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Remedial Investigation Work Plan to Evaluate the 100-OL-1 Operable Unit Pre-Hanford Orchard Lands

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

U.S. DEPARTMENT OF ENERGY | Richland Operations Office

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Summary

Prior to the acquisition of land by the U.S. Department of War in February 1943 for the creation of the Hanford Site, the land along the Columbia River was home to over 1000 people and was used for various farming and orchard operations by both homesteaders and commercial entities. Tree-fruit production increased around 1905, coinciding with the increased availability of irrigated water through pumping plants and canals provided by the Hanford Irrigation Company (and later the Priest Rapids Irrigation District). Control of codling moths was needed as the orchards expanded in the region. Beginning in the 1890s, lead arsenate was the pesticide of choice for codling moth control for most tree-fruits, which included apples, cherries, apricots, peaches, pears, plums, and prunes. The frequency and timing for lead arsenate applications increased in the 1920s and 1930s and then ceased as orchard activities ended on the Hanford Site. In some areas of the Hanford Site, there is still evidence of the old trees—stumps and branches mostly. Today, the residues from lead arsenate pesticide applications persist in soils in some areas on the Hanford Site.

In May 2012, the U.S. Department of Energy (DOE), U.S. Environmental Protection Agency (EPA), and the Washington State Department of Ecology (Ecology) established the 100-OL-1 Operable Unit (OU) through the Hanford Federal Facility Agreement and Consent Order. The Hanford orchard lands identified as part of the 100-OL-1 OU are located from the 100 Area of the Hanford Site (south side of the Columbia River) down to the Hanford townsite. The discontinuous orchard lands cover approximately 20 km^2 (5000 ac). While most of the former orchard lands were not disturbed by activities during the Manhattan Project or during subsequent Hanford Site activities, some former orchard lands are located across the River Corridor area and within some vadose zone operable units (specifically, 100-KR-1, 100-HR-1, 100-HR-2, 100-FR-2, 100-IU-2 and 100-IU-6). This work plan documents the decisions and evaluations made through a scoping process and identifies future tasks that will be undertaken to complete the remedial investigation (RI) for the 100-OL-1 OU. The feasibility study for the OU will be completed after the RI is approved by DOE, EPA, and Ecology.

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Acronyms and Abbreviations

ac	acre(s)
As	arsenic
ASTM	American Society for Testing and Materials
DOE	U.S. Department of Energy
DOE-RL	DOE Richland Operations Office
DOH	Washington State Department of Health
DQA	data quality assurance
DQO	data quality objective
DU	decision unit
DVZ-AFRI	Deep Vadose Zone Applied Field Research Initiative
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FSP	Field Sampling Plan
FP	fundamentals parameter
GIS	geographical information system
GPS	Global Positioning System
HASP	Health and Safety Plan
HASQARD	*Hanford Analytical Services Quality Assurance Requirements Documents*
HEIS	Hanford Environmental Information System
ICP-MS	inductively coupled plasma mass spectroscopy
LCS	laboratory control sample
MB	method blank
MDL	method detection limit
MS	matrix spike
MTCA	*Model Toxics Control Act*
NA	not applicable
OU	operable unit
Pb	lead
PD	percent difference
$PbHAsO_4$	lead arsenate, acidic form
QA	quality assurance
QAPjP	Quality Assurance Project Plan
QC	quality control
RI	remedial investigation
RPD	relative percent difference
RSD	relative standard deviation

RL	reporting limit
SAP	sampling and analysis plan
SD	standard deviation
SRM	standard reference material
TPA	Tri-Party Agreement
VSP	Visual Sample Plan (software tool)
WAC	*Washington Administration Code*
WCH	Washington Closure Hanford, Incorporated
WIDS	Waste Information Data System
XRF	X-ray fluorescence

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1.0 Introduction

This work plan was prepared to guide a remedial investigation (RI) of approximately 20 km^2 (5000 ac) of non-contiguous former orchard lands on the Hanford Site. The former orchard lands were planted with fruit trees where settlers developed and cultivated upland areas along the Columbia River from the late 1800s until orchard operations ceased. Inorganic pesticides containing arsenic and lead were applied in the orchards across the Hanford Site for over 40 years. Concern about residual lead and arsenic in soils of former orchards, on acreage from the 100 Area of the Hanford Site (south-side of the Columbia River) down to the Hanford townsite, led to the definition of the 100-OL-1 Operable Unit (100-OL-1 OU). This work plan defines the scope and describes the RI to be conducted under the regulatory context of the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* within the Hanford Tri-Party Agreement (TPA) (Ecology et al. 1989).

The TPA defined the area for the 100-OL-1 OU as shown in Figure 1.1 (TPA 2012a). A TPA milestone was identified to develop a remedial investigation/feasibility study work plan to evaluate the operable unit (TPA 2012b). The milestone was met with the submission of the Draft A remedial investigation/feasibility work plan in April 2012. TPA agencies identified the need for a pilot study to evaluate the effectiveness of using an X-ray fluorescence (XRF) analyzer to characterize the lead and arsenic on the surface of the soil in the OU. The results of that pilot study are summarized in Section 2.5. TPA managers subsequently agreed the revision presented here would be an RI work plan. The feasibility study will be completed after the approval of the RI.

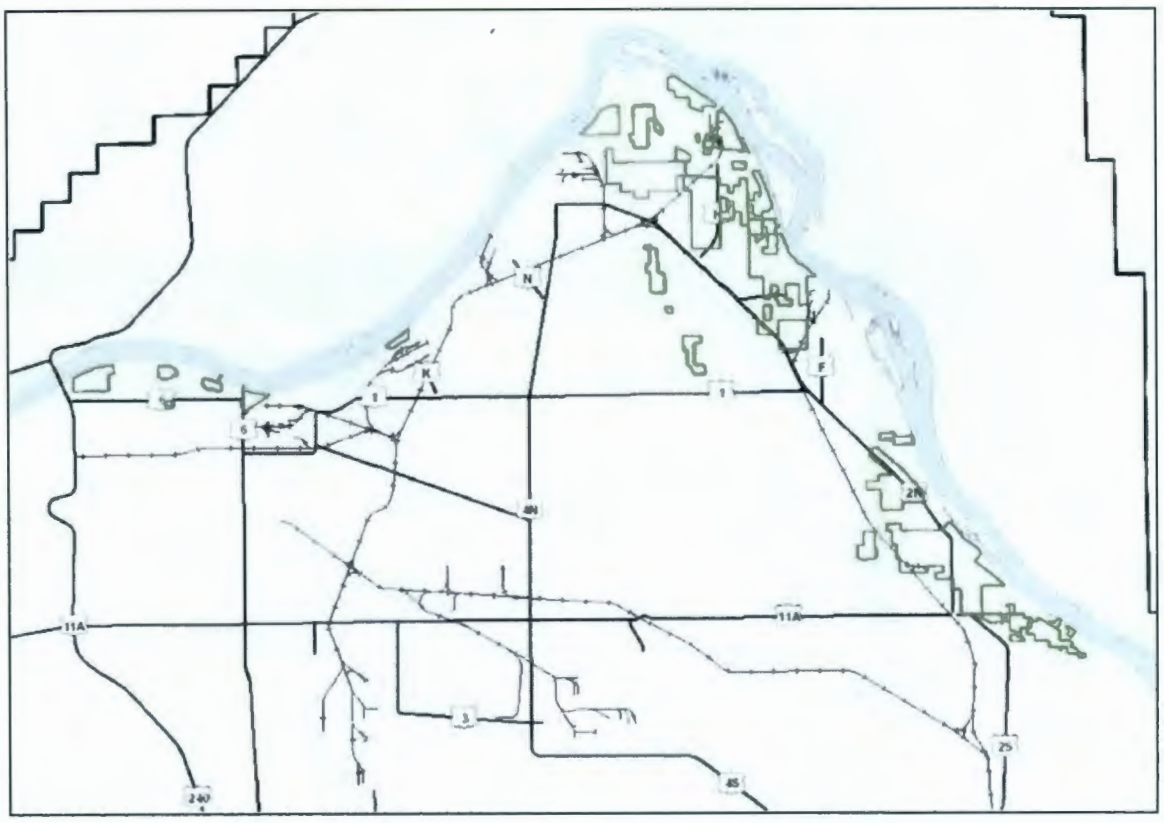


Figure 1.1. Section of the Hanford Site Showing Former Orchard Lands within the Green Boundaries (TPA 2012a)

The 100-OL-1 OU was organized using information from a number of sources on former orchard lands and farm sites, where lead arsenate pesticide was likely used and where residuals of the pesticide are likely found in the soil today. This operable unit is similar to other operable units on the Hanford Site in that the areas identified are associated with a common waste source; however, the areas within the 100-OL-1 OU are discontinuous and spread over a wide geographical area within the Hanford Site. Most of the areas within the 100-OL-1 OU are located outside of designated reactor operable units and relatively few of the orchard tracks have been disturbed by operations within the Hanford Site over time. Orchards are visible in aerial photos from 1943, and this information, along with other historical reports, continues to be useful for identifying the areas to investigate for residual lead arsenate in soil on the Hanford Site.

This work plan presents the historical background (Section 2.0) of former orchard operations, including application of lead arsenate pesticides and irrigation. A conceptual site model is developed to incorporate the limited lead and arsenic concentration data available, along with the history of activities within the OU. Also included is a summary of a pilot study to evaluate the use of an XRF analyzer and to optimize the sampling design for the evaluation of the OU. Section 3.0 discusses the rationale for the work plan and identifies data quality objectives (DQOs) for investigation of the site (incorporating the information obtained from the pilot study). Section 4.0 identifies the tasks required to conduct the RI. Section 5.0 presents the anticipated schedule for conducting the RI. Section 6.0 describes the project management approach and resources required to conduct the RI. Appendix A includes the sampling and analysis plan for the RI, as well as the quality assurance project plan, field sampling plan, and health and safety plan.

2.0 Site Background

The Hanford Site was established in 1943 as the location for production of weapons-grade plutonium during World War II. The residents of the area received only an official notification, known as a "declaration of taking," that informed them that the U.S. Army Corps of Engineers was taking their land for a top-secret project. As noted by Sharpe (1999), the Hanford Site is unique in that no other location in eastern Washington State contains an equivalent array of preserved agricultural information dating from 1900 to 1943. Today, the U.S. Department of Energy (DOE) manages the 1517 km^2 (586 mi^2) Hanford Site in the Pasco Basin of south-central Washington State, including the areas where orchards once were treated with lead arsenate pesticide.

This section provides background for understanding the approach to characterizing the magnitude and extent of the past use of lead arsenate pesticide on land encompassed by the Hanford Site. The extent of former orchard activities on the Hanford Site is still evident. A conceptual site model is discussed to integrate the information about former orchard activities and Hanford Site activities with the knowledge of the lead and arsenic fate and transport to support the approach for characterizing the residual lead arsenate contamination today. This section also includes background soil concentrations and an overview of human and environmental health screening levels for lead and arsenic.

2.1 History of Hanford Orchards within the Orchard Lands Operable Unit

Prior to the acquisition of land by the U.S. Department of War in February 1943 for the creation of the Hanford Site, the land along the Columbia River was home to more than 1000 people, who used it for various farming and orchard operations by both homesteaders and commercial entities. Tree-fruit production increased around 1905, coinciding with the increased availability of irrigated water through pumping plants and canals provided by the Hanford Irrigation Company (and later the Priest Rapids Irrigation District). Control of codling moths (*Cydia pomonella*) was needed as the orchards expanded in the region. Beginning in the 1890s, lead arsenate was the pesticide of choice for codling moth control for most tree-fruits, which included apples, cherries, apricots, peaches, pears, plums, and prunes. The application of lead arsenate ceased when orchard operations ended (Sharpe 1999; DOE 1997; DOE-RL 2011a). In some areas of the Hanford Site, there is still evidence of the old trees—stumps and branches mostly—and a few investigations have been conducted to evaluate lead arsenate residues in the soil (Yokel and Delistraty 2003; Delistraty and Yokel 2011; Bunn et al. 2014).

Sharpe (1999, 2000) summarized pre-Hanford agricultural history. The most common crops included alfalfa, strawberries, asparagus, peppermint, potatoes, apricots, cherries, pears, plums, prunes, peaches, and apples. Low precipitation, blowing dust, and jackrabbits limited dry-land crop development. Because irrigating land was labor-intensive, the typical orchard was no larger than 0.08 km^2 (20 ac). These small orchards required the attention of many people for pruning, spraying, and harvesting. When commodity prices fell below labor costs in the 1920s, many of the early orchards were abandoned. Irrigation of the orchards across most of the inland areas was dependent on water pumping plants and canals managed by the Hanford Irrigation Company and later the Priest Rapids Irrigation District. Because of drought conditions and low water supply in the canal system, many of the apple orchards failed in the 1930s; the abandoned trees were often cut down and used as firewood.

According to Sharpe (1999), orchards required protection from frost and pests. Heating systems and smudge pots, typically fueled by coal briquettes, were used to control frost in the spring. Rabbits were serious pests in orchards and other croplands. The rabbits chewed the bark around the bases of the trees, causing them to die. Rabbit drives were well-organized events across the region, with homesteaders rounding up and exterminating rabbits on a regular basis.

Insect management was used in the orchards to control codling moths, scale, and mites (State College of Washington 1918, 1937, and 1942; Sharpe 1999). While a variety of insecticides were used on orchards around the United States, at the time of orchard development in the region of the Hanford Site, lead arsenate was the most common and most effective insecticide used in Washington State (State College of Washington 1918, 1937, and 1942; Peryea 1998). The acidic form of lead arsenate, $PbHAsO_4$, was the most common type applied in Washington State (Peryea 1998). Lead arsenate could be sprayed as a powder or mixed in a solution and applied as a mist (Figure 2.1 and Figure 2.2, respectively). Lead arsenate could be mixed with soaps or oils to improve the spray coverage of the fruit and residue removal from the fruit after harvest (State College of Washington 1937 and 1942). Other insecticides included cryolite (sodium aluminum fluoride) for codling moths, "lime sulphur" to control scale, and "lime sulfur, atomic sulphur, or flours of sulphur" to control various orchard mites (State College of Washington 1937 and 1942; Sharpe 1999). Some extension service bulletins mentioned calcium arsenate as an alternative control for fruit-tree pests but lead arsenate was highly recommended (State College of Washington 1937).

Figure 2.1. Application of Lead Arsenate as a Powder on Orchards in the Region of the Hanford Site

Specific directions on the formulation of the lead arsenate, as well as the spraying schedule and the number of applications for lead arsenate, were available to the orchardist in the *White Bluffs Spokesman*, State College of Washington extension bulletins, and other news sources. Typically, applications of lead arsenate contained 2.7 kg (6 lb) of paste or 1.4 kg (3 lb) of powder to 757 L (200 gal) of water. The

schedule for spraying and the number of applications depended on the development of the fruit and changed over time as codling moths became resistant to lead arsenate (Sharpe 1999).

Figure 2.2. Application of Lead Arsenate as a Mist on Orchards in the Region of the Hanford Site

Today, residues from lead arsenate pesticide applications persist in soils at the Hanford Site as they do in other former orchard areas across Washington State and the nation. From 1910 to 1920, almost 14 million kg (30 million lb) of lead arsenate was used annually in the United States (ODEQ 2006). The levels of arsenic and lead in the soil from former orchard activities vary based on several factors: the number of applications in a season of production; the form of application (powder or solution); soil characteristics (soil texture, pH, organic matter, clay minerals, hydrous metal oxides, calcite); and precipitation rates (Frank et al. 1976; MacLean and Langille 1981; Veneman et al. 1983; Peryea and Creger 1994; Elfving et al. 1994; Peryea and Kammereck 1997; Peryea 1998; Sharpe 1999, 2000; Kabata-Pendias 2001; Yokel and Delistraty 2003; Newton et al. 2006; Renshaw et al. 2006; Staed et al. 2009; Cadwalader et al. 2011; Sloan 2011; Delistraty and Yokel 2011).

2.2 Conceptual Site Model

The conceptual site model for lead arsenate pesticide residues on the Hanford Site addresses the factors described above as well as contamination pathways in the environment (Figure 2.3). The former

orchard properties on the Hanford Site have residual lead arsenate contamination in the soil as a result of pesticide use in the first half of the 20th century Figure 2.3, top). This condition is consistent with orchard properties across Washington State and the United States where lead arsenate pesticides were applied to a variety of fruit trees (AWSCFT 2003a; Hood 2006; Schooley et al. 2008). The concentrations of lead and arsenic are expected to be highly variable across the Hanford Site orchards because of the differences in spraying practices, the number of years an orchard was in production, irrigation during orchard operation, the physical form of the pesticide when applied, the physical properties of the soil at each orchard, and the amount of contaminant loss from individual orchards. In addition, activities on the Hanford Site have and continue to occur in areas that once were occupied by orchards. Soil with lead arsenate residues has been moved, excavated, and buried by these activities (Figure 2.3, bottom). This section considers pathways for lead arsenate residues in the environment, background concentrations for lead and arsenic in soils, the waste sources and potential volume estimates for contaminated soil, and the history of disturbances.

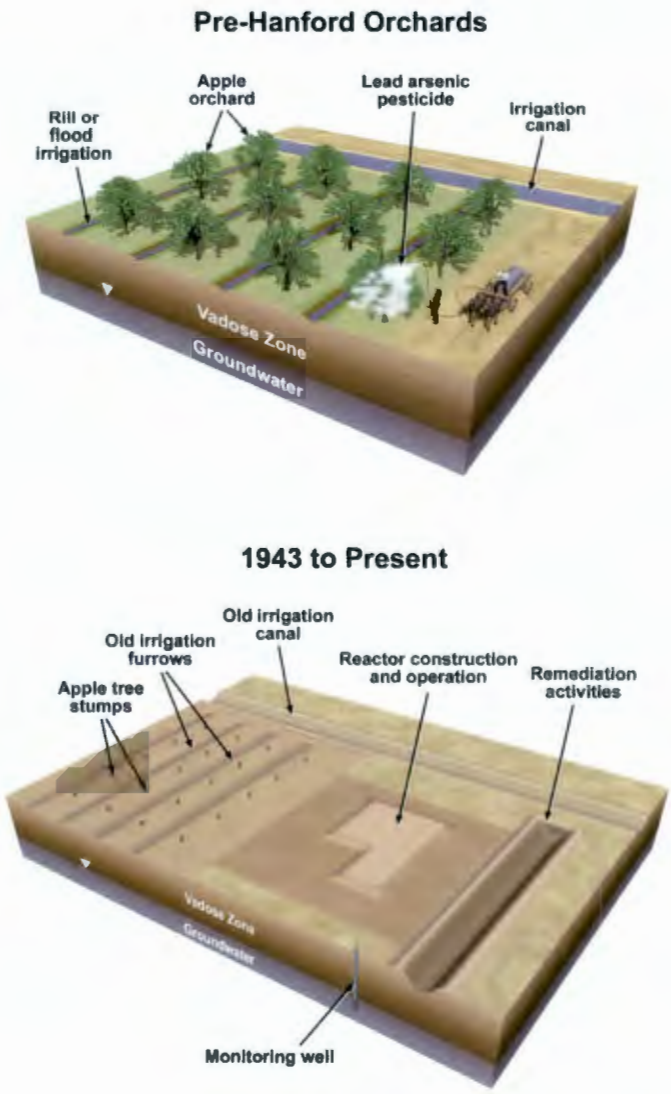


Figure 2.3. Conceptual Site Model for Lead Arsenate Pesticide Residues in Orchard Lands on the Hanford Site Prior to 1943 (top) and from 1943 to Present (bottom)

2.2.1 Historical Pathways for Lead Arsenate Residues in Hanford Orchards

During historical applications of lead arsenate pesticide, there were several pathways for contaminant migration: soil, water, air, and biota (Figure 2.3, top). The orchardists applied the lead arsenate pesticide onto individual fruit trees to deter codling moths from laying eggs on the fruit or leaves. Extension bulletins over time recommended more frequent applications of lead arsenate, with increasing saturation applications through the trees as well as on the trunk (State College of Washington 1918, 1937, and 1942). Pesticide would have dripped from the trees onto the soil, lead arsenate powder or solution would have spilled onto the soil, and dead leaves and fruit contaminated with lead arsenate would have accumulated on the soil. Accumulation of lead arsenate residues in the soil would have been the most significant pathway for lead and arsenic.

Less significant pathways would have included wind and water dispersion and the movement of people and animals through the orchards. Applications during windy conditions also could have led to dispersion of the lead arsenate beyond the orchards. Irrigation water, groundwater, or surface water (in the orchards close to the Columbia River) could have carried lead and arsenic away from the orchards in regions where applications were substantial. Overland flow from precipitation or irrigated water could have contributed to lead and arsenic in surface water sediments. In addition, human and animal activity could have tracked lead and arsenic away from the orchards. Certainly, the people who sprayed the lead arsenate and the ecological receptors using the orchards during pesticide application were exposed to the lead and arsenic.

2.2.2 Soil Pathway for Lead Arsenate Residues in Hanford Orchards

The highest concentrations of lead arsenate residues are likely to be in the soil and within the boundaries of the 100-OL-1 OU. Evaluations of lead arsenate dispersal on the Hanford Site have been limited to a few special studies (e.g., Yokel and Delistraty 2003; Delistraty and Yokel 2011; Bunn et al. 2014); waste site evaluations have assessed for the presence and determined the potential risk of lead and arsenic in soils and sediments from former orchard activities (e.g., DOE-RL 2010, 2011a and b, 2012a and b). Direct soil contact is the primary pathway of concern today for lead arsenate found on the former orchard properties.

Dispersal in the soil beyond the boundaries of the 100-OL-1 OU would be minimal on the Hanford Site. Numerous studies have shown that there is limited potential for lead arsenate residues to move overland when water (irrigation or precipitation) is limited (Frank et al. 1976; MacLean and Langille 1981; Veneman et al. 1983; Peryea and Creger 1994; Elfving et al. 1994; Peryea and Kammereck 1997; Peryea 1998; Kabata-Pendias 2001; Newton et al. 2006; Renshaw et al. 2006; Staed et al. 2009; Cadwalader et al. 2011).

Previous studies of the vertical transport of lead and arsenic through soil have indicated various depths of contamination below the surface. One consistent observation is that the arsenic is generally more mobile, moving somewhat deeper than lead. This finding would indicate that the lead and arsenic are no longer chemically associated and could be treated as two distinct contaminants, which is consistent with previous work (Renshaw et al. 2006). Figure 2.4 illustrates the vertical profile of lead and arsenic as reported by Peryea and Creger (1994) in six orchard soils from Washington State. The vertical migration of contaminants is a function of soil type, soil chemistry, and precipitation/irrigation (Veneman et al.

1983; Newton et al. 2006; MacLean and Langille 1981; Renshaw et al. 2006; Staed et al. 2009; Delistraty and Yokel 2011). The studies of vertical migration most relevant to the former orchard properties indicate that lead could be expected to have migrated down to 0.4 m (16 in.), and arsenic to 1 m (39 in.) (Peryea and Creger 1994; Yokel and Delistraty 2003).

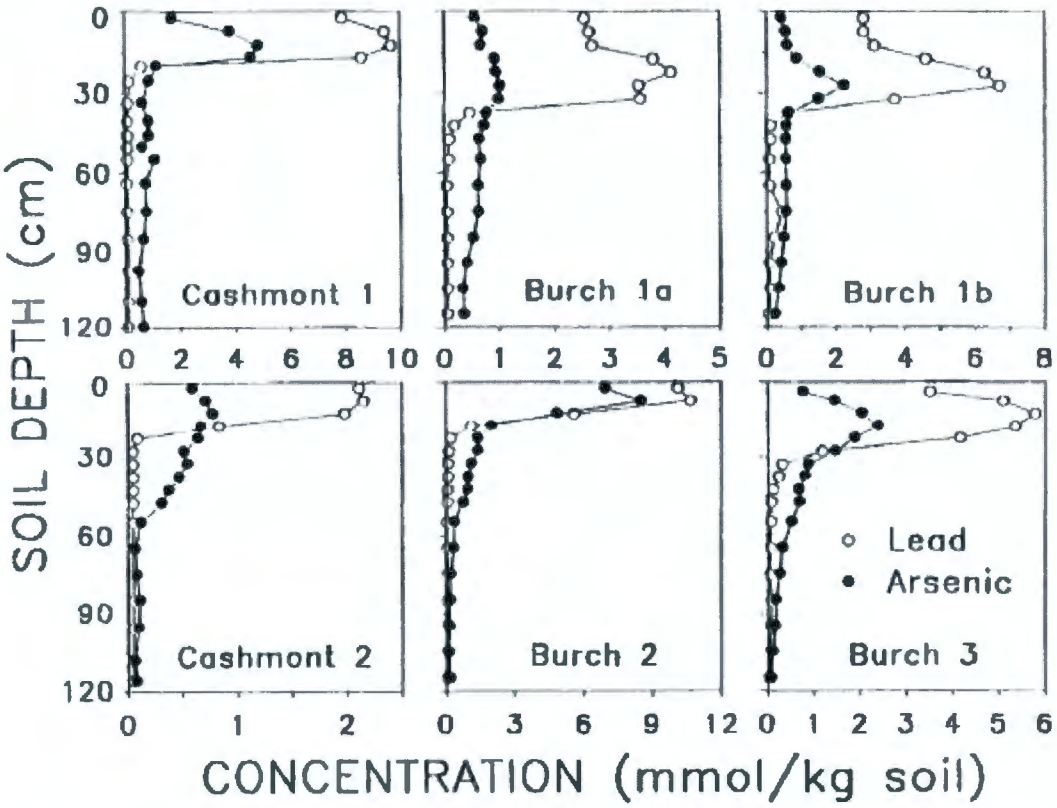


Figure 2.4 Vertical Profile of Lead and Arsenic in Six Lead Arsenate-Contaminated Orchard Soils (Peryea and Creger 1994; reproduced with publisher's permission)

Some limited data exist on the concentrations of lead and arsenic present in the surface soil of the former orchard properties at Hanford. These data provide evidence for what the expected concentrations of arsenic and lead in the upper 1 m (39 in.) might be on the former orchard sites (Table 2.1). A pilot study (Bunn et al. 2014) using XRF measurements to characterize four distinct areas within the 100-OL-1 OU determined that measured concentrations of lead and arsenic were within the range of concentrations previously observed (Table 2.1). Delistraty and Yokel (2011) found that more than 99% of the total arsenic in the soil was present as arsenic (V) in the former Hanford orchards. A separate study also identified the 100-F and 100-H Areas as having significantly higher concentrations of arsenic and lead than the 100-D Area or the Hanford townsite (Yokel and Delistraty 2003). The data in Table 2.1 from the Hanford Environmental Information System (HEIS) primarily were collected during remediation of other waste sites, and may not be representative of lead arsenate residues. While the soil samples were all taken from within the boundaries of the former orchards, the sampling sites were not evenly distributed in space so the samples might not be representative of the orchard soil, and they might not have been derived from the surface soils. The nature of the sampling results in some of the HEIS data could have biased the average concentration of the samples compared to the true average concentration expected on undisturbed

orchard soils. However, the concentrations of arsenic and lead in soil measured in these samples are consistent with soil sampling studies across the United States on orchards treated with lead arsenate.

Table 2.1. Surface Soil Concentrations of Arsenic and Lead Measured on Former Orchards on the Hanford Site, and Other Orchard Locations

	Arsenic (in mg/kg)					Lead (in mg/kg)				
Source	*n*	Mean	Median	SD	Max	*n*	Mean	Median	SD	Max
Yokel and Delistraty 2003	31	30	5.7	61	270	31	220	27	460	1,900
Delistraty and Yokel 2011	11	39.5	NR	40.6	128	11	208	NR	142	390
Pilot Study (Bunn et al. 2014)	160	18	6.5	38	415	160	164	33.7	390	4187
HEIS Data[(a)]	881	8.7	4.0	14	111	825	35	9.8	91	1,240
HEIS Data[(b)]	113	8.0	5.2	7.9	54	78	55	23	98	665
HEIS Data[(c)]	108	26	15	27	111	109	113	44	173	1,240

(a) All HEIS soil samples occurred within the boundaries of the orchards as shown in Figure 1.1. Data were removed if sampling records confirmed a result was not representative of orchard surface soils. For example, sludge collected from the bottom of a sump, or soil in an excavation collected more than 1.5 m (4.9 ft) below grade, did not qualify as surface soil samples.

(b) HEIS data from one orchard were used to determine distribution of soil concentrations (Decision Units DU-74, -75, -76, 116-F-1 Lewis Canal waste site). Soil sampling was conducted as part of the *Limited Field Investigation Report for the 100-FR-1 Operable Unit* (DOE-RL 1995).

(c) HEIS data from two orchards were used to determine distribution of soil concentrations (Decision Units DU-15 and -16).

Max = maximum number of samples.
n = number of samples.
NR = data not reported.
SD = standard deviation.

In an effort to make a more meaningful evaluation of existing Hanford Site data, data derived from a subset of soil samples collected from one former orchard property were evaluated. The samples were collected for evaluation of the 116-F-1 Lewis Canal, located north of the 100-F Area (DOE-RL 1995, 2012b). A cultural resource review of sample locations was completed before the samples were taken (HCRC# 97-100-013 and 97-100-013a). The data were selected for analysis because they were derived from samples collected from relatively evenly distributed sampling sites across the orchard, and represented enough samples to be statistically relevant (Figure 2.5). Histograms of the arsenic and lead concentrations indicate a log-normal distribution (Figure 2.6).

Key questions that typically are considered when evaluating soil exposure pathways are described below.

Are the contaminants moving? Most of the measurements of concentrations of arsenic and lead in Hanford Site soil on the former orchard properties occurred between 1995 and 2011. Given that the concentrations are still within the range of concentrations reported for other orchard sites (Kabata-Pendias 2001) and the vertical concentration data derived from Hanford soils show limited vertical movement through the soil column (Yokel and Delistraty 2003), the movement of arsenic and lead can be assumed to be very slow—on the order of 1 to 2 cm/yr (0.4 to 0.8 in./yr). This low transport rate is expected considering the low solubility of arsenic and lead (Liu et al. 2009), the low annual precipitation on the Hanford Site (17.7 cm [7 in.], Poston et al. 2004), and the fact that 99% of the total arsenic is present as

arsenic (V) rather than the more soluble arsenic (III) (Newton et al. 2006; Delistraty and Yokel 2011). Phosphate fertilizers have been demonstrated to enhance the mobility of arsenic in soil (Peryea and Kammereck 1995; Staed et al. 2009). However, phosphate fertilizers were not historically used on the former orchard sites (Peryea and Kammereck 1995). Arsenic and lead from historical lead arsenate application have been shown to be associated primarily with the fine silt and clay size fraction of the soil (Renshaw et al. 2006). This indicates that the mass loss rate of arsenic and lead from the former orchard sites could increase if the sites are disturbed; the small size fraction of soil is more mobile during erosion processes (Cadwalader et al. 2011).

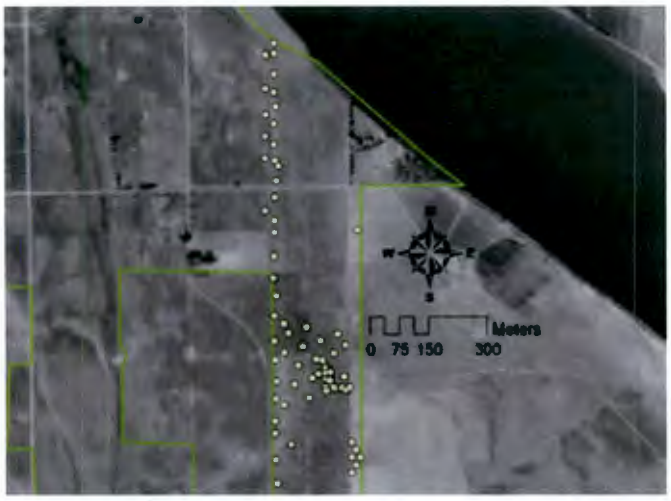
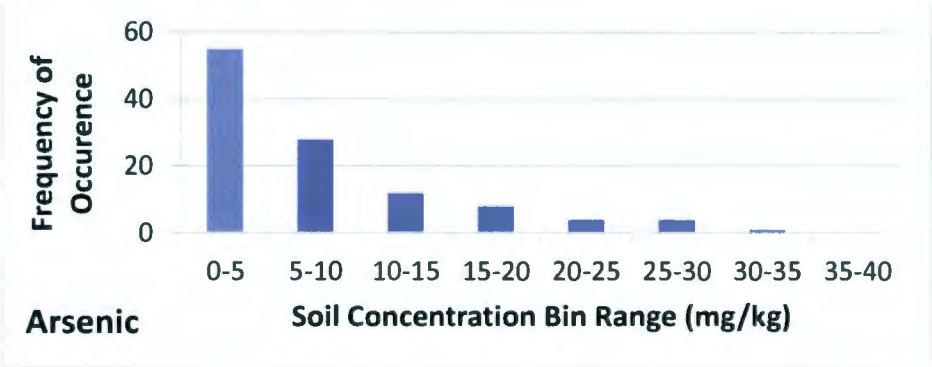


Figure 2.5. Soil Samples Collected on the Hanford Site, North of 100-F Area (116-F-1 Lewis Canal), with the 1943 Historical Aerial Imagery as a Background (results of soil sampling part of DOE-RL 1995)



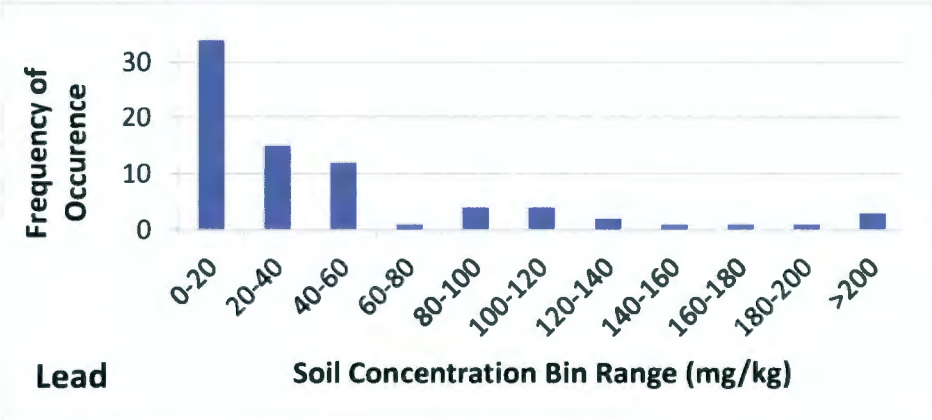


Figure 2.6. Histograms of Arsenic and Lead Soil Concentrations from 116-F-1 Lewis Canal Waste Site (results of soil sampling part of DOE-RL 1995)

How fast are contaminants dispersing along the flow path? Because arsenic and lead found in Hanford soil essentially are not moving, there is minimal dispersal along the flow path. The measured concentrations for vertical profile samples collected at the former orchards show that lead is dispersing even slower than arsenic (Yokel and Delistraty 2003). The concentrations decrease from 1100 mg/kg at a 10-cm (4-in.) depth to 30 mg/kg at a 50-cm (20-in.) depth, or by a factor of 36 over 40 cm (16 in.). Arsenic dispersal appears to be faster, with concentrations of 110 mg/kg at a 10-cm (4-in.) depth decreasing to 50 mg/kg at a 50-cm (20-in.) depth (Yokel and Delistraty 2003).

To what extent might natural attenuation be occurring? Natural attenuation of lead arsenate residues does not appear to be occurring in the soils in Washington State or across the nation. No mechanisms that could result in attenuation have been identified. As trace metals, arsenic and lead cannot be destroyed, and based on previous evaluations, the metals already appear to be in a relatively immobile state (Yokel and Delistraty 2003).

2.2.3 Other Pathways for Lead Arsenate Residues in Hanford Orchards

The groundwater pathway for lead arsenate residues is not significant at Hanford. Studies have shown that neither lead nor arsenic are mobile enough to have migrated downward to the top of the water table (Peryea and Creger 1994). Lead and arsenic are not detected routinely in Hanford Site groundwater and, therefore, are not mapped or tracked by the groundwater monitoring program (DOE-RL 2011b). To evaluate the arsenic and lead concentrations in Hanford Site groundwater, data from 26 Hanford Site

monitoring wells (located within the former orchard properties and close to the Columbia River) were evaluated. Analytical results for arsenic or lead (HEIS data) were reported for only eight of these wells. Of the 268 individual results, only 18 measurements did not have data qualifiers (measured concentrations above the required detection limit, high blank concentrations, etc.). Most of these 18 samples were taken from one location (199-F1-2), which had detectable concentrations of arsenic between 9 and 12 µg/L. The 199-F1-2 sampling location is north of the 100-F Reactor, close to the former town of White Bluffs. Two up-gradient groundwater wells (199-F7-2 and 199-F7-3) appear to have arsenic concentrations at somewhat lower concentrations (6 to 8 µg/L). To put this in context, the drinking water standard for arsenic is 10 µg/L. A recent evaluation of arsenic and lead in the 100-FR-3 OU concluded that the elevated levels detected in the groundwater were consistent with concentrations in background wells, and the contaminants were not retained for further evaluation in the feasibility study (DOE-RL 2012b). Lead arsenate residue does not appear to be transporting to groundwater at this time.

Lead arsenate residue in surface water today is unlikely. With no operating orchards on the Hanford Site, there is no lead arsenate application or irrigation to provide any potential for surface runoff from flood irrigating. The surface water sediment pathway is of limited concern because of the potential for lead arsenate residue to have eventually migrated to Columbia River sediment. However, it has been documented that Columbia River sediments have slightly elevated levels of both lead and arsenic, which have been attributed to upriver mining operations (Patton and Crecelius 2001; DOE-RL 2012a). The concentrations of arsenic measured in Columbia River sediments (6 mg/kg) are less than the 95th percentile of the background arsenic concentrations (DOE-RL 2001; Patton and Crecelius 2001; DOE-RL 2012a). While the concentrations of lead measured in Columbia River sediment (35 mg/kg) are higher than the background surface soil concentrations of lead, the concentrations are slightly lower than, and not statistically different from, the concentrations measured in sediments upstream of Priest Rapids Dam (DOE-RL 2001; Patton and Crecelius 2001; DOE-RL 2012a).

The air pathway may continue to contribute to the spread of lead arsenate residues; windblown dust from areas with disturbed surface vegetation is a well-documented occurrence on the Hanford Site (Poston et al. 2003; DOE-RL 2012b). However, it also is documented that once vegetation (either native or non-native) returns to disturbed areas, windblown dust decreases dramatically (Poston et al. 2004). The literature concerning lead and arsenic migration through the soil column indicates that the very top of the surface soil should not have the maximum concentrations (Peryea and Creger 1994). The maximum concentrations occur at depths of 5 to 30 cm (2 to 12 in.). The air pathway should be a concern only if activities on the former orchard properties result in the removal/destruction of surface vegetation and bring below-grade soil to the surface.

The biotic pathway also is a complete pathway. Exposure to lead and arsenic primarily is through ingestion of contaminated soil. Biointrusion into contaminated areas can move contamination up to the surface by plant uptake through their roots and burrowing activity by animals or insects (DOE-RL 2012b). While plant and animal uptake rates of lead and arsenic are relatively low, the potential exists for human and biotic exposure along the food chain pathway, although this pathway is not significant (DOE-RL 2010, 2011a, 2012a, b).

2.3 Background Concentrations in Soil for Lead and Arsenic

This section discusses background concentrations determined on the Hanford Site, in the region and across the nation. Several key reports (highlighted below) provide a range of expected background soil concentrations of lead and arsenic on and around the Hanford Site; the relevant background concentrations for arsenic and lead are provided in Table 2.2. These data will be used to determine the required analytical sensitivity and identify statistically significant differences between potentially contaminated orchard properties and background concentrations.

Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes. This report (DOE-RL 2001) documents the results of sampling and analysis activities designed to characterize the composition of soil background concentrations for nonradioactive analytes in the vadose (unsaturated) zone of the Hanford Site. For this study, samples were selected to provide a random, unbiased distribution of concentrations within the Hanford vadose zone; there were 104 samples with both arsenic and lead. While the samples consisted of soil taken from throughout the vadose zone, the soil model assumed that there would be very little depth variability in the concentrations of metals in the Hanford vadose zone. This is due to the nature of the Hanford Site vadose zone formation; namely, the reworking and deposition of the soil by the Missoula Floods. The results were analyzed using both log-normal and Weibull distribution techniques. In Table 2.2, only the log-normal distribution statistics are included because they are more directly comparable to other data sources; however, for lead and arsenic there was very little difference between the log-normal and Weibull distributions statistics.

Table 2.2. Relevant Background Concentrations (in mg/kg dry weight) for Arsenic and Lead

Analyte/Location	Mean	Standard Deviation	Range	90th Percentile
Arsenic (mg/kg dry weight)				
Hanford Site[a]	4.2 (3.55)[b]	1.68	3–11.4	6.47
Hanford Site[c]	3.11	2.04	1.1–22	NA
Eastern Washington[d]	2.53[b]	2.52[e]	0.5–7.19	5.76
United States, podzols and silty soils[f]	5.1	NA	<0.1–30	NA
United States, loamy and clay soils[f]	7.7	NA	1.7–27	NA
Lead (mg/kg dry weight)				
Hanford Site[a]	6.3 (5.45)[b]	3.46	1.1–26.6	10.2
Hanford Site[c]	10.3	7.67	3.21–60.3	NA
Eastern Washington[d]	6.4[b]	2.69[e]	4.2–11.7	9.85
United States, podzols and silty soils[f]	17	NA	<10–70	NA
United States, loess and silty soils[f]	19	NA	10–30	NA
United States, loamy and clay soil[f]	22	NA	10–70	NA

(a) DOE-RL 2001, as reported in the document.
(b) Median value, not mean.
(c) Fritz 2009.
(d) San Juan 1994, specifically for Group E, Benton, Spokane, Lincoln, Adams, Okanogan, and Whitman counties.
(e) Calculated from reported data as 90th percentile minus median, divided by 1.28.
(f) Kabata-Pendias 2001.
NA = not applicable.

A Review of Metal Concentrations Measured in Surface Soil Samples Collected on and around the Hanford Site. Fritz (2009) collected surface soil samples (top 2.5 cm [1 in.]) on and around the Hanford Site, primarily at undisturbed locations away from site operations. The concentrations of lead and arsenic measured were similar to the background concentrations determined by DOE and Washington State (Table 2.2). The highest lead and arsenic concentrations were measured in samples of shoreline soil and sediment. Columbia River sediment along the Hanford Reach is known to have higher concentrations of metal than local soil as a result of upstream mining operations (Patton and Crecelius 2001).

Natural Background Soil Metal Concentrations in Washington State. This report (San Juan 1994) characterizes the natural background concentrations of metals in surface soils in Washington State. The State defines background concentrations as the "concentration of a hazardous substance consistently present in the environment which has not been influenced by localized human activities." The State of Washington was divided into 12 regions based on soil type, and samples were collected in each region. The Hanford Site lies within the Central Columbia Basin Region, which is defined as having unconsolidated windblown and alluvial materials on the surface. This study used a compositing scheme to remove extremely localized effects; however, only three composite samples were collected from the Central Columbia Basin Region. Apparently for this reason, the average concentrations within the Columbia Basin Region were not calculated, but instead were combined with several other areas in eastern Washington State. The background concentrations reported for this region ("E") are similar to the background concentrations identified for the Hanford Site (Table 2.2).

Trace Elements in Soils and Plants. Kabata-Pendias (2001) provides a comprehensive review of published concentrations of metals in soils across the planet. For lead and arsenic, concentration ranges are provided for various soil types in multiple countries. Podzol and sandy soils in the United States were chosen as the type most representative of the Hanford Site (Table 2.2). The range of background concentrations reported for arsenic and lead across the United States in podzol and sandy soil are somewhat higher than the background concentrations reported closer to the Hanford Site.

2.4 Soil Surface History

Characterization of the 100-OL-1 OU requires an understanding of the changes in the landscape of the orchard areas over time. During the Manhattan Project, the construction activities were near the orchards. As seen in Figure 2.7, the orchards and agricultural fields are visible behind the new buildings around D reactor in 1944. However, the 100-KR-1, 100-HR-1, 100-HR-2, and 100-FR-2 vadose zone operable units, as well as Camp Hanford, were all built on or over agriculturally developed lands, including orchards. Documentation of these construction activities is very limited. Recent remediation activities around the operating areas have resulted in excavations and other activities that disturb the soil surface, and documentation on those activities is available.

As an example, consider the 100-K Area, where a former orchard area was located (Figure 2.8). From historical aerial photographs, as well as the geographical information system (GIS) coverage, it is clear that the area between the water intake structures is a former orchard. Two soil samples were collected from this area in 1992. The sample results indicated lead concentrations in surface soil of about 14 mg/kg, or slightly higher than background concentrations (HEIS data).

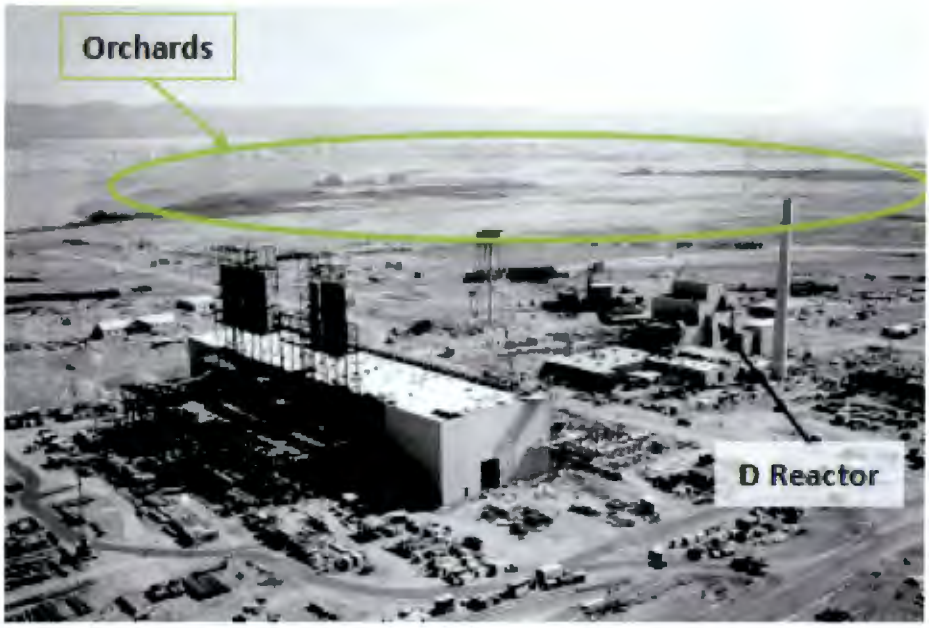


Figure 2.7. Orchards Located behind the Construction of Water Treatment Facility at D Reactor in June 1944

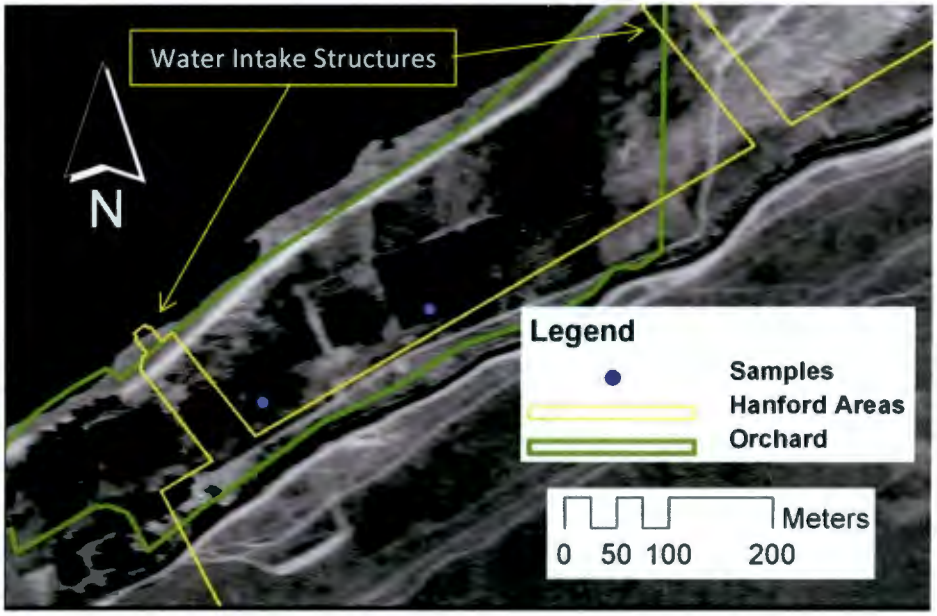


Figure 2.8. Map Showing the 100-K Area Boundary, Adjacent Orchard (1943) and the Location of Surface Soil Samples Collected inside the Former Orchard Area in 1992

An image from 1954 taken during construction of the 100-K reactors provides evidence that this area was covered with backfill. The changed topography of this area is still visible in more recent photographs (Figure 2.9) (DOE-RL 2011a). Although the area was clearly covered with soil, the measured lead concentrations were still above the background level. Backfill soil from the Hanford operations era was probably not evaluated for presence of contaminants (e.g., lead or arsenic, unlike backfill soils used in current remediation efforts). This example of disturbed soils near the 100-K Area is typical of several former orchards on or near operating areas, and around Camp Hanford (the Hanford townsite). This

example highlights some of the difficulties in fully assessing the soil pathway, and raises questions to be considered in determining the appropriate sampling strategy; that is, how to account for anthropogenic changes to the soil surface since the last application of lead arsenate.

Figure 2.9. Former Orchard Area (red circle) near the 100-K Area during Construction in 1954 (top) and in 2004 (bottom) (DOE-RL 2011a)

2.5 Summary of Pilot Study for 100-OL-1 OU

The pilot study evaluated the use of a field portable XRF analyzer for obtaining results of lead and arsenic concentrations on the soil surface as an indicator of lead arsenate pesticide residues in the OU (Bunn et al. 2014). There were four locations within the OU evaluated during the pilot study, which varied in size, previous agriculture activities, and level of soil disturbances since 1943. The objectives of the pilot study included evaluating a field portable XRF analyzer as the analytical method for decision making, estimating the nature and extent of lead and arsenic in surface soils in four decision units, evaluating the results to optimize the sampling approach implemented in the RI, collecting information to improve the cost estimate, and planning the cultural resources review for sampling activities in the RI. The following is a summary of the results and the recommendations for the RI.

XRF analysis performed within the quality control (QC) and quality assurance (QA) guidelines for evaluating lead as well as arsenic in surface soils as established by EPA for the field portable instrument

(EPA 2007). The Niton XLt3 950 demonstrated that the analyses were precise, accurate, and repeatable. The sensitivity of the instrument was low enough to distinguish between concentrations below and at the soil screening criteria for lead (250 mg/kg) and arsenic (20 mg/kg). Confirmatory soil samples analyzed by inductively coupled plasma mass spectroscopy (ICP-MS) and XRF demonstrated that the XRF measurements meet QC guidelines to consider the results for screening level data and potentially meet definitive level data criteria (EPA 2007). The pilot study recommended the work plan design the characterization efforts in the RI using XRF measurements with confirmatory ICP-MS analyses.

The evaluation of the four decision units demonstrated that a consistent size of decision units was important for interpreting the results. The three decision units with defined areas less than 50 acres (OL-14, OL-32, and FR2-1) revealed a pattern of elevated lead and arsenic concentrations. All four decision units evaluated in the pilot study failed the tests for compliance with screening levels. The spatial density of the evaluation of soil concentrations in IU6-4 (the largest decision unit at 250 acres) demonstrated that lead and arsenic concentrations in some of the agricultural areas exceeded the screening criteria, but the spatial density of the results does not indicate whether there are additional areas of concern. The pilot study recommended that the work plan establish decision units of similar defined areas, with divisions along roads or land use changes based on aerial imagery.

Concentrations of lead and arsenic exceeding the screening criteria were found in soil samples at locations along the edges of all four decision units. In some cases, the edge of the decision unit was the border to other decision units (where additional sampling would occur) rather than along the outside boundary of the OU (where no additional sampling would occur). The pilot study recommended that the work plan define the process for field investigation of soil concentrations exceeding the screening criteria at the edge of the 100-OL-1 OU.

The pilot study evaluated aspects of the sampling approach with the XRF analyzer to provide confidence in data for assessing areas above and below the lead and arsenic screening criteria. These include the number of locations to evaluate in a decision unit, the number of replicate soil analyses at each location, and the length of count time for the XRF analyzer to meet quality criteria for lead and arsenic data. The pilot study recommended updating the DQOs for the work plan to include a minimum spatial density for each decision unit evaluation, and updating the XRF field parameters for collecting the data.

2.6 Relevant Federal and Washington State Screening Levels for Protection of Human Health and the Environment

The complexity of arsenic and lead chemistry, varying toxicity effects based on exposure pathways, and natural background levels have resulted in numerous screening levels for the protection of human health and the environment. Arsenic is a known carcinogen, and lead is known to cause neurological damage, particularly for prenatal and young children (Hood 2006; ATSDR 2007a, b). While acute effects are known for humans exposed to high concentrations of arsenic and lead, there are no reported cases for acute effects from exposure to lead arsenate residues in soils from the former orchard sites (Hood 2006). Effects from exposure to arsenic and lead have been documented for plants, animals, and other ecological receptors (Eisler 1988a, b; Elfving et al. 1994; Schooley et al. 2008; Delistraty and Yokel 2011). To date, scientific studies have not found conclusive evidence that exposure to low to moderate levels of arsenic and lead contamination in soil has caused or is causing deleterious health effects (AWSCTF 2003a).

2.6.1 Arsenic and Lead Contamination in Washington

Several actions in Washington State concerning lead and arsenic are appropriate to consider for characterization of former orchards at the Hanford Site. Following are summaries of several actions in Washington addressing arsenic and lead soil contamination. These reports have established approaches for evaluating contaminated areas and action levels for remediation.

Asarco Tacoma Smelter Superfund Site, Ruston and Tacoma, Washington. Arsenic and lead are the primary contaminants of concern at the Asarco Tacoma Smelter Superfund site, located along the Commencement Bay shoreline within the municipal boundaries of the town of Ruston at the southern end of the main basin of Puget Sound. The site is an operational unit of the larger Commencement Bay Nearshore/Tideflats Superfund site, which was listed on the interim priority list by EPA in 1981 and included in the first published National Priorities List in September 1983. Operation of the Asarco smelter for over 95 years resulted in contamination, primarily by arsenic and lead, of the smelter site, offshore sediments, and the surrounding residential area. The former copper and lead smelter specialized in processing ores with high arsenic concentrations, and recovered arsenic trioxide and metallic arsenic as byproducts. In 1993, EPA issued the first Record of Decision for Ruston/North Tacoma Study Area Operable Unit 04 (EPA 1993). The 2009 Third Five-Year Review Report of the site summarized the remedy selection and remedial actions. Remedial action levels identified for soil removal of residential soil were 230 mg/kg for arsenic and 500 mg/kg for lead (EPA 2009). The 2014 Fourth Five-Year Review Report of the site stated that the cleanup actions were completed in 2012. Currently there are community protection measures in place for areas that have soil concentrations between the *Model Toxics Control Act* (MTCA) cleanup level of 20 mg/kg arsenic and the EPA action level of 230 mg/kg arsenic (EPA 2014).

Area-Wide Soil Contamination Project, Washington State Department of Ecology. The State of Washington created a task force in the early 2000s to develop a strategy for addressing "area-wide" soil contamination. Area-wide soil contamination refers to low-to-moderate-level arsenic and lead soil contamination dispersed over a large area in Washington, and the efforts of the task force are being used to address contamination from the Asarco Tacoma Smelter plume, the Everett Smelter, and at schools built on former orchard lands across the state. In 2003, the findings and recommendations of the Area-Wide Soil Contamination Task Force were published (AWSCTF 2003a). The task force identified six categories of protection: 1) education programs, 2) public health programs, 3) individual protection measures, 4) land-use controls, 5) physical barriers, and 6) contamination reduction. The task force used Ecology's current views of "low-to-moderate" levels of arsenic and lead in soil. In general, for schools, childcare centers, and residential land uses, the low-to-moderate range is up to 100 mg/kg for total arsenic and 500 to 700 mg/kg for lead. For properties where exposure of children is less likely or less frequent, the low-to-moderate range is up to 200 total mg/kg for total arsenic and 700 to 1000 mg/kg for lead (AWSCTF 2003a, b).

Asarco Tacoma Smelter Site Final Interim Action Plan for the Tacoma Smelter Plume. While EPA's Asarco Tacoma Smelter Superfund site is remediating the facilities and immediate area, Ecology is addressing air pollution contamination from the smelter in an area of over 2600 km^2 (1000 mi^2). The 2012 interim action plan describes how Ecology will remediate some of the Tacoma Smelter Plume and manage risk (Ecology 2012a). Ecology plans to take four actions regarding the Tacoma Smelter Plume: 1) clean up home yards in the worst areas of the plume; 2) clean up play areas at schools, childcare centers, parks, camps, multi-family public housing, etc.; 3) educate people about the risk and how to protect themselves; and 4) encourage soil testing and cleanup during property development. Interim

actions are a mix of physical cleanup methods (excavating, mixing, capping, etc.) and institutional controls (property use restrictions, environmental covenants or deed restrictions, zoning overlays, outreach, etc.). The action plan is divided into two phases. The first phase focuses on areas where children play and people live, and the second phase focuses on those areas not covered in the first phase. Action levels for each phase are divided into moderate zones and high zones. The moderate zone has an average concentration of 20 to 100 mg/kg arsenic (maximum concentration of 40 to 200 mg/kg arsenic) and an average concentration of 250 to 500 mg/kg lead (maximum concentration of 500 to 1000 mg/kg lead). The high zone has an average concentration of >100 mg/kg arsenic (maximum concentration >200 mg/kg arsenic) and an average concentration of >500 mg/kg lead (maximum concentration >1000 mg/kg lead).

Health Consultation Evaluation of Soil Contamination at Washington Schools in Eastern and Central Washington. The Washington State Department of Health (DOH) in cooperation with Agency for Toxic Substances and Disease Registry put together a health consultation to evaluate whether soil arsenic and lead levels found by Ecology between 2003 and 2006 on playgrounds at 113 eastern and central Washington elementary schools pose a health concern to children and residents in the nearby communities (DOH 2008). Of these 113 schools, 51 had maximum and/or mean arsenic and lead soil concentrations that exceeded the MTCA Method A cleanup levels of 20 mg/kg arsenic and 250 mg/kg lead (WAC 173-340-740). From these 51 elementary schools, 22 schools had 95th percentile upper confidence limit and/or mean values for arsenic and/or lead that exceeded MTCA Method A cleanup levels, and four schools exceeded both MTCA and Ecology's Interim Action Levels (100 mg/kg arsenic and 500 mg/kg lead) (AWSCTF 2003a). DOH recommended reducing or eliminating exposure to arsenic and/or lead at the schools where these contaminants exceed MTCA cleanup levels and/or Ecology's Interim Action Levels.

Bunker Hill Mining and Metallurgical Complex Superfund Site, Coeur d'Alene, Idaho. Lead and arsenic are major contaminants at the Bunker Hill Mining and Metallurgical Superfund site, located in the Coeur d'Alene River Basin of Northern Idaho. The site covers a historical location of ore-processing/smelting (21 square-mile area) as well as adjacent floodplains, downstream water bodies, tributaries, and fill areas. The Bunker Hill Mining site was placed on the National Priorities List in September 1983. Bunker Hill is considered one of the largest historical mining areas in the world with over 100 years of commercial mining, milling, and smelting. In the 2002 Record of Decision for OU 3, EPA established a sediment lead cleanup level for the Washington recreation areas along the Spokane River as 700 mg/kg for recreational use, and in consultation with Ecology, the arsenic cleanup level is 20 mg/kg (EPA 2010).

2.6.2 Relevant Federal and Washington State Screening Levels

Federal and state screening levels have been established for lead and arsenic. Table 2.3 includes selected screening levels for the protection of human health relevant to soil exposures at the Hanford Site. Table 2.4 includes ecological screening levels from scientific studies and Hanford Site-specific ecological risk assessments.

Table 2.3. Arsenic and Lead Screening Levels for Protection of Human Health

Exposure Scenario and Pathway	Arsenic (mg/kg dry wt)	Lead (mg/kg dry wt)	Reference
1E-6 cancer risk for humans, unrestricted land use (soil ingestion, dermal contact)	0.67	NA	Ecology 2012b
Unrestricted land use soil cleanup standards, Washington State, MTCA Method A	20	250	WAC 173-340-740
Schools, childcare centers, and residential land uses, low-to-moderate range for Area Wide Soil Contamination, Washington State	100	500-700	AWSCTF 2003a, b
Properties where exposure to children is less likely or less frequent, low-to-moderate range for Area Wide Soil Contamination, Washington State	100-200	700-1000	AWSCTF 2003a, b
Tacoma Smelter Plume, moderate zone, average concentration (maximum concentration)	20-100 (40-200)	250-500 (500-1000)	Ecology 2012a
Tacoma Smelter Plume, high zone (maximum concentration)	>100 (>200)	>500 (>1000)	Ecology 2012a
Remedial action goals for Ruston/North Tacoma Site	230	500	EPA 1993
Remedial action goals, direct exposure cleanup level	20	353	DOE-RL 2009

NA = not applicable.

Table 2.4. Arsenic and Lead Screening Levels for Protection of the Environment

Screening Level Basis	Arsenic (mg/kg dry wt.)	Lead (mg/kg dry wt.)	Reference
Lowest LOEC for soil microbial processes	100	900	Efroymson et al. 1997a
Plant, soil screening level	18	120	EPA 2005a, b
Plants, 10th percentile of ranked LOEC values for crop growth, soil screening level	10	50	Efroymson et al. 1997a, b
Plant	NR	50	WAC 173-340
Soil preliminary remediation goal for plants	128	9090	CHPRC 2012
NOEC for lettuce and earthworm bioassay	128	390	Delistraty and Yokel 2011
Soil biota	NR	500	WAC 173-340
Invertebrate, soil screening level	NR	1700	EPA 2005b
Invertebrate, LOEC for earthworm reproduction, soil screening level	60	500	Efroymson et al. 1997a, b
Soil preliminary remediation goal for invertebrates	128	1700	CHPRC 2012
As (III): All wildlife, risk-based soil concentration for Generic - MTCA	7	NA	WAC 173-340
As (V): All wildlife, risk-based soil concentration for Generic - MTCA	132	NA	WAC 173-340
Pb: All wildlife, risk-based soil concentration for Generic - MTCA	NA	118	WAC 173-340
Avian, soil screening level	43	11	EPA 2005a, b
All avian wildlife, risk-based soil concentration for Generic - EcoSSL	43	11	CHPRC 2011a
California quail, Tier 2	4776	559	CHPRC 2011b
Western meadowlark, Tier 2	7403	664	CHPRC 2011b
Killdeer, Tier 2	2284	156	CHPRC 2011b
Red-tailed hawk, Tier 2	40,102	2300	CHPRC 2011b
Mammalian, soil screening level	46	56	EPA 2005a, b
Great Basin pocket mouse, Tier 2	201	2672	CHPRC 2011b
Deer mouse, Tier 2	127	1578	CHPRC 2011b
Grasshopper mouse, Tier 2	302	3807	CHPRC 2011b
Badger, Tier 2	847	3966	CHPRC 2011b

Eco SSL = Ecological soil screening level.
LOEC = Lowest observed effect concentration.
NA = Not applicable.
NOEC = No observed effect concentration.
NR = Not reported.

2.7 100-OL-1 OU Boundaries

The TPA Change Control Form that established the 100-OL-1 orchard lands operable unit, C-12-02 (TPA 2012a), included a low-resolution map defining the boundaries of the operable unit (Figure 1.1). As part of the development of the conceptual site model for the work plan, it was necessary to obtain the map as a GIS layer. This proved difficult because the map had grown and changed in an undocumented manner over the years in response to numerous and diverse project and program objectives. Following is a description of the process used while developing the work plan to produce and verify a traceable history for the GIS coverage of the 100-OL-1 OU boundaries.

The first known version of the GIS coverage was a "Hanford Farm" layer. Washington Closure Hanford (WCH) inherited this GIS coverage from Bechtel Hanford, Inc., when WCH took over the contract. The origin of the initial coverage could not be verified. WCH staff modified the Hanford Farm layer based on manual inspection of and comparison with historical (1941 and 1943) and more recent (1999, 2002, and 2008) aerial photography. The modifications were thought to be limited to the shifting of boundaries to better match dividing points (e.g., roads) identified in the aerial photography.

WCH used the Hanford Farm layer to identify orchards by manually noting the presence or absence of orchard trees within a particular farm in the historical imagery (1943 aerial photography). In addition, field observations performed during orphan site evaluations and the 1943 platted lands map were used to provide evidence of orchard trees. If a farm was observed (by any method) to have evidence of orchard trees, it was classified as an orchard. If no orchard trees were observed, it was considered a farm and was not included in the "Orchards" GIS layer.

The WCH Orchards GIS layer then was used by CH2M Hill Plateau Remediation Company to prepare documentation for the DOE Richland Operations Office (DOE-RL) for the TPA Change Control Form establishing the 100-OL-1 OU. Through this process, some areas (or polygons) were added or removed. In addition, one orchard that is visible in the 1943 aerial photography was found to have been included in the Hanford Farm coverage, but not in any other versions of orchard layers. For completeness of this investigation, all versions of the Orchards GIS coverage were merged to include all potential orchard properties. The result was the 44 individual areas identified in the map included in TPA Change Control Form C-12-01 (TPA 2012a) and shown in Figure 1.1 of this work plan.

Two additional areas of orchards on the Hanford Site near other areas identified in TPA Change Control Form C-12-02 (TPA 2012a) were identified during preparation of this work plan. One area is next to the river upstream of the 100-F Area, and the other is located southwest of the 100-F Area. These areas are now included in the 100-OL-1 OU.

3.0 Investigative Approach

This section describes the approach for investigating the 100-OL-1 OU, including the DQOs for the RI. The sampling design and characterization approach incorporating the DQOs is discussed.

3.1 Data Quality Objectives

The DQO process involves a series of systematic steps to plan for resource-effective acquisition of data to characterize the Hanford orchard lands for the RI of the 100-OL-1 OU. The purpose of this process is to prepare project-specific DQOs to provide clear direction for data collection in the characterization of the orchard areas and to provide a framework for assessing the overall quality of the sampling strategy and analyses for use in the RI (EPA 2000).

3.1.1 State the Problem

Characterization of the magnitude and extent of lead and arsenic contamination (residue from lead arsenate pesticide) in the 100-OL-1 OU is incomplete. Characterization is needed to evaluate potential risk to human health and the environment and support remedial action decisions. A pilot study in 2014 (Bunn et al. 2014) provided limited characterization of the 100-OL-1 OU and optimized the sampling design for evaluation of the entire OU.

3.1.2 Identify the Decision

Characterization of the 100-OL-1 OU will evaluate the magnitude and range of lead and arsenic contamination within defined areas or "decision units" of the operational unit and will support refinement of the conceptual site model. The decisions for characterizing the magnitude and extent of lead and arsenic contamination in the 100-OL-1 OU are associated with the following:

- Areas of the Hanford Site identified as former orchard areas and the need to define decision units for areas where lead arsenate pesticide residues persist
- Physical/chemical characteristics of lead and arsenic in the soil in the former orchard areas
- Screening levels for characterizing lead and arsenic residue concentrations in soils that are protective of human health and the environment

The former orchard lands or suspected former orchard properties are shown in Figure 1.1. Information that can be used to establish the validity of the identified areas is not well documented (as discussed in Section 2.6). Historical aerial imagery shows regions with rows of trees in areas of known commercial orchards. Most areas making up the 100-OL-1 OU have historical aerial imagery that documents patchworks of trees along with other agricultural crops and outbuildings. The pilot study (Bunn et al. 2014) identified elevated lead and arsenic contamination in areas with orchard trees present in historical imagery and in areas with no orchards present in historical imagery.

Past studies at Hanford, in Washington State, and elsewhere indicated that the peak concentration of the lead and arsenate remains in the upper 30 cm to 1 m (12 to 39 in.) of the soil column (discussed further in Section 2.2.2).

Federal, Washington State, and Hanford Site-specific thresholds or screening levels identified for lead and arsenic range from below to well above the Hanford Site-specific background concentrations (see Table 2.3 and Table 2.4). The 90th percentile level for the Hanford Site-specific background concentrations are 6.47 mg/kg arsenic and 10.2 mg/kg lead (Table 2.2). One of these decisions is the number of soil samples needed to achieve a statistically relevant understanding of lead arsenate residue contamination in an area within the 100-OL-1 OU.

3.1.3 Identify Inputs to the Decision

To resolve the decision statement, a number of information inputs are required. These inputs address the distribution of contamination, the expected range and variability of concentrations in soil, and the acceptable concentrations in soil to protect human health and the environment. Table 3.1 lists information requirements and antecedent information sources required for the characterization study to enable informed decision-making that will answer the site assessment question.

3.1.4 Definition of Boundaries for the Study

This section describes the boundaries for characterization sampling of the 100-OL-1 OU. This includes spatial boundaries (in all three dimensions) as well as limitations in media sampled, compounds analyzed, analytical techniques, and temporal boundaries.

3.1.4.1 Media, Analytes, and Methods

Site characterization sampling will be limited to soil sampling because soil is the primary medium of concern identified in the conceptual model. It is the medium of interest that most likely will contain arsenic and lead concentrations at levels of concern for human or ecological health.

Soil samples will be analyzed in situ using a handheld XRF instrument. The pilot study (Bunn et al. 2014) demonstrated that in situ measurement of lead and arsenic concentrations by XRF could provide data of acceptable quality (adequate detection limit, good accuracy and precision).

Table 3.1. Information Inputs Necessary to Support the Decision

Information Input	Source of Information
Contaminant Distribution	
Contaminants of concern	Arsenic, lead
Spread of contamination within orchards	Conceptual site model
Spread of contamination beyond the orchards	Conceptual site model, pilot study
Vertical distribution of contaminants of concern	Conceptual site model, previous studies
Range and Variability of Concentrations	
Range of concentrations on Hanford Site orchards	Previous studies, HEIS data, pilot study
Range of concentrations on non-Hanford Site orchards	Literature review
Acceptable Soil Concentrations	
Soil screening levels	Federal and state regulations and criteria; Hanford Site-specific levels (see Table 2.3 and Table 2.4)
Comparison of Measured Results to Acceptable Concentrations	
Statistical comparison approach	Collaborative sampling strategy considers multiple analytical techniques for characterization of decision units
Parameters necessary for chosen statistical approach	Field/laboratory detection limits, spatial and depth variability (based on existing data), soil background concentrations for contaminants of concern, confidence limit, cost
Collection/Analysis Methodology	
Analogous site sampling density/number of samples	Conceptual site model with statistical protocol
Total depth of sample collection	Conceptual site model
Depth intervals sampled	Conceptual site model with statistical protocol

The soil samples will be analyzed only for lead and total inorganic arsenic content. Lead arsenate pesticide residue was the contaminant of concern identified in TPA Change Control Form C-12-02 (TPA 2012a). Previous work by Delistraty and Yokel (2011) demonstrated that more than 99% of the total inorganic arsenic existed as arsenic (V) in the surficial soils of the former orchards sites evaluated. This information supports the decision to characterize only for total inorganic arsenic.

Laboratory analyses of soil samples for QC purposes will be done by ICP-MS. This analytical technique will provide consistency with other characterization and waste-site verification efforts at Hanford (DOE-RL 2007).

3.1.4.2 Areas to Sample

The entire area of the OU will be sampled in a systematic process. Historical records and photographs provide the best tool available for predicting where lead arsenate pesticides may have been used in the OU, but actual pesticide use within these areas and subsequent land activities (e.g., other agricultural practices, Hanford-related activities) that may have added soil or mixed the soil horizons is unknown. Therefore, as shown in the pilot study (Bunn et al. 2004), the distribution of elevated lead and arsenic based on historical records and photographs has some unknown level of uncertainty. The OU will

be divided into decision units (as described in Section 3.1.5), and sample locations will be pre-selected within a decision unit in a systematic process using a software tool (e.g., Visual Sample Plan [VSP]) (Matzke et al. 2010). If concentrations exceed the screening level at the boundary of the OU, then additional locations may be analyzed as described in Section 3.1.5.

The examination of 1943 aerial imagery identified two additional areas of historical orchards that were not included in TPA Change Control Form C-12-02 (TPA 2012a). Historical records confirmed the presence of homesteads with orchards. One area is next to the river upstream of the 100-F Area (DU-50 and -51), the other area is located southwest of the 100-F Area (DU-88). Addition of these areas was consistent with the criteria used to develop the map in C-12-02 (TPA 2012a) as well as with the criteria used to define the decision units (see Section 3.1.4.5).

3.1.4.3 Depths to Sample

The characterization of the lead and arsenic will be on the soil surface using in situ measurements with XRF. The pilot study demonstrated that there is surface contamination of lead and arsenic (Bunn et al. 2014). This means that measured concentrations of lead and arsenic will only be representative of the top few millimeters of soil. However, previous work has shown lead arsenate to be relatively immobile, with maximum concentrations present at or near the soil surface, as discussed in Section 2.2.2 (Peryea and Creger 1994; Yokel and Delistraty 2003).

3.1.4.4 Time of Year to Sample

Soil moisture can affect XRF measurements, so the optimal time for sampling is in the summer months. The biological resources in some decision units may require adjustment to the sampling schedule (e.g., roosting bald eagles during the winter in decision units along the shoreline).

3.1.4.5 Decision Units

The orchard lands as presented in TPA Change Control Form C-12-02 (Figure 1.1) will be divided into decision units for characterization of lead and arsenic. The variability expected in residual lead arsenate concentrations identified in the conceptual model and demonstrated by the results of the pilot study (Bunn et al. 2014) can best be addressed by dividing the OU into decision units. Land management activities by the early settlers included taking orchards out of production, removing stumps, tilling, and re-purposing former orchards. These activities contributed to the observations during the pilot study where the high concentrations of lead and arsenic did not correlate with the images of trees in the 1943 aerial imagery. Dividing the OU into decision units will focus the sampling in the tracts and plots that may have had a common land management practice by the early settlers.

The process for dividing the orchards into decision units considered the location of the orchard on the Hanford Site as well as any soil disturbance, historical imagery of the Hanford orchard lands, available historical records, and the size of the decision unit. The decision units include the area described by TPA Change Control Form C-12-02 and the two additional areas. The additional of these decision units meet the criteria for inclusion in the OU (Section 2.6).

The first criterion for division of the 100-OL-1 OU into decision units considered the presence or absence of trees in the historical aerial imagery from 1941 and 1943. It is recognized that the polygons identified as orchards in TPA Change Control Form C-12-02 (TPA 2012a) may have been farms, of which a portion of the property was planted with fruit trees. Distinct differences are expected between the concentrations of lead and arsenic in the soil in areas where fruit trees were grown and concentrations in areas where no fruit trees were planted, based on the results of the pilot study (Bunn et al. 2014). The use of historical aerial imagery is consistent with the approach used by Ecology at the Mason area, Chelan County, Washington (Ecology 2003).

The second criterion for division of the OU was size. After division of the 100-OL-1 OU into decision units based on the presence of trees, larger decision units were further sub-divided. The maximum size was chosen based on results obtained in the pilot study (Bunn et al. 2014). The pilot study evaluated units of various sizes. While several areas of 0.16 km^2 (40 ac) were adequately characterized, a larger area (1 km^2 [250 ac]) was deemed to be inadequately characterized. Based on results from the pilot study (Bunn et al. 2014), a nominal maximum decision unit size of approximately 0.20 km^2 (50 ac) was selected. Using this guideline, there are 133 decision units in the OU.

The third criteria for the division of the OU into decision units was the presence of roads. Boundaries of the decision units considered the aerial imagery from 1943 and 2013 as well as the GIS layer that includes the roads on the Hanford Site. The boundary of a decision unit was placed down the middle of a road if it could be seen in the 1943 imagery or in the 2013 imagery (in that order). The boundaries of the OU were adjusted to capture the full extent of orchards near the decision unit based on both the 1943 and 2013 aerial imagery. In a few cases, the boundary was adjusted further. For example, the boundary of a few decision units was adjusted to follow a landscape feature (e.g., a steep slope or the edge of the Hanford Irrigation Canal) to make sampling easier.

Individual decision units are categorized according to the criteria outlined in Table 3.2. Another distinction used in categorizing the decision units was evidence of surface soil disturbance since 1943. Within a decision unit, areas where the soil has been excavated and backfilled to remediate the area will not be sampled. GIS information on the Hanford Site Waste Information Data System (WIDS) was used to exclude these areas for sampling locations. In addition, historic areas that are fenced off for protection (e.g., Bruggemann's warehouse and Hanford High School) are excluded. Table 3.3 lists each decision unit and describes the area of the decision unit, the criteria for defining the decision unit, and the category of the decision unit. Table 3.4 summarizes the characteristics of the decision units. The average size of the decision units is 36.9 acres. The largest decision unit, DU-100, is 0.22 km^2 (53.7 ac). The largest and smallest decision units are either isolated areas within the OU, could not be divided further based on 1943 imagery, or were created as smaller areas because the land use in 1943 was different from adjoining areas.

Table 3.2. Categories for the 100-OL-1 OU Decision Units

Decision Unit Category	Presence of Trees in 1943 Aerial Photos?	Evidence of Soil Disturbance Since 1943?	Number of Decision Units by Category
A	Yes	No	63
AX	Yes	Yes	46
B	No	No	17
BX	No	Yes	7

Table 3.3. Decision Units (DU) for 100-OL-1 Operable Unit

Orchard Area DU ID	Area of DU		Spatial Density (samples/ acre)	Number of Locations	WIDS site Within DU Boundaries?	Presence of Trees in 1943 Aerial Photos?	Evidence of Soil Disturbance Since 1943?	DU Category
	km^2	Acres						
DU-1	0.179	44.1	0.8	36	No	Yes	No	A
DU-2	0.196	48.4	0.8	39	No	Yes	No	A
DU-3	0.202	50.0	0.8	40	No	No	No	B
DU-4	0.047	11.5	1.1	13	Yes	No	Yes	BX
DU-5	0.164	40.6	0.8	33	Yes	Yes	No	A
DU-6	0.082	20.2	0.8	17	No	Yes	No	A
DU-7	0.136	33.7	0.8	28	No	Yes	No	A
DU-8	0.206	50.8	0.8	40	Yes	Yes	Yes	AX
DU-9	0.030	7.3	1.8	13	Yes	Yes	Yes	AX
DU-10	0.170	41.9	0.8	34	No	Yes	No	A
DU-11	0.122	30.2	0.8	25	No	Yes	Yes	AX
DU-12	0.161	39.8	0.8	32	No	Yes	No	A
DU-13	0.168	41.5	0.8	34	No	Yes	No	A
DU-14	0.205	50.6	0.8	40	Yes	Yes	No	A
DU-15	0.200	49.5	0.8	40	No	Yes	No	A
DU-16	0.185	45.7	0.8	37	Yes	Yes	No	A
DU-17	0.089	22.1	0.8	18	No	No	No	B
DU-18	0.098	24.3	0.8	20	No	Yes	No	A
DU-19	0.165	40.7	0.8	34	No	Yes	No	A
DU-20	0.188	46.4	0.8	37	Yes	Yes	Yes	AX
DU-21	0.073	17.9	0.8	15	No	Yes	Yes	AX
DU-22	0.173	42.9	0.8	35	Yes	Yes	Yes	AX
DU-23	0.157	38.8	0.8	32	Yes	Yes	Yes	AX
DU-24	0.200	49.4	0.8	40	Yes	Yes	Yes	AX
DU-25	0.074	18.3	0.8	15	Yes	Yes	Yes	AX
DU-26	0.021	5.3	2.5	13	Yes	Yes	No	A
DU-27	0.165	40.7	0.8	33	Yes	Yes	Yes	AX
DU-28	0.161	39.9	0.8	32	No	No	Yes	B
DU-29	0.165	40.7	0.8	33	No	Yes	No	A
DU-30	0.167	41.2	0.8	34	No	Yes	No	A
DU-31	0.166	41.0	0.8	33	Yes	Yes	No	A
DU-32	0.165	40.8	0.8	33	Yes	Yes	No	A
DU-33	0.084	20.7	0.8	17	No	No	No	B
DU-34	0.164	40.6	0.8	33	No	Yes	No	A
DU-35	0.153	37.8	0.8	31	Yes	Yes	No	A
DU-36	0.160	39.6	0.8	32	Yes	Yes	No	A
DU-37	0.165	40.7	0.8	33	No	Yes	No	A
DU-38	0.111	27.3	0.8	22	Yes	No	No	B
DU-39	0.124	30.6	0.8	25	No	Yes	No	A
DU-40	0.086	21.2	0.8	18	No	Yes	No	A
DU-41	0.082	20.3	0.8	17	No	Yes	No	A
DU-42	0.158	39.1	0.8	31	No	Yes	No	A
DU-43	0.163	40.3	0.8	33	No	Yes	No	A
DU-44	0.168	41.5	0.8	34	Yes	No	No	B
DU-45	0.174	42.9	0.8	35	No	No	No	B
DU-46	0.173	42.8	0.8	35	No	No	No	B
DU-47	0.162	39.9	0.8	32	No	Yes	No	A
DU-48	0.164	40.5	0.8	33	No	Yes	No	A
DU-49	0.163	40.3	0.8	33	No	Yes	No	A
DU-50	0.163	40.2	0.8	33	No	No	No	B

Orchard Area DU ID	Area of DU		Spatial Density (samples/ acre)	Number of Locations	WIDS site Within DU Boundaries?	Presence of Trees in 1943 Aerial Photos?	Evidence of Soil Disturbance Since 1943?	DU Category
	km^2	Acres						
DU-51	0.159	39.3	0.8	32	Yes	No	No	B
DU-52	0.147	36.4	0.9	33	No	Yes	No	A
DU-53	0.109	26.9	0.8	22	No	Yes	No	A
DU-54	0.160	39.6	0.8	32	No	Yes	No	A
DU-55	0.202	49.8	0.8	40	Yes	Yes	No	A
DU-56	0.075	18.5	0.8	15	No	No	No	B
DU-57	0.103	25.5	0.8	20	No	No	No	B
DU-58	0.183	45.2	0.8	37	No	Yes	No	A
DU-59	0.141	34.8	0.8	28	Yes	Yes	Yes	AX
DU-60	0.145	35.7	0.8	29	No	Yes	No	A
DU-61	0.118	29.1	0.8	24	No	Yes	No	A
DU-62	0.173	42.8	0.8	35	No	Yes	No	A
DU-63	0.137	33.9	0.8	27	No	Yes	Yes	AX
DU-64	0.180	44.4	0.8	36	Yes	Yes	Yes	AX
DU-65	0.158	39.0	0.8	32	Yes	Yes	No	A
DU-66	0.170	41.9	0.8	34	Yes	Yes	No	A
DU-67	0.185	45.7	0.8	37	No	Yes	No	A
DU-68	0.178	44.0	0.8	36	No	Yes	No	A
DU-69	0.072	17.7	0.8	15	No	Yes	No	A
DU-70	0.129	31.8	0.8	26	Yes	Yes	No	A
DU-71	0.179	44.2	0.8	36	No	Yes	No	A
DU-72	0.167	41.2	0.8	33	No	Yes	No	A
DU-73	0.176	43.4	0.8	35	Yes	Yes	No	A
DU-74	0.149	36.8	0.8	30	Yes	Yes	Yes	AX
DU-75	0.091	22.6	0.8	19	No	Yes	Yes	AX
DU-76	0.155	38.4	0.8	31	Yes	Yes	Yes	AX
DU-77	0.192	47.4	0.8	38	No	No	No	B
DU-78	0.059	14.5	0.9	13	Yes	Yes	No	A
DU-79	0.179	44.2	0.8	36	Yes	Yes	No	A
DU-80	0.048	11.8	1.1	13	No	Yes	No	A
DU-81	0.162	40.0	0.8	33	Yes	Yes	No	A
DU-82	0.187	46.1	0.8	37	No	No	No	B
DU-83	0.083	20.6	0.8	17	No	No	No	B
DU-84	0.084	20.8	0.8	17	No	Yes	No	A
DU-85	0.201	49.6	0.8	39	Yes	Yes	No	A
DU-86	0.180	44.6	0.8	36	Yes	Yes	No	A
DU-87	0.194	48.0	0.8	40	Yes	No	Yes	BX
DU-88	0.188	46.4	0.8	38	No	Yes	No	A
DU-89	0.205	50.6	0.8	40	No	Yes	No	A
DU-90	0.198	48.9	0.8	40	No	No	No	B
DU-91	0.159	39.2	0.8	32	No	Yes	No	A
DU-92	0.186	45.8	0.8	37	No	Yes	No	A
DU-93	0.106	26.3	0.8	22	Yes	Yes	No	A
DU-94	0.167	41.4	0.8	34	Yes	Yes	Yes	AX
DU-95	0.162	40.1	0.8	33	Yes	Yes	No	A
DU-96	0.125	30.8	0.8	25	Yes	Yes	No	A
DU-97	0.208	51.3	0.8	40	No	Yes	Yes	AX
DU-98	0.132	32.5	0.8	26	No	Yes	No	A
DU-99	0.131	32.3	0.8	26	No	No	No	B
DU-100	0.217	53.7	0.7	40	No	Yes	No	A
DU-101	0.187	46.1	0.8	37	No	Yes	Yes	AX

Orchard Area DU ID	Area of DU		Spatial Density (samples/ acre)	Number of Locations	WIDS site Within DU Boundaries?	Presence of Trees in 1943 Aerial Photos?	Evidence of Soil Disturbance Since 1943?	DU Category
	km^2	Acres						
DU-102	0.148	36.6	0.8	30	No	No	Yes	BX
DU-103	0.160	39.6	0.8	32	Yes	Yes	Yes	AX
DU-104	0.145	35.7	0.8	29	Yes	No	Yes	BX
DU-105	0.118	29.2	0.8	24	Yes	Yes	Yes	AX
DU-106	0.133	32.9	0.8	27	Yes	Yes	Yes	AX
DU-107	0.109	26.9	0.8	22	Yes	Yes	Yes	AX
DU-108	0.165	40.7	0.8	33	No	Yes	Yes	AX
DU-109	0.138	34.0	0.8	28	Yes	Yes	Yes	AX
DU-110	0.135	33.3	0.8	28	No	Yes	Yes	AX
DU-111	0.158	39.0	0.8	32	No	Yes	Yes	AX
DU-112	0.195	48.2	0.8	39	Yes	Yes	Yes	AX
DU-113	0.089	22.1	0.8	18	Yes	No	Yes	BX
DU-114	0.171	42.3	0.8	34	No	Yes	Yes	AX
DU-115	0.174	42.9	0.8	35	No	Yes	Yes	AX
DU-116	0.157	38.7	0.8	31	Yes	Yes	Yes	AX
DU-117	0.100	24.8	0.8	20	Yes	Yes	Yes	AX
DU-118	0.136	33.6	0.8	27	Yes	Yes	Yes	AX
DU-119	0.152	37.6	0.8	31	Yes	Yes	Yes	AX
DU-120	0.135	33.2	0.8	27	Yes	No	Yes	BX
DU-121	0.198	48.8	0.8	40	Yes	No	Yes	BX
DU-122	0.175	43.3	0.8	35	Yes	Yes	Yes	AX
DU-123	0.201	49.7	0.8	40	No	Yes	Yes	AX
DU-124	0.197	48.7	0.8	39	Yes	Yes	Yes	AX
DU-125	0.153	37.7	0.8	31	Yes	Yes	Yes	AX
DU-126	0.198	49.0	0.8	40	Yes	Yes	Yes	AX
DU-127	0.182	45.0	0.8	37	Yes	Yes	Yes	AX
DU-128	0.124	30.6	0.8	25	Yes	Yes	Yes	AX
DU-129	0.203	50.1	0.8	40	Yes	Yes	Yes	AX
DU-130	0.164	40.5	0.8	33	Yes	Yes	Yes	AX
DU-131	0.156	38.6	0.8	31	Yes	Yes	Yes	AX
DU-132	0.045	11.2	1.2	13	Yes	Yes	Yes	AX
DU-133	0.064	15.9	0.8	13	Yes	Yes	Yes	AX

Table 3.4. Summary of Characteristics of the Decision Units for 100-OL-1 OU

Total # of Decision Units	133
Total Acreage	4905
Average Size of Decision Unit (acres)	36.9
Maximum Size (acres)	53.7
Minimum Size (acres)	5.3
Total # of Analyses[a]	4008
Average # of Analyses/DU	30
Maximum # of Analyses/DU	40
Minimum # of Analyses/DU	13

(a) Does not include additional quality control analyses.

3.1.5 Decision Rule

The decision rule for characterization of a decision unit is the screening level of 250 mg/kg lead and 20 mg/kg arsenic. The screening level is important to the characterization design. The number of samples per decision unit, the QC/QA of the analyses, and the decision to examine areas beyond the boundary of the OU are all based on the screening level for lead and arsenic. Each decision unit will be randomly sampled. A random sampling approach provides the best opportunity to characterize the magnitude and extent of lead and arsenic in the soil across the decision units.

The number of locations for measuring lead and arsenic in each decision unit needed to make a statistically valid comparison against screening level concentrations is a function of the characterization screening level, background concentrations, tolerance for a false positive, statistical distribution assumptions, variability of concentrations measured within the decision unit, and the true average concentration within the decision unit. In situ analysis of former orchards during the pilot study indicated that the relative standard deviation (RSD) of the sampling units varied between 125% and 266% for lead and arsenic (Bunn et al. 2014). The pilot study also identified the number of samples necessary to determine, with 95% confidence, that a site is below the screening level for various average concentrations and RSDs (Section 4.2.2, Bunn et al. 2014). Table 3.5 shows the number of locations necessary to make a statistically valid comparison of different average concentrations of both lead and arsenic with varying RSDs within a decision unit. Based on this assessment, a minimum of 11 samples is necessary to determine, with 95% confidence, that an area with 100% RSD is below the screening level. For the RI, a minimum of 13 in situ analyses will be conducted within each decision unit. Additionally, the number of analyses conducted in each decision unit will be a function of size; the spatial density of soil analysis will be nominally 200/km^2 (0.8/ac), with a maximum of 40 analyses per decision unit. Table 3.3 includes the number of locations and the spatial density for the analyses in each decision unit.

Table 3.5. Number of Locations Required to Determine, with 95% Confidence, That a Site Is below the Screening Level for Various Average Concentrations and RSDs (from Bunn et al. 2014)

Average Concentration of Analyte (mg/kg)		Number of Locations with Varying RSDs within a Decision Unit			
Lead	Arsenic	100%	125%	185%	250%
30	2.4	11	11	11	11
50	4	11	11	12	13
100	8	12	13	18	28
150	12	15	19	32	54
250	20	28	39	78	137

Additional samples will be collected outside the OU when the concentration at the edge of the OU greater than the screening level for either lead or arsenic (250 mg/kg lead and 20 mg/kg arsenic). Figure 3.1 shows an example of the sampling process beyond the edge or border of the OU based on results from the pilot study. Sampling beyond the edge of the OU will continue at the same spacing used inside the OU. That is, if the locations for analyses within a decision unit are spaced 30 m (100 ft) apart, then the samplers will move 30 m (100 ft) from the analysis location on the edge of the OU and analyze the soil at that location. The samplers will continue to measure locations with the XRF until either two additional analyses have been conducted or the results are less than five times background for lead (i.e., 51 mg/kg lead) and less than 20 mg/kg arsenic. The samplers may move laterally to characterize the area from the

edge of the OU if the lead or arsenic concentrations continue to exceed the criteria (51 mg/kg lead and 20 mg/kg arsenic). If the lead and arsenic are still high after two additional analyses from the edge of the OU (i.e., 60 m from the boundary in this example), then the design of the decision unit is questionable and the samplers will consider additional information on the decision unit to determine if further sampling is warranted. The additional sampling effort beyond the edge of the OU is designed to provide sufficient information for the Tri Party agencies to evaluate the RI and determine the next steps for the OU.

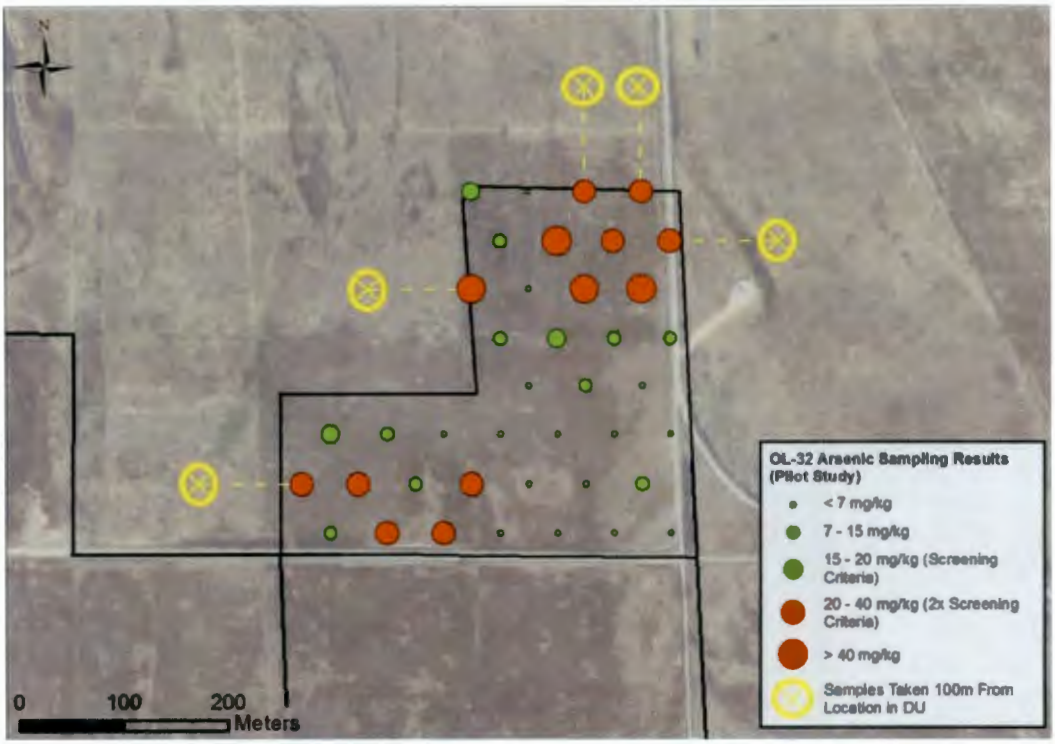


Figure 3.1. Example of Sampling outside the Operable Unit Borders

3.1.6 Specify Tolerable Limits on Decision Errors

The design of the characterization efforts for the 100-OL-1 OU is driven by the variability of lead and arsenic concentrations within a decision unit. The range of concentrations for arsenic and lead will likely vary from background concentrations (Table 2.2) to the highest values measured in the pilot study (Table 2.1). The pilot study demonstrated that the XRF analyzer provided measurements that met the QA criteria for soil concentrations ranging from background (6.47 mg/kg arsenic; 10.2 mg/kg lead) to values higher by two orders of magnitude (highest concentrations exceeded 1000 mg/kg arsenic and 5000 mg/kg lead). The quality of the characterization information with the XRF analyzer will not affect the decision to evaluate the decision units considering the screening level for lead and arsenic (Table 2.3 and Table 2.4).

3.1.7 Other Sampling Considerations

No other sampling considerations are identified for the RI.

3.2 Characterization Approach for the Remedial Investigation

The magnitude and extent of lead and arsenic soil contamination in the 100-OL-1 OU will be determined by characterization activities conducted as part of the RI. The sampling design for the characterization activities is based on the approach used for the pilot study (DOE-RL 2014), the DQOs, and the conceptual model for lead arsenate residues in Hanford Site soils. Figure 3.2 to Figure 3.16 show the decision units for evaluating the lead and arsenic in the OU.

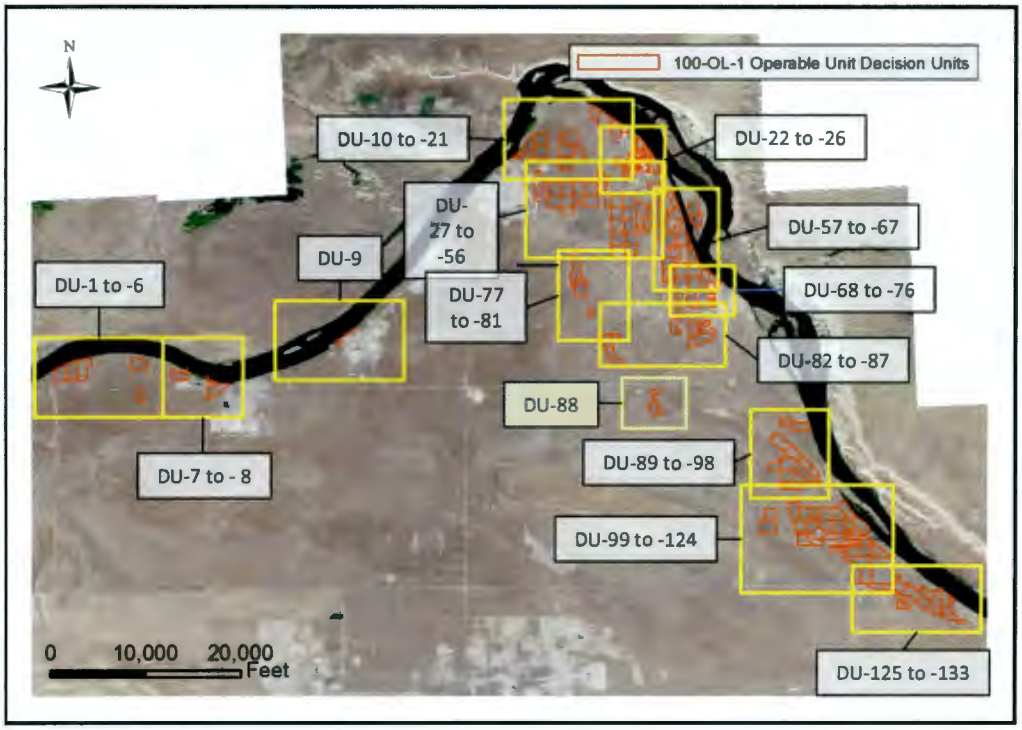


Figure 3.2. Overview of Decision Units throughout the 100-OL-1 OU

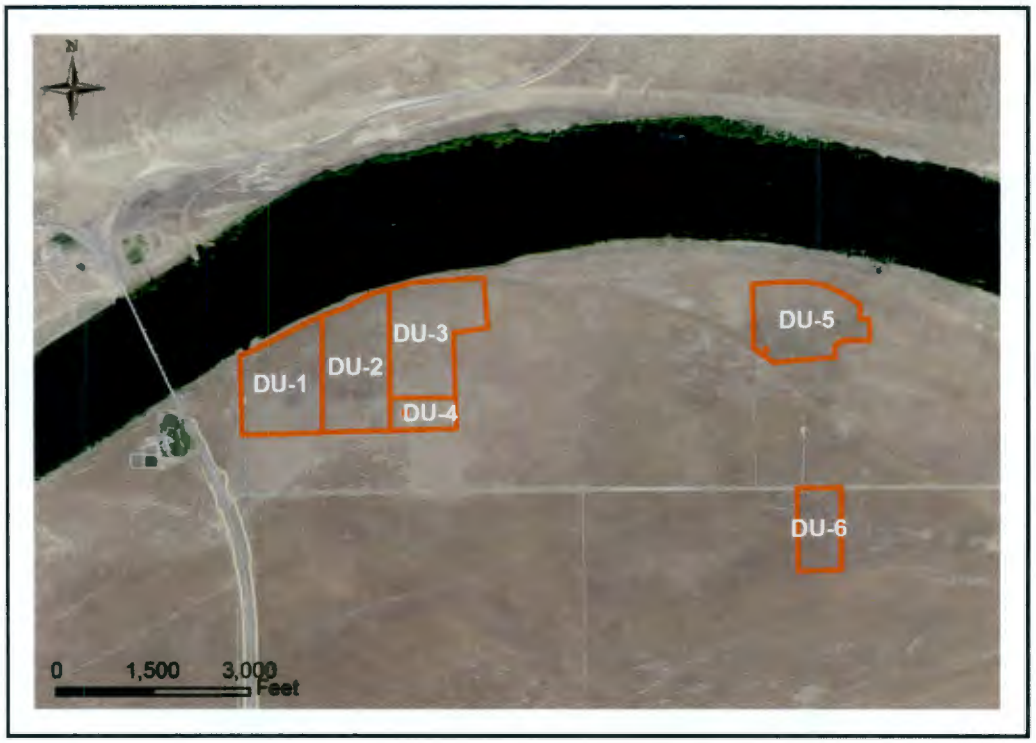


Figure 3.3. Decision Units 1 through 6, Located West of the 100-BC Area

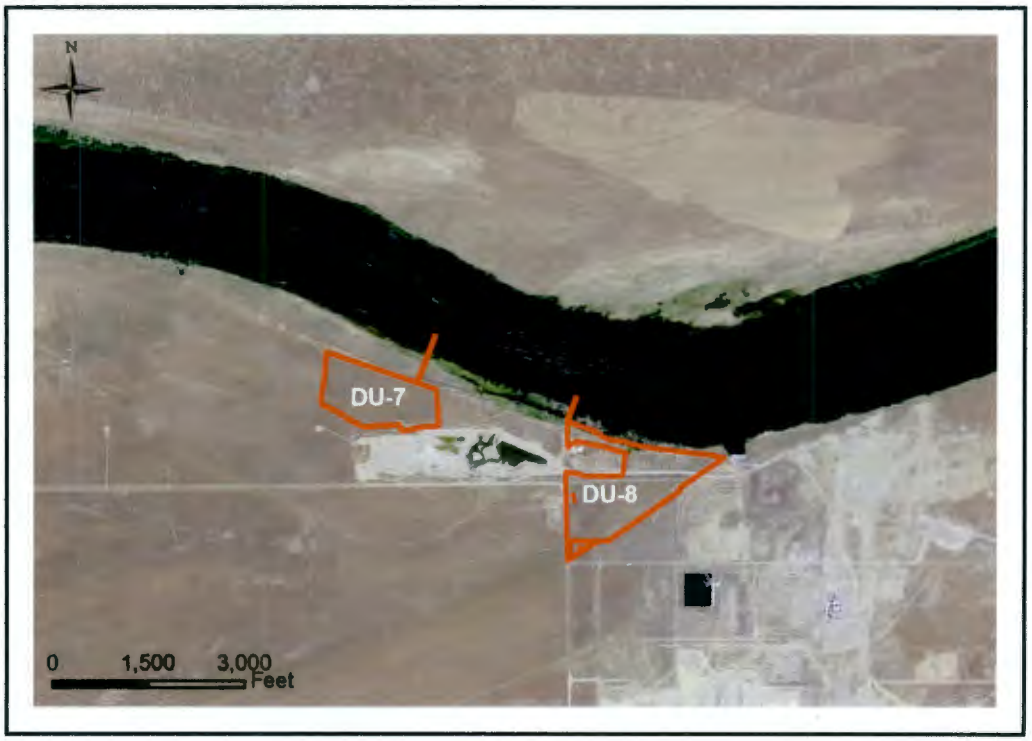


Figure 3.4. Decision Units 7 and 8, Located West and within 100-BC Area

Figure 3.5. Decision Unit 9, Located in the 100-K Area

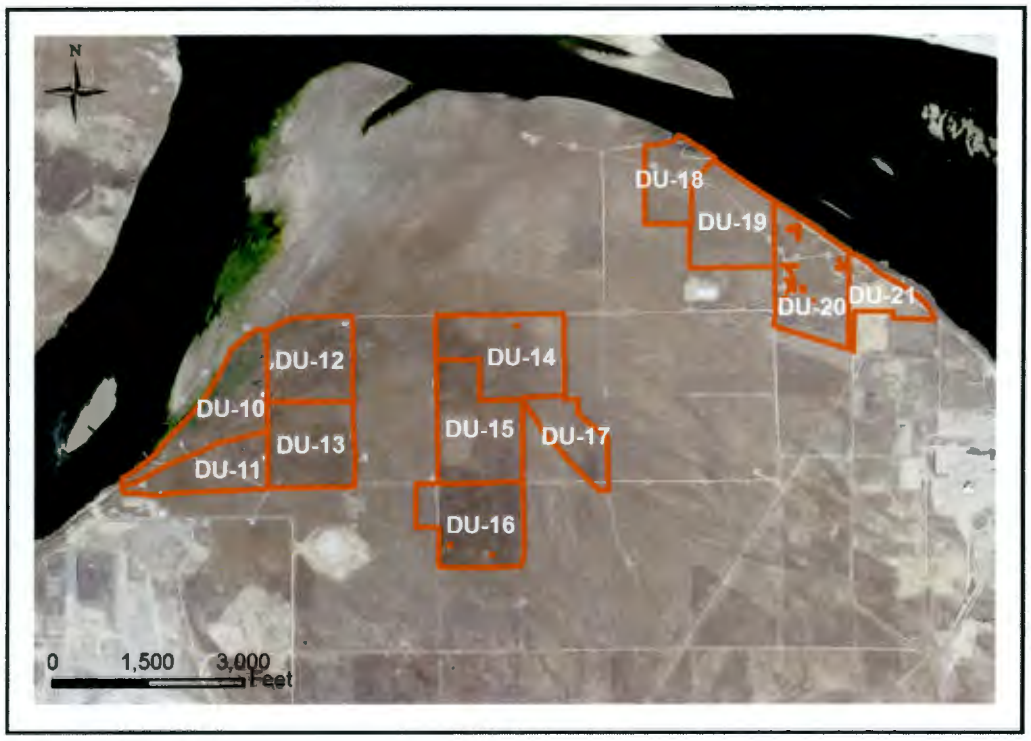


Figure 3.6. Decision Units 10 through 21, Located in the 100-D/H Area

Figure 3.7. Decision Units 22 through 26, Located within 100-H Area

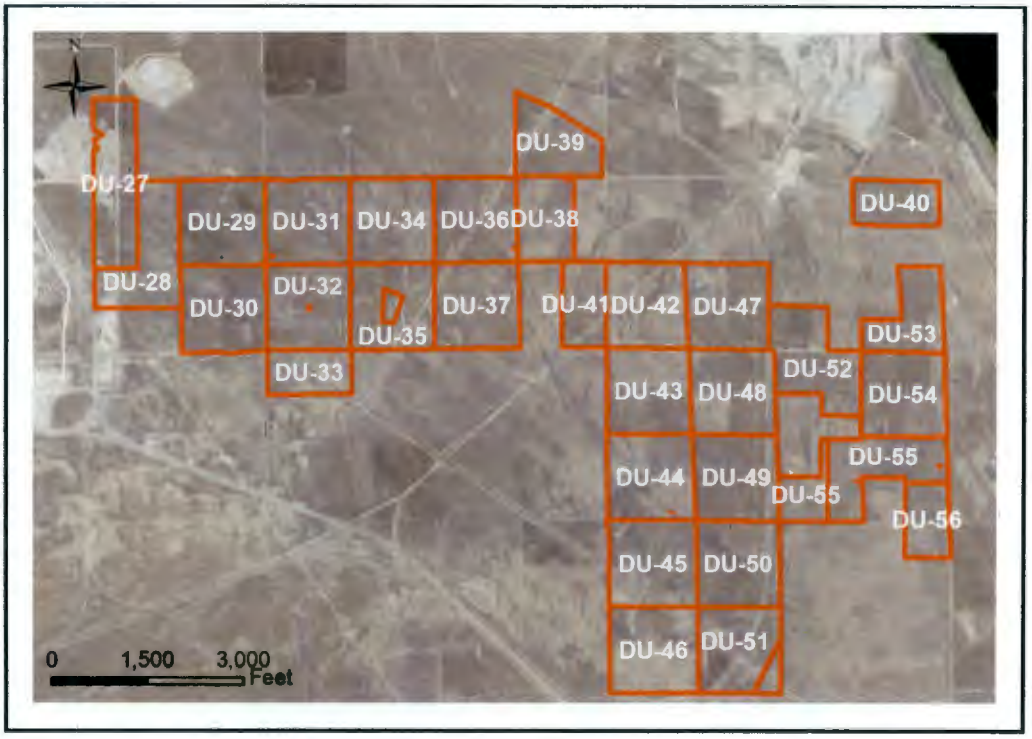


Figure 3.8. Decision Units 27 through 56, Located in the 100-D/H Area

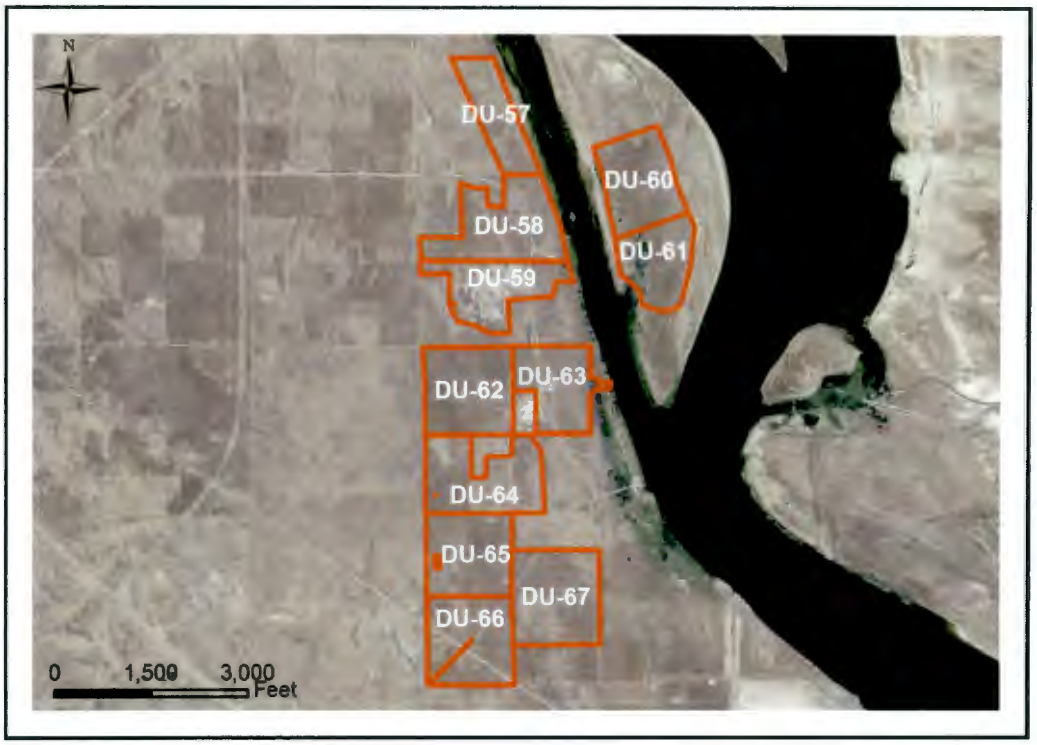


Figure 3.9. Decision Units 57 through 67, Located South of the 100-H Area

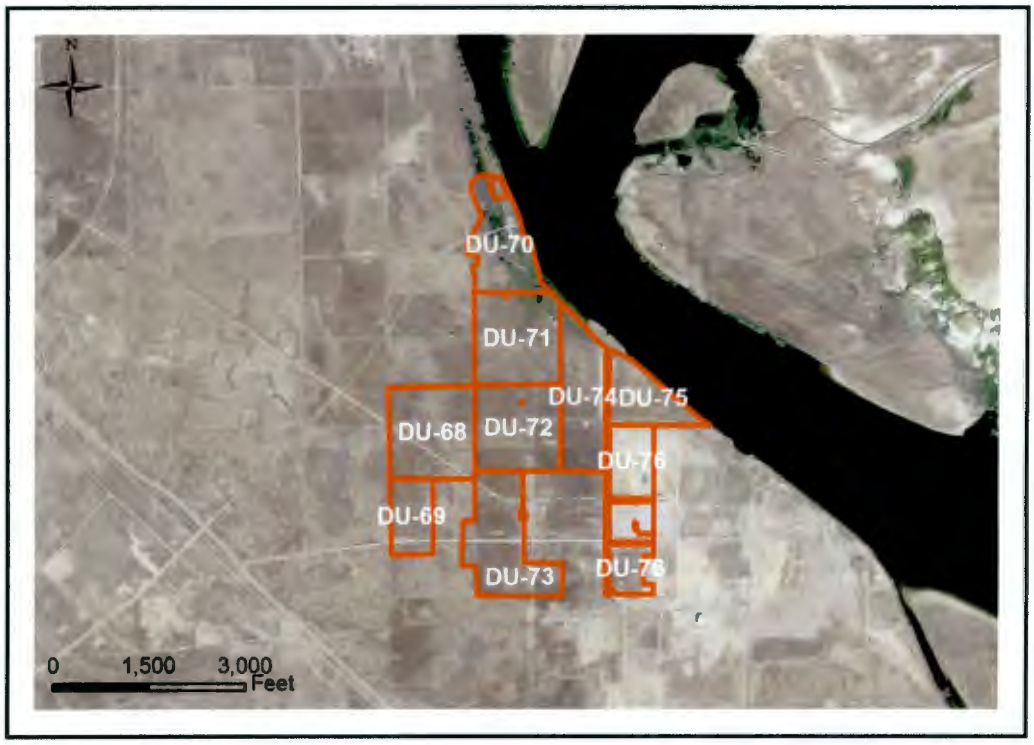


Figure 3.10. Decision Units 68 through 76, Located around 100-F Area

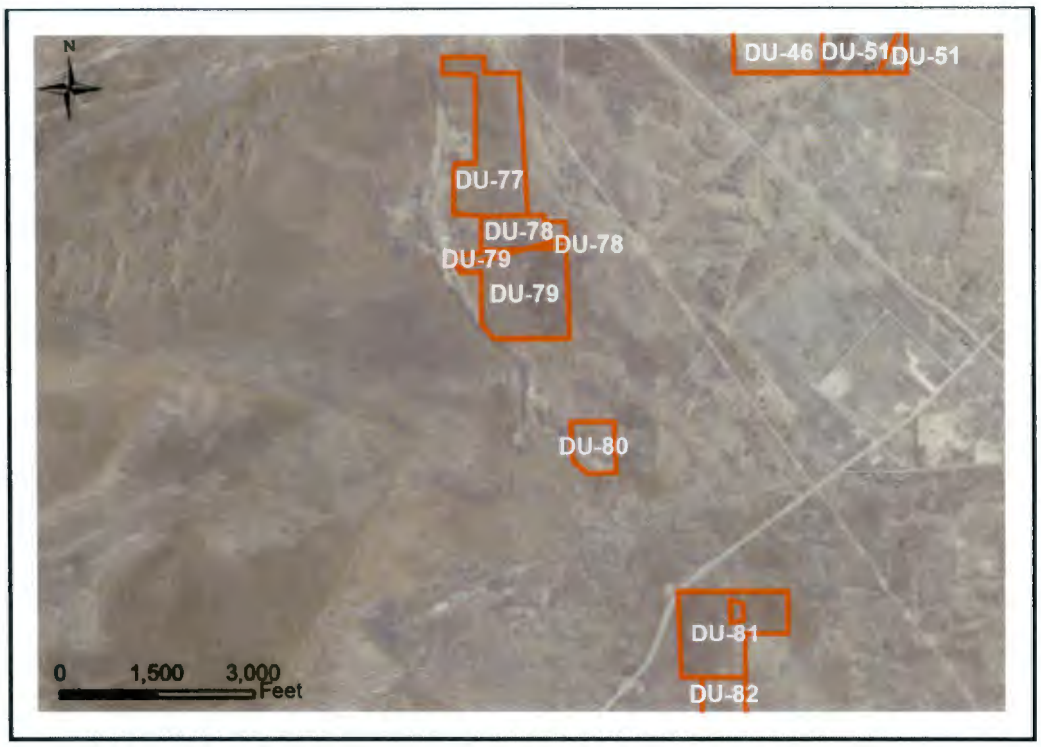


Figure 3.11. Decision Units 77 through 80, Located West of 100-F Area

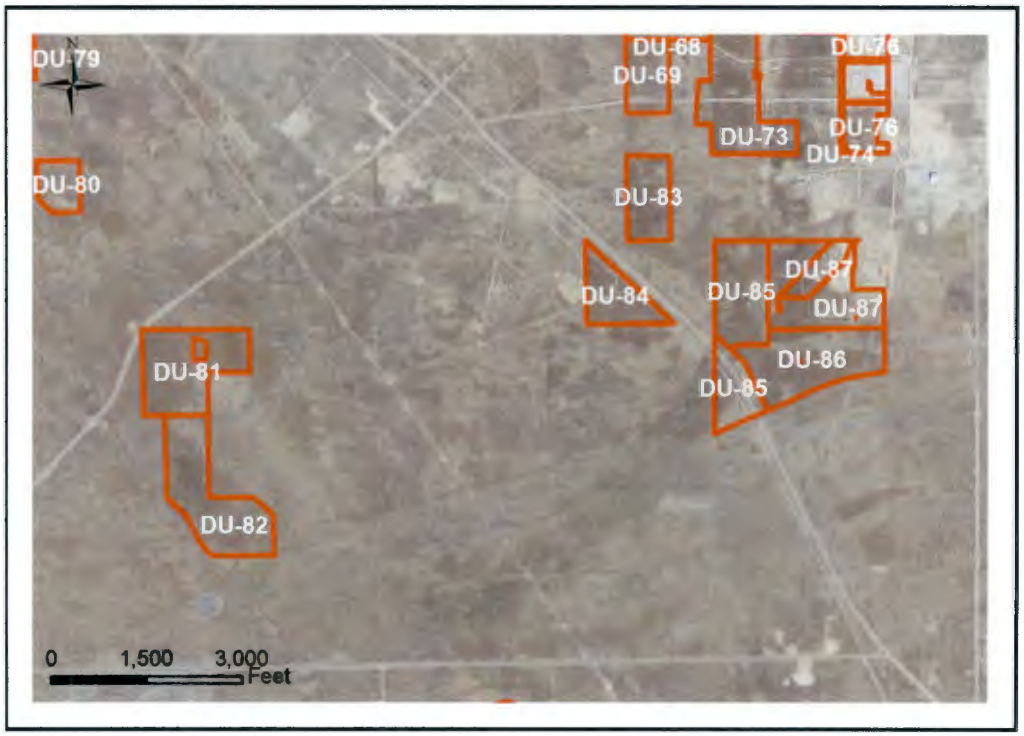


Figure 3.12. Decision Units 81 through 87, Located around 100-F Area

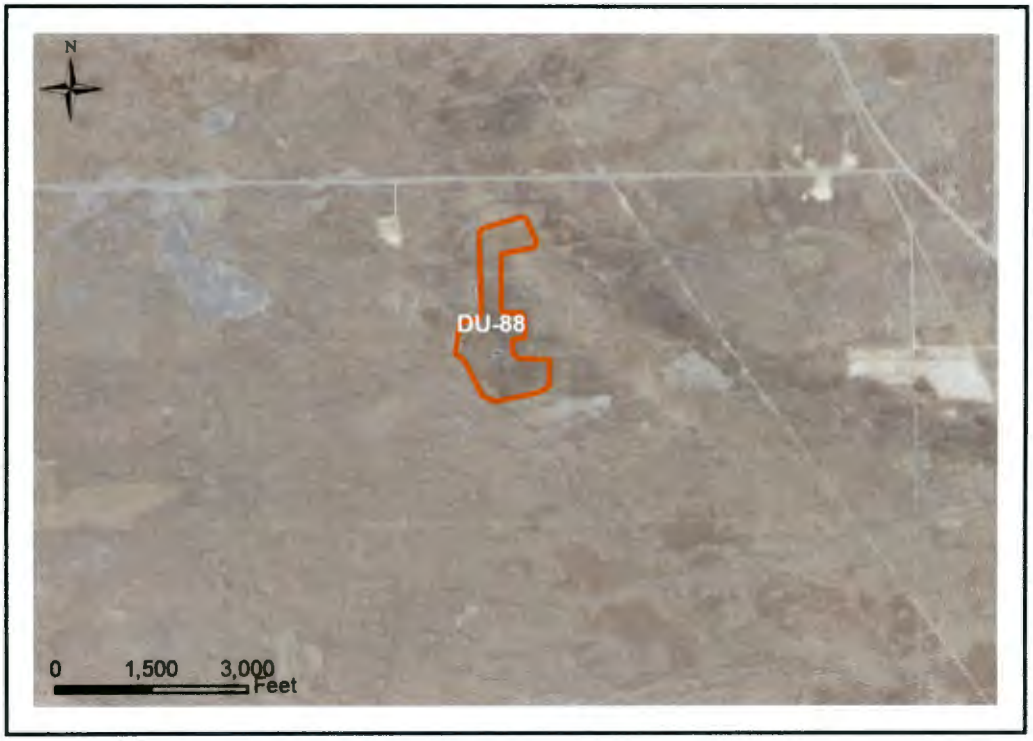


Figure 3.13. Decision Unit 88, Located Southwest of 100-F Area

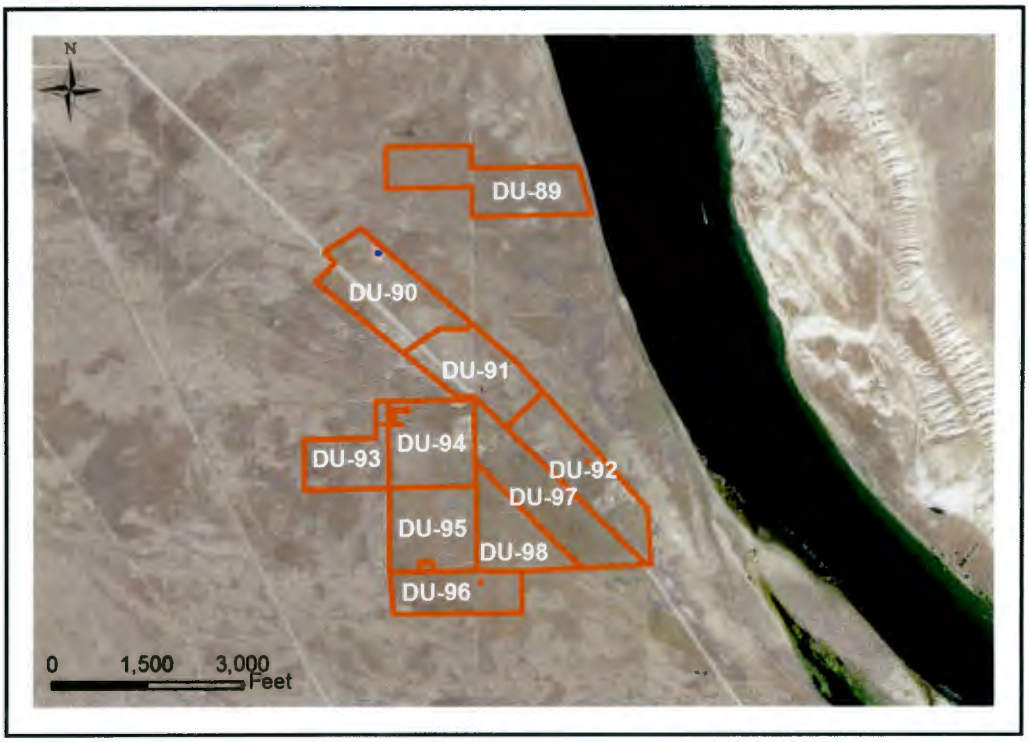


Figure 3.14. Decision Units 89 through 98, Located North of the Hanford Townsite

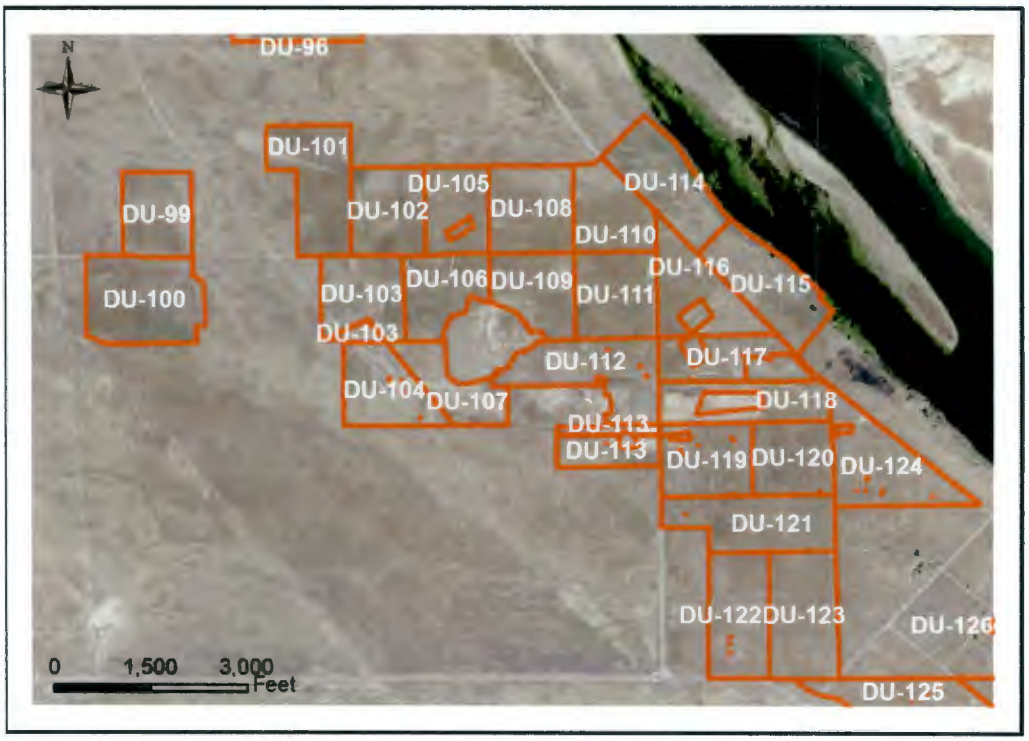


Figure 3.15. Decision Units 99 through 124, Located near the Hanford Townsite

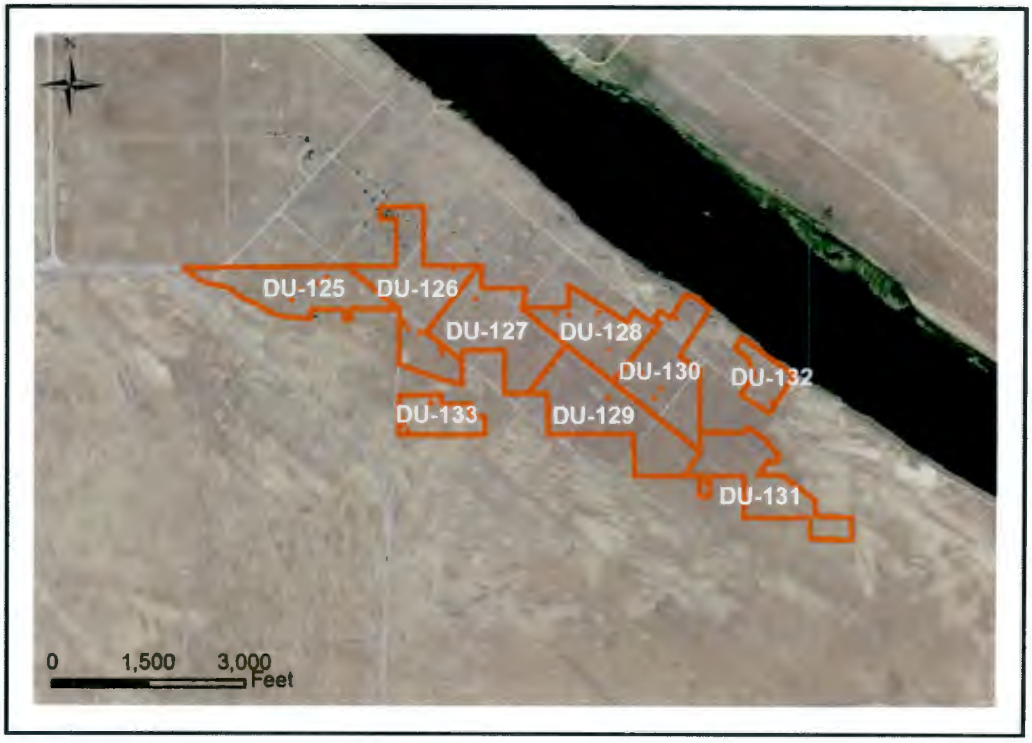


Figure 3.16. Decision Units 125 through 133, Located near the Hanford Townsite

4.0 Remedial Investigation Tasks

Table 4.1 includes the tasks identified for the 100-OL-1 OU RI. The feasibility study for the OU will be completed after the RI is approved by DOE, EPA, and Ecology. The RI tasks are discussed further below.

Table 4.1. RI Tasks

Task	Description of Task for Remedial Investigation
RI-1	Project Planning • RI Coordination • GIS Finalization of Decision Units • Cultural Resources Review • Ecological Compliance Review
RI-2	Field Characterization Activities
RI-3	Confirmatory Soil Analyses
RI-4	Data Evaluation
RI-5	Risk Assessment
RI-6	Remedial Investigation Report • Report Preparation • Review Cycle

Task RI-1: Project Planning. Several activities are included in project planning for successful implementation of the RI.

Subtask RI-1a – RI Coordination. Extensive fieldwork is planned for the RI. This task will coordinate the activities needed for the RI. Update plans for field characterization, including the health and safety plan, sampling and analysis plan (SAP), and quality assurance project plan. Coordinate with other work scope in the Hanford Site's River Corridor to facilitate characterization activities that are near other remediation actions (e.g., for DU-9 at 100-K Area). Coordination activities may include meetings with onsite contractors, additional site-specific training, and peer reviews. Communication on progress of field activities will occur weekly. Minor changes, including changes in sampling locations (e.g., less than 3 m [10ft]) due to obstructions, will be documented in field logs. More significant changes that result in impacts to meet the DQO and SAP (Appendix A) will require RL and regulator approval.

Subtask 1b – Finalization of Decision Units. Decision units identified in this work plan will be reviewed, updated, and finalized (Table 3.3). Finalize GIS documentation for the 100-OL-1 OU. This task includes providing metadata, any additional geo-referencing information, new information about former orchards, and anything necessary for the data to meet the Hanford GIS clearinghouse standards.

Subtask 1c – Cultural Resources Review (NHPA Section 106). Before the RI begins, a cultural resources review will be conducted to determine the potential for sampling locations to affect significant cultural resources and historic properties. This review will ensure that the field characterization activities are consistent with the *National Historic Preservation Act of 1966*. A similar review was performed for the 100-OL-1 OU pilot study (Bunn et al. 2014, MSA Service Catalog Request #KSR000000128277,

April 28, 2014). The cultural review will determine whether sample locations need to be moved to avoid cultural resources and when archaeological monitoring is required. The review will also describe any requirements for field sampling staff conducting work to ensure cultural resources are avoided during sampling activities.

Subtask 1d – Ecological Compliance Review. An ecological compliance review will be conducted, similar to the review performed for the 100-OL-1 OU pilot study (Bunn et al. 2014, MSA Service Catalog Request #KSR000000128277, April 28, 2014). This review will ensure that the field characterization activities do not conflict with laws, e.g., the *Endangered Species Act of 1973*, *Bald and Golden Eagle Protection Act*, *Migratory Bird Treaty Act*, and Washington State regulations protecting threatened, endangered, and listed species. A biological resource specialist will conduct the ecological compliance review.

Task RI-2: Field Characterization Activities. Field characterization activities will begin after the ecological and cultural review process is complete. Field activities for the characterization efforts will be completed in accordance with the SAP (Appendix A). Subcontracts for field activities may be required. Field characterization activities will be performed in accordance with the *Hanford Analytical Services Quality Assurance Requirements Documents* (DOE-RL 2007) and the *DVZ-AFRI Quality Assurance Plan* (Meier 2014). Data validation will be conducted by a third party who will perform an independent review of field data to ensure that the procedures, protocols, and requirements in the SAP were correctly followed. Data assessment will address any anomalies in the data and determine if corrective actions are needed. Validation and assessment of the data will be performed in accordance with the *DVZ-AFRI Quality Assurance Plan* (Meier 2014).

Task RI-3: Sample Analysis and Validation. Laboratory analyses of confirmatory soil samples (with ICP-MS) will be performed by a contract laboratory that has qualifications in accordance with the *Hanford Analytical Services Quality Assurance Requirements Documents* (DOE-RL 2007) and the *DVZ-AFRI Quality Assurance Plan* (Meier 2014). Data validation will be conducted by a third party who will perform an independent review of laboratory data to ensure that the procedures, protocols, and requirements in the SAP were correctly followed. Data assessment will address any anomalies in the data and determine if corrective actions are needed. Validation and assessment of the data will be performed in accordance with the *Hanford Analytical Services Quality Assurance Requirements Documents* (DOE-RL 2007) and the *DVZ-AFRI Quality Assurance Plan* (Meier 2014).

Task RI-4: Data Evaluation. Data from field characterization will be evaluated to determine the magnitude and extent of lead and arsenic in the 100-OL-1 OU. Data evaluation will be consistent with DQOs and include comparison of field characterization results to screening levels for arsenic and lead concentrations in soil from each decision unit. The characterization data will be evaluated to determine if the data is of the right type, quality, and quantity to support the RI.

Task RI-5: Risk Assessment. Field characterization information from each decision unit will be evaluated in comparison to selected risk-informed screening levels for human and ecological health. These screening levels provided in Table 2.3 and Table 2.4 include risk-informed decisions and action levels identified at Hanford and for other actions within the State of Washington (Yokel and Delistraty 2003; DOE-RL 2008; EPA 2009; Delistraty and Yokel 2011; CHPRC 2011a, b, and 2012; Ecology 2012a; WAC 173-340). The screening level risk assessment will evaluate human health based on the decision rule (250 mg/kg lead and 20 mg/kg arsenic). The screening level ecological risk in the baseline

risk assessment will compare the concentrations of lead and arsenic to the Tier 1 and Tier 2 screening levels in Table 2.4, also called the preliminary remediation goals for the ecological receptors at the Hanford Site (CHPRC 2011a, b, and 2012). After the screening level risk assessment is complete, DOE may propose additional risk assessment work.

Task RI-6: Remedial Investigation Report. This work element will consist of managing, compiling, and evaluating all of the data generated during the RI activities. The final report will cover activities ranging from field characterization of the orchards to evaluation of decision rules for determining further action in the decision units within the 100-OL-1 OU. Findings presented in this report will form the basis for future actions in the 100-OL-1 OU.

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5.0 Schedule

Table 5.1 is the schedule for the RI based on the sample design and activities discussed in Section 4.0. Several activities to prepare for the field work can be conducted concurrent with the cultural resources review, including finalizing decision units and sampling locations.

Table 5.1. Generic Schedule for Remedial Investigation Activities

Task	Description of Task for Remedial Investigation	Duration (in months)	Year 1								Year 2								
			5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
RI-1	**Project Planning**																		
	Project Support	17																	
	GIS Finalization of Decision Units	2																	
	Cultural Resources Review	2																	
	Ecological Compliance Review	2																	
RI-2	**Field Characterization Activities**	4																	
RI-3	**Sample Analysis and Validation**	5																	
RI-4	**Data Evaluation**	6																	
RI-5	**Risk Assessment**	3																	
RI-6	**Remedial Investigation Report**	11																	

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6.0 Project Management

This section addresses the basic aspects of project management, which will ensure that the project has defined goals, the project team understands the goals and the approaches used, and the planned outputs are appropriately documented. Project management roles and responsibilities discussed in this section apply to the major activities for the RI covered under this work plan. The approved contractor for the 100-OL-1 OU RI is responsible for planning, coordinating, collecting, and analyzing field samples and preparing, packaging, and shipping samples to the analytical laboratory, as defined in its contract. The following sections describe the project organization, relative to sampling and characterization, which is also shown in Figure 6.1. The project lead maintains a list of individuals or organizations as points of contact for each functional element shown in the figure. For each functional primary contractor role, a corresponding oversight role exists within DOE-RL.

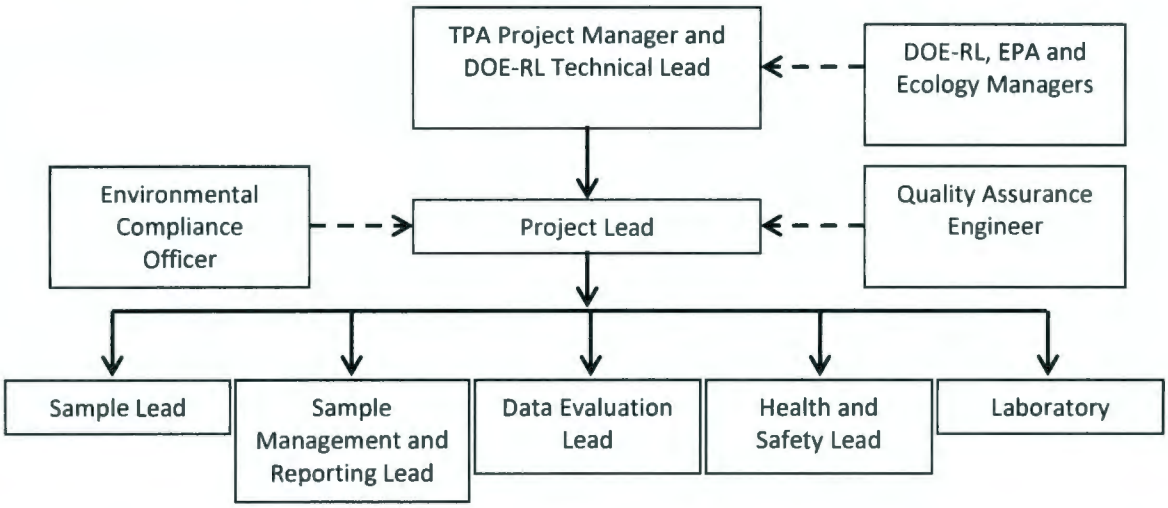

Figure 6.1. Project Organization

DOE-RL, EPA, and Ecology Project Managers. EPA and Ecology will be the lead regulatory organizations for the 100-OL-1 OU (TPA 2012b), working with DOE-RL. Each organization has assigned project managers responsible for overseeing the activities identified in the plan to accomplish the scope of this plan. EPA and Ecology will work with DOE-RL to resolve concerns about the work in accordance with the TPA (Ecology et al. 1989). The managers will be responsible for the risk management evaluation of the RI characterization results and will determine if additional characterization efforts are needed before proceeding with the feasibility study.

Tri-Party Agreement Project Manager and DOE-RL Technical Lead. The TPA project manager is responsible for:

- Authorizing RI activities for the 100-OL-1 OU
- Obtaining regulatory approval of the work plan and SAP that authorize the RI activities under the TPA (Ecology et al. 1989).

DOE-RL Technical lead. The DOE-RL technical lead is responsible for:

- Overseeing the contractor in performing the work scope
- Working with the contractor and the regulatory agencies to identify and work through issues
- Providing technical input to the TPA project manager.

Project Lead. The project lead is responsible for:

- Planning and implementing work scope
- Managing sampling documents and requirements, field activities, and subcontracted tasks, and ensuring that personnel are working in accordance with the most current job requirements
- Completion of the cultural resource review before initiating any field activities, and ensuring monitoring activities are incorporated and implemented into the field activities
- Requesting and obtaining an ecological review before initiating any field activities, and ensuring that findings are incorporated and implemented into the field activities
- Maintaining version control for the work plan.

The project lead will work closely with the QA engineer, the health and safety lead, and the sampling lead to integrate these and the other lead disciplines in planning and implementing the work scope. The project lead will maintain a list of individuals or organizations that fill each functional element of the project organization (Figure 6.1). The project lead will work with the sample management and reporting lead, data evaluation lead, and the sampling lead after field characterization begins to propose any changes to the SAP to optimize the sampling design. The project lead also will coordinate with DOE-RL and the primary contractor management on sampling activities. The project lead will support DOE-RL in coordinating sampling activities with the regulators, including any revisions to the work plan.

Environmental Compliance Officer. The environmental compliance officer will be responsible to the project lead, and will be responsible for:

- Providing technical oversight, direction, and acceptance of project and subcontracted environmental work
- Developing appropriate mitigation measures to minimize adverse environmental impacts
- Reviewing plans, procedures, and technical documents to ensure that environmental requirements have been addressed
- Identifying environmental issues affecting operations and developing cost-effective solutions
- Responding to environmental/regulatory issues or concerns raised by DOE-RL and/or regulatory agencies.

The environmental compliance officer also may oversee project implementation to ensure compliance with applicable internal and external environmental requirements.

Quality Assurance Engineer. The QA engineer will be responsible to the project lead and will be responsible for QA issues on the project. Responsibilities will include:

- Overseeing implementation of the project QA requirements
- Reviewing project documents, including data needs summary reports, the field sampling plan, and the quality assurance project plan
- Ensuring that the laboratories conform with Hanford Site internal laboratory QA requirements, or their equivalent, as approved by DOE-RL, EPA, and Ecology
- Participating in QA assessments on sample collection and analysis activities, as appropriate.

The QA engineer must be independent of the unit generating the data.

Sampling Lead. The sampling lead will have overall responsibility for planning, coordinating, and executing sampling activities. Specific responsibilities will include:

- Converting the sampling design requirements into field task instructions that provide specific direction for field activities
- Implementing any cultural resources monitoring and mitigation activities
- Directing training, mock-ups, and practice sessions with field personnel to ensure that the sampling design is understood and can be performed as specified
- Communicating with the project lead to identify field constraints or emergent conditions that will affect sampling design and/or execution
- Managing field collection efforts
- Procuring and installing material and equipment needed to support field work
- Preparing data packages based on instructions from the project lead and information contained in the project SAP.

Sample Management and Reporting Lead. The sample management and reporting lead will be responsible for:

- Managing and reporting of soil analyses
- Reviewing and completing all QA/QC documentation for field and laboratory analyses
- Coordinating with laboratory analytical work
- Coordinating all QA/QC documents with the QA engineer
- Entering data into HEIS
- Arranging for and overseeing data validation of all analyses
- Informing the project lead of any issues reported by the analytical laboratory.

The sample management and reporting lead also will be responsible for conducting the data needs process, or equivalent. Additional related responsibilities will include developing the SAP, including documenting the data needs and the sampling design, preparing associated presentations, resolving technical issues, and preparing revisions to the SAP. Samples collected in the field for shipping and

analysis, as well as the resulting data, will be managed in accordance with applicable procedures and work plans.

Data Evaluation Lead. The data evaluation lead will be responsible for evaluating the results of the field characterization, performing the statistical analyses, and evaluating the data to meet DQOs. The data evaluation lead will work with the project lead and sampling lead on the recommendations and any proposed revisions to the SAP.

Health and Safety Lead. The health and safety lead will be responsible for coordinating industrial safety and health support for the project through health and safety plans, job hazard analyses, and other pertinent safety documents required by federal regulations or by internal primary contractor work requirements. The health and safety lead will work with the project lead. In addition, the health and safety lead will assist project personnel in complying with applicable health and safety standards and requirements, particularly for decision units located in other operable units.

Laboratories. The laboratories will analyze samples in accordance with established procedures, provide necessary sample reports, and explain results in support of data validation. The laboratories must meet site-specific QA requirements and must have an approved QA plan in place.

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Appendix A

Sampling and Analysis Plan for the Remedial Investigation Work Plan to Evaluate the 100-OL-1 Operable Unit Pre-Hanford Orchard Lands

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Appendix A

Sampling and Analysis Plan for the Remedial Investigation Work Plan to Evaluate the 100-OL-1 Operable Unit Pre-Hanford Orchard Lands

A.1 Introduction

This sampling and analysis plan (SAP) presents the details of the proposed sampling identified in the Remedial Investigation Work Plan for Orchard Land (this document, hereafter called the RI work plan). This SAP is based on the data quality objective (DQO) process, which is summarized in the RI work plan (Section 3.1). The SAP addresses the characterization efforts necessary to evaluate the magnitude and extent of lead and arsenic soil contamination in the 100-OL-1 Operable Unit (OU).

The former orchard areas are located from the 100 Area of the Hanford Site (south side of the Columbia River) down to the Hanford townsite (Figure A.1). The discontinuous orchard lands cover approximately 20 km^2 (5000 ac). While most of the former orchard lands were not disturbed by activities during the Manhattan Project or during subsequent Hanford Site activities, some former orchard lands are located across the River Corridor area and within some vadose zone operable units (specifically, 100-KR-1, 100-HR-1, 100-HR-2, 100-FR-2, 100-IU-2 and 100-IU-6).

The quality assurance project plan (QAPjP), field sampling plan (FSP), and health and safety plan (HASP) are discussed in Sections A.2, A.3, and A.4, respectively. The SAP is intended as a standalone part of the RI work plan for the 100-OL-1 OU, as recommended in U.S. Environmental Protection Agency (EPA) guidance (EPA 1988), and contains redundant sections with the RI work plan. Prior to characterization activities, the SAP will be reviewed and updated to include any changes in locations and decision units as well as reflect any updates to the conceptual approach for evaluating lead and arsenic in soils at former orchard properties on the Hanford Site.

A.1.1 Orchard Lands History

Prior to the acquisition of land by the U.S. Department of War in February 1943 for the creation of the Hanford Site, the land along the Columbia River was home to more than 1000 people, who used it for various farming and orchard operations by both homesteaders and commercial entities. Tree-fruit production increased around 1905, coinciding with the increased availability of irrigated water through pumping plants and canals provided by the Hanford Irrigation Company (and later the Priest Rapids Irrigation District). Control of codling moths (*Cydia pomonella*) was needed as the orchards expanded in the region. Beginning in the 1890s, lead arsenate was the pesticide of choice for codling moth control for most tree-fruits, which included apples, cherries, apricots, peaches, pears, plums, and prunes. The application of lead arsenate ceased when orchard operations ended (Sharpe 1999; DOE 1997; DOE-RL 2011). In some areas of the Hanford Site, there is still evidence of the old trees—stumps and branches mostly—and a few investigations have been conducted to evaluate lead arsenate residues in the soil (Yokel and Delistraty 2003; Delistraty and Yokel 2011; Bunn et al. 2014).

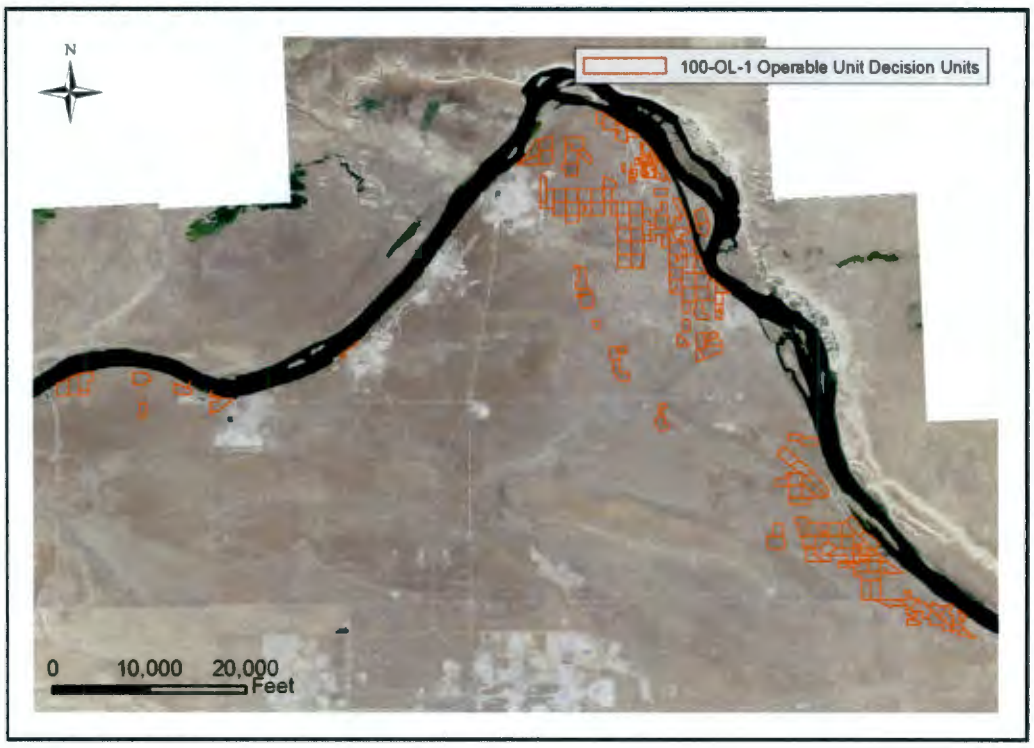

Figure A.1. The Areas Designated as the 100-OL-1 OU across the Hanford Site Identified as Decision Units in the RI Work Plan

Today, residues from lead arsenate pesticide applications persist in soils at the Hanford Site as they do in other former orchard areas across Washington State and the nation. From 1910 to 1920, almost 14 million kg (30 million lb) of lead arsenate were used annually in the United States (ODEQ 2006). The levels of arsenic and lead in the soil from former orchard activities varies based on several factors: the number of applications in a season of production; the form of application (powder or solution); soil characteristics (soil texture, pH, organic matter, clay minerals, hydrous metal oxides, calcite); and precipitation rates. The acidic form of lead arsenate, $PbHAsO_4$, was the most common type applied in Washington State (Frank et al. 1976; Maclean and Langille 1981; Veneman et al. 1983; Peryea and Creger 1994; Elfving et al. 1994; Peryea and Kammereck 1997; Peryea 1998; Sharpe 1999, 2000; Kabata-Pendias 2001; Yokel and Delistraty 2003; Newton et al. 2006; Renshaw et al. 2006; Staed et al. 2009; Cadwalader et al. 2011; Sloan 2011; Delistraty and Yokel 2011).

A.1.2 Characterization of the Orchard Land Soil

This SAP describes the activities planned to characterize the orchards in the 100-OL-1 OU. Based on comments received from EPA and Washington State Department of Ecology (Ecology), a pilot study was conducted to evaluate the use of a field-portable X-ray fluorescence (XRF) analyzer for evaluating lead and arsenic concentrations on the surface of the soil, as an indicator of past use of lead arsenate pesticide residue in the OU. Recommendations from the pilot study have been incorporated into the RI work plan and this SAP. The surface of the soil will be analyzed to evaluate the magnitude and extent of contamination across the 100-OL-1 OU (Bunn et al. 2014). The design of the characterization effort for the OU is based on the screening levels of 250 mg/kg lead and 20 mg/kg arsenic. Confirmatory soil samples from locations across the OU will be collected and analyzed with inductively coupled plasma

mass spectroscopy (ICP-MS) to meet the quality assurance (QA) criteria established by EPA for XRF analysis of soil (EPA 2007a). During the development of the work plan, decision units for sample planning and decision purposes were identified through an evaluation of geographical information system (GIS) data on the former orchards.

A.1.2.1 Decision Units for 100-OL-1 OU

The extensive areas of tree-fruit production in the 100-OL-1 OU were divided into decision units when developing the RI work plan. The intent was to define decision units that capture the areas where lead arsenate pesticide residues are likely to be found in the soil today from past application on orchard trees or other activities that might have contributed to lead and arsenic contamination of soil (e.g., storage, preparation of mixtures, or cleaning of equipment). Decision units encompass the source areas for the lead and arsenic contamination and the areas of human and ecological exposure today. The size of the decision unit is related to the sampling area, and the decisions associated with the sampling and characterization of the orchard area (ITRC 2012).

The process for dividing the orchards into decision units considered the location of the orchard on the Hanford Site as well as any soil disturbance, historical imagery of the orchard lands, and the size of the decision unit. The decision units include the area inscribed in Tri-Party Agreement (TPA) Change Control Form C-12-02 (TPA 2012a). The first criterion for division of the 100-OL-1 OU into decision units considered the presence or absence of trees in the historical aerial imagery from 1941 and 1943. The second criterion used in the creation of decision units for the 100-OL-1 OU was size. Another distinction used in categorizing the decision units was evidence of surface soil disturbance since 1943. Within a decision unit, areas that have been or will be remediated will not be sampled. GIS information on the Hanford Site Waste Information Data System (WIDS) will be used to exclude these areas for sampling locations. The third criteria for the division of the OU into decision units was the presence of roads. Boundaries of the decision units considered the aerial imagery from 1943 and 2013 as well as GIS layer that includes the roads on the Hanford Site. The boundary of a decision unit was placed down the middle of a road if it could be seen in the 1943 imagery or in the 2013 imagery (in that order). The boundaries of the OU were adjusted to capture the full extent of orchards near the decision unit based on both the 1943 and 2013 aerial imagery. In a few cases, the boundary was adjusted further. For example, the boundary of a few decision units was adjusted to follow a landscape feature (e.g., a steep slope or the edge of the Hanford Irrigation Canal) to make sampling easier.

Table A.1 describes the number of decision units by category. Table A.2 lists each decision unit and the criteria used to identify the decision unit. Table A.3 summarizes the characteristics of the decision unit. Figure A.2 through Figure A.16 show the decision units for the 100-OL-1 OU, with areas of existing waste sites excluded.

From the 44 areas in the map of the 100-OL-1 OU included in TPA Change Control Form C-12-02 (TPA 2012a), 133 decision units were identified when developing the RI work plan. Notable changes during the DQO preparation process included further division of decision units into areas with and without the presence of trees in the 1943. Three decision units, DU-60, -61, and -88 (Figure A.9 and Figure A.13), were added because review of the aerial imagery confirmed orchards were present in those areas in 1943. The addition of these decision units was consistent with the criteria used to develop the map in TPA Change Control Form C-12-02 (TPA 2012a) and to define the other decision units.

Table A.1. Categories for the 100-OL-1 OU Decision Units

Decision Unit Category	Presence of Trees in 1943 Aerial Photos?	Evidence of Soil Disturbance Since 1943?	Number of Decision Units by Category
A	Yes	No	63
AX	Yes	Yes	46
B	No	No	17
BX	No	Yes	7

Table A.2. Decision Units for 100-OL-1 Operable Unit

Orchard Area DU ID	Area of DU		Spatial Density (samples/ acre)	Number of Locations	WIDS site Within DU Boundaries?	Presence of Trees in 1943 Aerial Photos?	Evidence of Soil Disturbance Since 1943?	DU Category
	km^2	Acres						
DU-1	0.179	44.1	0.8	36	No	Yes	No	A
DU-2	0.196	48.4	0.8	39	No	Yes	No	A
DU-3	0.202	50.0	0.8	40	No	No	No	B
DU-4	0.047	11.5	1.1	13	Yes	No	Yes	BX
DU-5	0.164	40.6	0.8	33	Yes	Yes	No	A
DU-6	0.082	20.2	0.8	17	No	Yes	No	A
DU-7	0.136	33.7	0.8	28	No	Yes	No	A
DU-8	0.206	50.8	0.8	40	Yes	Yes	Yes	AX
DU-9	0.030	7.3	1.8	13	Yes	Yes	Yes	AX
DU-10	0.170	41.9	0.8	34	No	Yes	No	A
DU-11	0.122	30.2	0.8	25	No	Yes	Yes	AX
DU-12	0.161	39.8	0.8	32	No	Yes	No	A
DU-13	0.168	41.5	0.8	34	No	Yes	No	A
DU-14	0.205	50.6	0.8	40	Yes	Yes	No	A
DU-15	0.200	49.5	0.8	40	No	Yes	No	A
DU-16	0.185	45.7	0.8	37	Yes	Yes	No	A
DU-17	0.089	22.1	0.8	18	No	No	No	B
DU-18	0.098	24.3	0.8	20	No	Yes	No	A
DU-19	0.165	40.7	0.8	34	No	Yes	No	A
DU-20	0.188	46.4	0.8	37	Yes	Yes	Yes	AX
DU-21	0.073	17.9	0.8	15	No	Yes	Yes	AX
DU-22	0.173	42.9	0.8	35	Yes	Yes	Yes	AX
DU-23	0.157	38.8	0.8	32	Yes	Yes	Yes	AX
DU-24	0.200	49.4	0.8	40	Yes	Yes	Yes	AX
DU-25	0.074	18.3	0.8	15	Yes	Yes	Yes	AX
DU-26	0.021	5.3	2.5	13	Yes	Yes	No	A
DU-27	0.165	40.7	0.8	33	Yes	Yes	Yes	AX
DU-28	0.161	39.9	0.8	32	No	No	Yes	B
DU-29	0.165	40.7	0.8	33	No	Yes	No	A
DU-30	0.167	41.2	0.8	34	No	Yes	No	A
DU-31	0.166	41.0	0.8	33	Yes	Yes	No	A
DU-32	0.165	40.8	0.8	33	Yes	Yes	No	A
DU-33	0.084	20.7	0.8	17	No	No	No	B
DU-34	0.164	40.6	0.8	33	No	Yes	No	A
DU-35	0.153	37.8	0.8	31	Yes	Yes	No	A
DU-36	0.160	39.6	0.8	32	Yes	Yes	No	A
DU-37	0.165	40.7	0.8	33	No	Yes	No	A
DU-38	0.111	27.3	0.8	22	Yes	No	No	B

Orchard Area DU ID	Area of DU		Spatial Density (samples/ acre)	Number of Locations	WIDS site Within DU Boundaries?	Presence of Trees in 1943 Aerial Photos?	Evidence of Soil Disturbance Since 1943?	DU Category
	km^2	Acres						
DU-39	0.124	30.6	0.8	25	No	Yes	No	A
DU-40	0.086	21.2	0.8	18	No	Yes	No	A
DU-41	0.082	20.3	0.8	17	No	Yes	No	A
DU-42	0.158	39.1	0.8	31	No	Yes	No	A
DU-43	0.163	40.3	0.8	33	No	Yes	No	A
DU-44	0.168	41.5	0.8	34	Yes	No	No	B
DU-45	0.174	42.9	0.8	35	No	No	No	B
DU-46	0.173	42.8	0.8	35	No	No	No	B
DU-47	0.162	39.9	0.8	32	No	Yes	No	A
DU-48	0.164	40.5	0.8	33	No	Yes	No	A
DU-49	0.163	40.3	0.8	33	No	Yes	No	A
DU-50	0.163	40.2	0.8	33	No	No	No	B
DU-51	0.159	39.3	0.8	32	Yes	No	No	B
DU-52	0.147	36.4	0.9	33	No	Yes	No	A
DU-53	0.109	26.9	0.8	22	No	Yes	No	A
DU-54	0.160	39.6	0.8	32	No	Yes	No	A
DU-55	0.202	49.8	0.8	40	Yes	Yes	No	A
DU-56	0.075	18.5	0.8	15	No	No	No	B
DU-57	0.103	25.5	0.8	20	No	No	No	B
DU-58	0.183	45.2	0.8	37	No	Yes	No	A
DU-59	0.141	34.8	0.8	28	Yes	Yes	Yes	AX
DU-60	0.145	35.7	0.8	29	No	Yes	No	A
DU-61	0.118	29.1	0.8	24	No	Yes	No	A
DU-62	0.173	42.8	0.8	35	No	Yes	No	A
DU-63	0.137	33.9	0.8	27	No	Yes	Yes	AX
DU-64	0.180	44.4	0.8	36	Yes	Yes	Yes	AX
DU-65	0.158	39.0	0.8	32	Yes	Yes	No	A
DU-66	0.170	41.9	0.8	34	Yes	Yes	No	A
DU-67	0.185	45.7	0.8	37	No	Yes	No	A
DU-68	0.178	44.0	0.8	36	No	Yes	No	A
DU-69	0.072	17.7	0.8	15	No	Yes	No	A
DU-70	0.129	31.8	0.8	26	Yes	Yes	No	A
DU-71	0.179	44.2	0.8	36	No	Yes	No	A
DU-72	0.167	41.2	0.8	33	No	Yes	No	A
DU-73	0.176	43.4	0.8	35	Yes	Yes	No	A
DU-74	0.149	36.8	0.8	30	Yes	Yes	Yes	AX
DU-75	0.091	22.6	0.8	19	No	Yes	Yes	AX
DU-76	0.155	38.4	0.8	31	Yes	Yes	Yes	AX
DU-77	0.192	47.4	0.8	38	No	No	No	B
DU-78	0.059	14.5	0.9	13	Yes	Yes	No	A
DU-79	0.179	44.2	0.8	36	Yes	Yes	No	A
DU-80	0.048	11.8	1.1	13	No	Yes	No	A
DU-81	0.162	40.0	0.8	33	Yes	Yes	No	A
DU-82	0.187	46.1	0.8	37	No	No	No	B
DU-83	0.083	20.6	0.8	17	No	No	No	B
DU-84	0.084	20.8	0.8	17	No	Yes	No	A
DU-85	0.201	49.6	0.8	39	Yes	Yes	No	A
DU-86	0.180	44.6	0.8	36	Yes	Yes	No	A
DU-87	0.194	48.0	0.8	40	Yes	No	Yes	BX
DU-88	0.188	46.4	0.8	38	No	Yes	No	A
DU-89	0.205	50.6	0.8	40	No	Yes	No	A

Orchard Area DU ID	Area of DU		Spatial Density (samples/ acre)	Number of Locations	WIDS site Within DU Boundaries?	Presence of Trees in 1943 Aerial Photos?	Evidence of Soil Disturbance Since 1943?	DU Category
	km^2	Acres						
DU-90	0.198	48.9	0.8	40	No	No	No	B
DU-91	0.159	39.2	0.8	32	No	Yes	No	A
DU-92	0.186	45.8	0.8	37	No	Yes	No	A
DU-93	0.106	26.3	0.8	22	Yes	Yes	No	A
DU-94	0.167	41.4	0.8	34	Yes	Yes	Yes	AX
DU-95	0.162	40.1	0.8	33	Yes	Yes	No	A
DU-96	0.125	30.8	0.8	25	Yes	Yes	No	A
DU-97	0.208	51.3	0.8	40	No	Yes	Yes	AX
DU-98	0.132	32.5	0.8	26	No	Yes	No	A
DU-99	0.131	32.3	0.8	26	No	No	No	B
DU-100	0.217	53.7	0.7	40	No	Yes	No	A
DU-101	0.187	46.1	0.8	37	No	Yes	Yes	AX
DU-102	0.148	36.6	0.8	30	No	No	Yes	BX
DU-103	0.160	39.6	0.8	32	Yes	Yes	Yes	AX
DU-104	0.145	35.7	0.8	29	Yes	No	Yes	BX
DU-105	0.118	29.2	0.8	24	Yes	Yes	Yes	AX
DU-106	0.133	32.9	0.8	27	Yes	Yes	Yes	AX
DU-107	0.109	26.9	0.8	22	Yes	Yes	Yes	AX
DU-108	0.165	40.7	0.8	33	No	Yes	Yes	AX
DU-109	0.138	34.0	0.8	28	Yes	Yes	Yes	AX
DU-110	0.135	33.3	0.8	28	No	Yes	Yes	AX
DU-111	0.158	39.0	0.8	32	No	Yes	Yes	AX
DU-112	0.195	48.2	0.8	39	Yes	Yes	Yes	AX
DU-113	0.089	22.1	0.8	18	Yes	No	Yes	BX
DU-114	0.171	42.3	0.8	34	No	Yes	Yes	AX
DU-115	0.174	42.9	0.8	35	No	Yes	Yes	AX
DU-116	0.157	38.7	0.8	31	Yes	Yes	Yes	AX
DU-117	0.100	24.8	0.8	20	Yes	Yes	Yes	AX
DU-118	0.136	33.6	0.8	27	Yes	Yes	Yes	AX
DU-119	0.152	37.6	0.8	31	Yes	Yes	Yes	AX
DU-120	0.135	33.2	0.8	27	Yes	No	Yes	BX
DU-121	0.198	48.8	0.8	40	Yes	No	Yes	BX
DU-122	0.175	43.3	0.8	35	Yes	Yes	Yes	AX
DU-123	0.201	49.7	0.8	40	No	Yes	Yes	AX
DU-124	0.197	48.7	0.8	39	Yes	Yes	Yes	AX
DU-125	0.153	37.7	0.8	31	Yes	Yes	Yes	AX
DU-126	0.198	49.0	0.8	40	Yes	Yes	Yes	AX
DU-127	0.182	45.0	0.8	37	Yes	Yes	Yes	AX
DU-128	0.124	30.6	0.8	25	Yes	Yes	Yes	AX
DU-129	0.203	50.1	0.8	40	Yes	Yes	Yes	AX
DU-130	0.164	40.5	0.8	33	Yes	Yes	Yes	AX
DU-131	0.156	38.6	0.8	31	Yes	Yes	Yes	AX
DU-132	0.045	11.2	1.2	13	Yes	Yes	Yes	AX
DU-133	0.064	15.9	0.8	13	Yes	Yes	Yes	AX

Table A.3. Summary of Characteristics of the Decision Units for 100-OL-1 OU

Total # of Decision Units	133
Total Acreage	4905
Average Size of Decision Unit (acres)	36.9
Maximum Size (acres)	53.7
Minimum Size (acres)	5.3
Total # of Analyses[(a)]	4008
Average # of Analyses/DU	30
Maximum # of Analyses/DU	40
Minimum # of Analyses/DU	13

(a) Does not include additional quality control analyses.

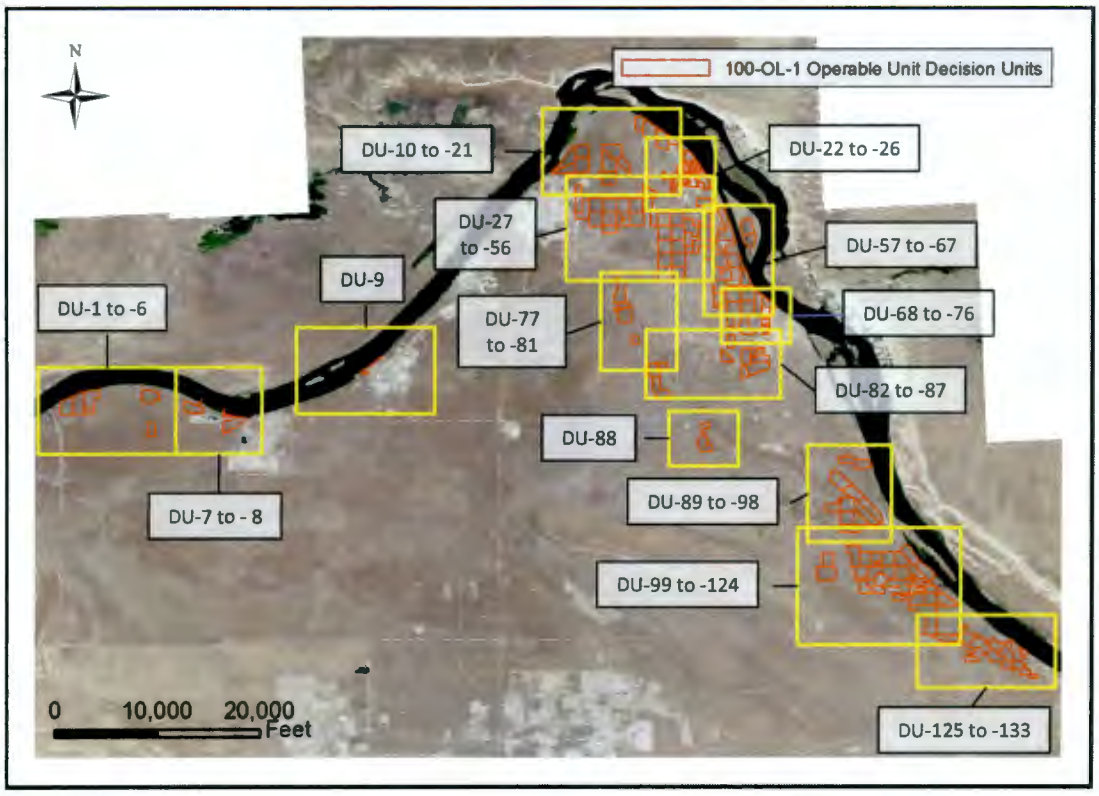

Figure A.2. Overview of Decision Units throughout the 100-OL-1 OU

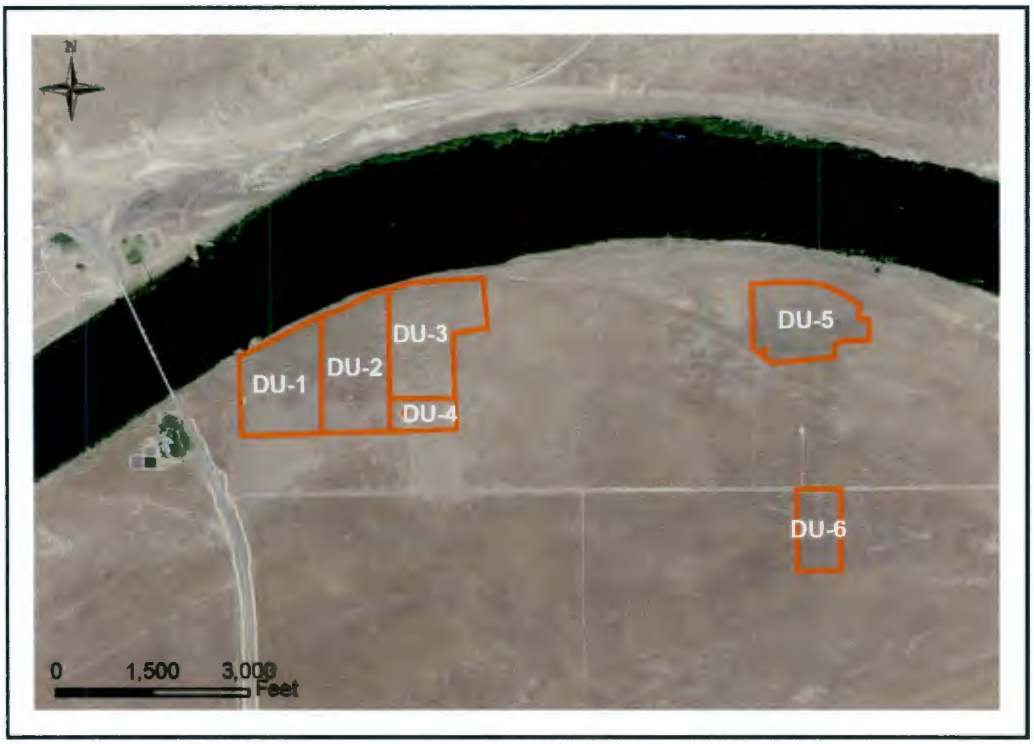

Figure A.3. Decision Units 1 through 6, Located West of the 100-BC Area

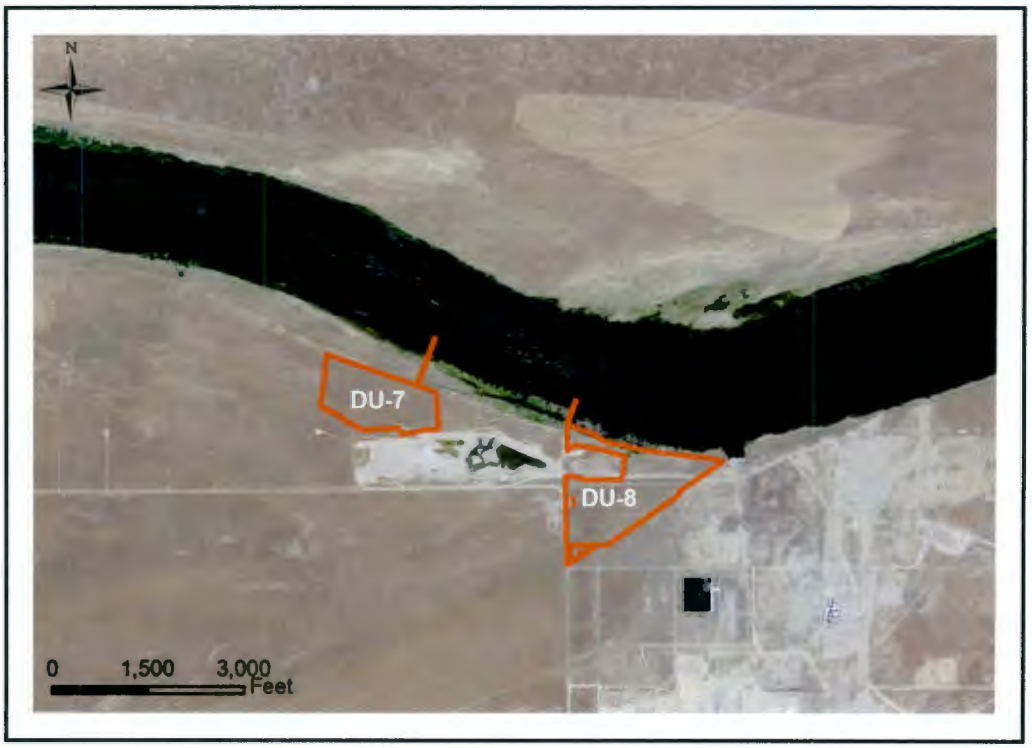

Figure A.4. Decision Units 7 and 8, Located West and within 100-BC Area

Figure A.5. Decision Unit 9, Located in the 100-K Area

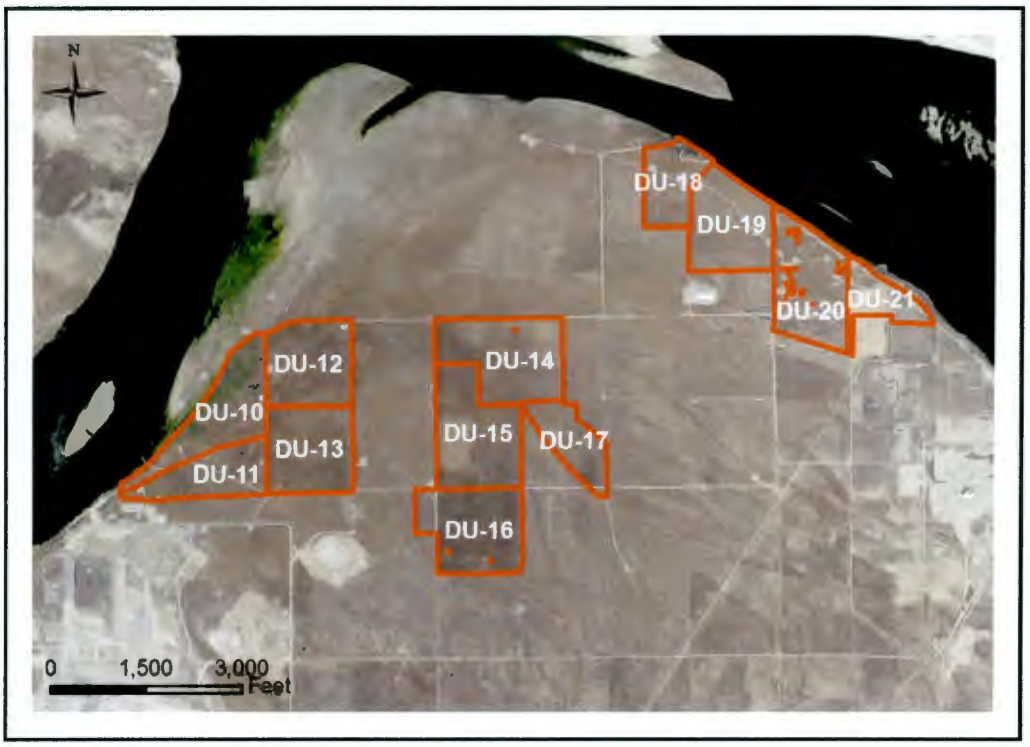

Figure A.6. Decision Units 10 through 21, Located in the 100-D/H Area

Figure A.7. Decision Units 22 through 26, Located within 100-H Area

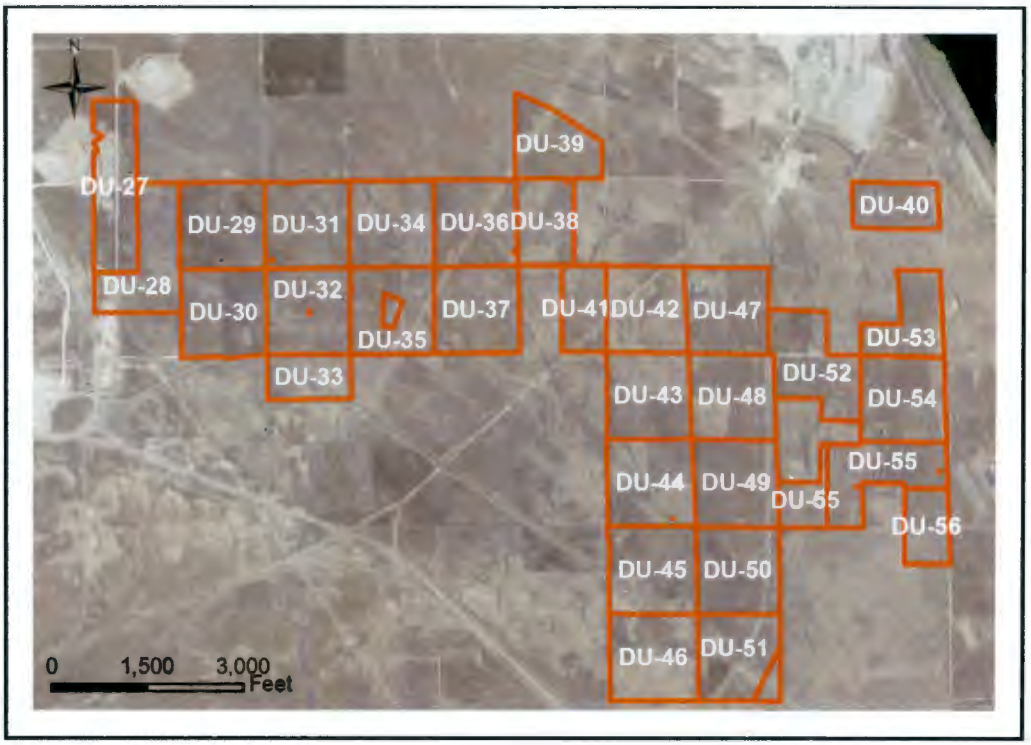

Figure A.8. Decision Units 27 through 56, Located in the 100-D/H Area

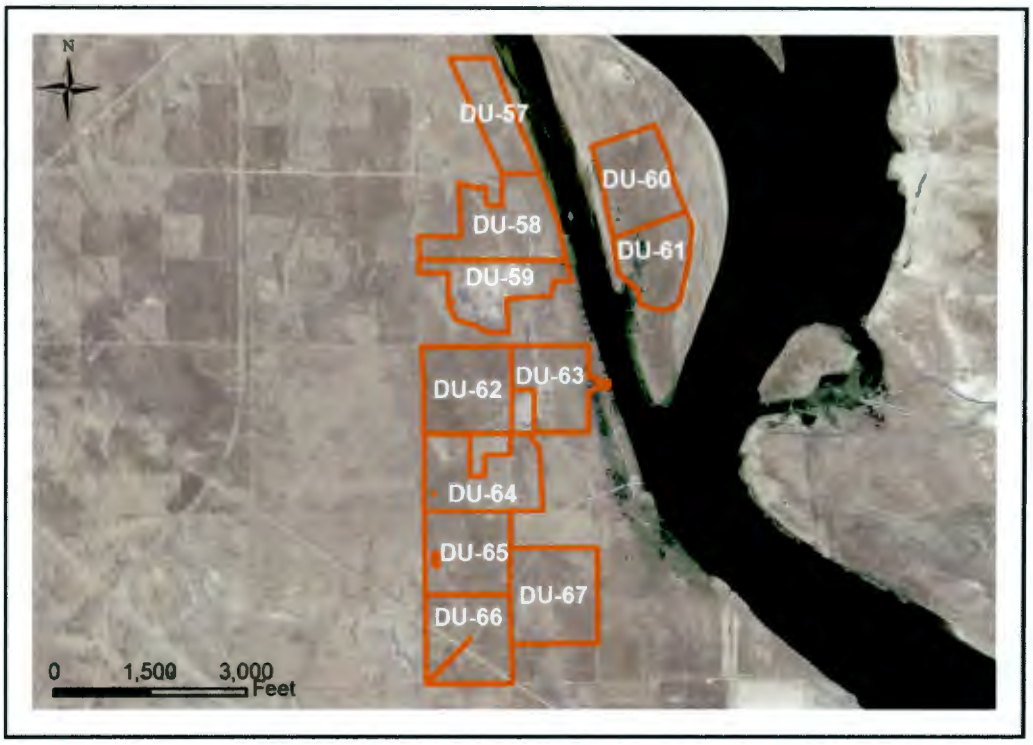

Figure A.9. Decision Units 57 through 67, Located South of the 100-H Area

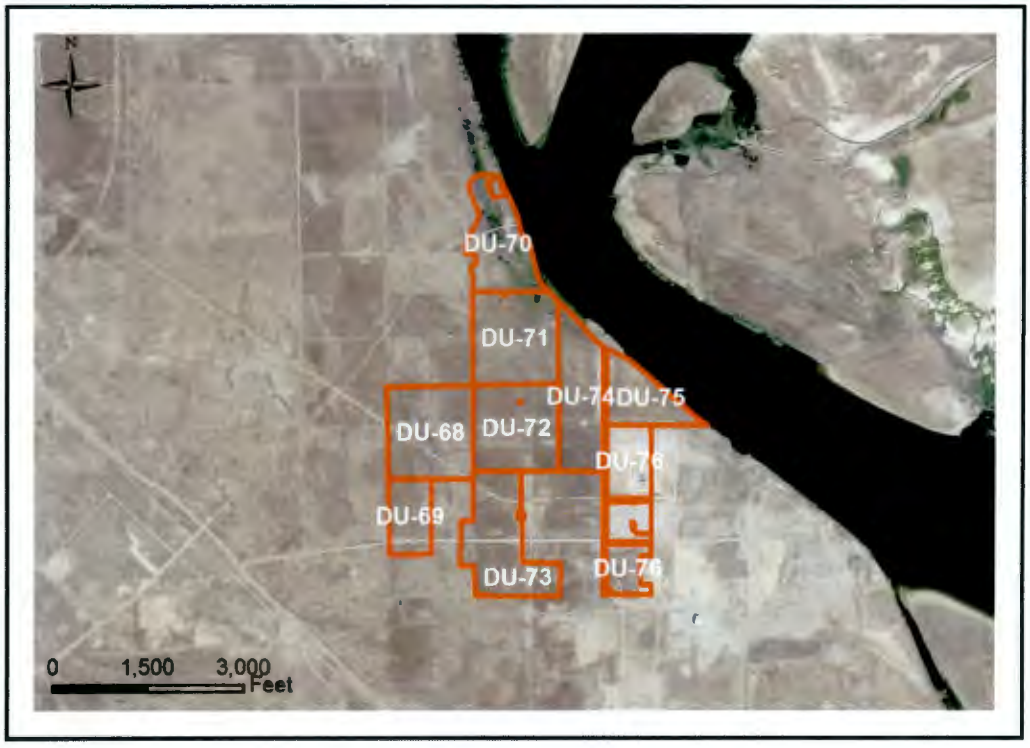

Figure A.10. Decision Units 68 through 76, Located around 100-F Area

Figure A.11. Decision Units 77 through 80, Located West of 100-F Area

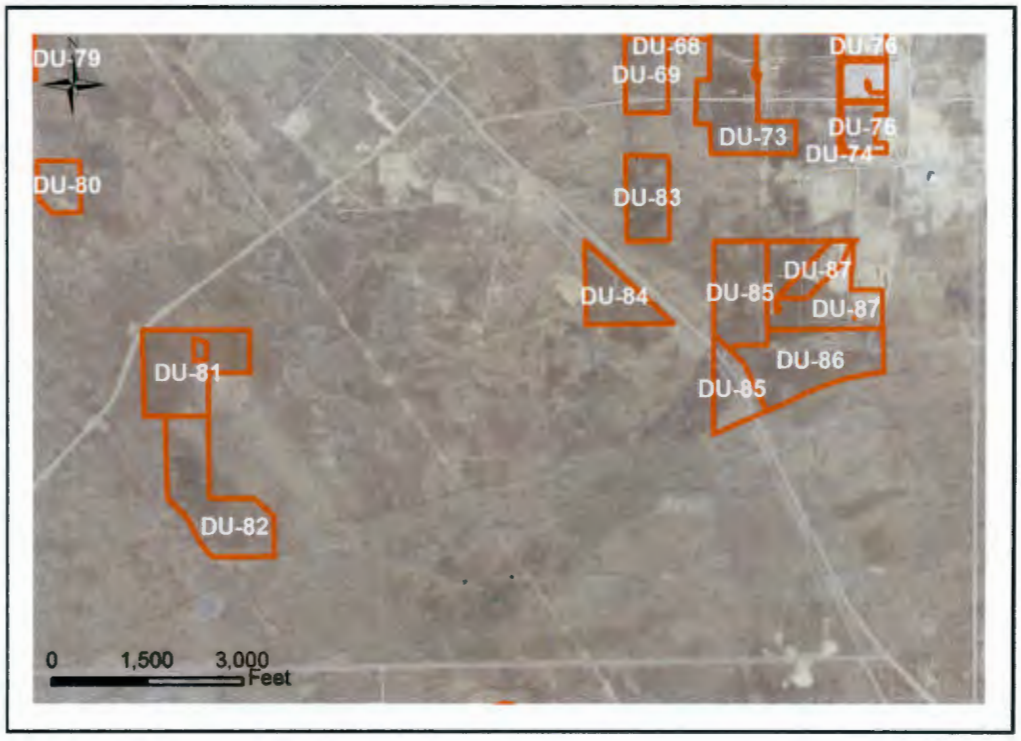

Figure A.12. Decision Units 81 through 87, Located around 100-F Area

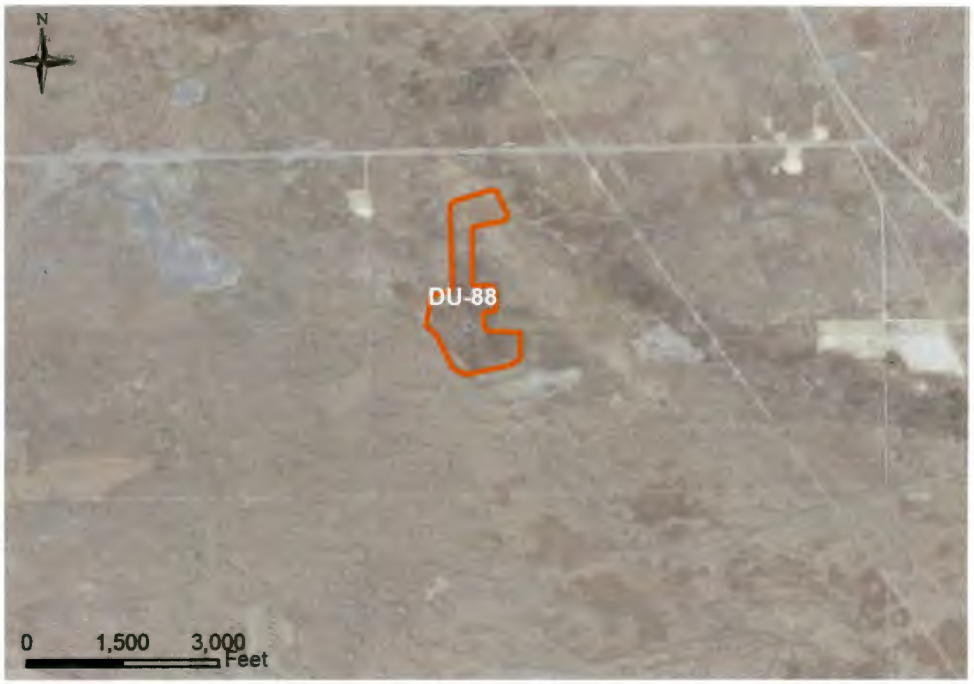

Figure A.13. Decision Unit 88, Located Southwest of 100-F Area

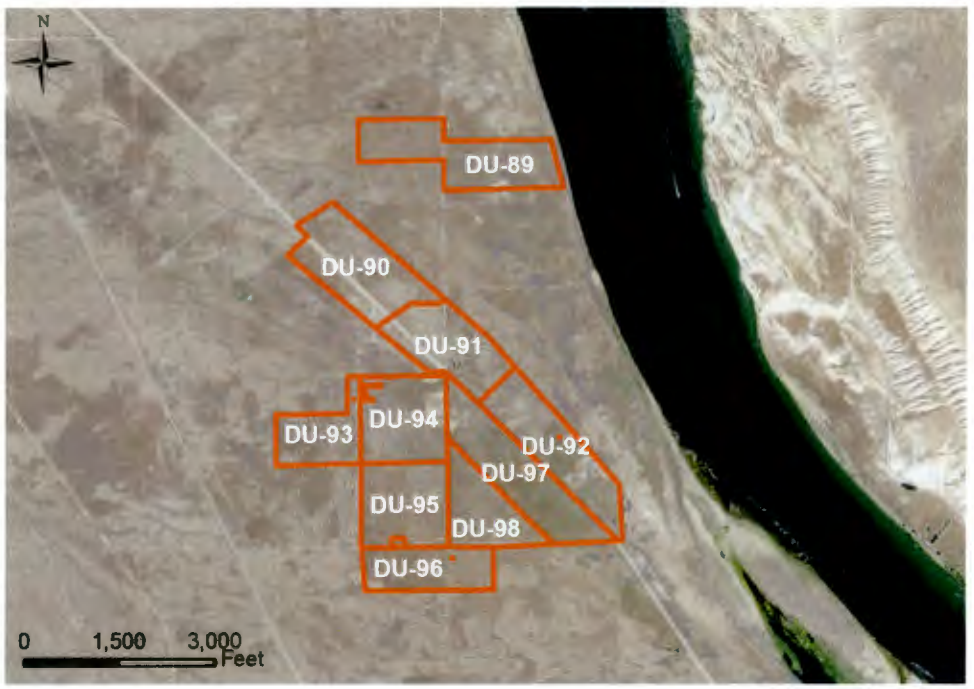

Figure A.14. Decision Units 89 through 98, Located North of the Hanford Townsite

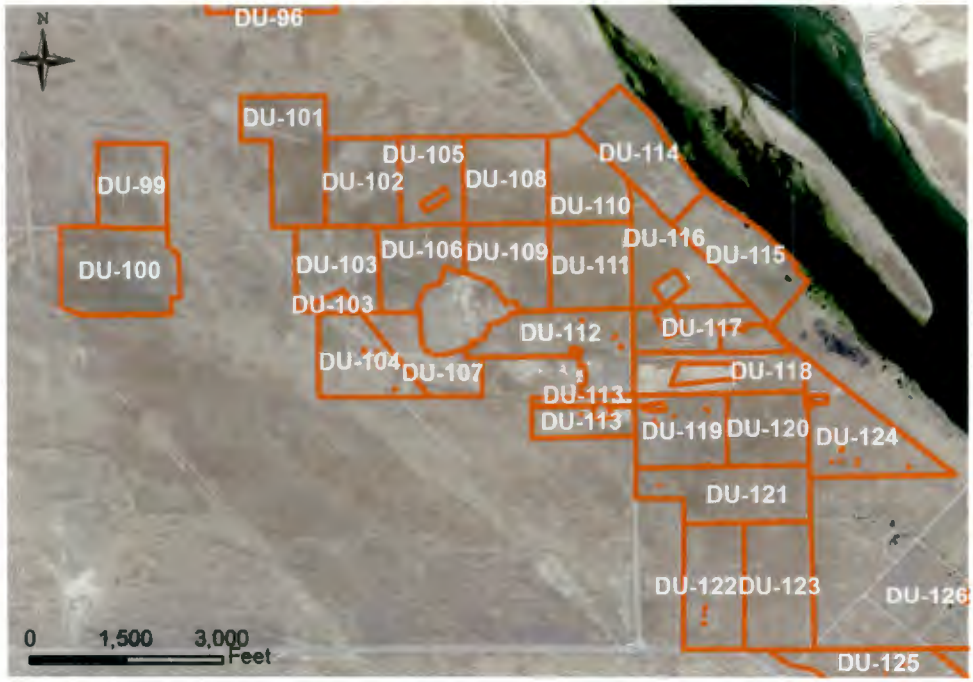

Figure A.15. Decision Units 99 through 124, Located near the Hanford Townsite

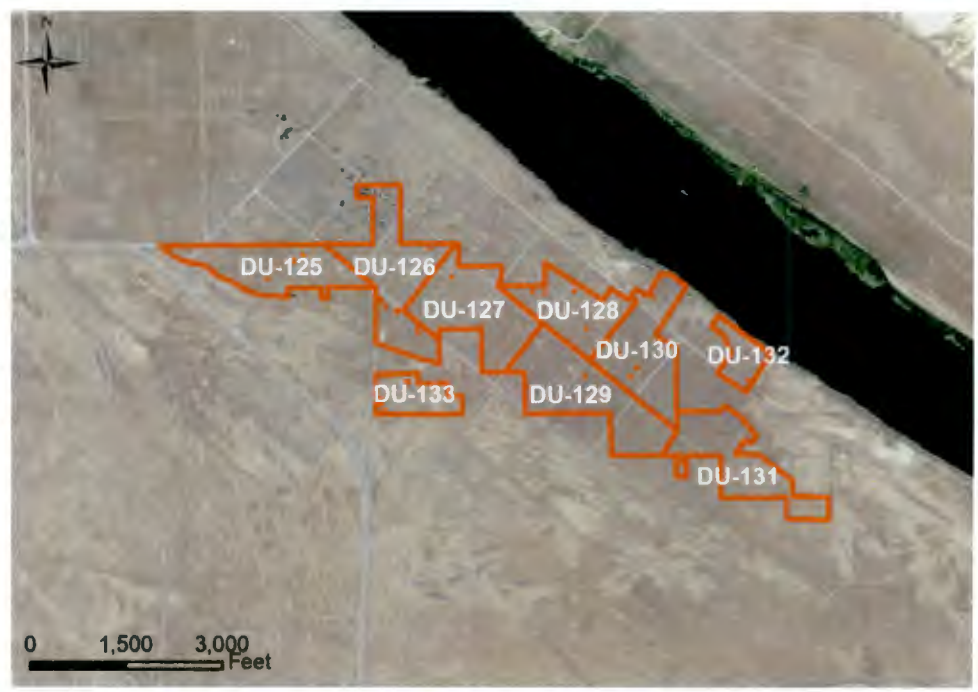

Figure A.16. Decision Units 125 through 133, Located near the Hanford Townsite

A.1.3 Contaminants of Concern

The DQOs included in the RI work plan for the 100-OL-1 OU identified lead and total inorganic arsenic in soil as the only contaminants of concern for the characterization efforts. DQOs were identified during meetings with program managers and technical leads from U.S. Department of Energy Richland Operations Office (DOE-RL), Ecology, and EPA. The decision was to limit the contaminants of concern to lead and total inorganic arsenic based on the conceptual site model for evaluating lead arsenate residues, research on historical orchard practices in the region, and the limits of the TPA description of the 100-OL-1 OU (TPA 2012a, b). Delistraty and Yokel (2011) demonstrated that >99% of the total inorganic arsenic existed as arsenic (V) in the surficial soils of the orchards sites evaluated. This supports the decision to characterize only for total inorganic arsenic. The description and justification for the 100-OL-1 OU (TPA 2012a) identified contamination from lead arsenate in the non-contiguous, historical orchard lands on the south side of the Columbia River.

A.1.4 Data Needs

The RI work plan for the 100-OL-1 OU identified several data needs that are time dependent. The cultural and ecological resources review of the 100-OL-1 OU decision units needs to be performed prior to field characterization activities and will identify locations for soil sampling as well as areas of concern for the field samplers to avoid during field characterization. Another task is modifying the boundaries of the decision units to reflect current GIS data. This task shall include modifying 100-OL-1 OU boundaries to match Hanford Site road data, which is a documented, managed GIS file. Another aspect of the task will be to identify the latest locations for waste sites and remediation activities within the decision units prior to field characterization activities. This will prevent unnecessary sampling from within the boundaries of other clean-up areas. Note that sampling may occur within those waste sites if warranted (see Section A.1.5).

A.1.5 Sampling Design

The probability-based sampling design provides the best approach for evaluating the magnitude and extent of the lead and arsenic soil concentrations within the decision units of the 100-OL-1 OU. A probabilistic sampling design meets the approach for evaluating the average concentration of lead and arsenic in a decision unit. An alternative sampling design, such as a judgmental sampling design, would be difficult because evidence of the orchards today is not significant. The orchards have not been in production for ~70 years, activities on the Hanford Site have removed many of the orchards and disturbed the soil, and wildfires have eliminated the presence of stumps and other signs of fruit trees. The pilot study (Bunn et al. 2014) demonstrated that current visual evidence and historical photographic evidence were not reliable predictors of residual lead or arsenic concentrations on orchard properties.

At a location within the decision unit, the soil surface will be cleared of debris and the portable XRF will be placed directly on the soil for in situ analysis. The pilot study demonstrated that the XRF count time was 60 seconds, which provided adequate detection and precision for both lead and arsenic. At each location, there will be one analysis of the soil with the XRF. For quality control (QC), there will be a duplicate analysis of the soil with the XRF at the first and last locations in a decision unit, as well as every 20 locations analyzed.

Soil analyses with XRF will primarily be limited to the area defined by the decision unit boundary. Table A.2 identifies the number of sample locations by decision unit. The layout of the XRF analysis locations within a decision unit will be selected using a random-start, systematic-grid-sampling design. Locations can be identified using software tools that support sample planning and statistical analyses of sample results, such as the Visual Sample Plan (VSP) tool (Matzke et al. 2010). As agreed during the DQO meetings, GIS information on WIDS will be used to determine locations to exclude. Figure A.17 illustrates location placement in decision unit DU-22 using VSP with a random-start, systematic-grid-sampling design, and exclusion of locations identified by WIDS. DU-22 is north of 100-H reactor.

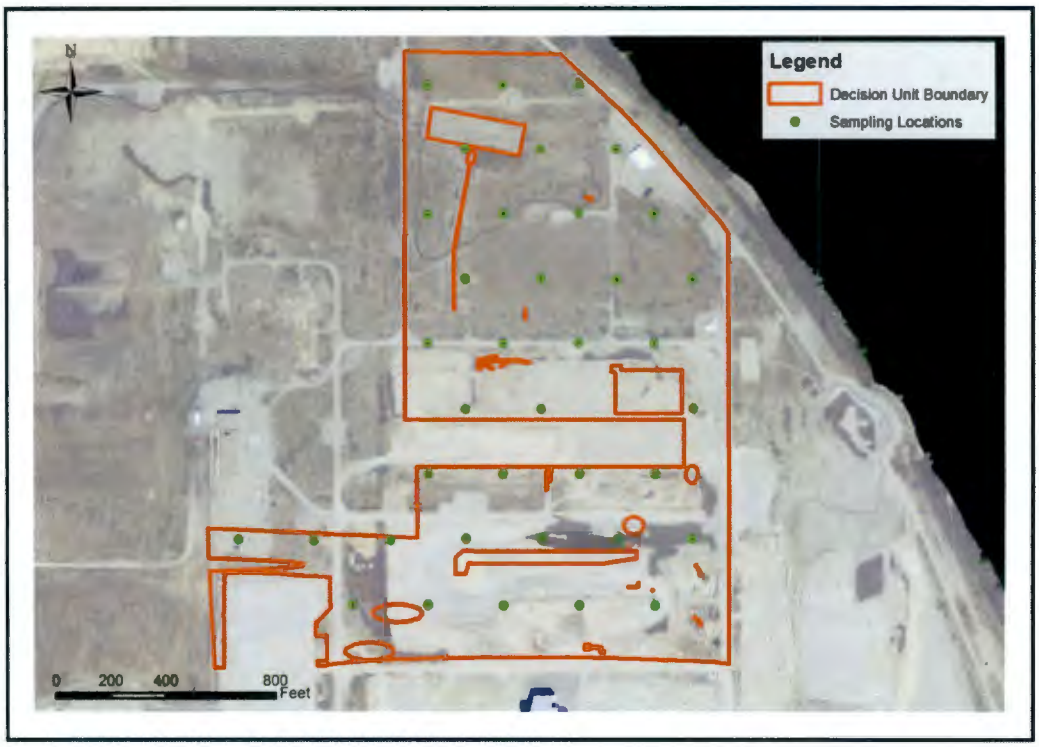

Figure A.17. Proposed Sample Locations within Decision Unit DU-22 using VSP to Select the Locations but Avoid Waste Sites and Remediation Sites

Additional samples will be collected outside the OU when the concentration at the edge of the OU is greater than the screening level for either lead or arsenic (250 mg/kg lead and 20 mg/kg arsenic). Figure A.18 shows an example of the sampling process beyond the edge or border of the OU based on results from the pilot study. Sampling beyond the edge of the OU will continue at the same spacing used inside the OU. That is, if the locations for analyses within a decision unit are spaced 30 m (100 ft) apart, then the samplers will move 30 m (100 ft) from the analysis location on the edge of the OU and analyze the soil at that location. The samplers will continue to measure locations with the XRF until either two additional analyses have been conducted or the results are less than five times background for lead (i.e., 51 mg/kg lead) and less than 20 mg/kg arsenic. The samplers may move laterally to characterize the area from the edge of the OU if the lead or arsenic concentrations continue to exceed the criteria (51 mg/kg lead and 20 mg/kg arsenic). If the lead and arsenic are still high after two additional analyses from the edge of the OU (i.e., 60 m from the boundary in this example), then the design of the decision unit is questionable and the samplers will consider additional information on the decision unit to determine if further sampling is warranted. The additional sampling effort beyond the edge of the OU is designed to

provide sufficient information for the Tri-Party agencies to evaluate the RI and determine the next steps for the OU.

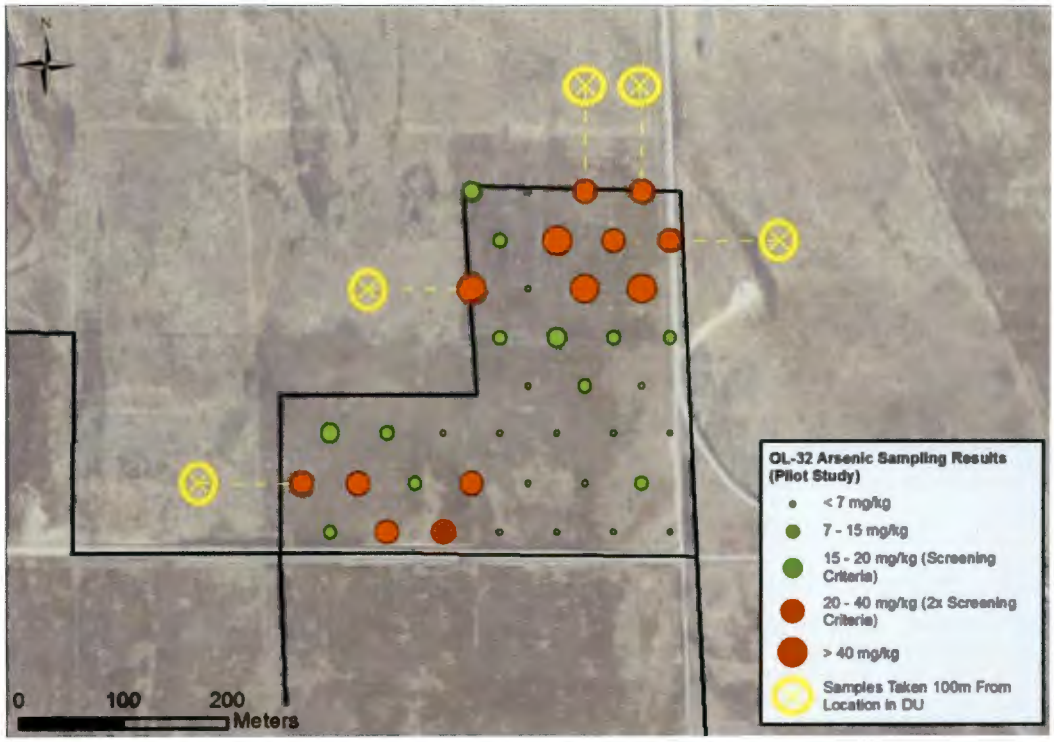

Figure A.18. Example of Sampling outside the Operable Unit Borders

Soil samples will be collected and analyzed using XRF and ICP-MS to confirm that the XRF is performing according to QC guidance (EPA 2007a). Soil samples will be collected, split, homogenized, and analyzed ex situ using both XRF and ICP-MS. ICP-MS has been used routinely to characterize soil samples for lead and arsenic at Hanford, including activities within former orchard lands during other remediation and monitoring activities, and well established QC and QA procedures for the technique have been implemented (DOE-RL 2007).

A.1.6 Project Schedule

The schedule for implementing the RI for the 100-OL-1 OU has not been determined. Table 5.1 in the RI work plan provides a generic schedule based on the sample design and activities to produce the RI final report. Before the RI begins, a cultural resources review will be conducted to determine the potential for sampling locations to affect significant cultural resources and historic properties. This review will ensure that the field characterization activities are consistent with the *National Historic Preservation Act*. Concurrent with the cultural resources review, an ecological compliance review will be conducted to ensure that the field characterization activities do not conflict with laws protecting ecologically sensitive species. Several activities to prepare for the field work can be conducted concurrent with the cultural and ecological resources reviews, including acquiring field equipment, finalizing decision units and sampling locations, and placing analytical laboratory contracts and other associated subcontracts. The Feasibility Study for the OU will be completed after the RI is approved by DOE, EPA, and Ecology.

A.2 Quality Assurance Project Plan

The PNNL QA Program is based on the requirements as defined in DOE Order 414.1D, *Quality Assurance*, and 10 CFR 830, *Energy/Nuclear Safety Management*, Subpart A, Quality Assurance Requirements (a.k.a. the Quality Rule). PNNL has chosen to implement the following consensus standards in a graded approach (ASME 2001):

- ASME NQA-1-2000, *Quality Assurance Requirements for Nuclear Facility Applications*, Part I, Requirements for Quality Assurance Programs for Nuclear Facilities.
- ASME NQA-1-2000, Part II, Subpart 2.7, Quality Assurance Requirements for Computer Software for Nuclear Facility Applications, including problem reporting and corrective action.
- ASME NQA-1-2000, Part IV, Subpart 4.2, Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development.

The procedures necessary to implement the requirements are documented through PNNL's "How Do I…? (HDI), a system for managing the delivery of laboratory-level policies, requirements, and procedures.

The *DVZ-AFRI Quality Assurance Plan* is the minimum applicable QA document for all Deep Vadose Zone Applied Field Research Initiative (DVZ-AFRI) projects. This QA plan also conforms to the QA requirements of DOE Order 414.1D, *Quality Assurance*, and 10 CFR 830, Subpart A, Quality Assurance Requirements. The DVZ-AFRI is subject to the *Price Anderson Amendments Act*.

The implementation of the DVZ-AFRI QA program is graded in accordance with NQA-1-2000, Part IV, Subpart 4.2, Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development.

The work for this report was performed under the technology level of Applied Research. Basic Research consists of research tasks that are conducted to acquire and disseminate new scientific knowledge. During basic research, maximum flexibility is desired in order to allow the researcher the necessary latitude to conduct the research.

Applied Research consists of research tasks that acquire data and documentation necessary to ensure satisfactory reproducibility of results. The emphasis during this stage of a research task is on achieving adequate documentation and controls necessary to be able to reproduce results.

Development Work consists of research tasks moving toward technology commercialization. These tasks still require a degree of flexibility and a degree of uncertainty still exists in many cases. The role of quality on development work is to make sure that adequate controls to support movement into commercialization exist.

Research and Development Support Activities are conventional and secondary in nature to the advancement of knowledge or development of technology, but allow the primary purpose of the work to be accomplished in a credible manner. An example of a support activity is controlling and maintaining documents and records. The level of quality for these activities is the same as for developmental work.

Within each technology level, the application process for QA controls is graded such that the level of analysis, extent of documentation, and degree of rigor of process control are applied commensurate with their significance, importance to safety, life-cycle state of a facility or work, or programmatic mission. This QAjPP is based on EPA's *Requirements for Quality Assurance Project Plans*, EPA QA-R-5 (EPA2001).

A.2.1 Project Management and Task Organization

PNNL is responsible for planning, coordinating, collecting, and analyzing field samples, and preparing, packaging, and shipping samples to the laboratory, as defined in its contract. The following sections describe the project organization, relative to sampling and characterization, which is also shown graphically in Figure A.19. The project lead maintains a list of individuals or organizations as points of contact for each functional element shown in the figure. For each functional primary contractor role, a corresponding oversight role exists within DOE.

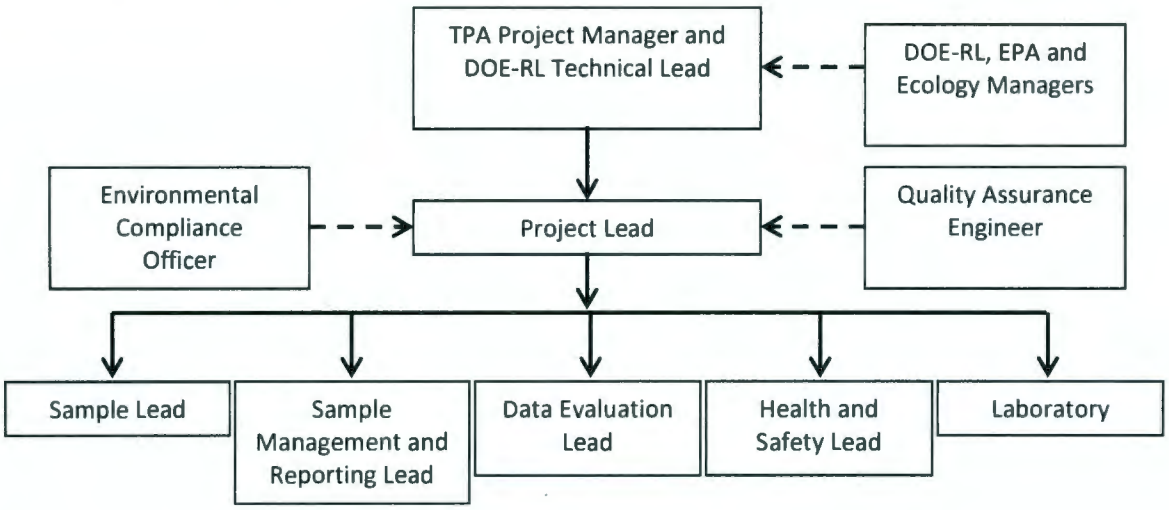

Figure A.19. Project Organization

DOE-RL, EPA, and Ecology Project Managers. EPA and Ecology will be the lead regulatory organizations for the 100-OL-1 OU (TPA 2012b), working with DOE-RL. Each organization has assigned project managers responsible for overseeing the activities identified in the plan to accomplish the scope of this plan. EPA and Ecology will work with DOE-RL to resolve concerns about the work in accordance with the TPA (Ecology et al. 1989). The managers will be responsible for the risk management evaluation of the RI characterization results and will determine if additional characterization efforts are needed before proceeding with the Feasibility Study.

DOE-RL Technical lead. The DOE-RL technical lead is responsible for:

- Overseeing the contractor in performing the work scope
- Working with the contractor and the regulatory agencies to identify and work through issues
- Providing technical input to the TPA project manager.

Project Lead. The project lead is responsible for:

- Planning and implementing work scope
- Managing sampling documents and requirements, field activities, and subcontracted tasks, and ensuring that personnel are working in accordance with the most current job requirements
- Completion of the cultural resource review before initiating any field activities, and ensuring monitoring activities are incorporated and implemented into the field activities
- Requesting and obtaining an ecological review before initiating any field activities, and ensuring that findings are incorporated and implemented into the field activities
- Maintaining version control for the work plan.

The project lead will work closely with the QA engineer, the health and safety lead, and the sample lead to integrate these and the other lead disciplines in planning and implementing the work scope. The project lead will maintain a list of individuals or organizations that fill each of the functional elements of the project organization (Figure A.19). The project lead will work with the sample management and reporting lead, data evaluation lead and the sample lead after field characterization begins to propose any changes to the SAP to optimize the sampling design. The project lead also will coordinate with DOE-RL and the primary contractor management on sampling activities. The project lead will support DOE-RL in coordinating sampling activities with the regulators.

Environmental Compliance Officer. The environmental compliance officer will be responsible to the project lead, and will be responsible for:

- Providing technical oversight, direction, and acceptance of project and subcontracted environmental work
- Developing appropriate mitigation measures to minimize adverse environmental impacts
- Reviewing plans, procedures, and technical documents to ensure that environmental requirements have been addressed
- Identifying environmental issues affecting operations and developing cost-effective solutions
- Responding to environmental/regulatory issues or concerns raised by DOE-RL and/or regulatory agencies.

The environmental compliance officer also may oversee project implementation to ensure compliance with applicable internal and external environmental requirements.

Quality Assurance Engineer. The QA engineer will be responsible to the project lead and will be responsible for QA issues on the project. Responsibilities will include:

- Overseeing implementation of the project QA requirements
- Reviewing project documents, including data needs summary reports, the FSP, and the QAPjP
- Ensuring that the laboratories conform with Hanford Site internal laboratory QA requirements, or their equivalent, as approved by DOE-RL, EPA, and Ecology.
- Participating in QA assessments on sample collection and analysis activities, as appropriate.

The QA engineer must be independent of the unit generating the data.

Sampling Lead. The sampling lead will have overall responsibility for planning, coordinating, and executing sampling activities. Specific responsibilities will include:

- Converting the sampling design requirements into field task instructions that provide specific direction for field activities
- Implementing any cultural resources monitoring and mitigation activities
- Directing training, mock-ups, and practice sessions with field personnel to ensure that the sampling design is understood and can be performed as specified
- Communicating with the project lead to identify field constraints or emergent conditions that will affect sampling design and/or execution
- Managing field collection efforts
- Procuring and installing material and equipment needed to support field work
- Preparing data packages based on instructions from the project lead and information contained in the project SAP.

Sample Management and Reporting Lead. The sample management and reporting lead will be responsible for:

- Managing and reporting of soil analyses
- Reviewing and completing all QA/QC documentation for field and laboratory analyses
- Coordinating with laboratory analytical work
- Coordinating all QA/QC documents with the QA engineer
- Entering data into the Hanford Environmental Information System (HEIS)
- Arranging for and overseeing data validation of all analyses
- Informing the project lead of any issues reported by the analytical laboratory.

The sample management and reporting lead also will be responsible for conducting the data needs process, or equivalent. Additional related responsibilities will include developing the SAP, including documenting the data needs and the sampling design, preparing associated presentations, resolving technical issues, and preparing revisions to the SAP. Samples collected in the field for shipping and analysis, as well as the resulting data, will be managed in accordance with applicable procedures and work plans.

Data Evaluation Lead. The data evaluation lead will be responsible for evaluating the results of the field characterization, performing the statistical analyses, and evaluating the data to meet DQOs. The data evaluation lead will work with the project lead and sampling lead on the recommendations and any proposed revisions to the SAP.

Health and Safety Lead. The health and safety lead will be responsible for coordinating industrial safety and health support for the project through health and safety plans, job hazard analyses, and other

pertinent safety documents required by federal regulations or by internal primary contractor work requirements. The health and safety lead will work with the project lead. In addition, the health and safety lead will assist project personnel in complying with applicable health and safety standards and requirements, particularly for decision units located in other operable units.

Laboratories. The laboratories will analyze samples in accordance with established procedures, provide necessary sample reports, and explain results in support of data validation. The laboratories must meet site-specific QA requirements and must have an approved QA plan in place.

A.2.1.1 Problem Definition/Background

The RI work plan describes the sampling and analysis approach for the characterization of soil in the 100-OL-1 OU. Figure A.2 through Figure A.16 show the OU as decision units for sampling within the scope of this work plan. The purpose and objectives of the work plan are described in Section A.1 of this report.

A.2.1.2 Quality Objectives and Criteria

The QA objective of this plan is to develop implementation guidance for providing data of known and appropriate quality. The applicable QC guidelines, quantitative target limits, and levels of effort for assessing data quality are dictated by the intended use of the data and the nature of the analytical method. The principal data quality indicators are precision, bias or accuracy, representativeness, comparability, completeness, and sensitivity. These data quality indicators are defined for the purposes of this document in Table A.4, and include precision, accuracy, representativeness, comparability, completeness, and sensitivity.

Table A.4. Data Quality Indicators

Data Quality Indicator	Definition	Example Determination Methodologies	Project-Specific Information	Corrective-Action Examples
Precision	The measure of agreement among repeated measurements of the same property under identical or substantially similar conditions; calculated either as the range or as the standard deviation. May also be expressed as a percentage of the mean of the measurements, such as relative range, relative percent difference, or relative standard deviation (coefficient of variation).	Use same analytical instrument to make repeated analyses on same sample. Use same method to make repeated measurements of same sample by laboratory Split a sample in field and submit for sample handling, preservation and storage, and analytical measurements. Collect, process, and analyze co-located samples for information on sample acquisition, handling, shipping, storage, preparation, and analytical	Field XRF precision: Analyze intrusive samples of low, medium, high site-specific reference material seven times at beginning of each day in field. Duplicate analysis of first and last location, and every 20 locations. 60-second count time. Laboratory precision for ICP-MS: analysis of laboratory duplicate or matrix spike duplicate samples.	If XRF precision check does not meet objective: • Evaluate apparent cause (e.g., sample heterogeneity). • Request reanalysis or re-measurement. • Qualify the data before use.

Data Quality Indicator	Definition	Example Determination Methodologies	Project-Specific Information	Corrective-Action Examples
		processes and measurements.		
Accuracy	A measure of the overall agreement of a measurement to a known value; includes a combination of random error (precision) and systematic error (bias) components of sampling and analytical operations.	Analyze a reference material or reanalyze a sample to which a material of known concentration or amount of pollutant has been added (a spiked sample).	Field accuracy for XRF based on intrusive sample of standard reference material (SRM) at beginning of day, every 20 samples and end of day. Laboratory accuracy for ICP-MS determination based on matrix spike and matrix spike duplicate results.	If recovery does not meet objective: • Qualify the data before use. • Request reanalysis or remeasurement.
Representativeness	A qualitative term expressing "the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition" (ANSI/ASQ 1995).	Evaluate whether measurements are made and physical samples are collected in such a manner that the resulting data appropriately reflect the environment or condition being measured or studied.	Samples will be collected as described in the sampling design. Judgment sampling ensures areas most likely to be contaminated, based on current information, will be evaluated.	If results are not representative of the system sampled: • Identify the reason the result is not representative. • Reject the data, or, qualify the data for limited use, and define the portion of the system the data represent. • Redefine sampling and measurement requirements and protocols. • Resample and reanalyze.
Comparability	A qualitative term expressing the measure of confidence that one data set can be compared to another and can be combined for the decision(s) to be made.	Compare count times, soil surface preparation, sample collection and handling methods, sample preparation and analytical procedures, holding times, stability issues, and QA protocols. Compare XRF and ICP-MS results on same soil samples.	Sampling personnel will use the same sampling protocols. Analyses with XRF will be completed with same analyzer. ICP-MS results will be completed on digested samples as stated in EPA Method 6200.	If data are not comparable to other data sets: • Identify appropriate changes to data collection and/or analysis methods. • Identify quantifiable bias, if applicable. • Qualify the data as appropriate. • Resample and/or reanalyze if needed. • Revise sampling/analysis protocols to ensure future comparability.

Data Quality Indicator	Definition	Example Determination Methodologies	Project-Specific Information	Corrective-Action Examples
Completeness	A measure of the amount of valid data needed to be obtained from a measurement system.	Compare the number of valid measurements completed (samples collected or samples analyzed) with those established by the project's data needs.	The percent complete will be determined during data validation. The number of analyses done in each decision unit will be a function of size; the spatial density of soil analysis will be nominally 200/km^2 [0.8/acre], with a maximum of 40 analyses per decision unit.	If data set does not meet completeness objective: • Identify appropriate changes to data collection and/or analysis methods. • Identify quantifiable bias, if applicable. • Qualify the data as appropriate. • Resample and/or reanalyze, if needed. • Revise sampling/analysis protocols to ensure future comparability.
Sensitivity	The capability of a method or instrument to discriminate among measurement responses representing different levels of the variable of interest.	Determine the minimum concentration or attribute to be measured by a method (method detection limit [MDL]), by an instrument (instrument detection limit), or by a laboratory (quantitation limit). The practical quantitation limit is the lowest level that can be routinely quantified and reported by a laboratory.	Ensure that sensitivity, as measured by detection limits, is appropriate for the action levels.	If sensitivity does not meet objective: • Request reanalysis or remeasurement. • Qualify/reject the data before use.

Table A.5 presents the DQOs, performance requirements for the XRF and ICP-MS analysis of soil samples based on site-specific lists for arsenic and lead. XRF analytical performance requirements were developed during the pilot study (Bunn et al. 2014). Laboratory operations and analytical services for the confirmatory analyses with ICP-MS will be performed in compliance with Volume 4 of the *Hanford Analytical Services Quality Assurance Requirements Documents* (HASQARD; DOE-RL 2007) and specific criteria identified in Table A.5. The criteria listed in Table A.5 take precedence over similar criteria in the HASQARD. In consultation with the laboratory, the project lead and/or sample management and reporting lead can approve changes to analytical methods as long as the method is based on a nationally recognized (e.g., EPA, American Society for Testing and Materials [ASTM]) method, the new method achieves project DQOs as well as or better than the replaced method, and the new method is required due to the nature of the sample.

Table A.5. Analytical Performance Requirements for XRF and ICP-MS Soil Analyses

Analyte	Benchmarks for the Work Plan[a]	Range of Recovery (Accuracy)	SRM Accuracy	Relative Precision	Achieved Detection Limits (µg/g dry wt.)	Reporting Limit (RL) (µg/g dry wt.)
Arsenic	Soil Background: 6.47 mg/kg Screening Criteria: 20 mg/kg	75–125%	±20%	≤25%	3.9[b] 0.3[c]	6.47[d] 1[e]
Lead	Soil Background: 10.2 mg/kg Screening Criteria: 250 mg/kg	75–125%	±20%	≤25%	2.6[b] 0.006[c]	10.2[d] 0.02[e]

(a) Soil background is the 90th percentile for the Hanford Site (DOE-RL 1993), and the unrestricted land-use soil cleanup standard is the *Model Toxics Control Act* Method A (WAC 173-340-740).
(b) MDL for XRF from pilot study (Bunn et al. 2014).
(c) ICP-MS sediment/soil MDL, annually verified.
(d) RL for XRF defined as MDL in pilot study (Bunn et al. 2014).
(e) RL for ICP-MS defined as 3.18*MDL.

A.2.1.3 Special Training and Certification

A graded approach is used to ensure workers receive a level of training commensurate with responsibilities, and it complies with applicable DOE orders and government regulations. The sample lead, in coordination with line management, will ensure that sample personnel meet special training requirements.

Because the 100-OL-1 OU includes areas that have minimal disturbances by the Manhattan Project or later soil-disturbing activities, training requirements for personnel will reflect what is needed to enter and perform sampling activities at these locations. These requirements may change for further work in the 100-OL-1 OU. Typical training requirements or qualifications include those imposed by the contract, regulations, DOE orders, DOE contractor requirements documents, the American National Standards Institute and the American Society of Mechanical Engineers, and the Washington Administrative Code. For example, the environmental, safety, and health training program provides workers with the knowledge and skills necessary to execute assigned duties safely. Sample personnel typically will have completed the following training before starting work:

- Hanford general employee radiation training
- Hanford general employee training

Project-specific safety training, geared specifically to the project and the day's activity, will be provided. Project-specific training requirements include the following:

- Training requirements or qualifications needed by sampling personnel will be in accordance with DVZ-AFRI QA program requirements.
- Samplers are required to have training and/or experience with soil sampling being performed in the field.

- Samplers are required to have Radiological Worker I (or Radiological Worker II) training. The reading assignment requirements include the user's guide for the Niton XL3t 950 analyzer (Thermo Scientific, Tewksbury, MA) and PNNL's Technical Work Document, *Niton XL3t XRF Standard Operating Procedure*.

In addition, pre-job briefings will be performed to evaluate an activity and its hazards by considering many factors, including

- objective of the activities
- individual tasks to be performed
- hazards associated with the planned tasks
- controls applied to mitigate the hazards
- environment in which the job will be performed
- facility where the job will be performed
- equipment and material required
- safety procedures applicable to the job
- training requirements for individuals assigned to perform the work
- level of management control
- proximity of emergency contacts.

Line management will confirm an individual employee's training is appropriate and up-to-date before performing any field work.

A.2.1.4 Documents and Records

The project lead is responsible for ensuring the current version of the SAP is being used and for providing updates to sample personnel. Version control is maintained through the administrative document control process. Before implementation of field activities, the project lead will obtain ecological and cultural clearance, and the project lead will update any part of the SAP necessary to incorporate mitigation actions. DOE-RL and the regulatory agencies will review and approve changes to the sampling plan that affect the data needs. Information pertinent to sampling and analysis will be recorded in field datasheets in accordance with existing sample collection protocols in the HASQARD (DOE-RL 2007) and the DVZ-AFRI QA plan (Meier 2014).

The sample lead is responsible for ensuring the field sampling protocol (Section A.2.1) is maintained up-to-date and aligned with revisions or other approved changes to the SAP. The sample lead will ensure that deviations from the SAP or problems encountered in the field are documented appropriately (e.g., in the field datasheet, on nonconformance report forms) in accordance with internal corrective action procedures.

The project lead, sample lead, or designee, will be responsible for communicating field corrective action requirements and for ensuring immediate corrective actions are applied to field activities. Table A.6 presents the change control for this project.

Table A.6. Change Control for the 100-OL-1 OU Remedial Investigation

Type of Change	Action	Documentation
By sample lead: • Relocation of a pre-determined soil sampling location due to cultural resources or presence of soil disturbances (e.g., waste site lay down material) • Additional samples outside of DU boundary where concentration exceeds benchmarks	No SAP revision necessary	Field datasheets
By project lead: • Changes to field sampling plan that change DQOs	Revise SAP; obtain regulatory approval; distribute SAP	Revised SAP or approved TPA change notice

Datasheets are required for field activities, and include the precision and quality checks as well as notations about each sampling location. Only authorized persons may make entries in datasheets. Datasheets will be maintained as part of the test data package in accordance with DVZ-AFRI QA program. Datasheet entries will be made in indelible ink. Corrections will be made by striking through the erroneous data with a single line of ink, entering the correct data, and initialing and dating the changes.

XRF analyzer results are electronic material, downloaded from the XRF instrument to the project share drive. The verification of the data will follow DVZ-AFRI QA plan (Meier 2014).

The project lead is responsible for ensuring the project file is properly maintained. The project file will contain the records or references to their storage locations. The project file will include the following, as appropriate:

- field datasheets or operational records
- Global Positioning System (GPS) data
- chain-of-custody forms for soil samples to laboratory
- sample receipt records
- inspection or assessment reports and corrective action reports
- interim progress reports
- final reports
- laboratory data packages
- verification and validation reports.

The laboratory is responsible for maintaining and having available upon request, the following:

- analytical logbooks
- raw data and QC sample records
- SRM and/or proficiency test sample data
- instrument calibration information.

Records may be stored in either electronic or hard copy format. Documentation and records, regardless of medium or format, are controlled in accordance with internal work requirements and processes to ensure accuracy and availability of stored records. Records required by the TPA will be managed in accordance with the requirements of the Agreement.

A.2.2 Data Generation and Acquisition

The following sections address data generation and acquisition to ensure the project methods for sampling, measurement and analysis, data collection or generation, data handling, and QC activities are appropriate and documented.

A.2.2.1 Sampling Process Design (Experimental Design)

As discussed previously, the sampling approach for XRF analysis of surface soils in select decision units uses a probability-based design. Probability-based sampling designs apply sampling theory and involve random selection of the location of the sampling. An important feature of a probability-based sample is that each member of the population from which the sample was selected has a known probability of being selected. Thus, when a probability-based design is used, statistical inferences are made about the sampled population from the data obtained; e.g., comparing the 95th percentile upper confidence limit for lead or arsenic in a decision unit to a benchmark. A random-start, systematic-grid-sampling design will be used to determine the locations within a decision unit. The sample lead, or designee, may modify the exact location for soil collection to avoid cultural resources or other features not readily observable prior to field activities. At each sample locations, the XRF will make a single 60-second count of the surface soil.

A.2.2.2 Sample Handling and Custody

There are no sampling handling issues for XRF analyses in situ.

Confirmatory soil samples for XRF and ICP-MS analyses will be collected from the culturally cleared areas in 100-OL-1 OU. The soil will be returned to a PNNL laboratory for homogenizing before further analysis (EPA 2007a). A sampling and data tracking database is used to track the samples from the point of collection through the laboratory analysis process. The field sample lead will obtain a DVZ chain-of-custody sample number for the soil samples. Laboratory analytical results are entered into project-specific files.

Sample custody during laboratory analysis is addressed in the applicable laboratory standard operating procedures. Laboratory custody procedures will ensure that sample integrity and identification

are maintained throughout the analytical process. Storage of samples at the laboratory will be consistent with laboratory instructions prepared by the sample management and reporting lead.

A.2.2.3 Analytical Methods

The analytical methods are controlled in accordance with the laboratory's QA plan and the requirements of this QAPjP. EPA Method 6200 (EPA 2007a) is the basis for the XRF analyses. The procedure for the digestion of confirmatory soil samples is based on EPA Method 3050B (EPA 1996a), and the procedures for ICP-MS analyses of the confirmatory soil samples are based on EPA Methods 200.8 and 1638 (EPA 1994 and 1996b).

If the laboratory uses a nonstandard or unapproved method for analyzing the confirmatory soil samples, the laboratory must provide method validation data to confirm the method is adequate for the intended use of the data. This includes information such as determination of detection limits, quantitation limits, typical recoveries, and analytical precision and bias. In consultation with the laboratory, the project lead and/or sample management and reporting lead can approve changes to analytical methods as long as the method is based on a nationally recognized (e.g., EPA, ASTM) method, the new method achieves project DQOs as well as or better than the replaced method, and the new method is required due to the nature of the sample.

Laboratories providing analytical services in support of this SAP will have in place a corrective action program addressing analytical system failures and documenting the effectiveness of corrective actions. Issues affecting analytical results are to be resolved by the sample management and reporting lead in coordination with the project lead.

A.2.2.4 Quality Control

Quality control procedures must be followed in the field and laboratory to ensure reliable data are obtained (DOE-RL 2007, Volume 2). Table A.7 provides information about the requirements and frequency for field and laboratory QC samples. Field personnel will collect QC samples to evaluate the potential for cross-contamination and to provide information pertinent to field variability. Field QC for sampling will require a daily instrument check for precision. For the confirmatory soil samples, the soil will be homogenized and split for intrinsic XRF samples and ICP-MS analyses, each in triplicate. The QC samples and frequency are listed in Table A.8 for XRF measurements and in Table A.9 for ICP-MS.

Table A.7. Definitions, Requirements, and Frequency for Field and Laboratory Quality Control Samples

QC Sample	Definition/Purpose	Frequency
Field Precision Checks	Estimate precision, including sampling and analytical variability	Precision instrument check once per field day
Method or Procedural Blank (MB) for ICP-MS	A combination of solvents, surrogates, and all reagents used during sample processing, processed concurrently with the field samples. Monitors purity of reagents and laboratory contamination.	1 per 20 samples batch for ICP-MS All analytes
Standard Reference Material (SRM)	An external reference sample that contains a certified level of target analytes; serves as a monitor of accuracy. For ICP-MS analyses, SRM is extracted and analyzed with samples of a like matrix.	XRF measurement of SRM at beginning of each field day, at first and last location within DU, and after every 20 locations 1 per sample batch for ICP-MS
Matrix Spike (MS)	A field sample spiked with the analytes of interest is processed concurrently with the field samples; monitors effectiveness of method on sample matrix; performed in duplicate for sediments. An MS must be processed for each distinct matrix.	1 per sample batch for ICP-MS
Duplicate Sample	Second XRF reading at a location	XRF measurement at first and last location, and after every 20 sample locations within the DU
	Second aliquot of a field sample processed and analyzed by ICP-MS to monitor precision	1 per sample batch for ICP-MS

Field assessment sampling as outlined in this plan is designed to assess sampling reproducibility. If sampling requirements cannot be met due to sampling or measurement system failure, field conditions, or other factors that cannot be controlled, corrective actions will be discussed with the sample lead, project lead, QA engineer, and DOE-RL technical lead. A corrective action will be agreed upon based on the critical/non-critical nature of the parameter, documented in the field datasheet, and communicated to the sampling team. In general, if critical measurements or samples cannot be collected, sampling will be rescheduled. If a non-critical measurement or sample cannot be collected, the deviation will be documented. The QA engineer will review corrective actions to assess their effectiveness. Any deviations from the SAP will be documented.

The study design and QC samples are intended to help assess the major components of total study error, which facilitates the final evaluation of whether environmental data are of sufficient quality to support the related decisions. The QC sample requirements are designed to provide measurement error information that can be used to initiate corrective actions with the goal of limiting the total measurement error. Measurement quality objectives for the analyses can be expressed in terms of accuracy, precision, completeness, and sensitivity goals. Accuracy and precision are monitored through the analysis of QC samples. Table A.8 and Table A.9 define the required accuracy and precision for QC samples, along with corrective actions that must be implemented when QC criteria are not met.

Table A.8. Measurement Quality Criteria for XRF

QC Parameter	Acceptance Criteria	Corrective Action
Accuracy: Standard Reference Material (SRM)	Metals: ≤20% PD (percent difference) Determined vs. certified range	Review data to assess impact of matrix. Reanalyze sample and/or document corrective action. If other QC data are acceptable, then flag associated data if sample is not reanalyzed.
Precision: Field precision check	Metals: ≥20% RPD (relative percent difference)	Review data to assess impact of matrix. If other QC data are acceptable, then flag associated data. If QC data are not affected by matrix failure, then reprocess duplicate. If not possible, then notify client and flag associated data.

Table A.9. Measurement Quality Criteria for ICP-MS

QC Parameter	Acceptance Criteria	Corrective Action
Accuracy: • Method Blank (MB) for ICP-MS	MB undetected or MB < MDL If MB > MDL and < RL, then perform corrective action	Review data and analysis for possible sources of contamination. Reanalyze and/or document corrective action.
	If MB > MDL and > RL; sample values >10X MB, then perform corrective action	Review data and analysis for possible sources of contamination. Reanalyze and/or document corrective action. Data must be flagged.
	If MB > MDL and > RL; sample values ≤10X MB, then perform corrective action	Perform corrective action as above and re-process (extract, digest) sample batch. If batch cannot be re-processed, notify client and flag data.
• Standard Reference Material (SRM)	Metals: ≤20% PD Determined vs. certified range	Review data to assess impact of matrix. Reanalyze sample and/or document corrective action. If other QC data are acceptable, then flag associated data if sample is not reanalyzed.
• Matrix Spike (MS)/ MS Duplicate (MSD)	Metals: 75% to 125% recovery	Review data to assess impact of matrix. If other QC data are acceptable and no spiking error occurred, then flag associated data. If QC data are not affected by matrix failure or spiking errors occurred, then reprocess MS. If not possible, then notify client and flag associated data.
• Laboratory Control Sample (LCS)	Metals: 75% to 125% recovery	Perform corrective action. Reanalyze and/or reprocess sample batch. Batch data associated with failed LCS (LCS data outside control limits) cannot be reported. If batch cannot be reprocessed, notify client, flag data, discuss impact in report narrative.
Precision: • Laboratory Duplicates	Metals: ≥25% RPD	Review data to assess impact of matrix. If other QC data are acceptable, then flag associated data. If QC data are not affected by matrix failure, then reprocess duplicate. If not possible, then notify client and flag associated data.

Table A.10 provides formulas for the calculation of QC sample assessment statistics. All QC sample failures and associated corrective actions will be documented. If data must be reported with failing QC results, then data qualifiers will be assigned to the QC sample data. Table A.11 defines project data qualifiers.

Table A.10. Calculation of Quality Control Assessment Statistics

Percent Recovery

The percent recovery is a measurement of accuracy, where one value is compared with a known/certified value. The formula for calculating this value is:

$$Percent\ Recovery = \frac{amount\ detected}{amount\ expected} \times 100$$

Percent Difference

The percent difference (PD) is a measurement of precision as an indication of how a measured value is different from a "real" value. It is used when one value is known or certified, and the other is measured. The formula for calculating PD is:

$$Percent\ Difference = \frac{X_2 - X_1}{X_1} \times 100$$

where X_1 is the known value (e.g., SRM-certified value) and X_2 is the determined value (e.g., SRM concentration determined by analyst).

Relative Percent Difference

The RPD is a measurement of ***precision***; it is a comparison of two similar samples (matrix spike/matrix spike duplicate pair, field sample duplicates). The formula for calculating RPD is:

$$RPD = \left| \frac{2 \times (X_1 - X_2)}{(X_1 + X_2)} \right| \times 100$$

where X_1 is the concentration or percent recovery in sample 1 and X_2 is the concentration or percent recovery in sample 2.

Note: Report the absolute value of the result – the RPD is always positive.

Relative Standard Deviation

The relative standard deviation (RSD) is a measurement of ***precision***; it is a comparison of three or more similar samples (e.g., field samples, initial calibration, MDLs). The formula for calculating RSD is:

$$\%RSD = \frac{Standard\ Deviation\ of\ all\ Samples}{Average\ of\ all\ Samples} \times 100$$

Table A.11. Project Data Qualifiers

	Method Qualifiers
NR	Method qualifier – Analyte was not required
P	Method qualifier – ICP-MS
	Data Qualifiers
B	Analyte found in both sample and associated blank. The "B" will be reported on the result associated with the field samples, not the blank.
J	Estimated concentration between the MDL and RL
U	The concentration is less than the MDL, or the analyte was not detected; the MDL value with a U flag is reported.
W	Post-digestion matrix or blank spike out of control limits
	Quality Control Qualifiers
N	Spiked sample recovery not within control limits
&	Accuracy result not within control limits (outside recovery of SRM)
*	Precision result not within control limits

A.2.2.5 Instrument and Equipment Testing, Inspection, and Maintenance

Equipment used for collection, measurement, and testing should meet the applicable standards (e.g., ASTM standards) or have been evaluated as acceptable and valid in accordance with the procedures, requirements, and specifications. The sample lead or equivalent will ensure that the data generated with computer software systems are backed up and/or downloaded on a regular basis. Software configuration will be acceptance tested before use in the field.

Measurement and testing equipment used in the field or in the laboratory that directly affects the quality of analytical data will be subject to preventive maintenance measures to minimize measurement system downtime. Laboratories and onsite measurement organizations must maintain and calibrate their equipment. Maintenance requirements (such as documentation of routine maintenance) will be included in the individual laboratory and the onsite organization QA plan or operating procedures, as appropriate. Maintenance of laboratory instruments will be performed in a manner consistent with three- and four-digit EPA methods (EPA 1983, 1994, 2007b), or consistent with auditable Hanford Site and contractual requirements. Consumables, supplies, and reagents will be reviewed in accordance with SW-846 (EPA 2007b) requirements and will be appropriate for their use.

A.2.2.6 Instrument and Equipment Calibration and Frequency

Section A.3, Field Sampling Plan, provides specific field equipment calibration information. Analytical laboratory instruments and equipment are calibrated in accordance with the laboratory's QA plan.

A.2.2.7 Inspection and Acceptance of Supplies and Consumables

Supplies and consumables used in support of sampling and analysis activities will be procured in accordance with internal work requirements and processes described in the contractor acquisition system. Responsibilities and interfaces necessary to ensure items are procured and/or acquired for the contractor

must be in place and meet specific technical and quality requirements. The procurement system ensures purchased items comply with applicable procurement specifications. Supplies and consumables will be checked and accepted by users before use. Supplies and consumables procured by the analytical laboratories will be purchased, checked, and used in accordance with the laboratories' QA plans.

A.2.2.8 Non-direct Measurements

Non-direct measurements include data obtained from sources such as computer databases, programs, literature files, and historical databases. Non-direct measurements will not be evaluated as part of the work within the scope of this SAP.

A.2.2.9 Data Management

The sample management and reporting lead, in coordination with the project lead, is responsible for ensuring analytical data are appropriately reviewed, managed, and stored in accordance with the applicable programmatic requirements governing data management procedures. Electronic data access, when appropriate, will be via a database (e.g., HEIS, a project-specific database). Where electronic data are not available, hard copies will be provided in accordance with Section 9.6 of the TPA (Ecology et al. 1989).

Laboratory errors will be reported to sample management and quality assurance engineer. For reported laboratory errors, a sample issue resolution form will be initiated in accordance with contractor procedures. This process is used to document analytical errors and to establish resolution with the project lead. The sample issue resolution forms become a permanent part of the analytical data package for future reference and for records management.

Planning for sample collection and analysis will be in accordance with the programmatic requirements governing fixed-laboratory sample collection activities, as discussed in sampling procedures. If specific procedures do not exist for a particular work evolution, or it is determined additional guidance is needed to complete certain tasks, a work package will be developed to adequately control the activities, as appropriate. Examples of the sampling procedure requirements include activities associated with

- chain-of-custody/sample analysis requests
- project and sample identification for sampling services
- control of certificates of analysis
- logbooks
- checklists
- sample packaging and shipping.

When this SAP is implemented, approved work control packages and procedures will be used to document field activities. Field activities will be recorded in the field logbook.

A.2.3 Assessment and Oversight

Assessment and oversight address the activities for assessing the effectiveness of project implementation and associated QA/QC activities. The purpose of assessment is to ensure that the QAPjP is implemented as prescribed.

A.2.3.1 Assessments and Response Actions

Project management, quality, and/or health and safety organizations may conduct random surveillance and assessments to verify compliance with the requirements outlined in this SAP, procedures, and regulatory requirements. Additional assessment activities will be performed if circumstances in the field dictate. Deficiencies identified by these assessments will be reported in accordance with existing programmatic requirements. The project's line management chain will coordinate the corrective actions and/or deficiencies in accordance with the contractor QA program, the corrective action management program, and associated procedures that implement these programs. Oversight activities in the analytical laboratories, including corrective action management, will be conducted in accordance with the laboratories' QA plans.

A.2.3.2 Reports to Management

Data quality issues will be reported to the project lead. Issues reported by the XRF samplers or by the laboratory will be communicated to the sample management and reporting lead, who will initiate a sample issue resolution in accordance with contractor procedures. This process is used to document analytical or sample issues and to establish resolution with the project lead.

At the end of the project, a data quality assurance (DQA) report will be prepared to determine whether the type, quality, and quantity of collected data met the quality objectives described in this SAP.

A.2.4 Data Validation and Usability

The elements under data validation and usability address the QA activities occurring after the data collection phase of the project is completed. Implementation of these elements determines whether the data conform to the specified criteria, thereby satisfying the project objectives.

A.2.4.1 Data Review, Verification, and Validation

The criteria for verification include, but are not limited to, review for completeness (samples were analyzed as requested), use of the correct analytical method or procedure, transcription errors, correct application of dilution factors, appropriate reporting of units (e.g., dry weight versus wet weight), and correct application of conversion factors. Laboratory personnel may perform data verification.

Validation activities will be based on EPA functional guidelines, HASQARD (DOE-RL 2007), and the *DVZ-AFRI Quality Assurance Plan* (Meier 2014). Data validation may be performed by the sample management and reporting organization and/or by a party independent of both the data collector and the data user. Data validation qualifiers must be compatible with the HEIS database.

Data validation will be performed to ensure that the data quality goals established during the planning phase have been achieved. Data validation will be performed in accordance with internal procedures. The criteria for data validation are based on a graded approach. Five levels of validation have been defined, Level A through Level E. Level A is the lowest level and is the same as verification. Level E is a 100% review of data (e.g., calibration data; calculations of representative samples from the data set). Validation will be performed to Level C, which is a review of the QC data. Level C validation specifically requires verification of deliverables; requested versus reported analyses; and qualification of the results based on analytical holding times, method blank results, matrix spike/matrix spike duplicate results, surrogate spike recoveries, and duplicate sample results. Level C validation will be performed on at least 5% of the data by matrix and analyte group. For this QAPjP, analyte group refers to categories such as lead or arsenic. The goal is to cover the various analyte groups and matrices during the validation.

When outliers or questionable results are identified, the data associated with these outliers and questionable data will be validated and additional data validation will be performed. This data validation will consist of selecting up to an additional 5% of the data for the analytical method for which statistical outliers and/or questionable data were found during the initial round of data validation. The additional validation will begin with Level C and may increase to Levels D and E, as needed, to ensure that data are usable. Level C validation is a review of the QC data, while Levels D and E include review of calibration data and calculations of representative samples from the data set. Data validation will be documented in data validation reports, which will be included in the project file.

Relative to analytical data in sample media, physical data and/or field screening results are of less importance in making inferences of risk. Field QA/QC data will be reviewed to ensure that physical property data and/or field screening results are usable.

A.2.4.2 Reconciliation with User Requirements

The DQA process compares completed field sampling activities to those proposed in corresponding sampling documents and provides an evaluation of the resulting data. The purpose of the data evaluation is to determine whether quantitative data are of the correct type and are of adequate quality and quantity to meet the project data needs. The results of the DQA will be used in interpreting the data and determining whether the objectives of this activity have been met. The DQA will be in accordance with EPA's *Data Quality Assessment: A Reviewer's Guide*, and *Data Quality Assessment: Statistical Methods for Practitioners* (EPA 2006a, b).

A.2.4.3 Corrective Actions

The responses to data quality defects identified through the DQA process will vary and may be data- or measurement-specific. Some pre-identified corrective actions are identified in Table A.8 and Table A.9.

A.3 Field Sampling Plan

The following sections provide additional details regarding field-specific sample and data collection requirements.

A.3.1 Site Background and Objectives

Site background information is contained in the RI work plan. The area of land potentially contaminated by lead arsenic pesticide use is 20 km^2 (5000 ac), and it is identified as the 100-OL-1 OU (TPA 2012a). Sections A.1.2 through A.1.5 of this SAP discuss the overall approach for field characterization of decision units identified in the 100-OL-1 OU. Section A.1.6 provides guidance for developing the schedule. FSP uses the sampling design identified during the systematic planning process and presents the design to identify sampling locations, the total number of samples to be collected, and analyses to be performed.

A.3.2 Documentation of Field Activities

Data forms are required for field activities (Section A.2.1.4 provides requirements). Data forms may be used to collect field information. The following is a summary of information to be recorded in logbooks:

- Purpose of the activity
- Day, date, time, weather conditions
- Names, titles, organizations of personnel present
- Deviations from the QAPjP or procedures
- All site activities or other relevant observations
- Location (GPS coordinates) and types of samples
- Field measurements
- Phone calls relating to field activities.

All field sampling forms will be completed using indelible ink. Data recording and documentation errors will be corrected as follows: 1) draw a single line through the error, 2) make the correction, and 3) initial, date, and provide justification for the error correction.

A.3.3 Sampling Design

Characterization of the 100-OL-1 OU decision units uses a probability-based sampling design. Sections A.1.5 and A.2.2.1 of this SAP describe the sampling design.

A.3.4 Instrumentation/Equipment Testing, Inspection, and Maintenance

The sampling lead is responsible for ensuring that field equipment is calibrated appropriately. Onsite environmental instruments are calibrated in accordance with the manufacturer's operating instructions and/or internal work requirements that provide direction for equipment calibration or verification of accuracy by analytical methods. The results from instrument calibration activities are recorded on the field data sheets. Hard-copy or electronic versions are acceptable.

Calibrations must be performed as follows:

- Before initial use of a field analytical measurement system
- At the frequency recommended by the manufacturer or procedure, or as required by regulations
- Upon failure to meet specified QC criteria.

Daily calibration checks will be performed and documented for each instrument used to characterize areas under investigation. These checks will be made on standard materials sufficiently like the matrix under consideration for direct comparison of data. Analysis times will be sufficient to establish detection efficiency and resolution (e.g., 60-second count time for the XRF to measure lead and arsenic).

The sampling lead is also responsible for ensuring that laboratory equipment to support field characterization is calibrated appropriately. All analytical instruments and equipment will be maintained according to standard operating procedures and the manufacturers' instructions. Equipment and instrument and maintenance and frequency are defined in standard operating procedures and are summarized in Table A.12. All routine maintenance and non-routine repairs are to be documented in a bound logbook. The information recorded should include analyst initials, date maintenance was performed, a description of the maintenance activity, and (if the maintenance was performed in response to a specific instrument performance problem) the result of retesting to demonstrate that the instrument performance had been returned to acceptable standards prior to reuse. The return to analytical control will be demonstrated by successful calibration. ICP-MS analyses are to be performed by a contractor, and that organization will be responsible for following all contractual requirements associated with testing, maintenance, and inspection.

Table A.12. Maintenance Procedures for General Laboratory and Equipment and Analytical Instruments

Equipment	Activity	Frequency
Deionized water system	Replace seals Replace cartridges	As needed for leaks and to maintain resistivity >18 mOhms
MilliQ® deionized water system	Replace seals Replace cartridges	Every 6 months or as needed for leaks and to maintain resistivity >18 mOhms
Electronic balances	Clean	As needed
Freezers/refrigerators	Clean Defrost	As needed As needed
Ovens	Clean	As needed
Glass thermometers	Store in protective case	Always except when in use
Digital thermometer	Avoid bending thermocouples	Always

A.3.5 Characterization of Representative Decision Units

Soil analysis will be conducted at all the locations identified by using a visual sample planning tool using the random-start, systematic-grid-sampling option. Areas designated as WIDS sites from the sample location will be excluded from the random-start, systematic-grid-sampling. Coordinates of all sampling locations will be used by the sampling lead to collect soil samples. However, the sampling lead, or designee, can relocate the position for sampling just beyond any area that is not representative of the

soil profile in the decision unit (e.g., a disturbed area next to a waste site, or a laydown area) or if cultural or biological resources are found at the location. The sampling location may be moved anywhere within a 5 m (16 ft) radius of the target sampling location without documentation of a deviation. Change in the sampling location beyond 5 m (16 ft) requires documentation of the deviation. Section A.1.5 discusses when additional samples may be required beyond the boundaries of the OU.

A.3.6 Standard Operating Procedure for XRF Analyzer

The standard operating procedure is based on EPA Method 6200, *Field Portable X-ray Fluorescence Spectrometry for the Determination of Elemental Concentration in Soil and Sediment* (EPA 2007a), and the Niton XL3 guide for soil analysis (Thermo Scientific). It is applicable for the analysis of lead and total inorganic arsenic in soil, as well as other metals of environmental concern. This procedure is for the soil analysis mode of the Niton XL3, and is optimum for any sample whose elements of interest are present at less than 1%. The Niton XL3 XRF can analyze for the following elements in standard soil mode: Ba, Cs, Te, Sb, Sn, Cd, Ag, Pd, Zr, Mo, Sr, U, Rb, Th, Pb, Se, As, Hg, Zn, Au, W, Cu, Ni, Co, Fe, Mn, Cr, V, Ti, Sc, Ca, K, and S.

The MDL for the Niton XL3t 950 XRF analyzer was determined using site-specific reference material in accordance with 40 CFR 136, Appendix B. The MDL is 2.6 mg/kg for lead and 3.9 mg/kg for arsenic. Thermo Scientific provided a certificate of analysis with the instrument, and the site-specific MDL is within the limits of quantification for the instrument. The XRF analyzer will not provide a measured sample concentration for a metal if the concentration is less than 1.5 times the standard deviation of the measurement. In that case, the instrument will record "<LOD" (less than level of detection).

A.3.6.1 Summary of Method

XRF spectrometry is an analytical technique that can provide rapid, multi-element analysis of metals. Samples are exposed to X-ray energy, which liberates electrons in the inner shell of metal atoms. As the outer electrons cascade toward the inner shells to fill the vacancies, energy is released (fluorescence). The fluorescing energy spectrum identifies the metals and the intensity is proportional to concentration.

Under this method, inorganic analytes of interest will be identified and quantitated using a Niton® XL3t™, 950 Series™ GOLDD+ Technology Mining and Environmental field portable XRF analyzer (Thermo Scientific, Tewksbury, MA) equipped with a Ag anode (6-50 kC, 0-200 μA max) tube and a Geometrically Optimized Large Area Drift Detector (GOLDD) with 180,000 throughput cps (resolution of <185 eV at 60,000 cps at 4 μ sec shaping time).

The Niton XL3t 950 XRF analyzer operates in two sampling modes: intrusive and in situ analyses. Intrusive analyses are performed in a laboratory and in the field with the XRF instrument analyzing previously collected soil packed into 33 mm sample cups (PN 187-466, Thermo Scientific, Tewksbury, MA) covered with polypropylene film (PN 187-461, Thermo Scientific, Tewksbury, MA). In situ analyses are performed in the field with direct contact between the XRF measurement window and the soil surface. The instrument is operated by hand or with a computer interface for either sampling mode.

The count time for the instrument was optimized with site-specific reference material in the sample cups with the intrusive XRF analyses. A 60-second count duration was chosen for the in situ analyses; for arsenic concentrations near the screening criteria, the variability attributable to the counting duration is expected to be less than 10% with a 60-second count.

XRF instruments can be calibrated using the following methods: empirically based on site-specific calibrations standards, semi-standardless calibration using fundamental parameters or Compton Peak ratio (EPA 2007a). For this method, the Niton XL3t 950 XRF analyzer automatically runs a Compton normalization calibration when set to the "soil mode." For the pilot study, the instrument was calibrated using an empirically based site-specific calibration standards technique.

A.3.6.2 Interferences

The total method error for XRF analysis is defined as the square root of the sum of squares of both instrument precision and user- or application-related error. Generally, instrument precision is the least significant source of error in XRF analysis. User- or application-related error is generally more significant and varies with each site and method used. Some sources of interference can be minimized or controlled by the instrument operator, but others cannot. Common sources of user- or application-related error are briefly discussed below. For a more detailed discussion of these interferences, see EPA Method 6200 (EPA 2007a).

Physical matrix effects result from variations in the physical character of the sample. These variations may include such parameters as particle size, uniformity, homogeneity, and surface conditions. Field studies have shown that the heterogeneity of the sample generally has the largest impact on comparability with confirmatory samples (EPA 2007a).

Moisture content affects the accuracy of analysis of soil sample analyses. Generally, the overall error from moisture may be minimal when the moisture content is between 5% and 20% (EPA 2007a). However, for arsenic analyses with XRF, Parsons et al. (2012) found that soil moisture was significant in altering the precision of arsenic analyses: 20% soil moisture resulted in a decrease in recorded arsenic concentration of 37.0% compared to the same dry sample.

Chemical matrix effects result from differences in the concentrations of interfering elements. These effects occur either as either spectral interferences (peak overlaps) or as X-ray absorption and enhancement phenomena. For example, iron tends to absorb copper X-rays, reducing the intensity of copper measured by the detector, while chromium will be enhanced at the expense of iron. These effects can be corrected mathematically using fundamental parameter coefficients or compensated for using site-specific calibration standards (EPA 2007a).

Spectrum overlaps occur when certain X-ray lines from different elements are close in energy and therefore cause interference by producing a severely overlapped spectrum. The degree to which a detector can resolve the two different peaks depends on the energy resolution of the detector. The most common spectrum overlaps are the K_α/K_β line overlaps (e.g., Fe:Co) and in some cases the K/L, K/M, and L/M line overlaps (e.g., As K_α /Pb L_α). No instrument can fully compensate for this interference. Various options exist for minimizing this and the other interferences previously discussed.

XRF analyses of site-specific reference material were recorded to evaluate the physical and chemical effects. The lead and arsenic concentration of the site-specific reference material was confirmed with ICP-MS analyses. Because XRF measures the total concentration of an element, a total digestion procedure (e.g., EPA Method 3052 [EPA 1996c]) allows for better comparability between XRF measurements and ICP results (EPA 2007a).

A.3.6.3 Standards

The standards needed for calibration and instrument QC procedures include blank samples, SRM, and site-specific reference material. The blank sample was a "clean" quartz or silicon dioxide matrix that was free of any analytes at concentration above the MDLs. Thermo Scientific supplied one blank sample, used in the instrument calibration and documented in the certificate of calibration. Other blanks were prepared during the pilot study with Accusand (Unimin silica sand, A20/30, Target Products, Ltd., Burnaby, British Columbia, Canada). These samples are used to monitor for cross-contamination and laboratory-induced contaminants or interferences.

Standard reference materials are standards containing certified amounts of metals in soil or sediments. These standards are used for accuracy and performance checks of XRF analyses. Several suppliers of certified reference material were evaluated for the pilot study. The National Research Council Canada (Ottawa, Ontario) had certified reference material with the values for lead and arsenic closest to the screening criteria for the pilot study. PACS-3 marine sediment certified reference material for trace metals (Lot G 4169010, Serial CC 569102) and other constituents had certified quantity values for lead (188 ± 7 mg/kg) and arsenic (30.3 ± 2.3 mg/kg).

Site-specific calibration standards were prepared from soil collected during the pilot study, homogenized, and then analyzed by ICP-MS (Bunn et al. 2014). The site-specific reference material was packed in sample cups for intrinsic analyses. The material confirmed the performance of the XRF analyzer in the field and in the laboratory.

A.3.6.4 Field Sampling Protocol

A field sampling protocol, similar to the step-by-step protocol in the pilot study (Bunn et al. 2014), will be used in the field as the operating procedures for sampling with the Niton XL3t XRF analyzer (Thermo Scientific, Tewksbury, MA). The protocol includes the precision check for the instrument at the beginning of each day, as well as the frequency for QC analyses during the sampling day. The protocol applies to both in situ and intrusive XRF analyses. It will also apply to collecting the soil for the site-specific reference material and confirmatory samples, and analyzing the sampling locations in the decision units.

A.3.7 Quality Control for the XRF Analyzer

This section provides an overview of the QC for the XRF analyses. This is performed in accordance with the QAPjP. Data quality criteria for XRF analysis of the soil samples are summarized in Table A.13.

Table A.13. Data Quality Criteria for XRF Analysis of Soil Samples

QC Parameter	Measure of Acceptance Criteria	Corrective Action
Accuracy	Sample values >10X	• Review data and analysis for possible sources of contamination. Reanalyze and document corrective action.
• Instrument Blank (quartz)	Method blank	
• Sample Reference Material (PACS-3)	± 20 % recovery	• Review data and analysis for possible sources of contamination. Reanalyze and/or document corrective action.
Precision	+ 20% RSD	• Review data to assess impact of matrix.
• Duplicate		• Document any corrective action.

A.3.7.1 System Check and Internal Calibration

The Niton XL3t 950 XRF analyzer performs a system check every time the instrument is turned on. The system check allows the instrument's electronics to stabilize and perform an internal calibration check. The four LED lights on the analyzer will blink during calibration. The system check and internal calibration requires about 5 minutes. During that time, the XRF analyzer should be isolated from any electronic devices (devices generating electronic fields) by 2 ft, and vibrations minimized.

A.3.7.2 Instrument Blank

The instrument blank is used to verify that no contamination exists in the spectrometer or on the probe window. The instrument blank is quartz sand (Accusand, Unimin silica sand, A20/30, Target Products, Ltd., Burnaby, British Columbia, Canada) packed into a polypropylene sample cup (Thermo Scientific Niton part number 187-466) covered with 1/4 mil polypropylene film (Thermo Scientific Niton part number 187-461). The instrument blank is analyzed on each working day before and after analyses are conducted and once per every 20 samples. No element concentrations above the MDLs should be found in the instrument blank.

A.3.7.3 Calibration Verification Checks

A calibration verification check sample is used to check for the accuracy of the instrument and to assess the stability and consistency of the analysis for the analytes of interest. Several sources for certified SRM are available. The pilot study used the National Research Council Canada "PACS-3" certified reference material to verify the accuracy of the instrument. PACS-3 is a marine sediment certified reference material for trace metals and other constituents. The certified quantity values are 188 ± 7 mg/kg lead and 30.3 ± 2.3 mg/kg arsenic, very similar to the screening levels for the RI work plan. The measured value for the SRM should be within 20% of the certified value for the calibration verification check to be acceptable.

A.3.7.4 Precision Measurements

The Niton XL3t XRF analyzer reports the results in parts per million, which is equivalent to mg/kg, and reports the precision of the measurement, which is two times the standard deviation (2σ). The

instrument will report a measurement as "<LOD" (less than the level of detection) if the measurement of that element is less than 1.5 times the precision of that measurement.

The precision of the method is monitored by analyzing a sample with low, moderate, or high concentration of lead and arsenic. A minimum of one precision sample should be run per day. Each precision sample should be analyzed three times in replicate. The RSD of the sample mean is used to assess method precision. The RSD should not be greater than 20% for each target analyte. The equation for calculating RSD is as follows:

$$RSD = (SD/\text{Mean Concentration}) \times 100$$

Where:

RSD = relative standard deviation for the precision measurement for the analyte
SD = standard deviation of the concentration for the analyte
Mean Concentration = mean concentration for the analyte.

The precision check for the field analyses of the decision units consists of measuring the low, medium, and high site-specific reference material soil samples. At the beginning of sampling at a decision unit, the precision check for the XRF analyzer included seven replicate measurements of each of the low, medium, and high site-specific reference material soil samples, triplicate measurements of the SRM, and triplicate measurements of the blank.

A.3.7.5 Detection Limits

The pilot study evaluated the MDL for the Niton XL3t 950 XRF analyzer (Bunn et al. 2014) using site-specific reference material soil collected within the 100-OL-1 OU. The MDL for the XRF analyzer was determined using EPA's procedure for determination of the MDL as described in 40 CFR 136, Appendix B. The site-specific reference material sample was measured seven times. Following the procedure, the average concentration of the replicate analyses, the standard deviation of the replicates, and the Student's T-value for seven samples were determined. The MDL is the product of the Student's T-value and the standard deviation. The results of the study indicate that under ideal conditions, the lead and arsenic MDLs for the XRF analyzer are 2.6 and 3.9 mg/kg, respectively. The MDL was used to replace "<LOD" recorded by the XRF and calculate the average of the three replicate samples at a location in a decision unit. The MDL for the XRF should be performed annually.

A.3.7.6 Calibration and Standardization

Instrument calibration procedures vary among XRF instruments. Generally, three types of calibration procedures exist for XRF instruments: Fundamentals parameter (FP) calibration, empirical calibration, and the Compton Peak ratio or normalization method. For more details regarding these procedures, see Method 6200 (EPA 2007a). The Niton XL3t 950 analyzer in the standard soil mode is calibrated using a semi-standardless FP routine.

The backscatter FP calibration is for soil analyses where the percentage of analytes of interest is less than 1.0%, light matrix material, and composition of elements with atomic number greater than iron does not exceed several percent. Based on the User's Guide (Thermo Scientific, Tewksbury, MA):

Standard Soil Mode utilizes the Compton Scatter (Inelastic Collisions) of a particular sample. Compton scatter occurs when primary X-rays do not cause fluorescence but instead collide with the atoms of the sample. The Compton Scatter that occurs is directly proportional to the density (average atomic number (Z)) of the sample. A light matrix material, such as an oil or sand, will have a much greater scatter than that of a heavy matrix, such as ore. The analyzer measures this scatter peak and automatically adjusts the concentration based on the matrix of the specific calibration standards.

Empirical calibration of the XRF analyzer is part of the daily precision instrument check described in the field sampling protocol. The User's Guide states that the frequency for measuring the SRM is after turning on the XRF analyzer and before analysis of soil samples, as well as every 1 to 2 hours thereafter. The frequency of sampling in the decision units (one location every 5 to 7 minutes) is equivalent to reading the SRM after every 20 locations.

A.3.7.7 Sample Preparation and Analysis Procedure

There are two ways to analyze soil with the XRF: by simply holding down the trigger on the instrument, or through a computer interface using manufacturer software (Thermo Scientific Niton XL3 Series Software, Version 8.4A). For in situ analysis, the analysis involved placing the XRF analyzer measurement window on the surface of the soil and holding the trigger on the analyzer for the predetermined period. The pilot study determined that a 60-second count was adequate for measuring the lead and arsenic concentrations in the surface soil (Bunn et al. 2014). The soil surface was cleared of debris before placement of the analyzer on the soil. "Intrusive analysis" is termed by EPA as a soil sample collected from the field, placed in a sample cup, and then analyzed with the XRF (EPA 2007a). For intrusive analysis, the analyzer will be set up with the measurement window on the sample cup packed with the soil sample. Intrusive analyses will be performed in the laboratory or in the field using previously collected samples packed into 33 mm (1.3 in.) sample cups (PN 187-466, Thermo Scientific, Tewksbury, MA) with polypropylene film (PN 187-461, Thermo Scientific, Tewksbury, MA). In both configurations, the XRF analyzer records the data in the same manner.

A.3.7.8 Data Analysis and Calculations

The Niton XL3t has a computer interface and all data and spectra are transferred from the instrument to a computer for data analysis. Field personnel will download the data file from the XRF and save the file as a .csv file. They will modify the file to include the sample location information and the predetermined location coordinates or new coordinates collected from the field (e.g., if the site was relocated). All modifications will be verified against the field data sheets.

A.3.8 Quality Control for the ICP-MS

Subsamples from soil collection for the site-specific reference material and confirmatory samples will be analyzed by ICP-MS. Soil samples will be analyzed for total lead and total arsenic using ICP-MS, following EPA Method 3050B (EPA 1996a) for soil digestion and EPA Methods 1638 and 200.8 (EPA 1994 and 1996b) for the analyses.

A.3.9 Management of Waste

All investigation-derived waste will be handled in accordance with contractor waste management procedures and applicable Hanford Site requirements. Expected waste streams may include the following:

- Miscellaneous solid waste such as wipes, gloves, and other personal protective equipment
- Decontamination solutions.

Miscellaneous solid waste that has contacted potentially contaminated soil will be segregated from other materials and will be transported offsite for disposal based on a waste designation in accordance with contractor waste management procedures. Waste will be designated in accordance with WAC 173-303, "Dangerous Waste Regulations," using a combination of process knowledge, historical analytical data, and analyses of samples collected from the site.

All generated decontamination water will be handled in accordance with Hanford Site requirements.

Waste generated by samples shipped offsite for laboratory analysis will be managed in accordance with contract specifications. Pursuant to 40 CFR 300.440, "National Oil and Hazardous Substances Pollution Contingency Plan," "Procedures for Planning and Implementing Off-Site Response Actions," approval from the CERCLA lead agency Remedial Project Manager is required before returning unused samples or waste from offsite laboratories.

A.4 Health and Safety Plan

An example Site-Specific HASP in the following pages addresses environmental safety and health hazards, risk analysis, hazard mitigation, training requirements, and emergency response. An approval section (not shown) is also provided such that staff can sign indicating they have read and understand the HASP. The HASP is updated each year, and a new HASP will be generated upon approval of this draft work plan.

Date:	**Author:**
Project #: 65905	**Project Title**: Soil Sampling former Hanford Orchards Properties

Describe Activities: Collect surface soil samples and analyze soil concentrations of metals in-situ with an XRF analyzer.

Between 4000 and 4500 locations across the Hanford Site will be analyzed for trace metals concentrations. This in-situ analysis will be done with a portable XRF instrument (Niton XL3T950). This instrument does not contain a sealed source; it generates x-rays using an x-ray tube. Additionally, 50-100 surface soil samples will be collected. These will be 10 to 3000 g samples scraped from the surface and stored in plastic bags or jars. All sampling locations will be accessed on foot; vehicles will not drive off-road. The summer conditions that will exist during the a portion of the collection effort will be the largest risk associated with this sampling effort. One shoreline sampling area may require access via boat- a float plan will be filed for any transportation via boat; the float plan addresses boat specific health and safety concerns.

Work Location(s): *Hanford Site*

Risk Sources:

- ☐ Basic lab work
- ■ Basic field work
- ☐ Chemical
- ☐ Special chem (Be, PCBs, Pb, asbestos, nanoscale)
- ☐ Biological
- ☐ Radiological
- ☐ Lasers/ magnetic field / NIR (RF)
- ☐ Pressure, vacuum or compressed gas system
- ☐ Electrical hazards
- ☐ Tools / machines
- ☐ Manual lifting
- ☐ Hoisting and rigging
- ☐ Work at heights
- ☐ Confined space
- ☐ Industrial site
- ☐ Noise
- ☐ Erecting structures
- ☐ Hot work (welding)
- ☐ Working alone
- ☐ Firearms / weapons
- ■ Vehicles/trailers
- ☐ Off-road vehicles
- ■ Boats / water hazards
- ☐ Diving underwater
- ☐ Aviation
- ☐ Human subjects
- ☐ Research animals
- ☐ Hazardous plants / animals
- ☐ Excavation / drilling
- ☐ Fatigue / physical stress
- ■ Weather or temperature extremes (thermal stress)
- ☐ Hazardous activities nearby
- ☐ Travel security concerns
- ☐ Security (physical, info)
- ☐ Air emissions
- ☐ Transport hazardous mat'ls
- ☐ Solid or liquid waste generation / treatment / disposal
- ☐ Federal, state, local required permits
- ☐ Federal Protected species (plants, animals, fish, and migratory birds)

■ Other risk sources: Ionizing radiation from the XRF

Risk Analysis: Minimual risk. The primary risk associated with this project is from conducting work in hot conditions at a remote field site. See attached exhibit on heat stress disorders and illnesses. Adequate water will be taken to the field by the field team; containers of "potable water" will be available for drinking, and "non-potable water" will be available for washing hands, etc. Sun block, appropriate clothing, etc., will minimize sun exposure. The work will not be physically strenuous (slow pace, no heavy lifting), which will minimize work load.

Risk Source Management:

Specific Activity	Risk Source(s)	Risk Controls / Mitigation
In-Situ soil analysis	Weather	- Wear appropriate clothing/sunscreen/hats/ etc. - Bring adequate water - Rest as necessary - Monitor each other for signs of heat stress - Avoid doing field work when thunder showers are expected. If storm is approaching, drive to nearest large enclosed building. If caught out in open when a thunder shower occurs, take shelter in vehicles with windows rolled up

In-Situ soil analysis (cont.)	Slips/tips/falls	- Wear appropriate boots- 6" boot height minimum - Conduct daily safety briefing as part of the pre-job
	Ionizing radiation (XRF)	- Follow all manufactures instructions - Wear dosimetry as required - XRF users must be a current RWI or RWII - Follow all instructions outlined in TWD "Niton XL3t XRF Standard Operating Procedure"
	HAZARDOUS FLORA/FAUNA Rattlesnakes, bees/wasps	Staff will make noise, walk with heavy steps, and remain alert for the presence of snakes. Avoid stepping over rocks with holes or gaps underneath. Try to walk in open spaces between brush and other potential cover used by snakes. Staff will not approach snakes. If a rattle is heard, staff members will stop, look around for the presence of the snake, back away from the snake (or sound) slowly and alert other staff. Be alert for bees and wasp. Avoid bushes or locations with bee/wasp activity
	CONTAMINATED SOIL	The concentrations of lead and arsenic expected in soil samples are less than OSHA standards. However, staff may elect to wear nitrile or latex gloves during sample collection. Additionally, wash water will be available in the field for staff to rinse hands. Staff will be expected to wash hands after handling soil and prior to eating or drinking.
	Remote Work Location	- Know your location- carry hard copy maps and gps - Communication available – cell service is available at all locations - Have first aid kit and trained personnel available. - Know emergency numbers. - Use buddy system- a minimum of two people required for sample collection

Emergency Response:

FOR ALL EMERGENCIES, CALL Hanford Site Emergency Number 373 - 0911

WHEN THE CONDITION HAS STABILIZED, report the emergency or incident (injuries, potential exposures, motor vehicle accident, fire, etc.) to the PNNL single point contact 375-2400

Nearest Hospital: Kadlec Medical Center
NOTE: If you need to make pen and ink changes to this plan or need clarification, contact your S&H Rep. (Mike Posada 372-6370) .

Approval: *(Consult with the project management office director to identify the required approvers.)*

Role	Print Name	Signature	Date
Project Manager			
S&H Rep (recommended)			
ECR (recommended)			
Technical Group Manager			
Project Management Office Director			

A.5 References

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