accredited by Washington State Department of Ecology (Ecology) for the PRC-performed analyses.

Note: Physical parameter measures (i.e., rather than chemistry or radiochemistry analyte measures) are the only measurements conducted for root characterization study samples collected under this SP (all root work is done within uncontaminated Hanford Site locations). Accordingly, data quality indicators typically specified in DOE contractor analysis plans for chemistry and radiochemistry measures are not applicable to the limited physical measures to be conducted in this root study (Table 2-1).

Table 2-1. Soil and Vegetation Tissue Holding Time Guidelines for Laboratory Analysis

Parameter	Matrix	Preservation	Holding Time
General Parameters			
Dry weight	Soil, plant, root tissue	None required	As soon as possible following sample receipt
Percent moisture	Soil, plant, root tissue	None required	As soon as possible following sample receipt
Fresh weight	Soil, plant, root tissue	None required	As soon as possible following sample receipt
Soil type	Soil	None required	None
Grain size	Soil	None required	None

Note: The information in this table does not represent U.S. Environmental Protection Agency requirements but is intended solely as guidance. Selection of container and applicable holding times should be based on the stated project-specific data quality objectives.

2.1.1.13 Quality Assurance

The QA point of contact provides independent implementation of the project QA requirements and addresses any QA issue. Responsibilities include reviewing project documents (including the QAPjP) and participating in QA assessments on sample collection and analysis activities.

2.1.1.14 Waste Management

The waste management organization is responsible for identifying waste management sampling and characterization requirements to ensure regulatory compliance and for interpreting data to determine waste designations and profiles. Waste management communicates policies and practices and ensures project compliance for storage, transportation, disposal, and waste tracking safely and cost effectively.

2.1.2 Special Training and Certification

The following subsections describe the required biological expertise and worker training requirements necessary for conducting the root characterization study.

2.1.2.1 Required Biological Expertise

The sample preparation laboratory personnel will possess the expertise and experience to perform nonroutine biological sample processing as defined in this SP. Botanical expertise (e.g., sample preparation laboratory lead, at a minimum) is required to identify and age deep-rooted perennial vegetation accurately, as characterized in this study. Plants of interest include deep-rooted annual and perennial species Russian thistle, sagebrush, antelope bitterbrush, and gray rabbitbrush.

Sample preparation laboratory personnel will be required to prepare representative samples of multiple plants and their root tissue. In addition, personnel will need to identify Russian thistle lifecycle stage at the time of sampling as well as competence to key out Russian thistle subspecies (*Sasola kali* ssp. *tragus*, etc.), big sagebrush subspecies (*Artemisia tridentata* ssp. *wyomingensis*, *tridentata*, and *vaseyana*) and other sagebrush species (*A. rigida*).

2.1.2.2 Other Worker Requirements

Workers receive a level of training commensurate with their responsibility for collecting samples and that complies with applicable DOE orders and government regulations. Line management will ensure that the special training requirements for sample designated personnel are met for this study.

The contractor management team has instituted training and qualification programs that satisfy multiple instructional drivers imposed by applicable DOE, *Code of Federal Regulations*, and *Washington Administrative Code* requirements.

Records are maintained for each employee in an electronic training database. The contractor's training organization maintains the training records system. Line management confirms that an employee's training is appropriate and updated prior to employee performing any fieldwork.

2.2 Documents and Records

The biomobilization project manager (or designee) is responsible for ensuring that the current version of the SP is being used and that version control is maintained by the administrative document control process. If any changes are made to the SP, the project manager communicates the updates to field personnel. Table 2-2 defines the types of changes that may impact sampling and the associated approvals, notifications, and documentation requirements.

Logbooks and data forms are required for field and sampling activities. The logbook must be identified with an unique project name and number. Individuals responsible for the logbooks (owners) shall be identified in the front of the logbook, and only authorized individuals approved by a listed owner may make entries into the logbooks. Logbooks will be controlled in accordance with internal work requirements and processes.

Table 2-2. Change Control Procedures for the Root Excavation Study Plan

Type of Change*	Action	Documentation
Minor change: Change has no impact on the sample or field analytical result, and little or no impact on performance or cost. Further, the change does not affect the DQOs specified in the SP.	The field personnel recognizing the need for the field change will consult with the sampling FWS who will contact the biomobilization project manager (or designee [typically the biomobilization technical lead]) prior to implementing the field change.	Minor field changes will be documented in the field logbook by the sampling FWS. The logbook entry will include the field change, reason for the field change, and names and titles of those approving the field change.
Significant change: Change has a considerable effect on performance or cost but still allow meeting the DQOs specified in the SP.	The biomobilization project manager will inform the DOE-RL project manager of the change and seek concurrence during a telephone call or brief meeting.	Documentation of this change approval would be in a change authorization form or comparable record.
Fundamental change: Change has significant effect on the sample or the field analytical result, performance, or cost, and the change does not meet the DQO requirements specified in this SP.	If it is anticipated that a fundamental change will require the approval of the applicable DOE-RL project manager, notification will be made by the biomobilization project manager or designee, who will be involved with DOE-RL in the decision prior to implementation of a fundamental change.	Revision of the sampling document.

*Consistent with DOE/RL-96-68, *Hanford Analytical Services Quality Assurance Requirements Document*.

DOE-RL = U.S. Department of Energy, Richland Operations Office
DQO = data quality objective
FWS = field work supervisor
SP = study plan

The FWS, SMR, and any field crew supervisor are responsible for guaranteeing that field instructions are maintained and aligned with any revisions or approved changes to the SP. SMR will make sure that any deviations from the SP are reflected in revised field sampling documents for the samplers. The FWS will ensure that deviations from the SP or problems encountered in the field are first discussed with the BTL (or designee) at location, and then documented appropriately (e.g., in the field logbook).

The BTL(or designee) and FWS are collectively responsible for communicating field corrective action requirements and ensuring that immediate corrective actions are applied to field activities.
The biomobilization project manager (or designee) is also responsible for ensuring that project files are appropriately set up and maintained.

The project files will contain project records or references to their storage locations and will include the following documented information:

- Communications of a significant nature
- Operational records and logbooks
- Field data forms (hardcopy or electronic)
- Sample logbooks and data forms
- Global positioning system (GPS) data (a copy will be provided to SMR)

- Photographs
- Inspection or assessment reports and corrective action reports
- Interim progress reports
- Final (only) reports

The following records are managed and maintained by SMR:

- Completed field sampling logbooks
- Field drilling, excavation, and sample preparation laboratory data, and data from the analytical laboratory
- Field audit forms
- Completed chain-of-custody forms
- Sample receipt records
- Laboratory data packages
- Analytical laboratory data verification and validation reports (as required)
- Analytical laboratory data case file purges provided by the offsite analytical laboratory (if required)

In accordance with their contract, external laboratories are responsible for maintaining and having available upon request the following for a minimum of 5 years following delivery of each data report:

- Equipment calibration and maintenance logbooks
- Raw data and QC sample records
- Sample chain-of-custody and sample storage temperature logs
- Employee training records as they relate to testing methods used during this study
- Laboratory state accreditation records
- Laboratory audit records

Records obtained from subcontracted laboratories may be stored in either electronic (e.g., in the managed records area of the Integrated Document Management System) or hardcopy format (e.g., DOE Records Holding Area). Regardless of medium or format, documentation and records are controlled in accordance with internal work requirements and processes that ensure accuracy and retrievability of stored records.

2.3 Data Generation and Acquisition

This section addresses data generation and acquisition methods for sampling measurement and analysis, data collection, data handling, and QC activities. Requirements for instrument calibration and maintenance, supply inspections, and data management are also addressed.

This section includes sample processing activities required by personnel at the sample preparation laboratory. Activities include descriptions of soil cores, root depths, root biomass, and photographing core depth segments (with and without the root tissue exposed). In addition, plant tissue and soil samples are composited into depth-discrete samples for chain-of-custody submission to the offsite laboratories that will perform plant and soil characterization.

2.3.1 Study Equipment

All field and laboratory equipment will function as expected, is properly handled, and is correctly calibrated in accordance with the manufacturers' specifications or other approved PRC method. It is required that onsite environmental instrument testing, inspection, calibration, and maintenance records are kept in accordance with approved PRC methods.

2.3.1.1 Instrument and Equipment Testing, Inspection, and Maintenance

Collection, measurement, and testing equipment will meet applicable standards (e.g., ASTM International [formerly the American Society for Testing and Materials]) or verified as acceptable and valid in accordance with methods, requirements, and specifications. Software applications will be acceptance tested prior to use in the field as outlined in PRC's Quality Assurance Program Management Plan.

Measurement and testing equipment used in field or laboratory will be subject to preventive maintenance to minimize downtime. Laboratories must maintain and calibrate equipment on a frequent basis. It is expected that maintenance documentation will be included in the laboratory's or onsite organization's QA plan and operating protocols. Laboratory instruments will be maintained in a manner consistent with applicable Hanford Site requirements.

2.3.1.2 Instrument/Equipment Calibration and Frequency

All field equipment and laboratory instrumentation used during the conduct of this study will be calibrated in accordance with manufacturers' operating instructions, internal work requirements and processes, or field instructions that provide direction for equipment calibration or verification of accuracy by published methods. Calibration records shall include raw calibration data, identification of the standards used, associated reports, date of analysis, and the analyst's name or initials. All instrument calibration activities are recorded in accordance with HASQARD requirements (DOE/RL-96-68). Field and onsite laboratory instrumentation calibration and QA checks will be performed as follows:

- Prior to initial use of a field or sample preparation laboratory measurement system
- At the frequency recommended by the manufacturer or methods, or as required by regulations
- Upon failure to meet specified QC criteria
- Daily calibration checks will be performed and documented for each instrument used
- Equipment that does not meet these requirements will be repaired before continued use or replaced

2.3.1.3 Inspection/Acceptance of Supplies and Consumables

Consumables, supplies, and reagents will be reviewed in accordance with ASTM International testing methods and/or evaluated specifically to PRC requirements, internal processes and specifications, technical quality requirements, and are to be checked and accepted prior to use. These actions must be in place prior to procurement because they guarantee that quality standards will be met. Supplies and consumables used in support of sampling and analysis activities are procured in accordance with internal PRC work requirements and processes. The procurement system ensures that purchased items comply with applicable procurement specifications. Supplies and consumables are checked and accepted by users prior to use.

2.3.2 Nondirect Measurements

Nondirect measurements include data from computer databases, programs, literature files, and historical documentation. Nondirect measurements will not be evaluated as part of this SP.

2.3.3 Data Management

In coordination with the biomobilization project manager (or designee), the SMR is responsible for ensuring data are appropriately reviewed, managed, and stored in accordance with programmatic requirements and governing data management methods. When appropriate, electronic data access will be through a Hanford Site database such as HEIS. Where electronic data are not available, hard copies will be provided.

Laboratory errors are reported to SMR through an established process. Briefly, a sample issue resolution form is filled out consistent with applicable methods and procedures. The form documents analytical errors, outlines their resolution, and becomes a permanent part of the analytical data package. The process guarantees that this information will be available for future reference and records management purposes.

2.3.4 Assessment and Oversight

Assessment and oversight activities ensure project implementation and QA/QC, and that the QAPjP is executed as prescribed.

2.3.4.1 Assessments and Response Actions

Contractor management, QA organization, and/or Health and Safety organization will determine the need for conducting random surveillances and assessments to verify compliance with the requirements outlined in this SP, project field instructions, and QAPjP. As primary SP author, the BTL may choose to conduct separate field oversight and assessments to establish compliance with SP technical requirements. Deficiencies identified by these assessments will be reported in accordance with existing programmatic requirements. The project line management chain coordinates the corrective actions or deficiency resolutions in accordance with the QA program, corrective action management program, and associated methods implementing these programs. When appropriate, the biomobilization project manager (or designee) will require corrective actions.

Oversight activities in the sample preparation laboratory, including corrective action management, are conducted in accordance with the laboratory's QA plan. SMR oversees offsite laboratories and verifies that they are qualified to perform Hanford Site work.

2.3.4.2 Reports to Management

Program and project management (as appropriate) will be made aware of deficiencies identified by internal self-assessments, condition reports, and findings from internal QA assessments and surveillances. Issues reported by the laboratories are communicated to SMR, which initiates a sample issue resolution form. This process is used to document sample issues and to establish resolution.

These assessments represent internal assessments. If an assessment finding results in sampling issues that impact study data quality objectives, then DOE will be informed.

2.4 Data Review and Usability

This section addresses QA activities that occur after data collection. These activities determine whether the data conform to the specified criteria, thus satisfying the project objectives.

2.4.1 Data Review and Verification

Data review and verification are performed to confirm that sampling, analysis, and chain-of-custody documentation was completed. This review includes linking sample numbers to specific sampling locations and reviewing sample collection dates, sample preparation dates, and analysis dates to assess whether holding times (if any) have been exceeded. Further, the QC data review is used to determine whether analyses have met the data quality requirements specified in this SP.

The criteria for verification include but are not limited to review for contractual compliance (i.e., samples processed, as requested), use of the correct methodology, transcription errors, appropriate reporting of dry versus wet weight, and correct application of conversion factors. Field QA/QC results, if any, will be reviewed to ensure usability.

The biomobilization technical lead (or designee) performs data reviews to determine if observed changes reflect potential data errors, which may result in submitting a request for data review for questionable data. The laboratory may be asked to check calculations or reanalyze the sample. The results of the request for data review are used to flag data appropriately in the HEIS database and/or to add comments.

2.4.2 Reconciliation with User Requirements

The purpose of reconciliation with user requirements is to determine if quantitative data (e.g., biomass measures and soil grain size profile) are of the correct type and adequate quality and quantity to meet project data needs. The data quality assessment (DQA) process is the scientific and statistical evaluation of previously verified and validated data to determine if information obtained from environmental data operations are of the right type, quality, and quantity to support their intended use. The DQA processes the entirety of the collected data to determine usability for decision making. If a statistical sampling design were used during field sampling activities, the DQA will be performed following guidance in EPA/240/B-06/003, *Data Quality Assessment: Statistical Methods for Practitioners*. When judgmental (focused) sampling designs are implemented in the field, applicable data quality indicators (DQIs) for specific data sets (individual data packages) will be evaluated in accordance with relevant U.S. Environmental Protection Agency (EPA) guidance. Data verification is integral to the statistical data and DQI evaluation processes. The biomobilization technical lead (or designee) will use the DQA or DQI process results, as applicable, to determine whether DQOs for this activity have been met.

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3 Field Sampling Plan

The objective of the field sampling plan (FSP) is to outline sampling and analysis activities for the root characterization study. The FSP follows the requirements provided in EPA/240/B-06/001, *Guidance on Systematic Planning Using the Data Quality Objectives Process*.

The FSP defines the study objectives, study design (including the number and type of samples to be collected), study location(s), sampling methodologies, equipment, documentation, and sample preparation laboratory activities in addition to laboratory processes to perform ASTM International testing methods.

3.1 Sampling Objective

The selected plants will be well established, mature, deep-rooted shrub-steppe species found on the Hanford Site Central Plateau as previously described. The focus on mature (perennial) plant specimens (i.e., as opposed to perennial specimens of any age) is to ensure that root intrusion and biomass are conservative in nature: that they are biased toward characterizing specimens on the deeper end of the root penetration and root biomass spectrum, thus representing the worst-case scenario for future establishment of shrub-steppe species on the Central Plateau.

Roots of identified shrub specimens will be characterized using both total root excavation and soil core drilling to determine root penetration and root biomass by depth. These methods are two of the best methods for characterizing roots and are well discussed in a seminal paper on the importance of studying deep-rooted vegetation (Maeght et al., 2013, "How to Study Deep Roots – And Why it Matters"). The data will be used to report mean observed root depth and mean root biomass by depth per species along with their associated standard deviations and standard errors. Additional physical measurements will include percent soil moisture and plant root tissue moisture, soil type, soil grain size profile, root tissue dry weight (root biomass) per depth interval, plant height, plant and canopy width, trunk circumference, root perimeter, aboveground plant dry weight otherwise referred to as plant biomass, and plant age.

3.2 Target Plant Species for Root Excavation and Core Drilling

A number of deep-rooted plant species with biointrusion potential occur across the Hanford Site Central Plateau and are summarized in recent (CHPRC-00651; Sample et al., 2015) and historical (Link et al., 1994, "Effects of Coppice Dune Topography and Vegetation on Soil Water Dynamics in a Cold-Desert Ecosystem"; Cline et al., 1980, "Loose Rock as Biobarriers in Shallow Land Burial"; PNL-5247, *Rooting Depth and Distribution of Deep-Rooted Plants in the 200 Area Control Zone of the Hanford Site*) publications. The deepest rooted vegetation species reported to occur on the Hanford Site include the following:

Perennial shrubs

- Big sagebrush (*Artemisia tridentata*): Maximum reported root depth 250 cm (8.2 ft) (PNL-5247; CHPRC-00651; Sample et al., 2015)
- Gray rabbitbrush (*Ericameria nauseosa*): Maximum reported root depth 250 cm (8.2 ft) (PNL-5247; CHPRC-00651; Sample et al., 2015)
- Green rabbitbrush (*Chrysothamnus viscidiflorus*): Maximum reported root depth 200 cm (6.6 ft) (PNL-5247; CHPRC-00651; Sample et al., 2015)
- Antelope bitterbrush (*Purshia tridentata*): Maximum reported root depth 300 cm (9.8 ft) (PNL-5247; CHPRC-00651; Sample et al., 2015)

- Spiny hopsage (*Atriplex [Grayia] spinosa*): Maximum reported root depth <220 cm (<7.2 ft) (Link et al., 1994; CHPRC-00651; Sample et al., 2015)

Annual forbs

- Russian thistle (*Salsola kali*): Maximum reported root depth 240 cm (7.9 ft) (Cline et al., 1980; CHPRC-00651; Sample et al., 2015)
- Tumble mustard (*Sisymbrium altissimum*): Maximum reported root depth <240 cm (7.9 ft) (CHPRC-00651; Sample et al., 2015)
- Bursage (*Ambrosia acanthicarpa*): Maximum root depth 180 cm (5.9 ft) (PNL-5247; CHPRC-00651; Sample et al., 2015)

All of these species occur on the Central Plateau, but not all of the above mentioned plants can practically be evaluated as a "target" species for root characterization due to the plant densities being too low to support sampling in addition to the destructive nature of the characterization methodologies. Further, the target species selected have reported root penetration depths that are the same as or deeper than that of nonselected species. Accordingly, a smaller subset was selected that includes sagebrush, gray rabbitbrush, antelope bitterbrush, and Russian thistle. The targeted species have relatively strong tap root development (PNL-5247) in addition to a lateral root system.

3.3 Study Design

The study will be conducted in uncontaminated locations of the Hanford Site. When determining study design, it is necessary to evaluate areas of concern or potential issues that may be encountered while conducting the study, consider the data quality information such as the purpose of the data collection, identify any spatial and temporal boundaries of the study, and determine the parameter(s) of interest. In addition, constraints include sampling limitations, time or scheduling issues, and cost considerations. Considerations specific to this study include the following:

- The limited number of mature plants per target species available for sampling in uncontaminated Hanford Site locations
- The limited number of uncontaminated locations available for plant sampling
- The destructive nature of root characterization methodologies (particularly for total excavation) and logistical and mitigation planning for conducting these activities at the identified uncontaminated locations
- The time (and cost) associated with drilling and excavating the statistically required number of plants

Important considerations for selecting uncontaminated sampling areas include the number and type of plants available, ability of the identified location to sustain high levels of damage (to be offset by mitigation as required), selected locations must be within the Hanford Site boundary, and area(s) must be cleared for sampling following the clearance review process (i.e., cultural, ecological, etc.). This study will determine root penetration and root biomass by (soil) depth for mature, well established Hanford Site plant species: big sagebrush (*Artemisia tridentata*); antelope bitterbrush (*Purshia tridentata*); gray rabbitbrush (*Ericameria nauseosa*); and Russian thistle (*Sasola kali*). These species are considered representative of deep-rooted vegetation in the Hanford Site shrub-steppe habitat that is likely to be present now and in the future following Central Plateau remediation. The proposed sampling strategy is judgmental by design due to the abovementioned sampling constraints as well as the need to sample mature target plant specimens, limiting the ability to randomize sample selection effectively.

Judgmental sampling is defined as the "selection of sample locations based on professional judgement alone, without any type of randomization. . . . it is useful when there is reliable historical and physical knowledge about a relatively small feature or condition" (EPA/240/B-06/003).

Reliable historical as well as physical knowledge of rooting depths of Hanford Site relevant species are available (Section 1.2.2). However, many of these studies have limitations prompting a need for further investigation to assess fully the root penetration and root biomass of the selected focal species. Selection of individual plants for excavation and soil core drilling activities proposed in this SP will be based on Hanford Site knowledge, use of published, peer-reviewed models to predict age and approximate rooting depth for the focal species, and expert knowledge and scientific judgement.

To determine how many shrubs (by species) are required to characterize the population of deep-rooted shrubs on the Central Plateau with reasonable confidence, a power analysis was conducted. Key assumptions included using a t-test to compare the sample mean to the population mean (when applicable) because the population standard deviation is unknown and the sample size is (practically speaking) expected to be small. In addition, a large effect (variability) is assumed. Specifically, the effect size can range from a small (0.2) to a large effect (0.8) (Cohen, 1988, *Statistical Power Analysis for the Behavioral Sciences*) to indicate the standardized difference between two means of interest. An effect size of 0.2 suggests that if the two group means do not differ by 0.2 standard deviations or more than the difference is trivial even if statistically significant. The results of the power analysis indicate that to determine a large effect (0.8) with a significance value of 0.05 and power of 0.8, a minimum of 14 plants per species would be required per root characterization method. To put that value into context, 198 plants per species would be needed to determine a small effect (0.2) with a significance level of 0.05 and power of 0.8. A larger effect level of 0.9 was also evaluated yielding a slightly lower minimum number (12) of plants per species for each root characterization method. The results of these power analyses were used to determine a realistic but statistically informed number of plants per species to sample (i.e., characterize roots). Twelve plants per species will be sampled over 3 yr per root characterization method. Each year, four plants per species will be excavated in addition to four additional plants per species undergoing soil core drilling (Figure 3-1). Data will be collected from uncontaminated locations within the Central Plateau. Individual mature specimens will examined under two different root characterization methods: complete shrub root excavation to a depth of 4.9 m (16 ft) and soil-root core drilling (taproot and dripline) depths to 4.9 m (16 ft).

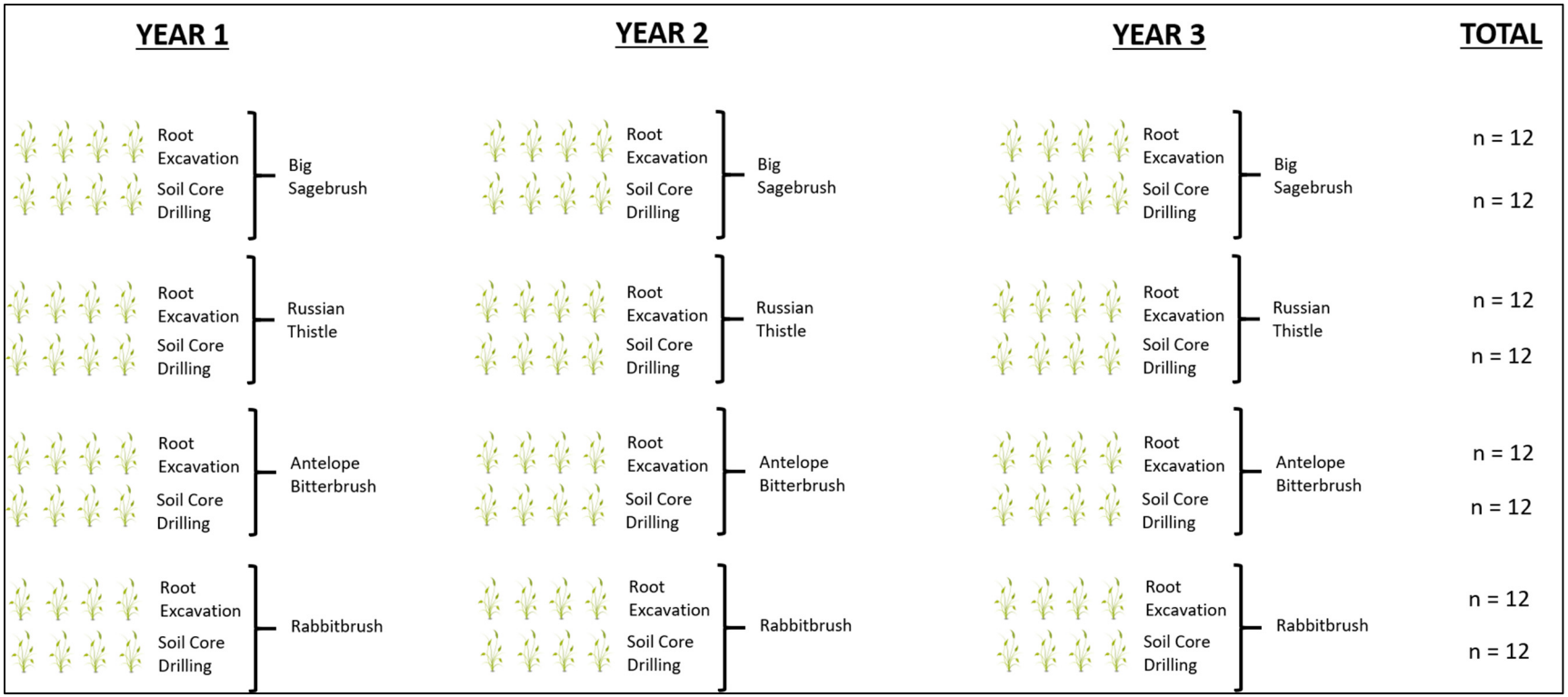

Figure 3-1. Root Characterization Study Design

3.4 Key Activities Prior to Root Study Implementation

This section outlines several key activities that will be conducted prior to initiating the root characterization field study.

3.4.1 Study Location Selection

The steps for identifying potential field study locales for conducting total root excavation and soil core drilling will be as follows:

- The BTL and BT will review historic data to identify potential locations for excavation and drilling. Considerations include the number of target species, the type and maturity of plants available for root characterization, the ability of the area to be mitigated following root characterization activities, locations that are uncontaminated, and study area(s) that are within the Hanford Site boundary. Some candidate study locations identified to date include the following: (1) a mature sagebrush stand next to US Ecology with a small area of mature antelope bitterbrush; (2) an identified area south of the Laser Interferometer Gravitational-Wave Observatory that contains mature antelope bitterbrush; (3) the Fast Flux Testing Facility with sagebrush, antelope bitterbrush, and rabbitbrush; (4) the Wye Barricade with sagebrush and antelope bitterbrush; and (5) the borrow pit with sagebrush. Each location requires further evaluation to determine suitability for use in the study. All of these candidate locations had Russian thistle. Figure 3-2 illustrates the potential study locations currently being considered (note: other uncontaminated areas may be added following completion of planned root study location scouting activities).

- Once all uncontaminated potential root characterization locations are identified, the BTL and BT will scout the areas to identify and flag candidate species specimens for excavation and soil-root core drilling. Plant height, canopy width, and trunk circumference will be measured for all identified specimens to estimate plant age using regression models published in the literature for antelope bitterbrush and sagebrush (McConnell and Smith, 1963, "Estimating Bitterbrush Age from Stem-Diameter Measurements"; Perryman and Olson, 2000, "Age-Stem Diameter Relationships of Big Sagebrush and Their Management Implications") in addition to models that can approximate lateral root length as well as rooting depth for shrub species (Schenk and Jackson, 2002, "Rooting Depths, Lateral Root Spreads and Below-Ground/Above-Ground Allometries of Plants in Water-Limited Ecosystems"). Based on these estimates along with scientific expertise and judgement, individual target plant specimens will be selected for excavation and drilling.

- Selected plant specimen coordinates will be documented. The GPS unit (Trimble® GeoXT™ Geoexplorer® 2008 Series) will use NAD 83, *North American Datum of 1983*, projection system (Washington State Plane in m), universal transverse mercator (UTM) coordinates specified in northing/easting, and horizontal coordinates with a precision of at least 0.1 m.

- All necessary field location and plant specimen information will be collected, summarized, reported, and submitted for cultural and ecological review. Table 3-1 provides an example of the plant documentation data to be collected during plant specimen scouting activities.

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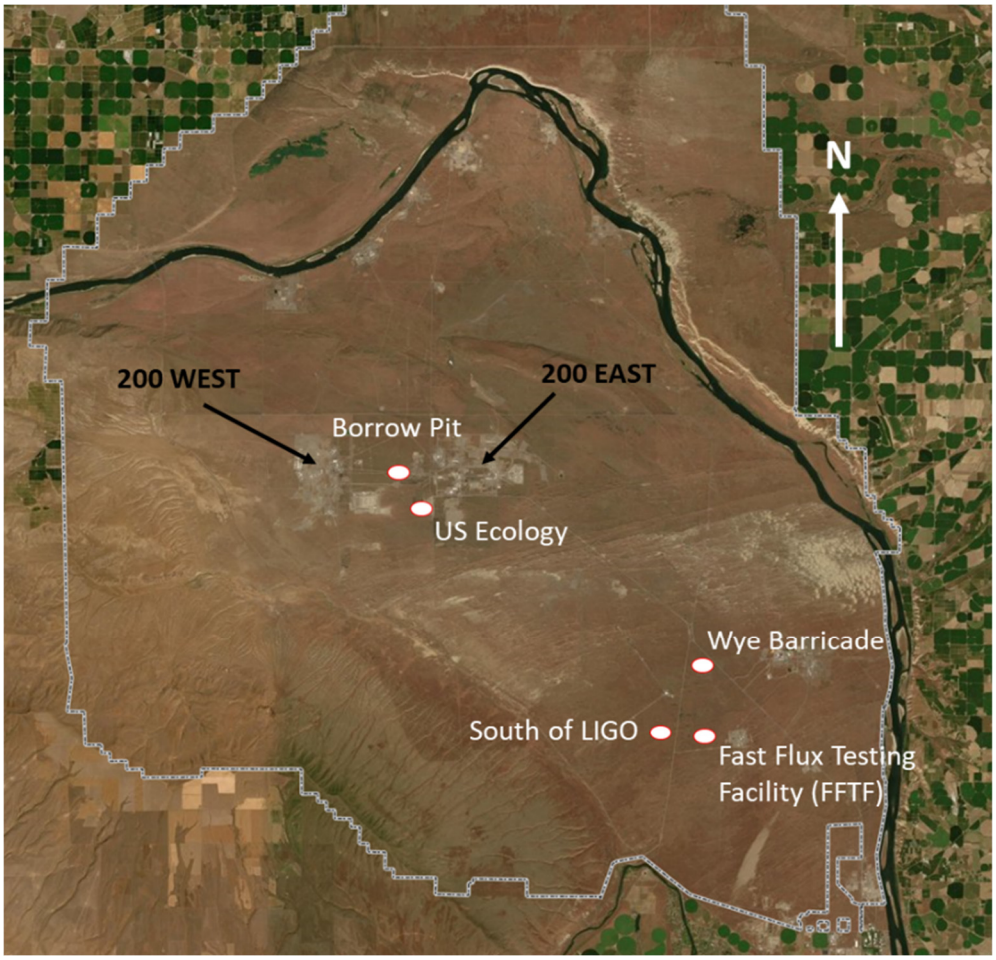

Figure 3-2. Map of Potential Study Locations

Table 3-1. Example of Plant Specimen Data Recorded During Field Scouting Activities

Location	Species	East (m)	North (m)	Plant Height (m)	Plant Width (m)	Trunk Circumference (cm)
A	Specimen 1	572120.00	134737.98	1.52	2.80	17
B	Specimen 2	572091.48	134739.35	1.73	3.38	16

3.4.2 Conduct Mock Field Trial of Root Characterization Study

Prior to initiation of the definitive root characterization study, a mock field trial will be conducted in an uncontaminated area within the Hanford Site boundary to work through key field and laboratory processes, refine methods and equipment, and evaluate and optimize activities that will inform the final study design (and need for written field procedure modifications). For example, the time it takes to excavate the root system of an individual plant will be examined to confirm (and refine, as needed) the existing estimate of how many plants will be excavated within a year.

By the time the root study mock field trial is initiated, the soil core drilling will have already been optimized based on findings from the mock field trial conducted in support of the opportunistic vegetation

sampling study (DOE/RL-2017-14). If deemed necessary, additional soil core drilling optimization will be incorporated into the design of the root characterization mock field trial.

3.4.3 Field Mobilization Planning Activities

The BTL and BT will work with the BTR to prepare both pre- and post-mock field trial training workshops for key representatives of PRC and contractor personnel involved in the mock field trial. The workshop(s) will provide a forum to discuss field personnel and their activities, field forms, drilling and excavation methods, change control, transport of samples, key field sampling, and sample preparation laboratory optimization opportunities to address the "workability" of certain study design elements. Observations, evaluations, and conclusions from a post-mock field trial "lessons learned" workshop held with all key study personnel shortly after completion of the mock field trial will directly support updating study documents (e.g., this SP, sampling analysis instructions, certain PRC technical procedures, and sample preparation laboratory study procedures). Updated documents and procedures will then be used to conduct the definitive root characterization study.

The BTR and BTL will coordinate on initiating pre-field activities necessary to initiate either the mock field trial or definitive root study. The BTR will coordinate with the excavation and drilling teams to identify dates for mock field trial and definitive study initiation and define the mobilization activities required for each field activity (e.g., sampling area road and pad preparation, identification of a central staging area, equipment purchasing, equipment calibration, sample labels and forms). This information is regularly communicated to the BTL, SMR, and BT under development and following completion.

The BTL and BTR prepare and facilitate a "readiness review" meeting for all study personnel within 2 weeks of initiation of field activities (i.e., mock field trial, definitive root study).

3.5 Plant Root Excavation Methodology

This section of the SP describes the methods for characterizing roots from excavated plant specimens located within uncontaminated areas on the Hanford Site Central Plateau. Activities outlined in this section are based on the root excavation procedure published in Böhm, 1979, *Methods of Studying Root Systems*. All contractor personnel will follow the procedures for measuring and recording root characterization data as described below and in their root SP-compliant work plans.

- On the day of the scheduled plant excavation, the BTL-designated field scientist(s) will record the date, time, weather conditions, names of participating scientists and field crew members, and location (GPS coordinates) of the shrub in the field logbook. The plant is flagged with identifying information in indelible marker. All GPS location coordinates will be recorded twice prior to documenting to ensure accuracy.
  - The GPS unit (Trimble GeoXT Geoexplorer 2008 Series) will use the NAD 83 projection system (Washington State Plane in m), UTM coordinates specified in northing/easting, and horizontal coordinates with a precision of at least 0.1 m.
- The BTL-designated field scientist(s) will record the following shrub information in the field logbook: plant species, trunk circumference, canopy circumference, plant height, and plant canopy width. These endpoints are measured twice to ensure accuracy. The BTL-designated field scientist will check and confirm that recorded GPS coordinates match previously recorded GPS coordinates from field scouting activities.
- The BTL-designated field scientist(s) will secure the shrub to ground stakes using rope to ensure plant stability once the excavation process begins.

- The perimeter of the plant's lateral root system is located using ground-penetrating radar (GPR) technology that was first used in mapping tree roots by Hruska et al., 1999, "Mapping Tree Root Systems with Ground-Penetrating Radar." Briefly, larger roots that make up the plant's shallow root perimeter are mapped using GPR instrumentation by following a line or system of lines that transmit and receive electromagnetic waves that produce pictures representing root structures. The distance, configuration, and steps required to map roots successfully (based on frequency) are location specific and include such things as soil type, rooting depth, and soil moisture. The BTL and BT will collaborate with the selected GPR contractor prior to conducting the mock field study to clearly describe what instrumentation will be used, what frequencies will be needed to resolve plant roots residing in Hanford Site soils, personnel or expertise required, and how/what data will be recorded.

- The root perimeter and the excavation area (root perimeter plus pre-defined buffer) are clearly marked (i.e., spray paint) to guide excavation work. The root perimeter and excavation area are recorded as the length and width in the field logbook. The information will be used to determine root biomass by volume. Volume will be calculated by multiplying length by width by depth. Root biomass by volume will be used to compare root excavation and soil core drilling root biomass and depth data.

- The excavation team will begin to remove soil along the marked root perimeter as specifically described in the excavation team's work plan. This plan will be drafted once the contract is awarded. The work plan will be a collaborative effort between the BTL, BTR, and excavators to outline clearly the excavation process and to describe BT excavation needs fully and address what equipment is appropriate for excavating the proposed depths for this study as well as other specific details needed to excavate the area that surrounds the plant excavation pit safely and successfully in 0.6 m (2 ft) intervals.

- Soil will be removed to a depth of 0.6 m (2 ft). Excavation laybacks (i.e., 1:1.5) will be required, including access ramps to safely enter and exit the excavation pit as it is enlarged (Figure 3-3). To determine the volume of soil excavated, soil should be removed only within the pre-defined excavation perimeter (fourth and fifth bullets above) to a depth of 4.9 m (16 ft).

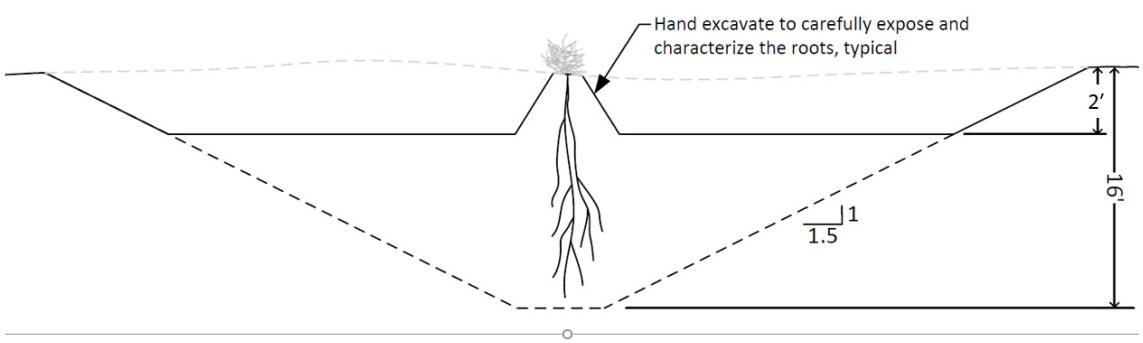

Figure 3-3. Schematic of Plant Excavation

- Once soil is removed to a depth of 0.6 m (2 ft) and the necessary laybacks are secured, soil depths (0.3 m [1 ft] increments) are marked on the soil profile with a laser guide or other means (e.g., a surface-mounted laser depth indicator, yard stick, tape measure) to monitor and record (field logbook) the excavation depth.

- Four 500 g aliquots of soil are collected using a 12-14 in. long handheld stainless steel soil sampling probe and placed in container clearly marked with a 500 g increment. Each 500 g aliquot is randomly

collected along predefined transects on the pit layback wall (transect number recorded) and composited into one prelabeled container (5 gal bucket) for a total of 2,000 g of collected soil for the specific soil excavation depth. Samples will be used to measure soil physical parameters by depth interval.

- To ensure a representative soil sample is collected, an additional four 500 g aliquots of soil are collected at additional layback wall locations as previously described and composited into the same 5 gal bucket (eight aliquots combined into one sample per 0.3 m [1 ft] interval for a total sample of 4,000 g [4 kg]). The amount of collected soil is greater than the sample requirements outlined in the ASTM International testing guidelines for soil grain size profiling (100 g soil required), soil moisture (500 g soil required), and soil type (1 kg soil required). Soil samples will be thoroughly mixed prior to analysis to ensure representative samples are utilized. Samples are packaged and sent to the analytical laboratory to determine soil physical parameters (soil type, moisture, grain size profile).
  - Soil collection containers are pre-calibrated and marked with a 500 g increment. The mark is based on weight (g) and is determined by filling the container with 500 g of soil (field soil will be collected and brought into laboratory for this purpose), soil weighed, and the container marked with a fill line once 500 g weight is achieved. This activity will occur prior to the initiation of field activities in a laboratory to ensure proper calibration and scale sensitivity.
- The BTL-designated field scientists begin at the base of the plant defined as where the trunk (or stem) meets the soil surface and carefully and methodically remove soil to expose the lateral root system. Once the lateral root system and its perimeter are exposed, soil is removed to expose root tissue to a depth of 0.3 m (1 ft). Note that soil is excavated in 0.6 m (2 ft) intervals with the appropriate field equipment followed by manually removing soil to expose and collect root tissue in 0.3 m (1 ft) intervals. Excavating at 0.6 m (2 ft) intervals ensures safety for field scientists, but manually working in 0.3 m (1 ft) intervals avoids unnecessarily drying out portions of root tissue during excavation.
- The root system is carefully excavated using shovels, hand tools, small picks, and brushes to a depth of 0.3 m (1 ft). Smaller hand tools, fine steel probes, and brushes are used for finer roots, whereas larger tools will be used for larger, more robust roots such as tap roots. Because varying sizes of root types (tap, fibrous, branching) will be encountered during excavation, several tools will be used, the type of which will be decided in the field based on the nature of roots encountered.
- Two or more BT field scientists will be in the excavation pit to share the work of root excavation and characterization, logbook maintenance, and sample collection (root and soil). The field scientists map, trace, and outline the root system in the field logbook; take necessary photographs; and record root measurements in the field logbook that include root diameter and length (penetration depth) of exposed tap root and major branch roots and general root description, including root health, spreading nature of root system, and type of roots present (fibrous, branching, and tap). Photographs using a digital camera with excellent resolution (a minimum of 300 px/in.) will be taken, and frame numbers and photographic descriptions recorded in the field logbook to document plant information and root excavation process.
- After careful excavation is achieved to a depth of 0.3 m (1 ft), the aboveground plant is separated from the root tissue at the ground surface.
- The plant trunk will be cut at the ground surface by a competent field crew member using a hand saw. A thin (1–2 in.) cross sectional slice is taken from the bottom of the trunk, and placed in a labelled container. This trunk sample is retained with the entire aboveground shrub specimen for later age analysis.

- The BT field scientists or designated FSO representatives (NCOs) will package and label the aboveground shrub (including the trunk cross sectional slice for aging) in compliant packaging for offsite local transport by the authorized shipper to the sample preparation laboratory following labeling and chain-of-custody procedures. SMR will be consulted prior to excavation initiation to establish package transport requirements.
  - One vegetation specimen and trunk cross-sectional slice (for age determination) will be included in each package. For especially large specimens the shrub should be cut into large pieces to facilitate packaging. The type of packaging used will be recorded in the field logbook for each specimen transported.
- The exposed root tissue is carefully photographed in situ and the depth of root penetration within the 0.3 m (1 ft) interval recorded in the logbook. The root mass is then cut at the soil surface (i.e., freeing the roots from the aboveground shrub) and cut a second time at exactly 0.3 m (1 ft) belowground. Excess soil is then carefully removed from the cut root tissue by gentle agitation, followed by a quick water rinse and paper towel blotting to remove excess water.
- The fresh root tissue is placed in a labeled compliant container, packaged, and sent to the analytical laboratory under chain of custody.
- Another 0.6 m (2 ft) area is mechanically excavated as previously described with the necessary laybacks and access ramps every 0.6 m (2 ft) until a 4.9 m (16 ft) depth is achieved.
- The earlier steps of this process are repeated at 0.3 m (1 ft) intervals (i.e., exposed roots, penetration depth recording within the interval, photographs, cutting roots, containerizing sample, labeling, and logbook recording) until a depth of 4.9 m (16 ft) is achieved.
- All excavation samples (aboveground shrub, depth interval root tissue samples, and soil samples) are labeled and transported under chain-of-custody procedures to either the analytical laboratory (root samples, soil samples) or the sample preparation laboratory (aboveground shrub with trunk age sample). The assumption is that one plant specimen can be excavated fully in a given sampling day. If not, then the samples collected at the end of a given sampling day will follow the labeling and chain-of-custody procedures below, and a notation will be made in the field logbook of exactly which plant specimens and soil samples were transported to either the sample preparation laboratory or the analytical laboratory on each sampling day.
  - Affix a custody seal to the sample container package(s) and initial.
  - The sample package or container(s) will include with indelible marker the date of collection, sampler name, sample number, location name, GPS coordinates of the specimen, type of sample (i.e., aboveground shrub tissue, root tissue, soil type), soil depth interval represented for sample type, and vegetation identification (species). Preprinted labels may also be used that contain this information.
  - Complete the chain-of-custody form (multiple forms may be needed), sign, and affix to the transported package for analytical laboratory acceptance and signature. If multiple vegetation specimens and their associated root and soil samples are transported in a day, one or more custody forms are used to document all sample types submitted for each species specimen (the number of custody forms submitted per plant specimen will be shown (e.g., one of two) on the custody form. A copy of all submitted chain-of-custody forms is made daily for SMR files.
  - The analytical and sample preparation laboratories receiving samples will review all chain-of-custody forms submitted to confirm the listed sample inventory and that sample numbers

are correct. The chain-of-custody forms are signed by the laboratory designee receiving the samples and a copy of the signed form retained by the person relinquishing custody.

- Provide a scanned copy of the field logbook entry(s) for each deep-rooted vegetation specimen sampled, and digital photographs with clear logbook descriptions of photographic content to the designated biomobilization team representative as soon as possible at the end of each sampling day for inclusion in the project files.

3.6 Soil-Root Core Drilling Methodology

This section of the SP discusses the methods for characterizing roots from plant specimens located within uncontaminated areas on the Hanford Site using soil-root coring techniques. All contractor personnel will follow the procedures for measuring and recording root characterization data as described below.

3.6.1 Soil Root Core Numbers, Type, Placement, and Depth

This section identifies the number, type, depth, and placement of soil-root cores to be collected at each plant specimen location.

- Up to four 4.9 m (16 ft) continuous tight[7] soil-root characterization cores will be drilled for each individual shrub specimen.
- Figure 3-4 depicts the placement of the (up to) four cores for each shrub and illustrates the two types of soil-root cores (defined below) that will be collected:
  - The center taproot core
    - Regardless of shrub size, one taproot core will be collected using the largest possible core barrel diameter (15 cm [6 in.] minimum is desired). The placement of this core is over the central taproot, typically in the center of the plant (Figure 3-4).

[7] "Tight" cores are contained within a rigid sleeve as opposed to "loose" cores, which represent cores in a loose core sleeve termed a "sausage bag." Tight 4.9 m (16 ft) continuous cores are assumed in the current study design. Driller capabilities may dictate whether the collection of 4.9 m (16 ft) continuous tight soil cores is actually achievable. A final decision on the core type (i.e., tight versus loose) will be made by the BTL and BTR weighing both driller capability and possible impacts on study design.

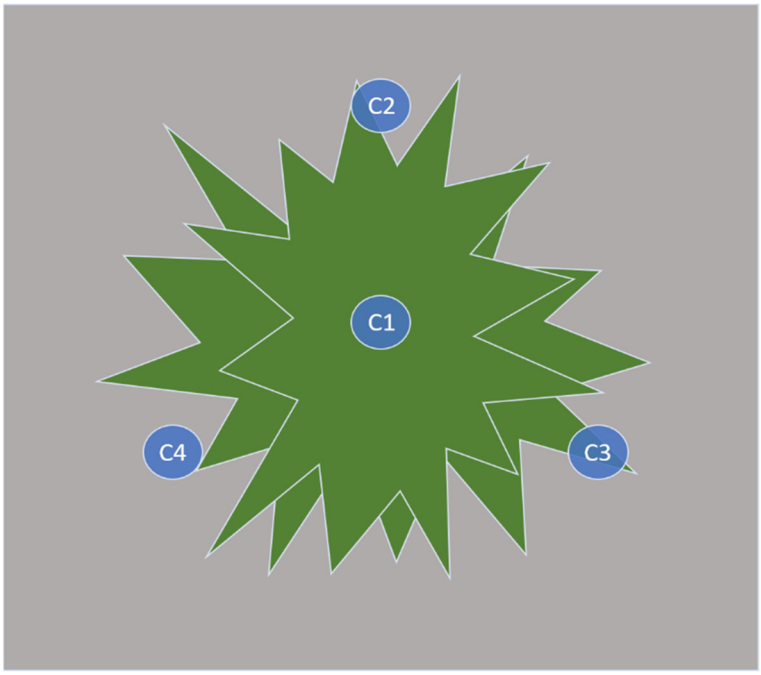

Figure 3-4. Continuous Core Placement Over Center Mainstem (Taproot) and Around Plant Specimen Dripline Perimeter

- Three dripline perimeter cores
  - Dripline perimeter cores are placed beneath the canopy edge (perimeter dripline) in three locations. Three dripline cores will be the default unless shrub diameter (dripline perimeter size) dictates that a smaller number of dripline cores be collected. For dripline cores, a 10 cm (4 in.) minimum core barrel diameter will provide the highest probability of obtaining three intact well defined cores within the dripline perimeter. When changes to the default number of dripline cores are necessary based on limitations in the size of the shrub's dripline perimeter, this decision will be made in the field based on the BTL-designated field scientist and driller's expert judgment. Such a change will be considered a "minor change" (minor field change) in accordance with the change control requirements discussed in Table 2-2.

3.6.2 Soil-Root Core Drilling Methods

The requirements for the drilling of tight, 4.9 m (16 ft) continuous soil-root cores and documentation methods are summarized in this section. All samples generated from soil-root core drilling, including aboveground shrub and belowground core depth intervals, are sent to the sample preparation laboratory for processing.

Drilling will follow established PRC procedures for driller contractors and also the requirements of this section as defined below.

- The BTL and BT will identify mature well-established plants (Section 3.4.1) that will undergo tight, continuous soil-root core drilling.
- On the day cores are to be drilled, record date, time, weather conditions, and location (GPS coordinates) of the shrub in the field logbook maintained by the designated field scientist. Measure twice to ensure accuracy. Log GPS coordinates into the field notebook. Flagging with identifying information in indelible marker is then tied to the plant.

  - The GPS unit (Trimble GeoXT Geoexplorer 2008 Series) will use the NAD 83 projection system (Washington State Plane in m), UTM coordinates specified in northing/easting, and horizontal coordinates with a precision of at least 0.1 m.

- The plant's dripline perimeter edge is clearly marked using suitable marking (e.g., spray paint or stakes) to ensure that the locations for drilling cores within the marked perimeter are visible.

- Physical shrub measurements are conducted and recorded. Perform measurements twice, and then record in the field logbook. These measurements are lateral root perimeter by GPR (as described above), plant height, canopy width, and trunk circumference (sagebrush only). Photographs using a digital camera with excellent resolution (a minimum of 300 px/in.) will be taken to document the intact shrub and frame numbers and photo descriptions recorded in the field logbook to document the steps of the soil-root core drilling process.

- The plant trunk will be cut closely to the ground surface by a competent field crew member using a small hand saw. A thin (1–2 in.) cross-sectional slice is sawed off from the bottom of the trunk and placed in a labelled container. This age sample is retained with the entire aboveground shrub specimen for later age analysis.

- The BT field scientists or designated FSO representatives (NCOs) will package the entire shrub (including the trunk cross-sectional age sample in compliant packaging) for offsite local transport by the authorized shipper to the sample preparation laboratory. SMR will be consulted as necessary to establish package transport requirements.

  - One vegetation specimen will be included in each package. The numerous extra-large shrubs should be cut to facilitate packaging. The type of packaging used will be recorded in the field logbook for each specimen transported.

- Taproot and dripline cores are collected by drilling tight, intact 4.9 m (16 ft) continuous cores.

  - The largest size core barrel diameter (6 in. [15 cm]) will be used for the taproot core. Smaller (4 in. [10 cm]) cores are recommended for use in collecting dripline cores. Core sizes smaller than 4 in. (10 cm) are not recommended to reduce the opportunity for drilling refusal, ensure lateral root depths are adequately captured, and ensure that sufficient soil is collected to meet project objectives.

- The first core drilled by the drilling team is always the taproot core placed squarely over the subsurface entry point of the shrub mainstem (trunk), which ensures that any dripline core drilling does not damage the taproot.[8]

- The intact taproot soil core will be placed in a core tray by the drilling team and photographed by a designated BT field scientist along its entire length. A designated FSO representative (NCO) will then cut the intact core into the required eight soil depth intervals (Table 3-2), package, and prepare for transport under chain of custody to the sample preparation laboratory.

[8] This scenario assumes that the taproot is vertically oriented within the soil column and captured fully within the taproot core.

Table 3-2. Number and Type of Collocated Soil Cores Collected

Type of Soil Core[a]	Number of Cores Drilled per Shrub Location[b]	Number of Soil Depth Intervals Per Core	Soil Core Depth Intervals (m)
Taproot core	1	8	0–0.3, 0.3–0.9, 0.9–1.5, 1.5–2.1, 2.1–2.7, 2.7–3.4, 3.4–4.0, 4.0–4.9
Dripline cores	Up to 3	8	

a. Collocated 4.9 m (16 ft) continuous soil cores.

b. One taproot core (always collected) and three dripline cores. Note that the number of dripline cores may be reduced based upon the size of the shrub dripline diameter and result in less than a total of four cores being collected (Section 3.6.1).

- Drilling will next proceed to the (up to) three dripline cores. The minimum core barrel diameter (10 cm [4 in.]) will be used for dripline cores. (Refer to Section 3.6.1 regarding BTL-designated field scientist and driller judgement-based changes to dripline core number when drilling shrubs with small dripline perimeters.) Each dripline core is similarly placed in a core tray, photographed along its length, cut into the required eight soil core depth intervals (Table 3-2), packaged, and prepared for transport under chain of custody to the sample preparation laboratory.
- The field logbook will document all personnel present, all core drilling data, field conditions, and other information required by standard PRC field documentation procedures.
- All field photographs at each shrub drilling location taken by the BT field scientists will support report preparation and serve as a reference by the biomobilization team. Notation of digital camera frame numbers and descriptions of each photograph taken (i.e., location identifier, type of sample shown [aboveground shrub specimen, taproot core, or numbered dripline core[9]], core number [1–4], and core depth interval designation) will be entered into the field logbook with any other required descriptions and sampling information (e.g., date, time, sampler).
- Following standard PRC procedure, each intact soil core depth interval (i.e., resulting from the cutting of each plant specimen's continuous taproot and dripline cores) will be packaged by a designated FSO representative. Together with the aboveground shrub package, these core intervals will be labeled and prepared for transport to the sample preparation laboratory under chain-of-custody procedures:
  - Labeling will include sampler initials, date, sample type (core or aboveground shrub), sample number, coring location identifier, core type (taproot or dripline), core number (for dripline cores only; see numbering convention for dripline cores), core depth interval represented, and the aboveground shrub species associated with the sample type.
  - Complete a chain-of-custody form, sign, and affix to the transported package(s) for sample preparation laboratory acceptance and signature. When multiple core depth intervals of multiple collocated cores are transported, multiple custody forms will be required. The sample transporter retains a copy of the signed form as well to document their relinquishment of custody. A copy of the sample preparation laboratory-signed form(s) is made for SMR.
  - Provide a scanned copy of the field logbook entry(s) for each deep-rooted vegetation specimen cored, and numbered digital photographs with clear descriptions of photographic content to the

[9] Dripline numbering example for three dripline cores collected: one, two, or three of three. The number of dripline cores may vary depending on the shrub diameter.

designated biomobilization team representative as soon as possible at the end of each sampling day for inclusion in the project files.

- At the end of each coring day, the designated BT field scientist will enter the time of field activity completion, weather conditions, scientist name, and number of samples (aboveground shrub, collocated cores) delivered to the sample preparation laboratory in the field logbook.
- Following aboveground shrub and core interval sample receipt, the sample preparation laboratory will confirm the identification of the original aboveground shrub species as identified on the sample label(s). Additional identification to subspecies is required for all plant specimen samples submitted.
- The sample preparation laboratory lead technician will review all chain-of-custody forms submitted to confirm the listed sample inventory and that sample numbers are correct. Sample labels will be reviewed for accuracy by the lead technician and a notation made in the laboratory notebook and data forms for soil core depth intervals processed of any differences or errors in field shrub species identification from the submitted soil core depth interval labels.

3.7 Sample Preparation Laboratory Activities

Collected field specimens are promptly transported to the sample preparation laboratory for processing. This section outlines the sample preparation laboratory general and training requirements as well as the specific procedures for preparing plant tissue, root tissue, soil samples, and soil core composite samples.

3.7.1 Laboratory General Requirements

Immediately following contract award, the laboratory will develop a project-specific health and safety plan with technician training. Samples processed under this project are intended to come from radiologically uncontaminated areas.

The laboratory will also immediately develop detailed SP-compliant laboratory procedures for personnel to follow during plant, root, and soil sample preparation and processing. Technicians will be trained to these study procedures by the laboratory management. Procedures will adhere to all established PRC sample handling requirements outlined in this SP and include the following items:

- Sample containers (Section 3.13.2)
- Labeling
- Chain-of-custody form completion
- Packaging and transport of all prepared samples to the contracted analytical laboratory for plant tissue and soil physical analyses (dry weight, percent moisture, soil type, grain size) according to published ASTM International methods (Table 3-3)

Table 3-3. Requirements for Soil and Vegetation Sample Analysis

Analysis	Method
General Soil Chemical Parameters (mg/kg or unitless)	
Soil type	ASTM D2487-06 (2006)
Physical Properties and Measurements	
Soil grain size profile (sieve) analysis	ASTM D422-63 (2007)
Soil and vegetation dry weight (all vegetation tissue types)	ASTM D2216-05

Table 3-3. Requirements for Soil and Vegetation Sample Analysis

Analysis	Method
Soil and vegetation percent moisture	ASTM D2216-05

References: ASTM D2487-17e1, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*.
ASTM D422-63(2007), *Standard Test Method for Particle-Size Analysis of Soils*.
ASTM D2216-19, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*.
Note: Soil samples include two types: those collected from the soil wall during total root excavation, and core depth interval-specific soil composite samples created by combining the same depth interval soils across each of up to four collocated soil cores.

For the root characterization study it is envisioned that the sample processing laboratory will require up to four technicians to conduct the processing work in a timely fashion that ensures that all the samples are shipped to the analytical laboratory as quickly as is possible (samples require a significant amount of processing and documentation) to maintain the samples in a fresh state. Laboratory personnel will be trained by their organization in the execution of these procedures as soon as possible following contract award. Additional training to ensure compliance with SP procedures will be provided to the sample preparation laboratory personnel by PRC. The sample preparation laboratory lead will be responsible for any final updates to laboratory procedures following PRC training and ensure that any additional personnel are trained prior to work initiation (as applicable).

A laboratory lead technician will be identified and included in the SP-compliant technical procedures along with the names of the other supporting technicians. The laboratory lead technician's contact information will be provided to the BTR and BTL. The laboratory lead technician will be the primary contact with the BTR for alerts regarding the schedule for imminent field sampling activities and the need for the sample preparation laboratory to be ready for delivery of vegetation and soil samples.

Processing of all aboveground plant tissue, root tissue, and soil will be initiated as soon as possible following receipt. Sufficient laboratory personnel will be available to prepare and process these samples quickly and efficiently for rapid submission to the analytical laboratory for moisture and other analyses, which are time sensitive.

3.7.2 Plant Tissue, Root Tissue, and Soil Core Sample Preparation and Processing

All samples of either field sampling method will be processed and documentation work concluded as soon as possible following sample receipt at the sample preparation laboratory. Sample processing addresses aboveground plant tissue (only) collected during the total root excavation process, and aboveground plant tissue, and soil and root tissue contained within each collocated soil core depth interval collected during soil-root core drilling.[10] The processes to be followed by the sample preparation laboratory during the preparation and documentation of these samples are outlined below.

3.7.2.1 Photography

Plant tissue and soil processing procedures conducted by the sample processing laboratory include photographic documentation. Specific photographic requirements for samples are identified in respective composite sample preparation subsections. However, general photographic requirements applicable to all photos taken by the sample preparation laboratory are as follows:

- All photographs will be taken with a high-resolution digital camera (minimum of 300 px/in.).

[10] Continuous 4.9 m (16 ft) tight soil cores are collected in the field at each plant specimen. The continuous cores (taproot, dripline) will be cut into the required soil depth intervals by a designated FSO representative in the field prior to delivery to the sample preparation laboratory.

- Photographs will be taken at a consistent height and angle for image consistency.
- Special lighting is not necessary, but the light source will be consistent in each photograph and noted in reporting and documentation.
- Image resolution should be of sufficient size for small-scale features (i.e., in the cores and in documenting root tissue) to be as clearly visible as possible in the photos.
- An information card should be present in each photograph that identifies the following (as applicable to sample type):
  - Date, time, and processing company name
  - Sample type (aboveground tissue, root tissue, and soil)
  - Core type (taproot or dripline)
  - Dripline core number (up to three are possible)
  - Core depth interval
  - Collection location descriptor
  - Species/subspecies of the affiliated aboveground vegetation specimen
- For core depth intervals, depth marks along the side of the core in feet and inches for perspective (i.e., a tape measure or yard stick showing).
- A grayscale card for checking brightness and contrast (as required).
- A color calibration card for checking color quality (as required).

The information shown in photographic cards will be documented in the laboratory logbook and on lab data forms for photos taken. Digital camera frame number(s) will be recorded in the laboratory logbook and on data forms.

All photographs will be prepared as digital files (JPG, TIFF, or similar) and placed on a hard disk or other device with more than sufficient capacity to store all of the photographic files. Given the number of photographs that can be taken each processing day (particularly for root tissue), the lead laboratory technician will audit the complete photograph log each processing day to confirm accuracy and proper documentation (and make corrections, if necessary).

Sample preparation documentation (e.g., scanned logbook pages and data forms prepared each processing day[11]) will also be stored electronically in an easily searchable laboratory sample processing database. All photographic documentation, sample preparation data forms and information, and chain-of-custody documentation will be stored in this database (which will be quality checked daily by the lead technician) and submitted electronically to the designated team representative at least monthly for the biomobilization program study files.

3.7.2.2 Aboveground Plant Tissue Sample Preparation

Aboveground plant tissue processing will be initiated as soon as possible following delivery of the shrub to the sample preparation laboratory. Processing steps for the plant tissues are as follows:

- The sample preparation laboratory logbook and laboratory data forms will document each aboveground shrub processed. The specimen processing steps described will be documented with digital photographs as discussed in Section 3.7.2.1 to illustrate procedure and for later PRC use in

[11] Electronic data forms are recommended for use by the sample preparation laboratory to support the future need of a searchable sample processing database by the biomobilization team during data analysis.

preparing the data report. Any unusual specimen features (technician judgment) will be photographed and documented.

- Upon receipt, the sample preparation laboratory lead technician will confirm identification of the shrub specimen delivered. For Russian thistle, the genus (*Sasola*), species (*kali*) and subspecies (e.g., *tragus*, etc.) should be identified using a recognized vegetation identification key or other scientifically accepted means. For sagebrush (*artemisia*), the species will be confirmed and the subspecies (*wyomingensis*, etc.) identified using a vegetation key or other scientifically accepted means. Record this information in the laboratory logbook and on a data form.
- For annual forbs (Russian thistle), the specimen age (approximate) and lifecycle stage will be described based on the shrub sampling date and physical shrub features.[12] Lifecycle stage includes describing whether the shrub is in reproductive mode (i.e., presence of flowers, seeds that are fully formed or developing). All information will be recorded in the logbook and on data forms.
- For perennial shrubs, the specimen's reproductive mode will be noted and the age of each specimen determined from a thin woody trunk slice submitted with each aboveground shrub. The age of the shrub specimen will be determined through growth rings or other scientifically accepted methods using this slice. The reproductive status of the specimen, age, and aging methodology will be documented in the laboratory logbook and data forms. Following aging, this slice can be incorporated with the rest of the aboveground shrub tissue for composite sample preparation.
- The entire shrub (including branches, stems, leaves, flowers, seeds, spines, main stem, or woody trunk) will be cut using a small hand or chain saw (minimizing tissue loss) and then into small pieces (using clippers or scissors) with higher surface area for ASTM International method analyses by the analytical laboratory. If any type of grinding equipment (e.g., drill and bit) is used to break down the aboveground specimen woody trunk, the selected method will need to minimize the occurrence of any significant tissue loss to ensure accurate biomass measures. In addition, such equipment needs to be cleaned between plant samples to avoid leaving any sample tissue residuals.

  PROCESSING NOTE: Most shrub samples submitted for processing will be extra-large because the entire shrub is submitted. Accurate biomass determinations in the study design require that all of the tissues of the entire shrub (i.e., leaves, branches, thistles, flowers, seeds, wood trunk, etc.) be used to determine fresh and dry weights. This process will require a breaking down of all the tissues of a full-sized plant into small pieces (high surface area) for fresh and dry weight determinations by the analytical laboratory. Subsampling of the aboveground shrub tissue in any manner as a substitute for the significant processing time required to breakdown the entire shrub is not acceptable.
- The entirety of all of the processed aboveground shrub fresh tissue is then packaged, labeled, and submitted to the analytical laboratory performing the required ASTM International testing under chain of custody as previously described in Section 3.5.

3.7.2.3 Root Tissue and Soil Composite Sample Preparation

The following sections discuss the specific steps for processing the collocated soil core depth intervals for each aboveground shrub to characterize and document root penetration depths, and prepare root tissue and core depth interval soil composite samples.

[12] In Benton County, the time of the first hard frost (often early to mid-October) usually marks the death of the mature Russian thistle plant. Time of death is not equivalent to the time of shrub separation from its dead belowground roots to become a tumbleweed, which occurs sometime later.

Root Tissue Composite Sample Preparation from Soil Cores. Each of the (up to) four collocated soil cores from the plant are cut into eight soil depth intervals (Table 3-2) prior to sample preparation laboratory delivery as previously described. Processing of each core depth interval facilitates root tissue characterization (root penetration depth, etc.) and the preparation of core depth interval root tissue composite samples for analysis by the analytical laboratory using ASTM International methods (Table 3-3).

Figure 3-5 illustrates the soil core depth interval composite scheme to be followed for the preparation of both belowground root tissue and soil composite samples.

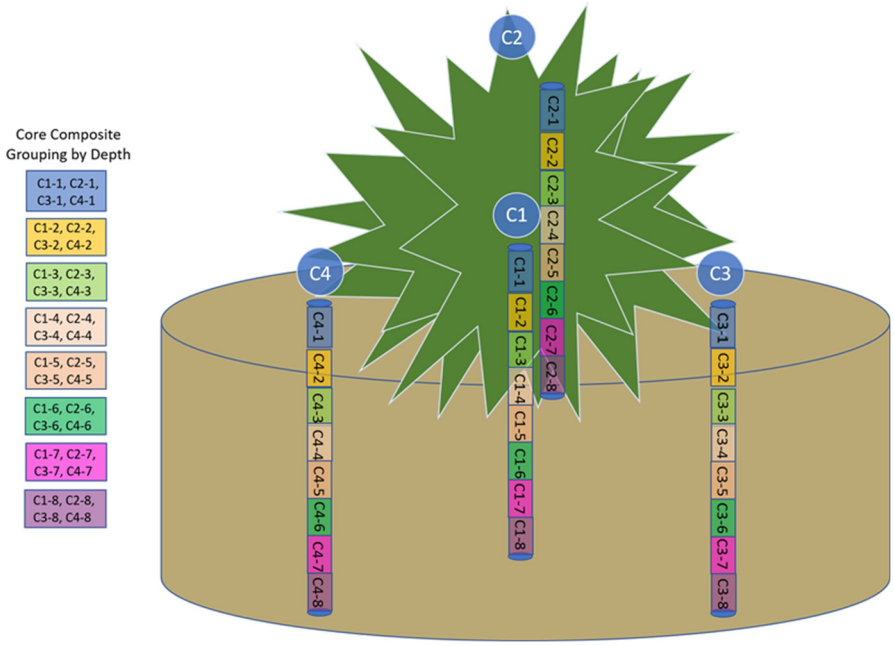

Figure 3-5. Depth Interval-Specific Sample Compositing Scheme for Root Tissue and Soil

Root tissue will be photographically documented for each core depth interval following the general photographic requirements in Section 3.7.2.1 as well as the specific photographic requirements documented in the following steps.

Root tissue composite sample preparation and documentation for the soil core depth intervals are described in the following steps.

Step 1: Each soil core will be delivered to the sample preparation laboratory as a series of eight tight core depth intervals corresponding to each of the eight soil depth intervals summarized in Table 3-2.

Step 2: Photographic documentation requirements for root tissue in each of the core depth interval are as follows:

- Photograph each labeled soil core depth interval separately (label clearly visible). Due to the presence of root tissue within the depth interval segments, the core will not be divided longitudinally.
- Intact cores for depth intervals will be photographed within their core sleeves as received by the sample preparation laboratory. A core interval length scale should always be visible in all required core photographs.

- Photography will then proceed after the core sleeve is gently cut away for each core depth interval and after the core surface is lightly brushed. Brushed soil is always kept with the core and depth interval being processed (for later soil composite sample preparation). Disposable brushes and metal probes are required, and a fresh brush and probe is used for each soil core and depth interval as part of good laboratory practice.
- A photograph(s) will then be taken following Section 3.7.2.1 photographic and documentation requirements that will show the intact lightly brushed core depth segment and any visible root tissue along the core sides. Any stratigraphy present in the core depth interval soil will be described in the logbook and data forms, and captured by one or more photograph (frame numbers recorded in the logbook and data form[s]).
- The depth interval core soil will then be gently probed to loosen any compacted soil and brushed further away to expose all (or a majority) of the root tissue within the length of the core depth interval (some root tissue may be fine). More photographs with length scale visible are taken to document the roots and their depth in the core interval. All brushed away soil continues to be kept with the other soil from the core and depth interval being processed (to prepare depth interval soil composite samples as discussed within Section 3.7.2.3). Photographic and descriptive documentation for each core depth interval will include requirements in Section 3.7.2.3 and the direction of root growth in each depth interval (i.e., for the taproot in particular in case of a change in growth direction) and any unique or unusual (technician judgment) root features observed. Some roots within the core interval soil may be fine, and care will be taken to include these fine roots with appropriate resolution in photographic documentation to the degree possible.

Step 3: Record the linear length of root penetration (in m) from the top of a core depth interval to its bottom. Record the measurement on a laboratory data form and in the laboratory logbook for that core depth interval. Intervals may have root tissue present in only part of the total depth interval. For example, roots may be noted to penetrate to only 0.5 m (1.5 ft) within a specific 0.6 m (2 ft) core depth interval.

PROCESSING NOTE: To ensure that no fine root tissue penetration depths in a soil core depth interval are missed, the disposable probe should always be used to confirm the presence or absence of smaller roots present throughout all the soil within each core depth interval. The linear root penetration depth in each core depth interval will be reflective of the deepest of the penetrating roots (coarse or fine) in that depth interval. Labeled photographs should be taken liberally (photo frames recorded on data forms and in the logbook) to document this situation. If root tissue of any type (coarse or fine) is not present or found within a given depth interval, record this information in the laboratory logbook and data form. All linear lengths of root penetration (or lack thereof) within each core depth interval will be recorded in the logbook and data forms.

Step 4: Once the linear root penetration depth information has been measured, recorded, and photographed for the core depth interval being processed, gently but completely separate all the root tissue from within the discrete soil core depth interval (including fine and ultrafine roots). Brush the removed roots lightly to remove as much adhered soil as possible, and continue to retain this soil for composite sample preparation (within Section 3.7.2.3).

Step 5: All of the extracted core depth interval root tissue is then lightly rinsed with distilled water, blotted dry carefully with paper towels, and placed in an ASTM International method (Table 3-3) compliant container of sufficient size to hold a complete depth interval specific root composite sample.

Step 6: Steps 2–5 are repeated for the root tissue occurring at the same soil core depth interval in each of the remaining collocated soil-root cores. The extracted depth interval root tissue is then combined with

the extracted depth interval root tissue in Step 5 to make up a complete depth interval-specific root tissue composite sample.

Step 7: Steps 2–6 are repeated for all remaining depth intervals from the collocated soil-root cores until a complete depth interval specific root tissue composite has been prepared for each of up to eight soil depth intervals (Table 3-2). The total number of complete soil depth interval specific root composite samples (up to eight) prepared from the collocated soil-root cores will be recorded in the laboratory logbook and on laboratory data forms.

PROCESSING NOTE: Fewer than eight complete depth interval specific root tissue composite samples may occur in the event that none of the (up to) four collocated soil-root cores contains any root tissue at a given soil depth interval(s).

Step 8: Each complete depth interval specific root tissue composite sample is labeled for shipment under chain of custody to the analytical laboratory conducting the ASTM International analyses (Table 3-3). The following information will be noted on the label of each complete depth interval root composite sample: date, processor name, sample type (root tissue composite), core depth interval represented (Table 3-2), number and type of cores represented in the root tissue composite aliquot (taproot [one always] and dripline [up to three]), species and subspecies of aboveground shrub associated with the root composite samples, and soil-root core location descriptor.

Soil Core Composite Sample Preparation by Core Depth Interval. Soil depth interval composite sample preparation follows the same composite scheme as described for root tissue (Section 3.7.2.3) and as illustrated in Figure 3-5. Photographic documentation for depth interval soil composite samples will representatively document the preparation steps (i.e., to support project data report preparation) as detailed photographs, and documentation of the soil core depth intervals is completed during root characterization and root composite sample preparation.

Core depth interval soil composite sample preparation steps are as follows:

- Soil from a specific core depth interval is combined in a large plastic bin with the soil from the same depth interval in the other collocated cores to create a single complete depth interval soil composite.
- The soil composite is thoroughly mixed by hand (top to bottom and side to side) for several minutes to ensure thorough mixing.
- A sample aliquot is taken from the complete depth interval soil composite for each ASTM International method identified in Table 3-3. Each sample aliquot will be placed in an ASTM International method-compliant container and will meet the minimum soil mass requirements for the method that will be identified once an analytical laboratory is assigned and placed under contract with PRC.
- The soil composite samples are packaged and labeled for shipment under chain of custody to the analytical laboratory. The following information will be noted on soil composite sample labels: date, processor name, sample type (soil composite), core depth interval represented, number and type of cores represented in the soil composite aliquot (taproot [one always] and dripline [up to three]), species and subspecies of aboveground shrub associated with the soil samples, and soil-root core location descriptor.
- The complete depth interval soil composite samples are shipped under chain of custody to the analytical laboratory conducting the ASTM International analyses.

PROCESSING NOTE: It is assumed that sufficient soil mass will be available from each complete core depth interval soil composite to meet the minimum mass requirements of each of the ASTM International methods identified in Table 3-3.

3.8 Aboveground Plant Tissue, Root, and Soil Sample Analyses

Root and plant tissues collected during the total root excavation and soil cores will be prepared for analysis as soon as possible following delivery to the sample preparation laboratory under chain of custody as previously described. Testing includes soil moisture, soil grain size profile, soil type, aboveground plant tissue fresh weight, aboveground plant tissue dry weight, depth interval specific root tissue fresh weight, depth interval specific root tissue dry weight, and plant tissue (aboveground, depth interval root) percent moisture. These measures are as summarized for both types of root sample collection methods (i.e., excavation, soil coring) in Table 3-4 using the ASTM International methods identified in Table 3-3.

3.8.1 Aboveground Plant Tissue Fresh and Dry Weight Analyses from Total Root Excavation and Soil-Root Coring

- The aboveground fresh shrub tissue sample, which can be as large as the entire shrub, is placed in a pre-weighed, clean, dry container or screen appropriate for the tissue amount being weighed. The weight of the container or screen is recorded in a laboratory notebook and laboratory data form.
- The shrub tissue plus the container or screen is placed on a calibrated surface loading scale of sufficient sensitivity,[13] and the fresh weight is recorded on a laboratory data form and in a laboratory notebook. Depending on scale sensitivity, a total fresh weight for a large tissue sample may need to be determined from multiple weighings.
- The plant tissue and the container or screen is placed in a thermostatically controlled oven at 110±5°C for at least 16 hours. Depending on drying oven size, large tissue samples may require multiple aliquot dryings to obtain a total dry weight or the use of multiple drying ovens.
- The tissue plus the container or screen is taken out of the oven and cooled.
- The shrub tissue on the container or screen is placed on a calibrated surface loading scale of sufficient sensitivity,[13] and the dry weight is recorded on a laboratory data form and in a laboratory notebook.
- The plant tissue and the container or screen are again placed in an oven at 110±5°C for at least 16 hours.
- The above process is repeated until successive dry weight differences are <0.1%.
- Once dry weight differences are <0.1%, the total shrub dry weight is recorded on a laboratory data form and in a laboratory notebook.

[13] The laboratory will have scales with the required sensitivity to weigh fresh and dried root tissues. Fresh root tissue weight may range across core intervals (e.g., deeper soil core depth intervals may have finer roots that weigh less requiring a scale with greater sensitivity). Dried root tissues will require even greater sensitivity.

Table 3-4. Number and Type of Sample Analysis per Excavation Interval for Total Root Excavation and Soil Core Drilling

Excavation Intervals	Root Excavation*				Soil Coring				
	Root Dry and Wet Weight	% Moisture Soil and Root	Soil Type/ Grain Size	Aboveground Plant Fresh and Dry Weights; Aboveground Plant % Moisture	Coring Depth Intervals	Root Dry and Wet Weight	% Moisture Soil and Root	Soil Type/ Grain Size	Aboveground Plant Fresh and Dry Weights; Aboveground Plant % Moisture
0–0.3m (1 ft)	Yes	Yes	Yes	Yes	0–0.3 m (0–1 ft)	Yes	Yes	Yes	Yes
0.3–0.6 m (2 ft)	Yes	Yes	Yes		0.3–0.9 m (1–3 ft)	Yes	Yes	Yes	
0.6–0.9 m (3 ft)	Yes	Yes	Yes						
0.9–1.2 m (4 ft)	Yes	Yes	Yes		0.9–1.5 m (3–5 ft)	Yes	Yes	Yes	
1.2–1.5 m (5 ft)	Yes	Yes	Yes						
1.5–1.8 m (6 ft)	Yes	Yes	Yes		1.5–2.1 m (5–7 ft)	Yes	Yes	Yes	
1.8–2.1 m (7 ft)	Yes	Yes	Yes						
2.1–2.4 m (8 ft)	Yes	Yes	Yes		2.1–2.7 m (7–9 ft)	Yes	Yes	Yes	
2.4–2.7 m (9 ft)	Yes	Yes	Yes						
2.7–3.0 m (10 ft)	Yes	Yes	Yes		2.7–3.4 m (9–11 ft)	Yes	Yes	Yes	
3.0–3.3 m (11 ft)	Yes	Yes	Yes						
3.3–3.6 m (12 ft)	Yes	Yes	Yes		3.4–4.0 m (11–13 ft)	Yes	Yes	Yes	
3.6–3.9 m (13 ft)	Yes	Yes	Yes						
4.2–4.5 m (14 ft)	Yes	Yes	Yes		4.0-4.9 m (13–16 ft)	Yes	Yes	Yes	
4.5–4.8 m (15 ft)	Yes	Yes	Yes						
4.8–5.1 m (16 ft)	Yes	Yes	Yes						
TOTAL samples	16 (dry), 16 (wet) 32 TOTAL	16	16	1 (dry), 1 (wet), 1 (% moisture): 3 TOTAL	TOTAL samples	8 (dry), 8 (wet) 16 TOTAL	8	8	1 (dry), 1 (wet), 1 (% moisture): 3 TOTAL

*Root excavation measurements will be measured and recorded at 0.3 m (1 ft) intervals as shown. During data analysis, excavation depth interval data will be combined to represent the eight soil depth intervals from this table that are necessary comparisons between soil coring and root excavation data. For example, 0.3–0.6 m interval data combined with 0.6–0.9 m interval data for root excavation is directly comparable to the 0.3–0.9 m data reported for soil coring.

3.8.2 Root Tissue Fresh and Dry Weight Analyses from Total Root Excavation and Soil Coring

- The root tissue is placed in a preweighed clean, dry container or screen appropriate for the tissue amount. The weight of the container or screen is recorded on a laboratory data form and in a laboratory notebook.
- The root tissue on the container or screen is placed on a calibrated surface loading scale of sufficient sensitivity,[13] and the fresh weight is recorded on a laboratory data form and in a laboratory notebook.
- The root tissue and the container or screen are placed in a thermostatically controlled oven at 110±5°C for at least 16 hours.
- The tissue on the container or screen is removed from the oven and cooled.
- The root tissue on the container or screen is placed on a calibrated surface loading scale of sufficient sensitivity,[13] and the dry weight is recorded on a laboratory data form and in a laboratory notebook.
- The root tissue and the container or screen are again placed in a thermostatically controlled oven at 110±5°C for at least 16 hours.
- The above process is repeated until a constant mass is achieved (<0.1%).
- Once dry weight differences are <0.1%, the root sample dry weight is recorded on a laboratory data form and in a laboratory notebook.

3.8.3 Soil Moisture Analysis for Root Excavation and Soil Core Composite Samples

- Method specified soil mass (per depth interval) is placed in a preweighed clean, dry container appropriate for the sample amount. The weight of the container or dish is recorded on a laboratory data form and in a laboratory notebook.
- The soil sample in the container or dish is placed on a calibrated surface loading scale of sufficient sensitivity,[13] and the wet weight is recorded on a laboratory data form and in a laboratory notebook.
- The soil sample inside the container is placed in a thermostatically controlled oven at 110±5°C for at least 16 hours.
- The soil sample is removed from the oven and cooled.
- The soil sample is placed on a calibrated surface loading scale of sufficient sensitivity,[13] and the dry weight is recorded on a laboratory data form and in a laboratory notebook.
- The soil sample is again placed in an oven at 110±5°C for at least 16 hours.
- The above process is repeated until successive dry weight differences are <0.1%.
- Once dry weight differences are <0.1%, the soil sample dry weight is recorded on a laboratory data form and in a laboratory notebook.

3.8.4 Soil Type and Soil Grain Size Profile Analyses for Root Excavation and Coring Soil Samples

Soil grain size profile analyses will be performed according to ASTM D422-63(2007), *Standard Test Method for Particle-Size Analysis of Soils*, for each of the soil depth interval soil composite samples described for root excavation and soil coring methods. Analysis will be performed by the analytical laboratory selected to perform the required ASTM International testing. Briefly, a representative soil sample will be weighed and particle sizes separated by sieving soil through various mesh sizes. Soils retained on each sieve will be weighed so that percentages of grain sizes can be calculated and reported.

Soil type is analyzed for each core depth interval soil composite sample and will be determined by implementing ASTM D2487-17e1, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*. Briefly, the soil type will be classified by using the data from the previously described soil grain size profile analysis and textural data for identifying soil type. Table 3-3 summarizes the specific ASTM International test methods required for each sample type.

3.9 Data Analysis

Once data from the laboratory conducting ASTM International testing is received from SMR, statistical analysis comparing all measured endpoints will be initiated. Prior to data analysis, assumptions of normality will be evaluated to select the appropriate statistical test (parametric verses nonparametric tests). Data to be analyzed include root penetration and root biomass by depth per plant per species and per sample collection method). Arithmetic mean, n-values, median, minimum, and maximum, along with standard deviations and standard error, will be reported. Additional endpoints summarized are soil type, soil grain size profile, percent soil and plant moisture, plant height, canopy width, trunk circumference, and plant age. Relationships between aboveground plant and soil characteristics and how they relate to root penetration as well as root biomass by depth will be explored using regression analysis. Finally, differences between root excavation methodologies will be assessed using Welsh's t-test or analysis of variance (ANOVA) to determine which methodology provides the most efficient and effective means to characterize soil and roots. This information is critical for supporting future biomobilization root penetration depth validation studies for deep-rooted shrub-steppe vegetation species on the Central Plateau. Specific statistical tests and underlying assumptions are summarized below and support the comprehensive DQO planning conducted (Appendix A).

3.9.1 Hypotheses Testing

The five PSQs with their associated hypothesis testing and population parameters are listed below:

- For focal mature shrub-steppe vegetation species on the Central Plateau, what is the deepest observed root penetration depth (i.e., across discrete soil depth intervals) within the study targeted soil depth range (0-4.9 m [0-16 ft])?

  Descriptive statistics only. Data will include arithmetic mean, minimum, median, maximum, standard deviation, and standard error of the maximum root depth by species.

- For focal, mature shrub-steppe vegetation species on the Central Plateau, what is the distribution of root biomass per unit of soil volume within discrete soil depth intervals of the study targeted soil depth range (0-4.9 m [0-16 ft])?

  Descriptive statistics only. Data will include arithmetic mean, minimum, median, maximum, standard deviation, and standard error of root biomass per unit of soil volume within discrete soil depth intervals.

- For focal mature shrub-steppe vegetation species on the Central Plateau, do aboveground physical shrub measurements (aboveground biomass, plant height, canopy width, canopy perimeter, wood trunk circumference, age, etc.) have a significant relationship with belowground root penetration depth and root biomass per soil volume unit within the study targeted soil depth range (0-4.9 m [0-16 ft])?

  H_o: There is not a significant relationship between aboveground plant measurements and root penetration depth ($\mu_{plantcharacterstic} = \mu_{rootdepth}$)

H_a: There is a significant relationship between aboveground plant measurements and root penetration depth ($\mu_{plantcharacterstic} \neq \mu_{rootdepth}$)

Population parameters: coefficient of determination (r^2); correlation coefficient (r) significance level (p-value = 0.05); slope of the regression line between the selected aboveground shrub measurements and root penetration depth (β_o); and the y-intercept of the regression line (β_1)

H_o: There is not a significant relationship between aboveground plant measurements and root biomass ($\mu_{plantcharacterstic} = \mu_{rootbiomass}$)

H_a: There is a significant relationship between aboveground plant measurements and root biomass ($\mu_{plantcharacterstic} \neq \mu_{rootbiomass}$)

Population parameters: coefficient of determination (r^2); correlation coefficient (r) significance level (p-value = 0.05); slope of the regression line between the selected aboveground shrub measurements and root biomass (β_o); and the y-intercept of the regression line (β_1)

- For soil within the study targeted soil depth range (0-4.9 m [0-16 ft]) occurring beneath focal mature shrub-steppe vegetation specimens on the Central Plateau, is there a significant relationship between the soil grain size profile and root penetration depth and belowground biomass per unit of soil volume?

  H_o: There is not a significant relationship between the soil grain size profile and root penetration depth ($\mu_{soilgrainsize} = \mu_{rootdepth}$)

  H_a: There is a significant relationship between the soil grain size profile and root penetration depth ($\mu_{soilgrainsize} \neq \mu_{rootdepth}$)

  Population parameters: coefficient of determination (r^2); correlation coefficient (r) significance level (p-value = 0.05); slope of the regression line between soil grain size profile and root penetration depth (β_o); and the y-intercept of the regression line (β_1)

  H_o: There is not a significant relationship between the soil grain size profile and root biomass ($\mu_{soilgrainsize} = \mu_{rootbiomass}$)

  H_a: There is a significant relationship between the soil grain size profile and root biomass ($\mu_{soilgrainsize} \neq \mu_{rootbiomass}$)

  Population parameters: coefficient of determination (r^2); correlation coefficient (r) significance level (p-value = 0.05); slope of the regression line between the selected soil grain size profile and root biomass (β_o); and the y-intercept of the regression line (β_1)

- For focal mature shrub-steppe vegetation specimens on the Central Plateau, does shrub root penetration depth and root biomass per unit of soil volume within the study targeted soil depth range (0-4.9 m [0-16 ft]) differ based on the type of root characterization method used (i.e.., root excavation versus root coring)?

  H_o: The mean root penetration depth reported for root excavation methodology is equal to the mean root penetration depth reported for soil coring ($\mu_{RDexcavation} = \mu_{RDcoring}$).

  H_a: The mean root penetration depth reported for root excavation methodology is not equal to the mean root penetration depth reported for soil coring ($\mu_{RDexcavation} \neq \mu_{RDcoring}$).

  Population parameters: p-value = 0.05, treatment mean, n=12, degree of freedom (n-1), F-statistic (F), sums of squares (SSE), mean squares (MS) for ANOVA, Welsh's t-test

H_o: The mean root biomass by depth reported for root excavation methodology is equal to the mean root biomass reported for soil coring ($\mu_{RBexcavation} = \mu_{RBcoring}$).

H_a: The mean root biomass reported for root excavation methodology is not equal to the mean root biomass reported for soil coring ($\mu_{RBexcavation} \neq \mu_{RBcoring}$).

Population parameters: p-value = 0.05, treatment mean, n=12, degree of freedom (n-1), F-statistic (F), sums of squares (SSE), mean squares (MS), Welsh's t-test

3.9.2 Statistical Design

Given the primary study questions and the nature of this study, a judgmental sampling collection and study design were selected. To review justification of the study design and strategy, see Section 3.3 and Figure 3-3.

Observed root depth, root biomass, and their associated standard deviations, standard errors, and additional descriptive statistics will be reported for both methodologies (Table 3-5). Additional measurements include percent soil and plant moisture, soil type and grain size, root tissue dry weight (per soil depth interval), plant height, plant and canopy width, trunk circumference, root perimeter, aboveground plant dry weight, and (perennial) plant age. Simple linear regression analyses will be performed to explore the relationships between aboveground plant and soil variables with root penetration depth as well as root biomass (Table 3-6). Other regression analyses may include multiple linear regression and multivariate linear regression analyses if preliminary results deem further investigation is warranted. Finally, a t-test will be conducted on the population means of the two root characterization methodologies (Table 3-7). If it is determined that the population means have homogeneity of variance, then sample pooling across methodology would be implemented, increasing the n value to 24 instead of 12 samples per species. Additional ANOVA may be conducted if necessary.

Table 3-5. Descriptive Statistics Overview

Plant Species	Parameter	Descriptive Statistics	
		Central Tendency	Dispersion
Sagebrush, antelope bitterbrush, rabbitbrush, Russian thistle	Root depth, root biomass by depth, plant height, canopy width, trunk circumference, age, root perimeter area, percent soil and plant moisture, soil and plant dry weight, plant and root fresh weight, soil grain size profile	Mean, mode, median	Minimum, maximum, standard deviation, standard error

Table 3-6. Simple Linear Regression Analyses – Aboveground Plant and Soil Characteristics Relationship to Root Depth and Root Biomass

Variable[a]	Plant Species	Assumptions	Model Equation
Plant height × Root depth	Sagebrush, antelope bitterbrush, rabbitbrush, Russian thistle	Homoscedasticity, Independent, Normality[b]	$E[Y] = \beta_o + \beta_1 X$
Plant height × Root biomass	Sagebrush, antelope bitterbrush, rabbitbrush, Russian thistle		
Plant/Canopy length × Root depth	Sagebrush, antelope bitterbrush, rabbitbrush, Russian thistle		

Table 3-6. Simple Linear Regression Analyses – Aboveground Plant and Soil Characteristics Relationship to Root Depth and Root Biomass

Variable[a]	Plant Species	Assumptions	Model Equation
Plant/Canopy length × Root biomass	Sagebrush, antelope bitterbrush, rabbitbrush, Russian thistle		
Root perimeter × Root depth	Sagebrush, antelope bitterbrush, rabbitbrush, Russian thistle		
Root perimeter × Root biomass	Sagebrush, antelope bitterbrush, rabbitbrush, Russian thistle		
Age × Root depth	Sagebrush, antelope bitterbrush, rabbitbrush, Russian thistle		
Age × Root biomass	Sagebrush, antelope bitterbrush, rabbitbrush, Russian thistle		
Trunk circumference × Root depth	Sagebrush; possible antelope bitterbrush		
Trunk circumference × Root biomass	Sagebrush; possible antelope bitterbrush		
Soil grain size profile × Root depth	Sagebrush, antelope bitterbrush, rabbitbrush, Russian thistle		
Soil grain size profile × Root biomass	Sagebrush, antelope bitterbrush, rabbitbrush, Russian thistle		

a. Correlation coefficient (r) to be determined in addition to regression analysis.

b. Assumes normality, balanced data. If data do not meet assumptions of normality, an appropriate nonparametric test will be used.

Table 3-7. Statistical Test to Compare Methodologies

Variable	Complete Excavation (n = 12 per species)	Soil Core Drilling (n = 12 per species)	Statistical Test[a]
Maximum root penetration depth (m)	μ_{RD}	μ_{RD}	Welsh's t-test[b] and/or ANOVA
Root biomass (0.61 m [2 ft])	μ_{RB1}	μ_{RB1}	
Root biomass (1.2 m [4 ft])	μ_{RB2}	μ_{RB2}	
Root biomass (1.8 m [6 ft])	μ_{RB3}	μ_{RB3}	
Root biomass (2.4 m [8 ft])	μ_{RB4}	μ_{RB4}	
Root biomass (3.0 m [10 ft])	μ_{RB5}	μ_{RB5}	
Root biomass (3.7 m [12 ft])	μ_{RB6}	μ_{RB6}	
Root biomass (4.3 m [14 ft])	μ_{RB7}	μ_{RB7}	
Root biomass (4.9 m [16 ft])	μ_{RB8}	μ_{RB8}	
Root biomass – total (0–4.9 m [16 ft])	μ_{RBT}	μ_{RBT}	

a. Assumes normality, balanced data. If assumptions of normality are not met, an appropriate nonparametric t-test will be used.

b. If statistical differences between methodologies are not observed, sample pooling will occur (n=24 per species).

3.10 Documentation of Field and Laboratory Activities

Logbooks and data forms (field and laboratory) are typically required for field sampling and sample preparation laboratory activities conducted on the Hanford Site. Field logbooks and data forms will comply with HASQARD requirements (DOE/RL-96-68).

Logbooks (field and sample preparation laboratory) must be identified with a unique project name, number, and the type of logbook (field and sample preparation laboratory). The individual(s) responsible for logbooks will be identified in the front of the logbook, and only authorized persons can make entries in the logbook. The sampling FWS or other responsible field manager will review the logbook entries documented by signature and date. Logbooks will be permanently bound, waterproof, and ruled with sequentially numbered pages. Pages will not be removed from logbooks for any reason. Entries will be made in indelible ink. Corrections will be made by marking through erroneous data with a single line, entering the correct data, and initialing and dating the changes.

Hardcopy field data forms may be used to collect field information; however, information recorded on hardcopy data forms must follow the same requirements as those for logbooks. If used, the data forms must be referenced in the logbooks. A summary of information to be recorded in logbooks or on data forms includes but is not limited to the following:

- Day and date; time task started; weather conditions; and names, titles, and organizations of personnel present and performing the task.
- Purpose of visit to the task area.
- Activities in specific detail (e.g., maps and drawings) or the forms used to record such information (e.g., soil boring log). Also, details of any field tests that were conducted, and reference to any forms that were used, other data records, or methods followed while conducting activities.
- Details of any field equipment calibrations. Reference any forms that were used, other data records, and the methods followed while conducting the calibrations.
- Detail of any sample collected. Reference the methods followed for collecting and preparing samples. List the locations of samples collected, sample types, each label or tag number, sample identification, sample containers and volume or mass, preservation method, packaging, chain-of-custody form number, and analytical request form number pertinent to each sample or sample set. Note the time and the name of the individual to whom sample custody was transferred.
- Time, equipment type, serial or identification number, method, and equipment maintenance performed. Reference the page number(s) of any logbook where detailed information is recorded.
- Any equipment failures or breakdowns that occurred, with a brief description of repairs or replacements.
- Photograph frame numbers for all documentary field and sample preparation laboratory photographs taken.

3.11 Corrective Actions and Deviations for Sampling Activities

The sampling FWS, appropriate field crew supervisors, and SMR personnel must document deviations from protocols, procedures, issues pertaining to vegetation and collocated soil core collection, chain-of-custody forms, sample transport, noncompliant monitoring, or other required activities. As SME on all methods and procedures supporting the study design in this SP, the biomobilization technical lead

(or designee) conducts field oversight assessment audits to ensure compliance. Examples of major deviations that require documentation and corrective action include but are not limited to the following:

- Not following the notification and communication procedures specified in this SP
- Sampling an incorrect target vegetation species specimen
- Not collecting tissue or soil core samples due to "field conditions"
- Not following the sample preparation laboratory composite sample (aboveground tissue, root, soil) processing requirements
- Not taking prescribed photographic documentation steps (during field sampling, sample preparation laboratory sample processing)
- Not following labeling procedures (field, sample preparation laboratory)
- Not completing and quality checking required paperwork (e.g., laboratory logbook, laboratory data forms, chain-of-custody forms, and sample analysis forms)

The biomobilization technical lead (or designated field scientist) and sampling FWS, respectively, for this study will be responsible for documenting and communicating to the sample preparation laboratory and field sampling personnel (respectively) corrective action requirements and for ensuring that these respective corrective actions are undertaken. The sampling FWS is responsible for communicating field corrective action requirements to the soil and vegetation sampling team and confirming that corrective actions are applied as soon as possible. The biomobilization technical lead (or designee) is responsible for communicating any identified corrective action requirements to the sample preparation laboratory as soon as possible.

Changes in any sampling activities that require notification, approval, and documentation will be performed as specified in Table 2-2.

3.12 Calibration of Field and Sample Preparation Laboratory Equipment

Field or sample preparation laboratory environmental instruments required to conduct the study are calibrated in accordance with manufacturers' operating instructions, internal work requirements and processes, and field instructions that provide direction for equipment calibration or verification of accuracy. The results from all instrument calibration activities are recorded in accordance with HASQARD requirements (DOE/RL-96-68). Field and onsite laboratory instrumentation calibration and QA checks will be performed as follows:

- Prior to initial use of a field or sample preparation laboratory measurement system
- At the frequency recommended by the manufacturer or methods, or as required by regulations
- Upon failure to meet specified QC criteria
- Daily calibration checks performed and documented for each instrument used
- Equipment not meeting these requirements for repair before continued use or replacement

3.13 Sample Handling

Sample handling and transfer by the sample preparation laboratory will be performed in accordance with established procedures to preclude loss of identity, damage, deterioration, and loss of sample material. Custody seals or custody tape will be used to verify that sample integrity has been maintained during sample transport from the field to the sample preparation laboratory and from the sample preparation

laboratory to the analytical laboratory. The custody seals in each transport will be inscribed with the sampler's initials and date. During the chain-of-custody process, if it is discovered that the custody tape has been tampered with or broken on one or more of the sample aliquot bottles or the sample transport container to the analytical laboratory, the sample(s) will be analyzed but the results will include a flag to indicate that the custody tape was broken. If the sample data did not trend with other data or were not as expected, the data from the sample will be flagged accordingly.

A sampling and analytical database is used by SMR to track samples from the point of collection through the laboratory analysis process.

3.13.1 Sample Preservation

For the vegetation tissue and soil collected in this study, no preservation requirements are necessary.

3.13.2 Containers

For this study, plant and root tissue along with soil samples are placed in method-compliant containers both in the field during shrub excavation and in the sample preparation laboratory following soil-root core processing. The field sample collection record shall indicate the containers used for transport to the analytical laboratory. Field sampled materials (e.g., deep-rooted vegetation root tissues, and soils) are shipped directly to the analytical laboratory.

Soil core depth intervals collected during soil-root coring are transported intact to the sample preparation laboratory where descriptive information and photographs are collected, followed by tissue and soil composite sample preparation using method-compliant containers. After sample processing, the tissue and soil samples are placed in method-compliant containers and shipped to the contracted analytical laboratory performing ASTM International methods testing.

In all cases, commercially precleaned container lots used during field sample preparation, in the sample preparation laboratory, and the analytical laboratory will be documented, including manufacturer name, lot identification, and certification and retained for documentation. SMR can assist as needed in clarifying procedure.

ASTM International method-compliant containers may be nonstandard (for collecting extra-large shrubs from the field for transport to the sample preparation laboratory). Container types are identified in the field sampling collection record and in laboratory logbooks, data forms, and on chain-of-custody forms.

3.13.3 Container Labeling

Each sample is identified by affixing a standardized label or tag to the container that includes the sample identification number and other required information. The label shall identify or provide reference to the following information: sample number, sample type (aboveground plant tissue, depth-discrete belowground root tissue, depth-discrete soil) date, time, and location (e.g., location identifier), shrub species associated with the sample, soil depth interval, type of soil root cores represented, preservative used (not applicable for the analyses under this SP), analyses required, and sampling technician or sample preparation laboratory technician's name or initials. Sample labels may be either preprinted or handwritten in indelible or waterproof ink.

3.13.4 Sample Custody

Sample custody will be maintained in accordance with existing protocols to ensure that sample integrity is maintained throughout the analytical process. SMR chain-of-custody protocols will be followed throughout sample collection, transfer, analysis, and disposal to ensure that sample integrity is maintained.

A chain-of-custody record will be prepared for all field collected samples transported to either the analytical laboratory (excavation work only) or the sample preparation laboratory (excavation and soil-root coring work). A chain-of-custody record is also prepared following completion of all tissue and soil composite preparation activities in the sample preparation laboratory and will accompany each set of samples shipped to the analytical laboratory conducting ASTM International testing.

Shipping requirements will determine how sample containers are prepared for shipment. The analyses requested for each sample will be indicated on the accompanying chain-of-custody form. Each time the responsibility for sample custody changes, the new and previous custodians will sign the record and note the date and time. The sampling FWS and designated field scientist (SMR or BT) prepare the field chain-of-custody form for transport of field collected samples to either the analytical laboratory (direct shipment) or the sample preparation laboratory. In the sample preparation laboratory, the lead technician will be responsible for adherence to SMR custody procedures (as incorporated in the sample preparation laboratory's technical procedures for conducting this study), including cross-checking the custody form for accuracy, making a copy of the signed record before processed sample shipments to the analytical laboratory, and transmitting a copy to SMR.

The following minimum information is required on a completed chain-of-custody form (or as otherwise required by SMR):

- Project name
- Sample collectors' or laboratory sample processors' name(s)
- Sample composite matrix type (aboveground whole plant tissue, belowground root tissue, soil)
- Depth interval associated with each root tissue or soil composite sample
- Unique sample identification number (specific enough to reflect sample depth interval, sample matrix type [e.g., aboveground tissue, root tissue, soil]) and the target vegetation specimen species (or subspecies as applicable to Russian thistle and sagebrush) with which the composite samples of aboveground vegetation, belowground root tissue, and soil are associated
- Date, time, and location (or traceable reference thereto) of sample collection
- Preservatives (none required for this SP)
- Chain-of-custody information (i.e., signatures and printed names of each individual involved in the transfer of sample custody and storage locations, and dates and times of receipt and relinquishment)
- Requested analyses (or reference thereto)
- Shipping information (i.e., analytical laboratory performing the analysis or the sample preparation laboratory)

The sample preparation laboratory and analytical laboratory lead technicians will note any anomalies with the samples received. If anomalies are found, the laboratory will inform SMR, who will immediately inform the biomobilization technical lead or designee (i.e., if the anomaly resolution will result in changes to study outcomes) so that special direction for analysis can be provided to the laboratory, as necessary.

3.13.5 Sample Transportation

Packaging and transportation instructions shall comply with applicable transportation regulations and DOE requirements. Regulations for classifying, describing, packaging, marking, labeling, and transporting hazardous materials, hazardous substances, and hazardous wastes are enforced by the

U.S. Department of Transportation (DOT) as described in 49 CFR 171, "Transportation," "General Information, Regulations, and Definitions," through 177, "Carriage by Public Highway."[14] Carrier-specific requirements defined in IATA, 2020, *Dangerous Goods Regulations*, shall also be used when preparing sample shipments conveyed by air freight providers.

Samples containing hazardous constituents above regulated amounts shall be considered hazardous material in transportation and transported in accordance with DOT or International Air Transportation Association (IATA) requirements. If the sample material is known or can be identified, then it will be packaged, marked, labeled, and shipped according to the specific instructions for that material. Appropriate laboratory notifications will be made through the SMR project coordinator, if necessary.

DOT or IATA classify materials as radioactive when the isotope specific activity concentration and the exempt consignment limits described in 49 CFR 173, "Shippers—General Requirements for Shipments and Packagings," are exceeded. Samples shall be screened (or relevant historical data will be used) to determine if these values are exceeded. When screening or historical data indicate that samples are radioactive, the samples shall be properly classified, described, packaged, marked, labeled, and transported according to DOT or IATA requirements.

Note that sampling conducted under this SP is intended to be completed within areas on the Hanford Site that are uncontaminated so that issues related to radioactive sample transport are not anticipated.

[14] Transportation regulations 49 CFR 174, "Carriage by Rail," and 49 CFR 176, "Carriage by Vessel," are not applicable, as these two transportation methods are not used.

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4 Management of Investigation-Derived Waste

Because the wastes generated by this project are expected to consist of uncontaminated media and miscellaneous solid wastes that have contacted uncontaminated media, they need not be managed as more traditional *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* wastes such as investigation-derived waste (IDW) or remediation waste. Uncontaminated miscellaneous solid waste (MSW) released from radiological control may be disposed in an offsite municipal landfill like any other non-hazardous waste. Field MSW includes but is not limited to disposable gloves, knives, saws (and saw blades), clippers, or scissors used in deep-rooted vegetation specimen collection and for continuous soil core depth interval cutting. MSW from the sample preparation laboratory includes but is not limited to disposable gloves, any disposable tissue grinding equipment, mixing bins, weighing sheets, disposable saw blades, clippers or scissors, and paper toweling.

As a conservative measure, excess uncontaminated biological media and soils identified in the field or in the sample processing laboratory (i.e., not shipped to the analytical laboratory) will be returned to the environment at or near the points from which they were taken. Sample residuals at the offsite analytical laboratory will be managed in accordance with existing PRC and analytical laboratory waste management processes.

Offsite analytical laboratories are typically responsible for the disposal of unused sample quantities and wastes generated during analytical processes. On a monthly basis, the laboratory will coordinate sample disposal and status with SMR by providing a list of samples more than 90 days post data delivery for which disposal is requested in the following month. The laboratory will also provide on a monthly basis a list of samples disposed in the preceding month that includes disposal date and method or other relevant information. Signed chain-of-custody forms indicating sample disposal will be retained in laboratory case files pending return of case files to the contractor.

Any unexpected contaminated media or MSW that are not releasable from radiological control will be managed as IDW in accordance with the most current IDW procedures agreed upon by DOE, EPA, and Ecology. Such IDW will be managed according to the requirements of the most applicable waste control plan for the area in which they are encountered, and a waste planning checklist will be provided by the waste management representative.

No dangerous wastes are anticipated in the execution of this project; however, in the unlikely event that they are encountered, any MSW that has contacted suspect dangerous waste will be managed as dangerous waste.

Decontamination fluids will be collected and managed in accordance with DOE/RL-2011-41, *Hanford Site Strategy for Management of Investigation Derived Waste*. Waste materials requiring collection will be placed in containers appropriate for the material and the receiving facility in accordance with the applicable waste management or waste control plan and applicable substantive federal and/or state requirements.

Packaging and labeling during waste storage and transportation will meet the appropriate requirements of WAC 173-303, “Dangerous Waste Regulations,” and DOT. Packaging exceptions to DOT requirements may be used for onsite waste shipments if documented as such and if the packaging provides an equivalent degree of safety during transportation.

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5 Health and Safety

All participating organizations in this root characterization study will prepare an organization- and project-specific health and safety plan. Each organization will train participating project personnel on health and safety plan requirements that address the sampling and sample processing activities to be conducted in this study to ensure personnel health and safety.

DOE established the hazardous waste operations safety and health program pursuant to the *Price-Anderson Amendments Act of 1988* to ensure the safety and health of workers involved in mixed waste site activities. The program was developed to comply with the requirements of 10 CFR 851, "Worker Safety and Health Program," which incorporates the standards of 29 CFR 1910.120, "Occupational Safety and Health Standards," "Hazardous Waste Operations and Emergency Response"; 10 CFR 830, "Nuclear Safety Management"; and 10 CFR 835, "Occupational Radiation Protection." The health and safety program defines the chemical, radiological, and physical hazards and specifies the controls and requirements for daily work activities on the overall Hanford Site. Personnel training; control of industrial safety and radiological hazards; personal protective equipment; stop work authority; site control; and general emergency response to spills, fire, accidents, injury, site visitors, and incident reporting are governed by the health and safety program.

This study includes unique health and safety issues of which the field sampling and sample preparation laboratory processing teams must be aware in the preparation of their organization's specific health and safety plans as follows:

- During field sampling activities, depending on the time of year when sampling may occur, there is a risk of insect bites or encountering aggressive wildlife (e.g., badgers). Sampling personnel will take precautions to avoid interactions with wildlife (e.g., snakes) to the extent possible to minimize nuisance insects that may interfere with sampling activities.
- Vegetation will need to be cut or (for thick woody trunks) sawed off as close as is possible to the ground surface, cut into manageable portions, delivered to the sample preparation laboratory, and processed to prepare a "whole plant" tissue sample. Use of cutting instruments in the field or in the sample preparation laboratory can result in cuts or scrapes, and the sampling personnel will need to take precautions to avoid injury.
- The sample preparation laboratory will grind the woody trunk or woody branches of perennial shrub tissue to achieve smaller surface area during the preparation of composite vegetation samples for determining entire aboveground shrub tissue dry weight. Grinding equipment (e.g., drill with bit) use instructions should be followed carefully to avoid hazards as required in laboratory-specific project procedures to which personnel are trained.
- Vegetation field sampling and processing by the sample preparation laboratory will include Russian thistle plants that depending on the subspecies can have spiny growths that can easily injure hands. Appropriate personal protective equipment will be worn during vegetation sampling and processing activities to avoid injury.

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6 References

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Appendix A

Systematic Planning Record

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Rev 0, Chg. 0	**PRC-PRO-SMP-53095**	
	Data Quality Objectives Information Summary	
Published Date: 02122020		**Effective Date:** 02122020

Appendix A – Systematic Planning Record

Characterization Data Collection Planning Record

NOTE: In cases where the requested information is not applicable, state that, and explain why it is not applicable so that it is clear that a required field has not been forgotten.

Project Summary

Project Name:	Root Characterization Study	Date:	02122020
Name of Person Completing Record:	Sue Robinson	Position:	Principal Ecotoxicologist
Name of Responsible Manager:	Alaa Aly		

Project Background:

Intrusion of biological vectors into contaminated subsurface soil with subsequent radionuclide biomobilization to the soil surface is a known transport mechanism at the Hanford Site. Hanford studies have quantitatively characterized the magnitude of biomobilization at various scales within the Central Plateau (i.e., BHI-00032, *Ecological Sampling at Four Waste Sites in the 200 Areas*; WMP-18647, *Historical Site Assessment of the Surface Radioactive Contamination of the BC Controlled Area*; WHC-EP-0771, *Comparison of Radionuclide Levels in Soil, Sagebrush, Plant Litter, Cryptogams, and Small Mammals*). Biomobilization studies, including this root characterization study, are under development to support future risk management and cleanup decision making. For example, a general remedial option under consideration for future feasibility studies evaluating soil cleanup on the Central Plateau is a "leave in place option," which assumes protection that poses no unacceptable human receptor risk. It is therefore important to understand whether a radionuclide biomobilization exposure pathway to receptors (i.e., onsite workers specifically) from deep-rooted successional shrub-steppe vegetation species (e.g., sagebrush) could continue to exist if this option were implemented on the Central Plateau. Historical reports have characterized maximum shrub rooting depths and root masses by depth for a limited number of shrub-steppe vegetation specimens on the Hanford Site and in areas with similar habitat. Collectively, these studies are summarized in CHPRC-00651, Draft B, *Evaluation of Biointrusion at the Hanford Site for Protection of Ecological Receptors*. Root characterization study data collection methods and quality assurance procedures vary across these compiled studies, and sample sizes were typically limited.

The purpose of this root characterization study is to develop a more robust Hanford Site-specific root characterization data set (e.g., shrub root penetration depths, shrub root biomasses by soil depth, and shrub or soil physical measures, the latter of which are planned for in models to predict root penetration depth and root mass by depth) for focal, deep-rooted shrub-steppe vegetation species on the Central Plateau.

All root characterization work will be conducted in uncontaminated locations on the Central Plateau (i.e., outside of "posted" radiation areas). Mature specimens of deep-rooted shrub-steppe perennial vegetation species that are the focus of this root characterization study are as follows: antelope bitterbrush (*Purshia tridentata*), big sagebrush (*Artemisia tridentata*), and gray rabbitbrush (*Ericameria nauseosa*). An annual vegetation species, Russian thistle (*Sasola kali*), is also a focal deep-rooted study species. The focus on mature perennial shrub-steppe vegetation specimens (as opposed to perennial shrub-steppe vegetation specimens of any age) is meant to ensure that root intrusion and biomass data measured in the study (and used in any predictive models) are conservative in nature, biased toward characterizing specimens on the deeper end of the root penetration and root biomass spectrum.

Appendix A – Systematic Planning Record

Characterization Data Collection Planning Record

NOTE: In cases where the requested information is not applicable, state that, and explain why it is not applicable so that it is clear that a required field has not been forgotten.

Project Background:

Planning Type:
(If systematic planning is not required, state the reason)
Systematic DQO Planning (Decisional Draft and Rev 0 submissions to DOE/RL; no regulator submission)

Organization, Schedule, and Goal

(State the problem, requirements, schedule, PSQs, and outcomes)

State the Problem
(Describe the reason/need for data collection and project goals/objectives)
Historical operations and waste management at the Hanford Site have resulted in the presence of radiologically contaminated soils and structures at the surface and at depth. Waste sites with shallow radioactive contamination typically have been stabilized by adding clean cover (soil, gravel, etc.) to reduce exposure to site workers from radionuclides. Deep-rooted shrub-steppe vegetation species may extend their roots into contaminated soils and translocate radionuclide contamination to the surface as documented through routine radiation monitoring and control operations on the Hanford Site. It is necessary to understand whether a radionuclide biomobilization exposure pathway to onsite workers from deep-rooted successional shrub-steppe vegetation species could continue to exist following remediation on the Central Plateau.

Conceptual model: At the Hanford Site, deep-rooted vegetation is known to bring subsurface radionuclides to the surface through root uptake with subsequent translocation of radionuclides to the aboveground portion of the plant (vertical biomobilization). Once radionuclides are transported to the aboveground plant tissue, radioactively contaminated vegetation may represent an exposure pathway and potential risk to onsite workers. The biological exposure pathway of concern addressed is from perennial and annual deep-rooted vegetation species known to vertically biomobilize (transport) soil radionuclides from varying soil depths. The primary exposure pathway for humans resulting from vertical biomobilization is non-contact gamma radiation to onsite workers in areas with biomobilized radiological contamination present at the surface in aboveground vegetation tissues. However, other exposure pathways not addressed may contribute to risk on a site-specific basis. A Central Plateau conceptual site exposure model addressing vertical radionuclide biomobilization in plant tissue and the associated human non-contact gamma radiation pathway is shown in Figure A-1.

Principal Study Questions *(What questions are data needed to answer?)*	**PSQ 1**	For focal mature shrub-steppe vegetation specimens on the Central Plateau, what is the deepest observed root penetration depth within the study targeted soil depth range (0–4.9 m [0–16 ft])?	**PSQ 6**	
	PSQ 2	For focal mature shrub-steppe vegetation specimens on the Central Plateau, what is the distribution of root biomass per unit of soil volume within discrete soil depth intervals	**PSQ 7**	

Appendix A – Systematic Planning Record

Characterization Data Collection Planning Record

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		of the study targeted soil depth range (0-4.9 m [0-16 ft])?		
	PSQ 3	For focal mature shrub-steppe vegetation specimens on the Central Plateau, do aboveground physical shrub measurements (biomass, height, width, perimeter, wood trunk circumference, age, etc.) correlate with belowground root penetration depth and root biomass per soil volume unit within the study targeted soil depth range (0–4.9 m [0–16 ft])?	**PSQ 8**	
	PSQ 4	For soil in the study targeted soil depth range (0-4.9 m [0-16 ft]) occurring beneath focal, mature shrub-steppe vegetation specimens on the Central Plateau, is there a correlation between the soil grain size profile and root penetration depth and belowground biomass per unit of soil volume?	**PSQ 9**	
	PSQ 5	For focal mature shrub-steppe vegetation specimens on the Central Plateau, does shrub root penetration depth and root biomass per unit of soil volume within the study targeted soil depth range (0–4.9 m [0–16 ft]) differ based on the type of root characterization method used (root excavation vs root coring)?	**PSQ 10**	
Define alternative outcomes or actions that can occur upon answering PSQs.	**AA 1A**	This is an estimation study (measure root penetration depth, root biomass distribution and physical shrub and soil parameters) associated with focal vegetation specimens) rather than a decision-based study. Therefore, defining alternative outcomes (i.e.,	**AA 6A**	

Appendix A – Systematic Planning Record

Characterization Data Collection Planning Record

NOTE: In cases where the requested information is not applicable, state that, and explain why it is not applicable so that it is clear that a required field has not been forgotten.

		based on specific decision criteria) is not applicable.		
	AA 1B		**AA 6B**	
	AA 2A		**AA 7A**	
	AA 2B		**AA 7B**	
	AA 3A		**AA 8A**	
	AA 3B		**AA 8B**	
	AA 4A		**AA 9A**	
	AA 4B		**AA 9B**	
	AA 5A		**AA 10A**	
	AA 5B		**AA 10B**	

Identify the decision statements or estimation statements needed to address the PSQs.	1. For PSQ 1, the principal estimate to be made for each focal mature vegetation specimen is the observable root penetration depth within the study targeted soil depth range (0–4.9 m [0–16 ft]). It is expected that the deepest root penetration will be observed in the most mature (oldest) specimens (soil grain size profile may also play a role in root penetration depth).
	2. For PSQ 2, the principal estimate to be made for each focal mature vegetation specimen is the root mass per unit of soil volume (eight soil depth intervals) within the study targeted soil depth range (0–4.9 m [0–16 ft]). It is expected that the greatest root mass per soil volume will be observed in shallow soil depth intervals.
	3. For PSQ 3, the principal estimates to be made for each focal mature vegetation specimen are correlation coefficients and simple linear regression analyses to explore relationships between aboveground shrub specimen measurements (shrub height, width, perimeter, aboveground biomass, circumference of the wood trunk, and age via trunk ring counting) as well as both root penetration depth and biomass measurements. There are no a priori expectations regarding potential relationships (which will be determined through the regression analyses conducted in this study).
	4. For PSQ 4, the principal estimates to be made are correlation coefficients and simple linear regression analyses between soil grain size profiles beneath each specimen within the study targeted soil depth range (0–4.9 m [0–16 ft]) and root penetration depth and root biomass. There are no a priori expectations regarding these potential relationships (will be determined through the analyses conducted in this study).
	5. For PSQ 5, the principal estimate to be made is whether significant differences in mean specimen root penetration depth and mean root biomass by soil depth intervals are evident between the root characterization methods: excavation and coring. There are no a priori expectations regarding whether a statistically significant difference will be observed between methods used to determine mean root penetration or mean biomass.
	6.

Appendix A – Systematic Planning Record

Characterization Data Collection Planning Record

NOTE: In cases where the requested information is not applicable, state that, and explain why it is not applicable so that it is clear that a required field has not been forgotten.

	7.
	8.
	9.
	10.

Data Needs

(Define the spatial and temporal boundaries of the study)

Define what constitutes a sampling unit: A sampling unit is an individual mature vegetation specimen of each of the following focal shrub-steppe species: big sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), gray rabbitbrush (*Ericameria nauseosa*), and Russian thistle (*Sasola kali*). Data for these species will be collected over 3 years within multiple non-contaminated and cleared cultural, ecological, etc.~~)~~ locations within the Central Plateau. Individual, mature specimens will be characterized using two different root characterization methods: complete shrub root excavation to a depth of 4.9 m (16 ft) and shrub root coring (taproot and dripline) core depths to 4.9 m (16 ft).

What is the smallest unit upon which decisions or estimates will be made?

The root characterization data collection during this study will be conducted at specific uncontaminated Central Plateau locations with mature focal vegetation species present that are cleared for subsurface soil characterization work. These data are based on individual plants and are expected to be representative of individual plants located within each waste site. In future remedial decision making, the data from this and other biomobilization studies are expected to be applied collectively on a decision-unit scale. Each operable unit at the Hanford Site contains multiple decision units. These decision units are commonly defined by waste site boundary and depth. An individual waste site could have multiple decision units such as shallow, shallow focused, and deep. The RI/FS work plans for each operable unit define the spatial extent of decision units at the scale used to design and select remedial actions.

Appendix A – Systematic Planning Record

Characterization Data Collection Planning Record

NOTE: In cases where the requested information is not applicable, state that, and explain why it is not applicable so that it is clear that a required field has not been forgotten.

Data Needs Summary

(Information inputs to answer PSQs: target population, characteristics of interest, spatial and temporal limits, scale of inference)

- Target population: Deep-rooted focal vegetation species in uncontaminated and cleared (cultural, ecological, etc.) Central Plateau locations.
- Characteristics of interest: Root penetration depth and root biomass per unit of soil volume (collected at eight soil depth intervals); aboveground shrub measurements (height, width, length, trunk circumference) and (perennial) age (wood trunk sample ring counting); aboveground biomass dry weight and percent moisture; belowground root biomass dry weight and percent moisture; and soil measurements at shrub specimen locations: soil grain size profile, and soil type, and soil moisture content.
- Spatial limits: Shrubs can be located only in uncontaminated (i.e., not in "posted" radiation areas) locations that have been cleared (cultural, ecological, etc.) for subsurface work. Characterization will occur in and around each shrub down to a study targeted soil depth range of 0-4.9 m (16 ft).
- Root characterization methods: Full shrub root excavations and shrub root coring. Both for eight soil depth intervals within the study targeted soil depth range of 0–4.9 m (0–16 ft) beneath each shrub.
- Temporal limits: The study will be conducted over 3 years for each of two characterization methods (root excavation and root coring).
  - Four specimens will be excavated annually for each of four focal species until a total of 12 specimens per species are excavated (48 shrubs over 3 years).
  - Four shrub specimens are cored annually for each of four focal species until a total of 12 specimens per species are cored (48 shrubs over 3 years)

Scale of inference: Central Plateau operable units where a "leave-in-place soil alternative" is considered.

PSQ	Data Need	Media of Interest	Location	Sampling Method	Action Level	Frequency	Practical Constraints	Analytical Method	Potential Source of Data
See Table A-1									

Performance or Acceptance Criteria

(Determine the quality of data needed and analytical approach)

Specify the population parameter *(e.g., mean, median, or percentile)*, appropriate for making decisions or estimates:

Descriptive statistics will be reported at the conclusion of the 3-year study for all PSQs, including minimum, median, maximum, mean, standard deviation, and standard error. Hypotheses testing will not be conducted for PSQs 1 and 2 (only descriptive statistics reported).

Appendix A – Systematic Planning Record

Characterization Data Collection Planning Record

NOTE: In cases where the requested information is not applicable, state that, and explain why it is not applicable so that it is clear that a required field has not been forgotten.

Specify the population parameter *(e.g., mean, median, or percentile)*, appropriate for making decisions or estimates:

PSQs 3, 4, and 5 (hypotheses, population parameters):

PSQ 3:

H_o: There is not a significant relationship between aboveground shrub measurement and root penetration depth and root biomass.

H_a: There is a significant relationship between aboveground shrub measurement and root penetration depth and root biomass.

Population parameters:

(1) The coefficient of determination (r^2); correlation coefficient (r); significance level (*p*-value = 0.05); slope of the regression line between the selected aboveground shrub measurements; root penetration depth and root biomass (β_o); and the y-intercept of the regression line (β_1)

PSQ 4:

H_o: There is not a significant relationship between the soil grain size profile and root penetration depth and root biomass.

H_a: There is a significant relationship between the soil grain size profile and root penetration depth and root biomass.

Population parameters:

(2) The coefficient of determination (r^2); correlation coefficient (r); significance level (*p*-value = 0.05); slope of the regression line between the selected aboveground shrub measurements; root penetration depth and root biomass (β_o); and the y-intercept of the regression line (β_1)

PSQ 5:

H_o: The mean root penetration depth reported for root excavation methodology is equal to the mean root penetration depth reported for soil coring ($\mu_{RDexcavation} = \mu_{RDcoring}$).

H_a: The mean root penetration depth reported for root excavation methodology is not equal to the mean root penetration depth reported for soil coring ($\mu_{RDexcavation} \neq \mu_{RDcoring}$).

Population Parameters:

(3) P-value = 0.05, treatment mean, n=12, degree of freedom (n-1), F-statistic (F), sums of squares (SSE), mean squares (MS) for ANOVA, Welsh's t-test

H_o: The mean root biomass by depth reported for root excavation methodology is equal to the mean root biomass by depth reported for soil coring ($\mu_{RBexcavation} = \mu_{RBcoring}$).

H_a: The mean root biomass by depth reported for root excavation methodology is not equal to the mean root biomass by depth reported for soil coring ($\mu_{RBexcavation} \neq \mu_{RBcoring}$).

Population parameters:

(4) p-value = 0.05, treatment mean, n=12, degree of freedom (n-1), F-statistic (F), sums of squares (SSE), mean squares (MS), Welsh's t-test

Rev 0, Chg. 0

PRC-PRO-SMP-53095

Data Quality Objectives Information Summary (Continued)

Published Date: 02122020 **Effective Date:** 02122020

Appendix A – Systematic Planning Record

Characterization Data Collection Planning Record

NOTE: In cases where the requested information is not applicable, state that, and explain why it is not applicable so that it is clear that a required field has not been forgotten.

Specify the population parameter *(e.g., mean, median, or percentile)*, appropriate for making decisions or estimates:

Decision Problem	Provide a decision rule related to the Action Level identified above that includes a clear "if…then…else" statement: Not applicable (estimation study)
	What are the consequences of making an incorrect decision and what is the tolerance for an incorrect decision? Not applicable (estimation study)
Estimation Problem	Develop the specification of the estimator by combining the true value of the selected population parameter with the scale of estimation and other boundaries: PSQs 1 and 2: Will report descriptive statistics (no statistical testing) for root penetration and root biomass. PSQ 3 and 4: Will estimate the strength and significance of the relationships between aboveground shrub measurements and root penetration and root biomass by depth. PSQ 5: Will determine significant differences between the root excavation and soil coring methodologies for both the reported mean root penetration depth (PSQ 1), and the mean root biomass by depth (PSQ 2).
	What are the acceptable limits on uncertainty? *Uncertainty in the sampling design (PSQs 3,4, and 5 only)* The consequence of incorrectly determining there is a significant relationship between aboveground shrub measurements, the soil grain size profile and sampling method for root penetration depth and root biomass, when in fact there is not, could result in an under or overestimation of key assumptions or parameters employed in risk management decisions and feasibility studies evaluated during a "leave-in-place" remedial alternative. The acceptable limit of uncertainty for PSQs 3,4, and 5 of this Type I error (rejecting H_0 when it is true) is 5.0% (overall alpha value) based on a *p*-value = 0.05 and an analysis number of 1. *Uncertainty in the measurements (population parameters)* For PSQs 3, 4, and 5: Coefficient of determinations, correlation coefficients significance levels (*p*-value) of 0.05, evaluation of residuals to confirm the assumption of normality and independence, verifying the variance of the residuals is homoscedastic*; and use of best professional judgment to determine the strength, validity, and meaning of the results of statistical tests and nature of the datasets when considered as a whole. _____ *Homoscedastic means the variance in a sequence or vector of random variables is the same. In other words, the "noise" in the data is the same across all values of the independent variables.

Plan for Obtaining the Data

(Specify the general plan of obtaining the needed data and explain where and how the information in this Planning Record will be formalized in a data collection plan)

Study Design

The field work will be performed in non-contaminated areas to measure the following: (1) root penetration depth and root biomass over eight discrete soil depth intervals using two root sampling methods (root excavation, root coring); (2) physical measurements of mature focal specimens (e.g., height, width, perimeter; trunk circumference and age);

Appendix A – Systematic Planning Record

Characterization Data Collection Planning Record

NOTE: In cases where the requested information is not applicable, state that, and explain why it is not applicable so that it is clear that a required field has not been forgotten.

Plan for Obtaining the Data

(Specify the general plan of obtaining the needed data and explain where and how the information in this Planning Record will be formalized in a data collection plan)

and (3) the soil grain size profile and soil type associated with each specimen at eight soil depth intervals.

These data will be used to describe mature focal species specimen physical attributes and determine relationships between shrub physical attributes and soil grain size profiles with root penetration depth and root biomass. The results from this study together with other biomobilization lines of evidence (i.e., future studies to be documented in future study plans) will be used in risk management decisions for sites or operable units within the Central Plateau, thus reinforcing the importance of this research.

The statistically based number of mature focal species specimens (Russian thistle, gray rabbitbrush, big sagebrush, antelope bitterbrush) for this proposed study was determined using a power analysis conducted in Statistica™, with a large effect size (0.90), an alpha of 0.05, and beta of 0.2 resulting in a desired sampling size (n) of 12 specimens sampled per species per root sampling method.

The data to be collected during the conduct of this study are outlined in the Data Needs Summary section of this DQO. The detailed plan of study, team organization, quality assurance, data collection methods, and health and safety and waste management information are detailed in DOE/RL-2019-70, *Study Plan to Characterize Root Depth and Mass of Focal Shrub-Steppe Vegetation Species on the Hanford Central Plateau.*

All required clearances (cultural, ecological, etc.) will be obtained prior to the initiation of the study.

For the annual forb Russian thistle (only) seasonal rainfall and temperature patterns during each year of the root characterization study will be evaluated from the Hanford Site weather station relative to average rainfall and temperature conditions to assess potential climatic factors that may influence the rooting depth and root biomasses observed for this species during the study.

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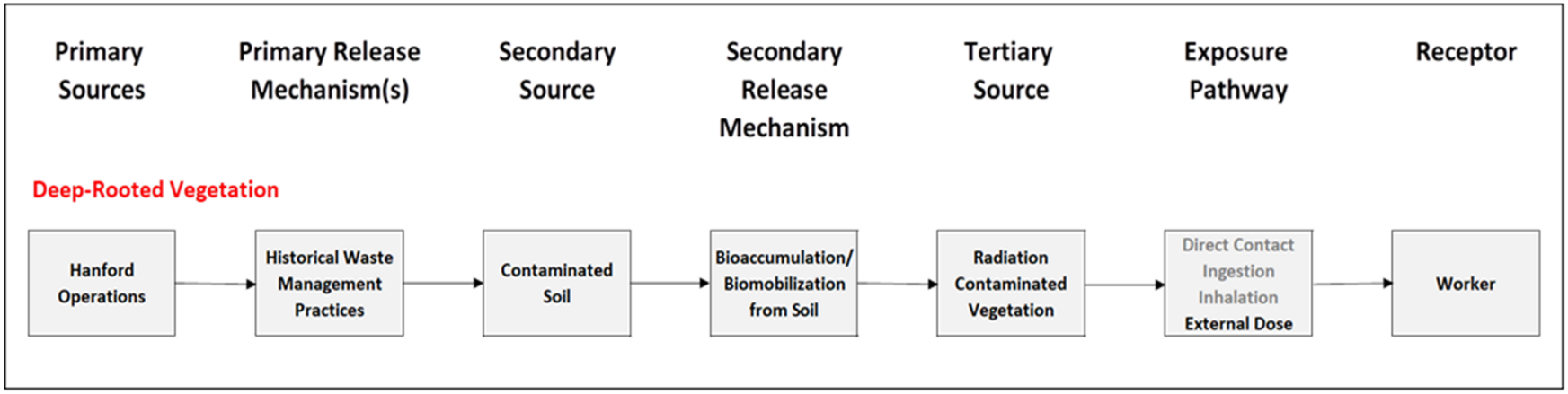

Figure A-1. Outdoor Worker Exposure to Soil Radiological Contaminants Biomobilized by Deep-Rooted Vegetation

Table A-1. Data Needs

PSQ	Data Need	Media of Interest	Location	Sampling Method	Action Level	Frequency	Practical Constraints	Analytical Method	Potential Source of Data
PSQ 1	Deepest rooting depth beneath shrub within 0-4.9 m study targeted soil depth range	Shrub roots	Cleared, uncontaminated shrub specimen locations on Central Plateau	Full shrub excavation and shrub soil coring	NA	Annually over 3 years: four specimens per each of four shrub species per sampling method per year	Distinguishing fine root hairs from other organic matter in soil. Feasibility of using direct push (continuous coring method) through cobbly soil and plant roots for root depth measures)	Not applicable	This study
PSQ 2	Dry weight root tissue biomass and percent moisture	Belowground root tissue	Cleared, uncontaminated shrub specimen locations on Central Plateau	Full root excavation and root soil coring	NA	Annually over 3 years: four specimens per each of four shrub species per sampling method per year	Feasibility of using direct push (continuous root coring method) through cobbly soil and plant roots for root biomass measures)	ASTM D2216-19 or other more appropriate standard for tissue dry weight and moisture content	This study
PSQ 3	Shrub physical measures: length, width, height, trunk circumference, age, aboveground shrub dry weight biomass/ percent moisture	Aboveground portion of shrub	Cleared, uncontaminated shrub specimen locations on Central Plateau	Tape measure (field); growth ring count age (perennial shrubs only) in lab; composite sample of all aboveground shrub tissue (prepared in sample preparation lab)	NA	Annually over 3 years: four specimens per each of four species per sampling method per year	None	For dry weight/ moisture: ASTM D2216-19 or other more appropriate standard for tissue dry weight and moisture content	This study
PSQ 4	Soil grain size profile at each shrub location	Soil grain Size profile around shrub roots	Cleared, uncontaminated shrub specimen locations on Central Plateau	Eight soil composite samples collected in the study targeted soil depth range (0-4.9 m) at each of eight discrete soil depth intervals for each sampling method (excavation, coring).	NA	Annually over 3 years: four specimens per each of four species per sampling method per year	None	ASTM D422-63(2007); ASTM D2487-17e1	This study
PSQ 5	See data needs identified for PSQs 1 and 2 (for statistical means testing between two root sample methods)	Shrub roots	Shrubs from cleared, uncontaminated shrub specimen locations on Central Plateau	Two root sampling methods specified in PSQs 1-2	NA	Sampling frequencies as specified in PSQs 1-2	As identified in PSQs 1-2	As identified in PSQ 2	This study

References: ASTM D2216-19, 2019, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*, ASTM International, West Conshohocken, Pennsylvania.

ASTM D2487-17e1, 2017, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*, ASTM International, West Conshohocken, Pennsylvania.

ASTM D422-63(2007)e2, 2007, *Standard Test Method for Particle-Size Analysis of Soils (Withdrawn 2016)*, ASTM International, West Conshohocken, Pennsylvania.

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