10.0 Biota Monitoring

JR Draper

The U.S. Department of Energy's (DOE) subcontractor Mission Support Alliance (MSA) monitors the biota, including state and federally listed species, to assess the abundance, vigor or condition, and distribution on the Hanford Site. The associated data is used by DOE and Hanford Site contractors to support environmental cleanup and restoration activities, mitigation actions, and land use planning and to maintain compliance with ecological resource laws. MSA's Ecological Compliance staff conducts ecological compliance reviews for most projects on the Hanford Site to determine if the proposed scope of work will adversely impact biological resources and to provide recommendations to reduce environmental impacts.

10.1 Agricultural Monitoring

ME Hoefer

Food and farm products (apricots, corn, leafy vegetables, melons, milk, potatoes, tomatoes, and wine must) were collected in 2016 at locations near the Hanford Site (Figure 10-1; note not all agricultural monitoring locations shown are sampled each year due to program efficiencies, budgetary restrictions, and historical trending purposes). These products are used to determine pathway-specific exposure assumptions by way of annual dose calculations based on a 1 mrem/yr (10 microsievert [µSv]/yr) threshold and ingestion pathways for annual intake, assuming 100% of each food originated in the affected area.

Water removed from the river immediately downstream of the Hanford Site is used to irrigate a small portion of agricultural crops in Benton and Franklin counties. The majority of irrigation water utilized by Franklin County residents originates at Grand Coulee Dam and is provided through its extensive water delivery systems (i.e. canals). Likewise, Benton County relies heavily on the Yakima River for irrigation purposes.

Samples analyzed to determine radiological contaminant concentrations were obtained from the following locations:

- Generally downwind (east and southeast) of the Hanford Site where airborne emissions or contaminated dust from the site potentially would be deposited
- Generally upwind of and distant from the Hanford Site to provide information about reference (background) contaminant levels
- From farms irrigated with water taken from the Columbia River downstream of the Hanford Site.

Sample analyses are used to assess the amounts of Hanford Site-origin contaminants in food and farm products by comparing the following:

- Analytical results obtained from similar samples collected from the same regions over long periods of time

- Samples collected at downwind locations to results from samples obtained from generally upwind or distant locations
- Samples collected in areas irrigated with water withdrawn from the Columbia River downstream of the Hanford Site to analytical results from samples obtained from locations irrigated with water from other regional sources.

Radionuclide concentrations in most food and farm product samples in 2016 were below the analytical laboratory detection levels; however, some potential Hanford Site-produced contaminants (e.g., tritium) were found at low levels in some samples. Data for potassium-40 and beryllium-7 are included to show the natural radioactive elements that exist in food products relative to concentrations of potential Hanford Site-produced contaminants. Radiological doses associated with potential Hanford Site-produced contaminants are discussed in Section 4.0. Where possible, the measured concentrations are compared to the applicable unusual concentration reporting levels. Unusual concentration reporting levels have been established based on environmental concentrations that would result in a dose of 1 mrem/yr (10 µSv/yr) (DOE/RL-91-50). Agricultural products sampled in 2016 are listed in Table 10-1 and described in the following sections.

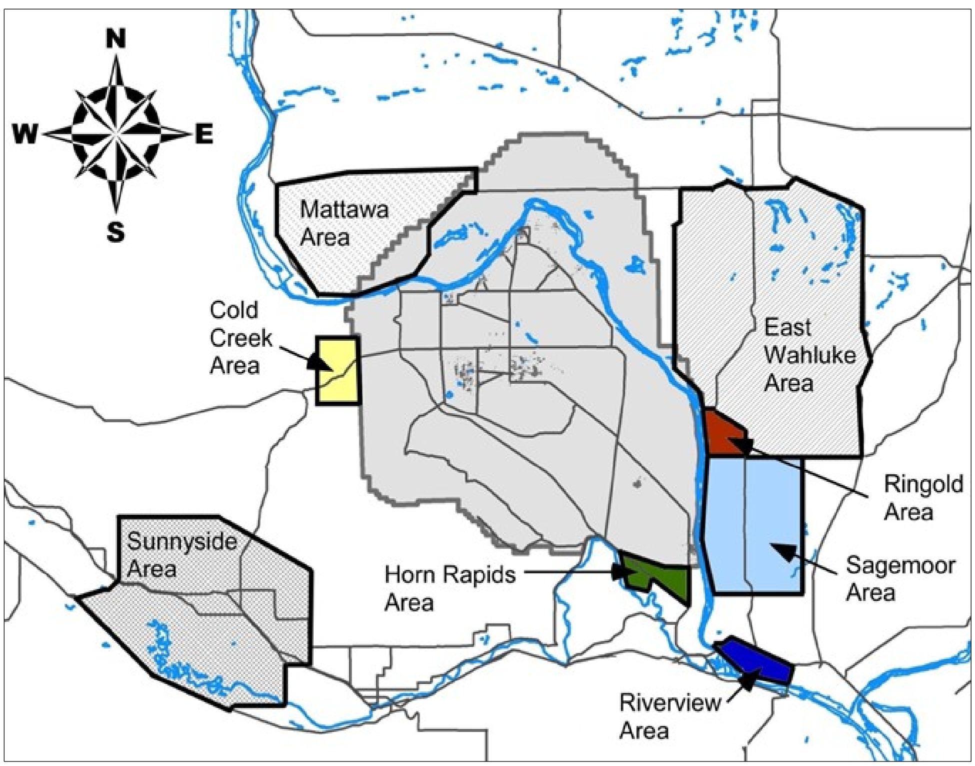


Figure 10-1. Agricultural Monitoring Locations.
NOTE: Duplicate information may or may not be included in this data.

Table 10-1. Agricultural Monitoring Location.

Product	Sampling Locations	Analytes
Apricots	East Wahluke, Riverview, Sagemoor, and Sunnyside	^{14}C, Gamma, Sr-90
Corn	East Wahluke, Riverview, Sagemoor, and Sunnyside	^{14}C, Gamma, Sr-90
Leafy vegetables	Riverview, Sagemoor, and Sunnyside	Gamma, Sr-90
Melons	East Wahluke, Riverview, Sagemoor, and Sunnyside	^{14}C, Gamma, Sr-90
Milk	East Wahluke, Sagemoor, and Sunnyside	Gamma, Sr-90, Tritium
Potatoes	East Wahluke, Riverview, and Sunnyside	Gamma, Sr-90
Tomatoes	Riverview and Sunnyside	Gamma, Sr-90, Tritium
Wine must	Columbia Basin, Mattawa, and Yakima Valley	Low-level Tritium, Gamma

10.1.1 Milk

Milk samples were obtained quarterly in 2016 from several dairies in the East Wahluke and Sagemoor sampling areas, and one dairy in Sunnyside.

The Sagemoor and East Wahluke sampling areas are located near the Hanford Site perimeter and could potentially be affected by airborne contaminants from the site. The Sunnyside area is a reference location generally upwind of the Hanford Site. If milk was obtained from more than one dairy within a sampling area, the milk samples were combined and the composite sample was analyzed. All samples were analyzed for gamma-emitting radionuclides, tritium, and strontium-90. Milk sampling was conducted because Hanford Site-produced radionuclides have the potential to move through the air-pasture-cow-milk or water-pasture-cow-milk food chains to humans. In recent years, levels of Hanford Site-produced radiological contaminants in milk samples have diminished in conjunction with facility shutdowns and remedial efforts. Concentrations in samples obtained from dairies downwind of the Hanford Site are now similar to levels measured in samples obtained from the dairy generally upwind of the Hanford Site.

10.1.1.1 Tritium. Tritium was detected in all milk samples collected in 2016. Overall concentrations ranged from a maximum of 59 pCi/L (2.2 Bq/L) in a Sagemoor area sample to a minimum of 14 pCi/L (0.52 Bq/L) in an East Wahluke area sample. Annual average concentrations for the three sampling areas were 34 pCi/L (1.3 Bq/L). Specific location average was 38 pCi/L (1.4 Bq/L) for Sagemoor (n = 5); 30 pCi/L (1.1 Bq/L) for East Wahluke (n = 4); and 32 pCi/L (1.2 Bq/L) for Sunnyside (n = 2). The maximum concentration for Sagemoor was greater than those measured at this location in the last few years, and overall averages for all areas were slightly higher than historically measured.

10.1.1.2 Strontium-90. No detectable concentrations were found in 2016 milk samples.

10.1.1.3 Cesium-137. No synthetic gamma emitters were detected in milk samples collected and analyzed in 2016.

10.1.1.4 Potassium-40. Naturally occurring potassium-40 was detected in all milk samples collected in 2016. Concentrations ranged from a maximum of 1,600 pCi/L (59 Bq/L) in a Sagemoor area sample to a minimum of 1,250 pCi/L (46 Bq/L) in a Sunnyside sample. The East Wahluke area had a maximum of 1,470 pCi/L (54 Bq/L) and the overall average was 1,451 pCi/L (54 Bq/L) for all results.

10.1.2 Fruit, Vegetables, and Farm Products

Apricot, corn, leafy vegetable (e.g., lettuce), melon, potato, tomato, and wine must samples were collected from upwind and downwind sampling areas during the 2016 growing season (Figure 10-1; Table 10-1). All fruit and vegetable samples were analyzed for gamma-emitting radionuclides and strontium-90. Corn, leafy vegetables, and melons were also analyzed for carbon-14 for additional monitoring due to increased concentrations in the 100-K-Area and to further support Waste Treatment Plant-monitoring. Wine must was analyzed for gamma-emitting radionuclides and tritium. Tomato samples were also monitored for tritium (Table 10-1) and showed no detectable concentrations during 2016.

A single leafy vegetable sample (Sunnyside area) had slightly elevated concentrations of beryllium-7; however, these concentrations were within historical range and follow typical result patterns. Two additional samples had detections of strontium-90 (East Wahluke and Riverview areas) but values reported were well below DOE project dose-based reporting limits and were within historical limits measured at these locations. All fruit and vegetable concentrations of cesium-137, cobalt-60, and tritium were reported as non-detects and were well within historical range.

All wine must samples had detectable concentrations of tritium; were well within the historical range; and mirrored tritium concentrations found in Columbia River fixed-station water collection areas, as well as irrigation water results for 2016.

All apricot, corn, leafy vegetable, melon, potato, tomato, and wine must samples had detectable concentration levels of naturally occurring potassium-40.

10.2 Fish and Wildlife Monitoring

JW Wilde

Fishing is a popular activity along the Hanford Reach of the Columbia River. The fish and wildlife species sampled and analyzed for Hanford Site operations-produced contaminants during the 2016 calendar year were smallmouth bass (*Micropterus dolomieu*), common carp (*Cyprinus carpio*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and California quail (*Callipepla californica*). Monitoring fish and wildlife for uptake and exposure to Hanford Site operations-produced contaminants ensures that consumption of fish and wildlife obtained from Hanford Site environs does not pose a threat to human health and provides long-term contamination trends. These species were selected and monitored because they provide a potential pathway for offsite human consumption. Figure 10-2 shows locations on and around the Hanford Site where fish and wildlife were collected in 2016. Samples of fish and wildlife were analyzed for selected (suspected or known to be present) radionuclides and metals (Table 10-2). In addition, samples were collected from locations distant from the Hanford Site to obtain reference (background) contaminant measurements. All fish and wildlife samples were monitored for strontium-90 contamination and analyzed by gamma spectrometry to detect a number of gamma emitters, including cesium-137. Since the 1990s, strontium-90 and cesium-137 have been the most frequently measured radionuclides in fish and wildlife samples.

Most fish and wildlife samples are collected on and around the Hanford Site and analyzed for human-pathway exposure every 2 to 3 years and reference samples obtained at locations determined not to be affected by Hanford Site effluents and emissions at least every 5 years.

Table 10-2. Animal Monitoring Analysis.

Biota	Offsite Locations	Onsite Locations	Gamma	Strontium-90	Trace Metals
Fish (smallmouth bass)	1	2	14	14	3
Fish (common carp)	1	2	11	22	11
Mammals (deer/elk)	0	4	7	4	4
Waterfowl (California quail)	0	2	8	8	0

Strontium-90 is present in Hanford Site environments because of past Hanford Site operations and waste disposal practices. Contaminated groundwater entering the Columbia River through shoreline springs in the 100-N and 100-H Areas is the primary source of measurable Hanford Site-produced strontium-90 in the Columbia River. Chemically similar to calcium, strontium-90 consequently accumulates in hard tissues rich in calcium such as bones, antlers, and eggshells. In addition, strontium-90 has a biological half-life in hard tissue from 14 to 600 days (PNL-9394, *Ecotoxicity Literature Review of Selected Hanford Site Contaminants*). Hard-tissue concentrations may profile an organism's lifetime exposure to strontium-90; however, because strontium-90 does not accumulate in edible portions of fish and wildlife, it generally does not contribute much to the human dose (NCRP 2009).

Cesium-137 is present in Hanford Site environments because of past Hanford Site operations, waste disposal practices, and from historical worldwide fallout resulting from nuclear weapons testing. Cesium-137 is particularly important to the human food chain because the isotope is chemically similar to potassium and is found in the muscle tissues of fish and wildlife. Cesium-137 is an indicator of recent exposure to radioactive materials because it has a relatively short biological half-life (less than 200 days in muscle and less than 20 days in the gastrointestinal tract [PNL-9394]).

Gamma spectrometry results for most radionuclides generally are too low to measure or the concentrations measured are considered artifacts of low background counts. Low background counts occur at random intervals during sample counting and can produce occasional spurious false-positive results. For many radionuclides, concentrations were below analytical laboratory detection levels.

A number of trace metals associated with Hanford Site operations have a potential to accumulate in certain fish and wildlife tissues. These metals are contaminants of potential concern (e.g., copper, lead, and mercury), particularly along the Hanford Site Columbia River shoreline where contaminated groundwater flows into the river. Hanford Site historical operations have resulted in the production of both radiological and non-radiological wastes, including trace-metal emissions in a variety of forms. Liquid and solid wastes that were placed in disposal sites (e.g., trenches, cribs, ditches, ponds, and underground storage tanks), and fly ash (produced from burning coal in coal-fired steam/power plants associated with some Hanford Site reactors) released to the atmosphere. The fly ash contains trace metals and natural radionuclides that may have deposited on soil surfaces around the 100 Area reactors.

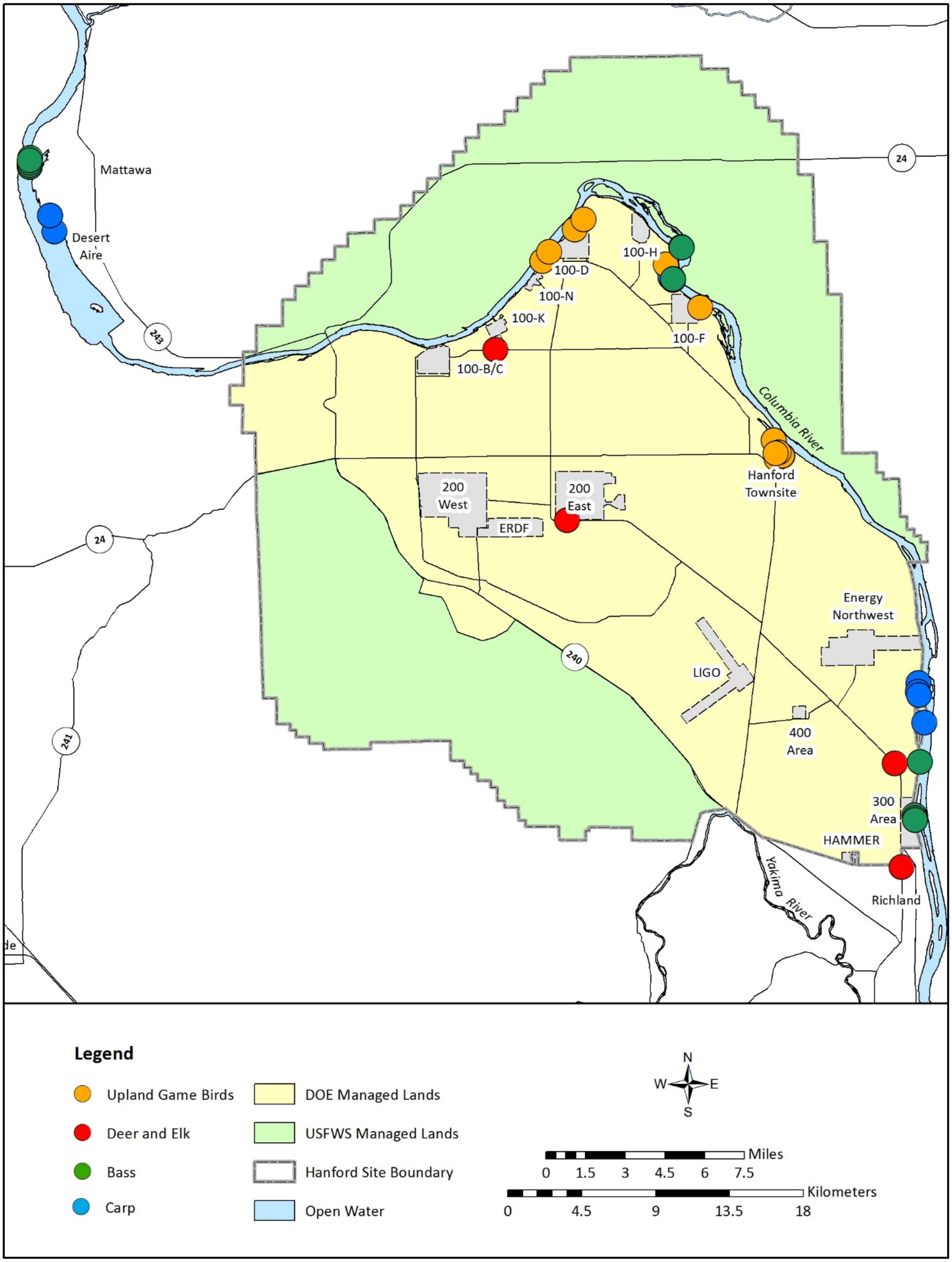


Figure 10-2. Animal Monitoring Locations.

10.2.1 Smallmouth Bass

Fish, such as the smallmouth bass, are sometimes harvested for food and could potentially contribute to human exposure. Smallmouth bass are a predatory fish that feed on invertebrates and smaller fish along the Hanford Reach and, therefore, may be exposed to trace metals and persistent radionuclides in the Columbia River environment through food sources.

Twenty-one smallmouth bass were collected in 2016 from three locations in the Hanford Reach and a reference location: Nine fish were collected from the Hanford Townsite to the 300 Area; six fish from the 100 Area and six reference samples were obtained in 2016 in the pool between Wanapum and Priest Rapids Dams. Fillets and the eviscerated remains (carcasses) of the smallmouth bass were analyzed for a variety of radiological contaminants; three samples had metals, isotopic uranium, and isotopic plutonium analyses added to the suite.

10.2.1.1 Cesium-137. Manmade gamma-emitting radionuclides, including cesium-137, were not detected in 2016 in any of the muscle samples analyzed. These results are consistent with those reported historically near the Hanford Site.

10.2.1.2 Strontium-90. Strontium-90 was not detected in smallmouth bass samples collected in 2016 from the reference area or Hanford Reach locations. These results are consistent with those reported throughout the past 10 years for smallmouth bass collected from the reference area and Hanford Site sampling locations.

10.2.1.3 Trace Metals. Three bass samples were analyzed for 17 different trace metal concentrations. Barium, copper, manganese, mercury, selenium, silver, and zinc were detected above the analytical detection limit (Table 10-3).

Surveillance data sets for trace-metal concentrations in fish, both on and near the Hanford Site, are relatively small and the results are variable. At this time, no established state or federal adverse-effects values (i.e., benchmark criteria) are available for trace-metal concentrations in fish tissue. Identifying Hanford Site contributions to trace-metal concentrations or drawing conclusions about the effects of this contribution are limited by the factors above. Monitoring fish for uptake and exposure to radionuclides and metals at locations both near to and distant from the Hanford Site will continue to provide important information for tracking the extent and long-term trends of contamination in the Hanford Reach environment.

Table 10-3. Smallmouth Bass Metals Analyses.

Isotope	Samples	Detects	Isotope	Samples	Detects
Aluminum	3	0	Manganese	3	2
Antimony	3	0	Mercury	3	1
Arsenic	3	0	Nickel	3	1
Barium	3	2	Selenium	3	1
Berylium	3	0	Silver	3	1
Cadmium	3	0	Thallium	3	0
Chromium	3	1	Thorium	3	0
Copper	3	3	Uranium	3	0
Lead	3	0	Zinc	3	3

10.2.2 Common Carp

Fish, such as the common carp, are sometimes harvested for food and could potentially contribute to human exposure. Common carp are an omnivorous fish that feeds on a diet of plants, insects, crustaceans, crawfish, and benthic worms on the bottom of the Columbia River along the Hanford Reach and, therefore, may be exposed to trace metals and persistent radionuclides in the Columbia River environment through food sources. Carp is a common food in many cultures; therefore, it is included in the sampling rotation.

Fourteen common carp were collected in 2016 from two locations in the Hanford Reach and a reference location (five fish were sent to Washington State Department of Health [WDOH] for oversight analysis). Eleven samples were submitted to laboratory for analyses (nine standard samples, one duplicate, and one lab split): There were four fish collected from the region known as the White Bluffs Slough for the 100 Area and five fish from the waters around the wooded island section of the river above the 300 Area. Five reference samples were obtained in 2016 in the pool between Wanapum and Priest Rapids Dams. Fillets and the eviscerated remains (carcasses) of the common carp were analyzed for a variety of radiological contaminants, metals, isotopic uranium, and isotopic plutonium.

10.2.2.1 Cesium-137. Manmade gamma-emitting radionuclides, including cesium-137, was not found in 2016 in any of the muscle samples analyzed. These results are consistent with those reported historically near the Hanford Site.

10.2.2.2 Strontium-90. Strontium-90 was not detected in common carp filet or carcass samples in 2016. These results are consistent with those reported historically near the Hanford Site.

10.2.2.3 Uranium. Uranium isotopic analysis was performed on 11 carp samples in 2016. Uranium-234 was detected in 7 of the 11 samples. Uranium-235 was detected in 4 of the 11 samples. Uranium-238 was detected in 6 of the 11 samples for 2016. This was slightly less detects than in 2014 in a similar number of samples (10).

10.2.2.4 Trace Metals. Eleven (including a duplicate and lab split) carp samples were analyzed for 17 different trace metal concentrations. Barium, copper, lead, manganese, mercury, selenium, thorium, uranium, and zinc were detected above the analytical detection limit (Table 10-4). Foraging methods of the common carp on invertebrates, insects, and plants in the sediment of the river where these metals can concentrate increase the potential for bioaccumulation in sampled tissues. Figure 10-3 shows that in 2016 the mercury levels in carp were higher in the Hanford Townsite area of the Hanford Site when compared to the carp of the 100 Area and reference area.

Surveillance data sets for trace-metal concentrations in fish, both on and near the Hanford Site, are relatively small and the results are variable. At this time, no established state or federal adverse-effects values (i.e., benchmark criteria) are available for trace-metal concentrations in fish tissue. Identifying Hanford Site contributions to trace-metal concentrations or drawing conclusions about the effects of this contribution are limited by the factors above. Monitoring fish for uptake and exposure to radionuclides and metals at locations both near to and distant from the Hanford Site will continue to provide important information for tracking the extent and long-term trends of contamination in the Hanford Reach environment.

Table 10-4. Common Carp Metals Analyses.

Isotope	Samples	Detects	Isotope	Samples	Detects
Aluminum	11	0	Manganese	11	1
Antimony	11	0	Mercury	11	6
Arsenic	11	0	Nickel	11	0
Barium	11	1	Selenium	11	11
Berylium	11	0	Silver	11	0
Cadmium	11	0	Thallium	11	0
Chromium	11	1	Thorium	11	2
Copper	11	10	Uranium	11	10
Lead	11	1	Zinc	11	11

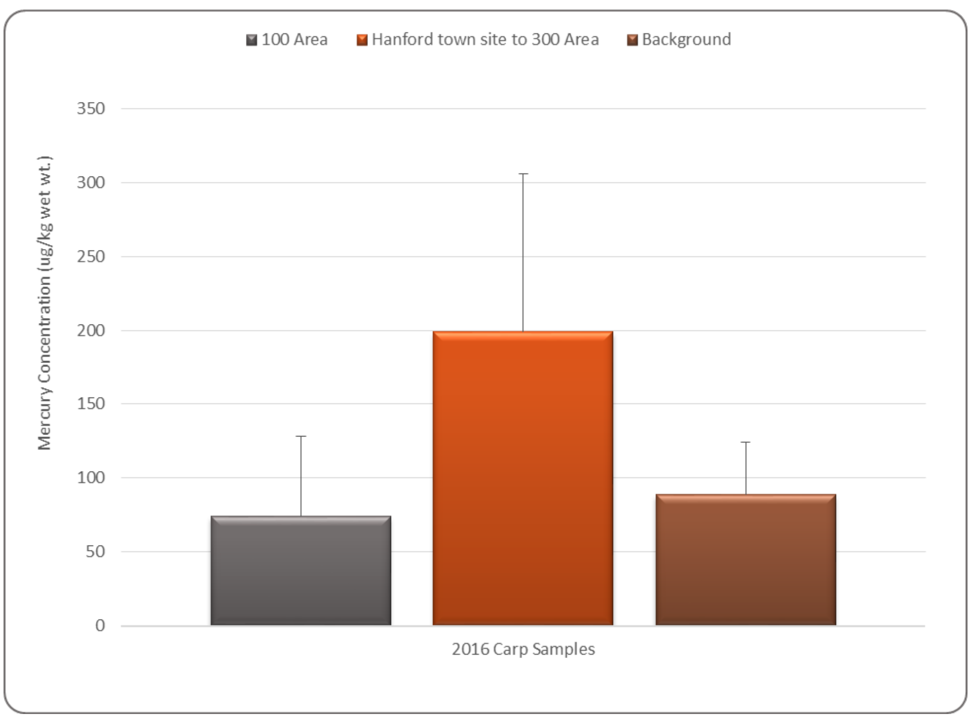


Figure 10-3. Carp Mercury Concentrations Compared in the 100, 300, and Reference Areas.

10.2.3 Mule Deer and Elk

Deer and elk can be exposed to metals and persistent radionuclides when they forage on plants whose roots have access to contaminated groundwater or soil, drink contaminated water, or incidentally ingest contaminated soil. Deer and elk hunting is not allowed above the high-water mark on the Benton County side of the Columbia River (at the Hanford Site), but the river is not a barrier to large mammal movements. In 2016, the Hanford Site Environmental Surveillance Program collected deer and elk killed due to road strikes rather than hunting animals onsite. Deer and elk have been captured and tagged at the Hanford Site that were legally killed by hunters on the Hanford Reach shoreline below the high-water mark and across the Columbia River in Franklin County. Harvesting deer for food could potentially contribute to human exposure to contaminants.

A total of three deer and one elk were collected from vehicle collisions with animals. All samples were collected when the location led investigators to believe the herd could contact Hanford Environs. Radionuclide levels in the four animals collected on the Hanford Site in 2016 were compared to levels from a reference elk collected in 2014 by the WDFW in western Washington. The results from deer collected in 2016 were compared to samples collected in previous years from background locations distant from the Hanford Site and to results reported for deer and elk collected from the Hanford Site over the last 15 years.

10.2.3.1 Cesium-137. Cesium-137 was not detected in any of the seven muscle tissue samples collected as a Hanford sample or a reference sample. Cesium-137 was not detected in any of the seven liver samples collected as a Hanford sample or a reference sample. These results are consistent with a decline in cesium-137 levels in wildlife examined from the preceding 10 years.

10.2.3.2 Strontium-90. Strontium-90 was detected in all four bone samples analyzed during 2016. Concentrations of strontium-90 detected in deer bone samples collected ranged from 0.0891 pCi/g (0.0033 Bq/g) wet weight to 0.163 pCi/g (0.006 Bq/g) wet weight. Strontium-90 concentrations measured in bone samples from 2014 at the reference location were 229 pCi/g (0.0085 Bq/g) wet weight (Figure 10-4).

10.2.3.3 Trace Metals. Trace metals were analyzed in mule deer and elk liver samples collected from Hanford Site samples and the reference location. Ten metals (aluminum, barium, cadmium, chromium, copper, manganese, selenium, silver, thorium, and zinc) were found above analytical detection limits in 2016.

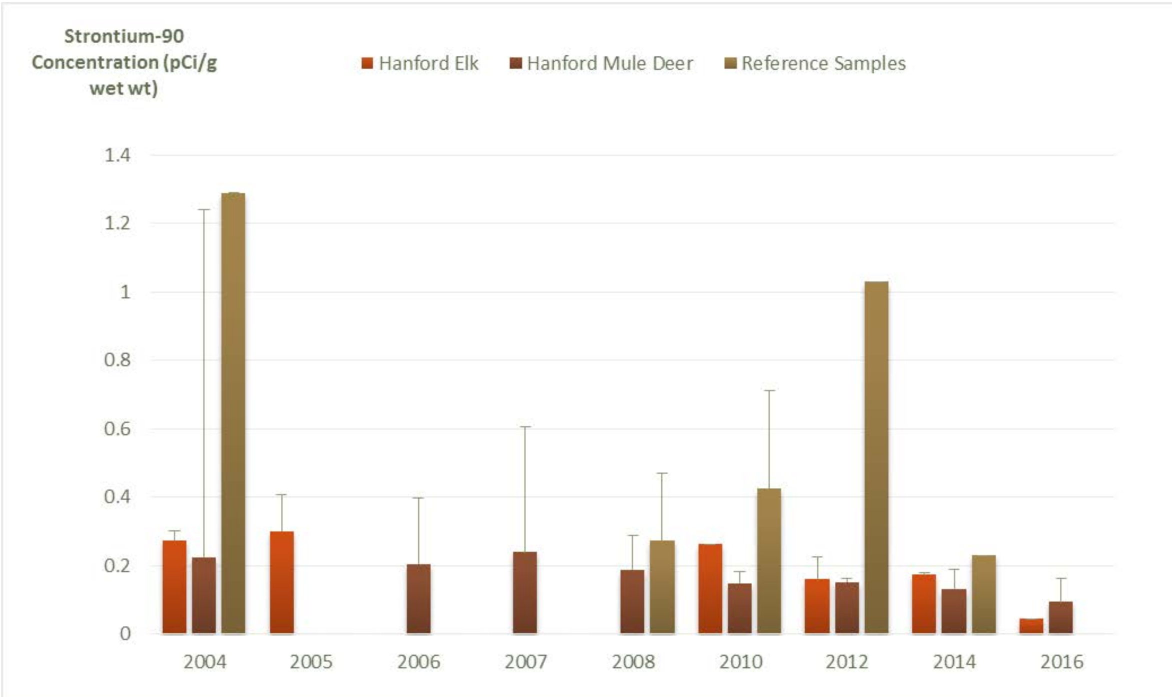


Figure 10-4. Mule Deer and Elk Bone Strontium-90 Concentrations.
(Maximum concentrations are represented by the upper bar)

10.2.4 Upland Game Birds

California quail are one of the most prevalent upland game birds found at the Hanford Site. Most quail that reside onsite are found along the Columbia River where trees and shrubs provide shelter. Quail forage for seeds, other plant parts, and grit in grassy and weedy places not far from cover. Ordinarily, quail do not travel far from where they hatch; as such, individual birds on the Hanford Site may spend their entire lives in the area they are collected. Quail can be exposed to persistent radionuclides when they forage on materials from plants that have roots in contact with contaminated groundwater or soil, drink contaminated water, or ingest contaminated grit. In 2016, 8 California quail were collected on the Hanford Site from the 100 Area and 10 were collected in the Hanford Townsite region. No quail were collected from a reference location in 2016 and all results will be compared to reference from 2014 and earlier. These quail were processed into eight samples, four from each region (including one duplicate sample and one lab split sample). Two quail from the Hanford Townsite location were sent to the WDOH oversight program for analysis. All quail were monitored for cesium-137 in muscle and strontium-90 in bone. Radionuclide levels found in muscle and bone samples analyzed during 2016 were compared to levels measured in upland game bird samples collected on the Hanford Site during the last 10 years and samples collected from reference locations.

10.2.4.1 Cesium-137. Manmade gamma-emitting radionuclide, cesium-137, was not detected above the detection limit (0.03 pCi/g [0.001 Bq/g] wet weight) for any upland game bird muscle samples analyzed in 2016. These results are consistent with those reported over the last 15 years, illustrating the continued downward trend in worldwide levels of cesium-137 fallout resulting from materials released to the atmosphere during the nuclear weapons testing era (1950s through the 1970s).

10.2.4.2 Strontium-90. Strontium-90 concentrations were detected in two quail bone samples collected in 2016. Comparisons of the maximum and median strontium-90 concentrations reported for game bird bone samples collected at the Hanford Site since 2002 and reference locations are consistent with these results, which do not indicate elevated levels of strontium-90 (Figure 10-5).

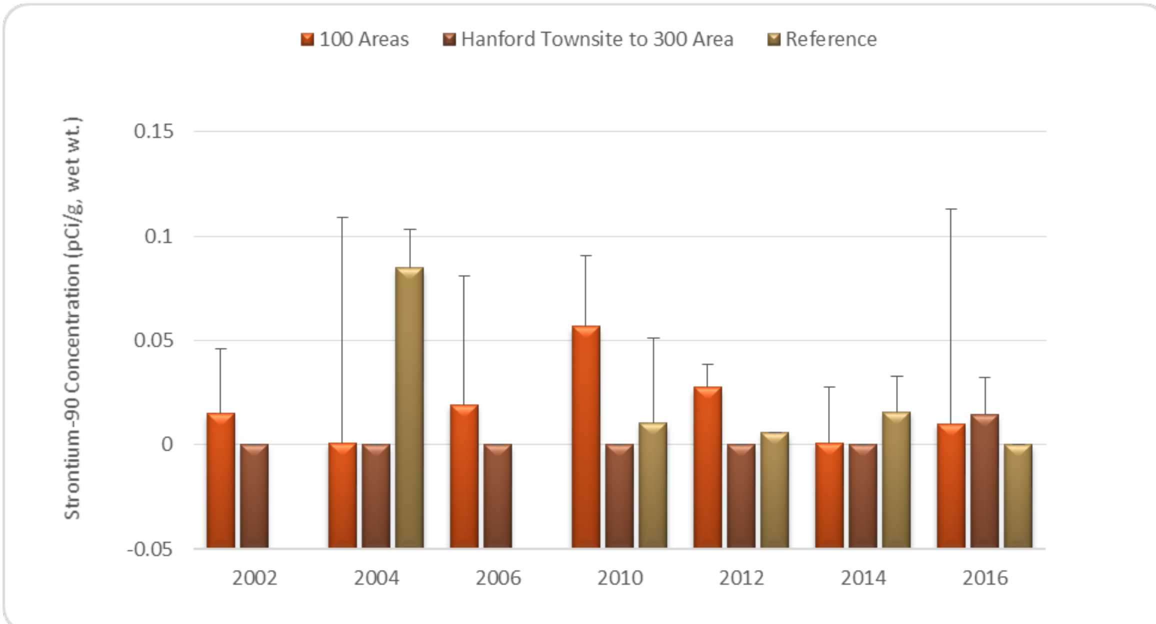


Figure 10-5. California Quail Bone Strontium-90 Concentrations.
(Upper bar represents maximum concentrations)

10.3 Vegetation Monitoring

JW Wilde

Vegetation monitoring conducted on and around the Hanford Site is summarized in this section. Included are discussions of surveying and monitoring of Hanford Site plant populations, monitoring contaminants in perennial vegetation growing near facilities and operations, and controlling contaminated or unwanted vegetation.

Plant populations and habitats that occur on the Hanford Site are surveyed and monitored to assess the abundance, vigor or condition, and distribution of populations and species. These data can be integrated with contaminant monitoring results and used to help characterize potential risks or impacts to biota. Vegetation near onsite facilities, waste sites, contamination areas and operations is monitored for radiation to determine the effectiveness of effluent monitoring and radioactive material controls, assess the adequacy of containment at waste disposal sites, and detect and monitor unusual conditions. Hanford Site and historical offsite vegetation samples are analyzed for information about atmospheric deposition of contaminants in and around areas onsite and in uncultivated areas offsite. These data provide a baseline against which unplanned releases can be compared. Vegetation management activities help prevent, limit, or remove contaminated plants or undesirable plant species. For further information about monitoring and control efforts, purpose, and programs that support them, refer to Section 10.3.3 or DOE/RL-91-50.

Monitoring rabbitbrush and sagebrush leaves and stems provides information about atmospheric deposition of radioactive materials in uncultivated areas and at Hanford Site locations that potentially could be affected by contaminants from Hanford Site operations. Collected on and around the Hanford Site for over 50 years, vegetation samples are maintained in a database to document onsite and offsite levels of synthetic radionuclides in vegetation at specific locations. This database contains baseline data against which statistics from unplanned releases from the Hanford Site can be compared.

Vegetation samples were collected on or adjacent to waste disposal sites and from locations downwind and near or within the boundaries of operating facilities and remedial action sites. Samples were collected to evaluate long-term trends in environmental accumulation and potential migration of radioactive material. Contamination in vegetation can occur as the result of surface deposition of radioactive materials from other radiologically contaminated sources or by absorption of radionuclides through the roots of vegetation growing on or near former waste disposal sites.

The number and location of Hanford Site vegetation samples collected are summarized in Table 10-5. Only those radionuclides with concentrations consistently above analytical detection limits are discussed in this section. Data obtained from onsite vegetation samples are used as a qualitative indicator and verification of ambient air sampling results per FF-01. Vegetation samples from offsite locations were collected in 2015, these samples are collected every 3 to 5 years.

Table 10-5. Vegetation Monitoring Locations.

Samples Analyzed	Operational Area (discrete samples analyzed)					
	100-N	200-East Area	200-West Area[a]	300 Area[a]	400 Area	600 Area[a]
49	2	9	21	2	1	14

[a] Sample numbers include one or more duplicates.

Individual vegetation samples (approximately 17.6 oz [500 g]) consisted of new-growth leaf cuttings taken from the available brushy, deep-rooted species (e.g., sagebrush and/or rabbitbrush). To avoid decimation of any individual plant through overharvesting, samples may consist of mixed biota representing several like members of the sampling site plant community. Vegetation samples were dried prior to analyses and analytical results were reported on a dry weight basis.

Individual samples are processed using a gridded pattern approach and combined with other samples from the decision unit to create a composite sample that represents the decision unit as a whole. This compositing limits the variability of selected environmental contaminant concentrations in a given area and reduces the amount of sampling error due to heterogeneity while allowing for a reproducible mean concentration for the decision unit.

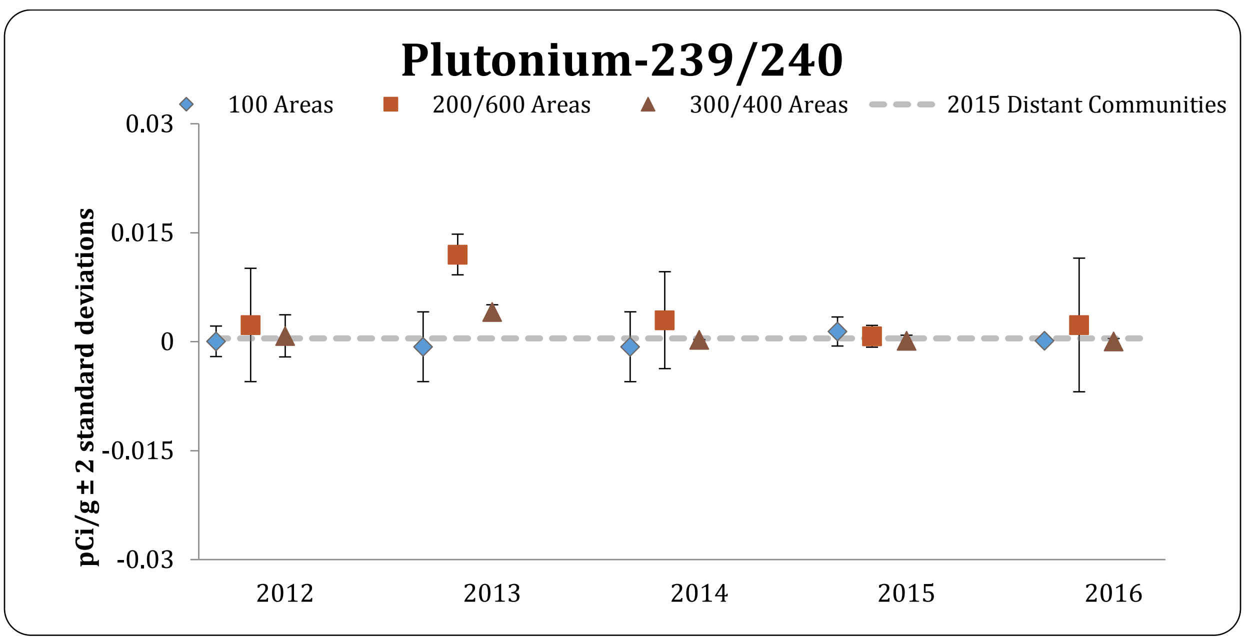
Samples were analyzed for the radionuclides expected to occur in the areas sampled (i.e., gamma-emitting radionuclides [cobalt-60 and cesium-137], strontium-90, uranium isotopes, and/or plutonium isotopes). Selected analytical results were compared to concentrations in samples collected during 2015 at offsite sampling locations in Yakima, Grant, and Franklin Counties. Comparisons can be used to determine the differences between contributions from site operations and remedial action sites, and contributions from natural sources and worldwide fallout.

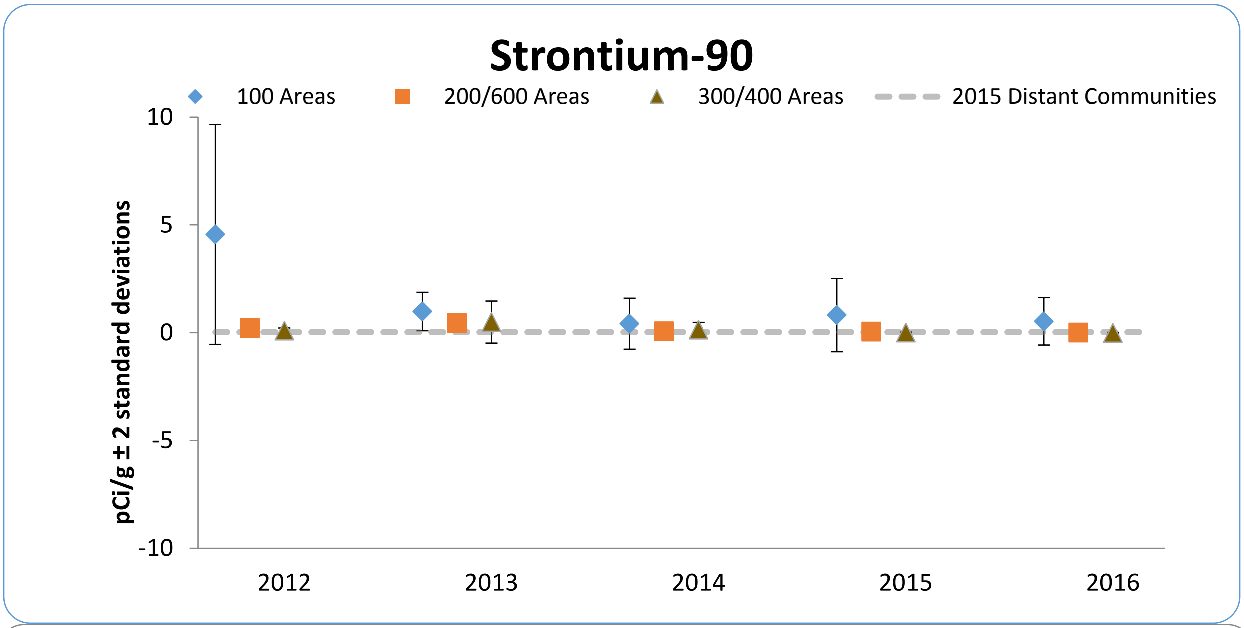
10.3.1 Vegetation Monitoring Results.

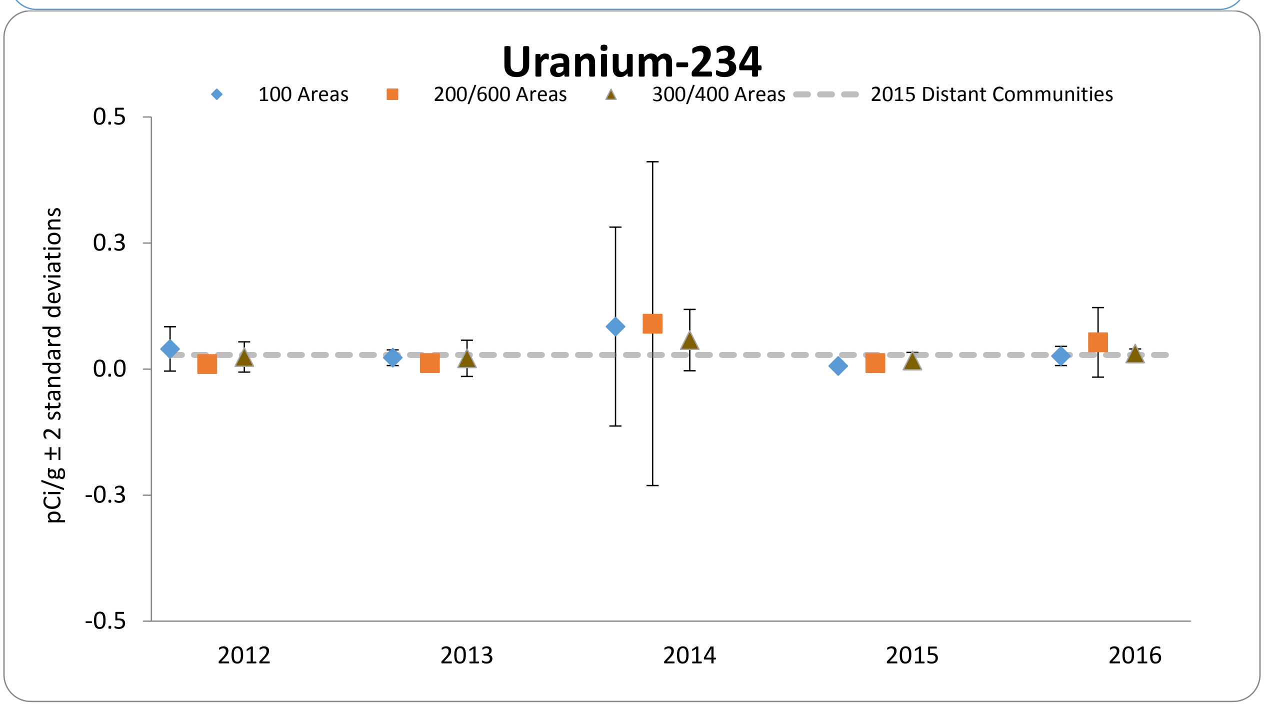
Some degree of variability is always associated with collecting and analyzing environmental samples; therefore, variations in sample concentrations are expected annually. In general, radionuclide concentrations in vegetation samples collected from or adjacent to waste disposal facilities in 2016 were similar to or slightly higher than concentrations in samples collected farther away, including concentrations measured offsite in 2015. Generally, the predominant radionuclides were activation and fission products in the 100 Area, fission products in the 200 and 600 Areas, and uranium in the 300 and 400 Areas.

Uranium-234, uranium-235, and/or uranium-238 were regularly detected in the 2016 samples. Three samples showed detectable concentrations of cesium-137 and three samples showed detectable strontium-90 levels. Concentrations of detected radionuclides were elevated near and within facility boundaries compared to historic concentrations measured at distant communities; however, they remained within the historical range of those collected within facility boundaries. Figure 10-6 shows the Hanford Site average concentration of selected radionuclides for vegetation samples.

Table 10-6 provides a summary of selected radionuclides detected in vegetation samples collected and analyzed in 2016 and previous years. The average and maximum results are reported for the six primary waste facility/operational areas of interest, including comparative data for the preceding 5 years.




Strontium-90
100 Areas
200/600 Areas
300/400 Areas
2015 Distant Communities
pCi/g ± 2 standard deviations
10
5
0
-5
-10
2012
2013
2014
2015
2016


Uranium-234
100 Areas
200/600 Areas
300/400 Areas
2015 Distant Communities
pCi/g ± 2 standard deviations
0.5
0.3
0.0
-0.3
-0.5
2012
2013
2014
2015
2016

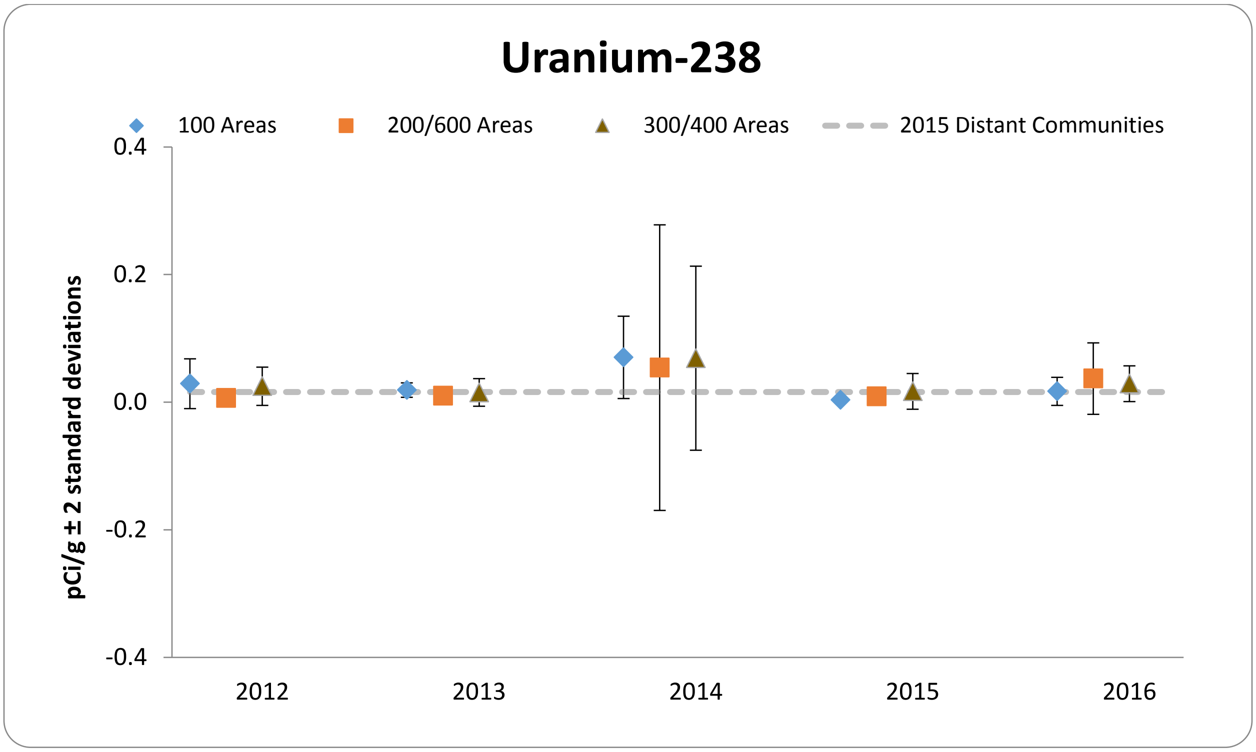


Figure 10-6. Hanford Site Vegetation Average Concentrations of Select Radionuclides.

Table 10-6. Hanford Site Vegetation Concentrations of Select Radionuclides. (3 Pages)

Isotope	Hanford Area	2016 Number of Samples	2016 Number of Detects	2016 Average[a] (pCi/gm)	2016 Maximum[b] (pCi/gm)	2011–2015 Number of Samples	2011–2015 Number of Detects	2011–2015 Average[a] (pCi/gm)	2011–2015 Maximum[b] (pCi/gm)
Cobalt-60	100	3	0	3.1E-02 ± 6.9E-02	7.7E-02 ± 6.7E-02	12	0	-7.5E-05 ± 2.7E-02	1.9E-02 ± 4.4E-02
	200-East	9	0	5.3E-03 ± 2.7E-02	2.7E-02 ± 3.4E-02	38	0	1.7E-03 ± 4.1E-02	5.4E-02 ± 1.1E-01
	200-West	21	0	2.0E-03 ± 2.8E-02	3.5E-02 ± 3.4E-02	65	0	-3.8E-03 ± 4.3E-02	6.4E-02 ± 4.7E-02
	300	2	0	1.5E-02 ± 3.0E-04	1.5E-02 ± 2.8E-02	27	0	-8.3E-03 ± 5.8E-02	3.9E-02 ± 3.5E-02
	400	1	0	2.40E-02	2.4E-02 ± 2.4E-02	4	0	-5.7E-03 ± 3.4E-02	2.1E-02 ± 5.2E-02
	600	14	0	6.0E-03 ± 3.0E-02	3.0E-02 ± 2.2E-02	46	0	9.8E-03 ± 4.1E-02	6.7E-02 ± 6.5E-02
Cesium-137	100	3	0	5.3E-03 ± 4.0E-02	2.2E-02 ± 5.9E-02	12	1	1.4E-02 ± 4.7E-02	5.7E-02 ± 5.0E-02
	200-East	9	1	2.4E-02 ± 5.6E-02	9.1E-02 ± 3.3E-02	38	16	6.2E-02 ± 1.1E-01	2.4E-01 ± 2.6E-02
	200-West	21	1	1.9E-02 ± 4.4E-02	8.6E-02 ± 2.9E-02	65	17	4.8E-02 ± 1.2E-01	3.2E-01 ± 1.2E-01
	300	2	0	3.3E-02 ± 2.0E-02	4.3E-02 ± 4.8E-02	27	9	7.4E-02 ± 1.9E-01	3.6E-01 ± 9.7E-02
	400	1	0	-2.50E-03	-2.5E-03 ± 1.9E-02	4	0	2.5E-02 ± 6.5E-02	7.7E-02 ± 5.9E-02
	600	14	1	2.2E-02 ± 6.9E-02	1.3E-01 ± 3.5E-02	46	10	4.2E-02 ± 1.1E-01	2.0E-01 ± 8.6E-02
Plutonium-238	100	3	0	-1.8E-04 ± 7.1E-04	9.3E-05 ± 3.3E-04	11	0	-4.9E-04 ± 4.3E-03	2.7E-03 ± 6.5E-03
	200-East	6	0	4.3E-05 ± 1.2E-04	1.4E-04 ± 1.9E-04	38	2	7.5E-04 ± 1.0E-02	1.6E-02 ± 1.9E-02
	200-West	20	2	4.6E-05 ± 3.3E-04	4.6E-04 ± 3.4E-04	65	3	5.3E-04 ± 1.1E-02	2.7E-02 ± 1.2E-02
	300	2	0	-7.3E-05 ± 1.1E-04	-2.0E-05 ± 1.6E-04	27	1	1.9E-03 ± 1.1E-02	1.9E-02 ± 2.1E-02
	400	1	0	4.60E-05	4.6E-05 ± 2.0E-04	4	0	3.4E-05 ± 1.3E-03	8.1E-04 ± 5.4E-03
	600	13	0	2.0E-05 ± 2.6E-04	2.1E-04 ± 2.4E-04	45	0	1.1E-03 ± 1.4E-02	3.2E-02 ± 2.3E-02
Plutonium-239/-240	100	1	0	1.40E-04	1.4E-04 ± 4.1E-04	12	1	2.6E-04 ± 2.3E-03	2.1E-03 ± 1.0E-03
	200-East	8	3	7.9E-04 ± 2.4E-03	3.7E-03 ± 6.8E-04	38	4	1.3E-03 ± 3.3E-03	5.7E-03 ± 5.6E-03
	200-West	21	15	4.2E-03 ± 1.2E-02	2.1E-02 ± 2.0E-03	65	31	2.4E-02 ± 3.2E-01	1.3E+00 ± 2.8E-01
	300	2	0	-9.3E-05 ± 6.6E-05	-6.0E-05 ± 2.4E-04	27	0	9.9E-04 ± 2.9E-03	4.4E-03 ± 5.5E-03
	400	1	0	3.20E-04	3.2E-04 ± 2.8E-04	4	0	7.7E-04 ± 3.5E-03	3.7E-03 ± 4.3E-03

Table 10-6. Hanford Site Vegetation Concentrations of Select Radionuclides. (3 Pages)

Isotope	Hanford Area	2016 Number of Samples	2016 Number of Detects	2016 Average[a] (pCi/gm)	2016 Maximum[b] (pCi/gm)	2011–2015 Number of Samples	2011–2015 Number of Detects	2011–2015 Average[a] (pCi/gm)	2011–2015 Maximum[b] (pCi/gm)
	600	14	3	2.4E-04 ± 8.6E-04	1.3E-03 ± 5.5E-04	46	7	6.6E-04 ± 4.5E-03	7.3E-03 ± 9.7E-03
Strontium-90	100	3	3	5.3E-01 ± 1.1E+00	1.3E+00 ± 2.6E-01	12	11	2.3E+00 ± 7.6E+00	1.3E+01 ± 1.7E+00
	200-East	9	0	-1.8E-03 ± 3.6E-02	2.5E-02 ± 2.9E-02	38	23	2.8E-01 ± 5.1E-01	1.0E+00 ± 2.8E-01
	200-West	21	0	8.5E-03 ± 4.0E-02	4.2E-02 ± 3.3E-02	65	18	1.3E-01 ± 3.7E-01	7.4E-01 ± 2.0E-01
	300	2	0	-2.6E-02 ± 1.7E-02	-1.7E-02 ± 2.3E-02	27	10	1.6E-01 ± 4.1E-01	8.4E-01 ± 1.9E-01
	400	1	0	7.50E-03	7.5E-03 ± 2.4E-02	4	0	4.0E-02 ± 1.3E-01	1.5E-01 ± 1.7E-01
	600	14	0	5.2E-03 ± 4.3E-02	3.5E-02 ± 2.7E-02	46	9	1.0E-01 ± 4.3E-01	1.3E+00 ± 3.4E-01
Uranium-234	100	3	2	2.6E-02 ± 1.9E-02	3.9E-02 ± 1.3E-02	12	9	3.6E-02 ± 1.0E-01	1.8E-01 ± 1.4E-01
	200-East	9	9	7.9E-02 ± 5.3E-02	1.2E-01 ± 4.0E-02	38	25	4.1E-02 ± 1.8E-01	3.6E-01 ± 1.8E-01
	200-West	21	19	3.1E-02 ± 4.5E-02	9.4E-02 ± 4.5E-02	65	48	2.8E-02 ± 1.3E-01	3.4E-01 ± 1.7E-01
	300	2	2	3.4E-02 ± 3.8E-03	3.5E-02 ± 1.4E-02	27	23	2.9E-02 ± 5.2E-02	1.1E-01 ± 3.8E-02
	400	1	1	2.50E-02	2.5E-02 ± 1.3E-02	4	3	1.9E-02 ± 2.1E-02	3.6E-02 ± 1.2E-01
	600	14	13	6.9E-02 ± 6.7E-02	1.4E-01 ± 4.7E-02	46	30	1.1E-02 ± 7.5E-02	1.3E-01 ± 1.3E-01
Uranium-235	100	3	2	1.7E-02 ± 2.5E-03	1.8E-02 ± 1.1E-02	12	3	1.0E-02 ± 2.4E-02	4.4E-02 ± 1.1E-01
	200-East	9	9	5.0E-02 ± 3.3E-02	8.1E-02 ± 3.8E-02	38	9	4.3E-02 ± 3.3E-01	1.0E+00 ± 0.0E+00
	200-West	20	8	1.7E-02 ± 4.0E-02	6.8E-02 ± 3.6E-02	65	19	7.9E-03 ± 9.6E-02	1.6E-01 ± 1.2E-01
	300	2	2	2.30E-02	2.3E-02 ± 1.2E-02	27	4	2.9E-03 ± 1.2E-02	8.8E-03 ± 7.3E-03
	400	1	1	1.30E-02	1.3E-02 ± 1.1E-02	4	0	2.5E-02 ± 7.4E-02	8.9E-02 ± 1.1E-01
	600	14	8	3.6E-02 ± 5.0E-02	7.7E-02 ± 3.9E-02	45	9	-3.8E-04 ± 5.8E-02	5.8E-02 ± 1.0E-01
Uranium-238	100	3	2	1.7E-02 ± 2.2E-02	2.7E-02 ± 1.2E-02	12	8	2.8E-02 ± 6.1E-02	1.0E-01 ± 1.2E-01
	200-East	9	8	5.2E-02 ± 3.3E-02	8.7E-02 ± 3.6E-02	38	19	2.5E-02 ± 7.7E-02	1.4E-01 ± 1.3E-01
	200-West	21	13	2.6E-02 ± 5.7E-02	1.2E-01 ± 3.8E-02	65	41	1.5E-02 ± 6.7E-02	1.4E-01 ± 1.1E-01
	300	2	2	3.8E-02 ± 6.0E-03	4.1E-02 ± 1.5E-02	27	26	3.1E-02 ± 5.6E-02	1.2E-01 ± 1.1E-01

Table 10-6. Hanford Site Vegetation Concentrations of Select Radionuclides. (3 Pages)

Isotope	Hanford Area	2016 Number of Samples	2016 Number of Detects	2016 Average[a] (pCi/gm)	2016 Maximum[b] (pCi/gm)	2011–2015 Number of Samples	2011–2015 Number of Detects	2011–2015 Average[a] (pCi/gm)	2011–2015 Maximum[b] (pCi/gm)
	400	1	0	9.40E-03	9.4E-03 ± 9.1E-03	4	3	1.1E-02 ± 8.8E-03	1.8E-02 ± 7.9E-02
	600	14	10	4.4E-02 ± 5.2E-02	9.4E-02 ± 4.3E-02	46	32	9.8E-03 ± 9.7E-02	1.6E-01 ± 2.5E-01

[a] Average ± two standard deviations
[b] Maximum ± analytical uncertainty

Vegetation samples collected in 2016 at locations in the 100-N, 200-East, 200-West, 400, and 600 Areas were comparable to those collected in previous years. Vegetation samples collected in the 200 and 600 Areas showed concentrations of uranium-234, uranium-235, and uranium-238 that were comparable to historical data. The uranium levels are a result of uranium releases to the environment during past fuel-fabrication operations in that area. The range of strontium-90 concentrations was comparable to historical levels.

10.3.2 Radiological Contamination

JW Wilde, RC Roos

Investigations of radioactive contamination were conducted in and near operational areas to monitor the presence or movement of radioactive materials around areas of known or suspected contamination or to verify radiological conditions at specific project sites. All surveys performed during investigations were field-surveyed for alpha- and beta-gamma radiation.

Radiological contamination was found in vegetation during 45 incidents during the 2016 investigations; 44 were Russian thistle (*Salsola tragus*) plants or fragments and 1 plant material was unidentified. No samples were analyzed for specific radionuclides. Surveys resulted in 3 locations posted as contamination areas; 42 contaminated vegetation discoveries were disposed at a licensed facility.

Section 10.3.3 provides a discussion of the vegetation control on the Hanford Site. Table 10-7 summarizes the number and general locations of vegetation contamination incidents discovered from 2000 to 2016.

Table 10-7. Hanford Site Vegetation Contamination Incidents Investigated. (2 Pages)

Location	2016 Incidents	Year	Incidents
100 Area	0	2000	66
200-East Area		2001	20
Tank farms	5	2002	16
Burial grounds	11	2003	32
Cribs, ponds, and ditches	3	2004	60
Fence lines	6	2005	66
Roads and railroads	0	2006	75
Unplanned release sites	0	2007	62
Underground pipelines	1	2008	127
LERF/ETF	10	2009	109
Miscellaneous	0	2010	36
200-West Area		2011	10
Tank farms	3	2012	18
Burial grounds	1	2013	35
Cribs, ponds, and ditches	4	2014	50
Fence lines	1	2015	48
Roads and railroads	0	**2016**	**45**
Unplanned release sites	0		
Underground pipelines	0		
Miscellaneous	0		
Cross-site transfer line	0		

Table 10-7. Hanford Site Vegetation Contamination Incidents Investigated. (2 Pages)

Location	2016 Incidents	Year	Incidents
600 Area burial grounds	0		
200-North Area	0		
300 Area	0		
400 Area	0		
600 Area	0		
1100 Area	0		
Total	**45**		

10.3.3 Vegetation Control

JM Rodriguez, RC Roos

The purpose of vegetation control at the Hanford Site is effective control and minimization of noxious weeds, industrial weeds, and other vegetation to ensure protection of Hanford Site workers, the public, facilities, property, and the site's cultural and environmental (including biological) resources. Risks that are mitigated through effective vegetation control are the spread of contamination, wildfire fuel loading, harborage of vermin and insect pests around facilities, damage and destruction of native plant communities, damage to facilities, and interference with work and transportation.

Approximately 5,444 ac (2,203 ha) were treated with herbicides in 2016 on radiological waste sites, around operations areas, and along roadways to keep areas free of deep-rooted vegetation (e.g., Russian thistle, also known as tumbleweed). Follow-up treatments are included in the total treated acres; several areas received more than one herbicide application.

Noxious Weeds. Noxious weeds are controlled at the Hanford Site to prevent their spread and eliminate populations. A noxious weed is a legal and administrative category designated by federal or state regulatory agencies (e.g., the U.S. Department of Agriculture or Washington State Department of Agriculture). Noxious weeds are non-native, aggressively invasive, and hard to control. Noxious weed plant communities degrade ecosystems unless control measures are taken. Control measures can be mechanical, chemical, cultural, or biological. Approximately 85 ac (34 ha) of noxious weeds on the Hanford Site were treated with herbicides in 2016 along roadways and abandoned rail lines. The *Environmental Assessment: Integrated Vegetation Management on the Hanford Site, Richland, Washington* (DOE/EA-1728-F) was completed in 2012.

Ten plant species are on a high-priority list for control at the Hanford Site. These species are described in the following paragraphs, along with a summary of 2016 control activities.

Yellow Starthistle (Centaurea solstitialis). Yellow starthistle represents the most rapidly expanding weed infestation in the western United States. Since 1995, yellow starthistle has been the highest priority weed for the Hanford Site noxious-weed control program because it has the potential to invade the entire site and have a dramatic impact on the ecology of the site and neighboring lands. Control measures for yellow starthistle have included spot treatments and broadcast applications by ground equipment and aerial sprayers, biological control, and hand weeding in critical locations. Major populations near the Hanford Townsite have been reduced to scattered individual plants, mostly near live trees where aerial herbicide applications were not made. Control of yellow starthistle in 2016 consisted of hand pulling individual plants as they were identified and spot treatment with herbicides on roadways and in areas of the Hanford Townsite.

Yellow starthistle seeds are known to remain viable for 10 years in the soil. The small number of seedlings found over much of the area of infestation indicates the seed bank is being exhausted. If diligent control efforts are continued over the next few years, the yellow starthistle population at Hanford can change from a major infestation to a monitoring and eradication effort.

Biological control agents for yellow starthistle are widely distributed across the infested area and have been highly effective during the early part of the flowering season. However, the adult phase of the control agent's annual lifecycle is completed before the end of the flowering season. Consequently, flowers opening late in the season are largely spared the effects of insect predation.

Successful control of yellow starthistle in the past has substantially reduced populations in both area and density. The biological control organisms require yellow starthistle in order to complete their lifecycle. The reduced plant population can no longer sustain a robust population of biological control organisms. As the population of bio controls fails, greater emphasis needs to be placed on effective monitoring and control of the plants to continue toward eradication of yellow starthistle at Hanford.

Rush Skeletonweed (Chondrilla juncea). Rush skeletonweed is a challenging species to control because their seeds are spread by the wind, allowing seedlings to germinate and begin new populations miles away from other plants. The deep and extensive root system of rush skeletonweed makes it extremely difficult to control using herbicides. Herbicide application may kill the main plant, but roots deep in the soil or far from the green portion of the plant often avoid the effects of herbicide. Those roots can remain living in the soil for several years, eventually sending sprouts to the surface to begin new plants long after the effects of herbicide application have ended.

Rush skeletonweed is scattered over large areas of the Hanford Site. Areas of dense rush skeletonweed infestation north of the Wye Barricade largely have been eliminated. Nevertheless, considerable rush skeletonweed remains as scattered individual plants. Populations of rush skeletonweed have increased south of the Wye Barricade. Reduction in active control efforts over the past few years, while NEPA requirements have been evaluated, has allowed populations of skeletonweed to increase in both aerial extent and density. Rush skeletonweed has become the most challenging noxious weed to control on the Hanford Site due to the large aerial extent of infestation, density of infestation, and sustained effort required to eliminate individual plants and populations.

Biological control agents commonly applied to rush skeletonweed at the Hanford Site have not significantly reduced plant populations or seed production.

Babysbreath (Gypsophila paniculata). Babysbreath is generally resistant to control by herbicides; however, the above-ground portion of the plant can be destroyed by some herbicides that can prevent flowering and seed production. The plants should be eradicated by continually removing the top portions through herbicide use. By removing the green portions of the plants, the energy reserves in the roots will eventually be depleted, killing the plant. Mainly found in the Hanford Townsite, babysbreath was not controlled in 2016 due to limited resources for the effort.

Dalmatian Toadflax (Linaria genistifolia ssp. dalmatica). A small population of dalmatian toadflax is found near Energy Northwest on the Hanford Site. Sprouts and seedlings of the long-lived perennial plant will be eliminated as they are identified. The current population consists of plants widely scattered across the area of infestation. The low-density population is not conducive to successful establishment of predatory species. Consequently, no biological controls have been released at the Hanford Site for dalmatian toadflax. Toadflax growing along road shoulders were controlled using herbicides.

Diffuse Knapweed (Centaurea diffusa). In 2016, control of diffuse knapweed was limited to herbicide application on roadways and railroad right-of-ways, and hand pulling in critical areas. The population of this species near the Columbia River high watermark has not been actively controlled by herbicides because of the biological sensitivity of the area. Several biological control agents are established at Hanford.

Tackweed (Tribulus terrestris). Tackweed has become increasingly common on the Hanford Site over the past several years. In 2016, a large population found at the Hanford Townsite was controlled using a combination of herbicide application and hand pulling. Other tackweed found across the Hanford Site as individual plants or small populations were also controlled.

Purple Loosestrife (Lythrum salicaria). The banks of the Columbia River and islands along the Hanford Site are monitored for purple loosestrife, as these locations in these areas are appropriate for this weed. Individual plants and small populations are found along the south and west bank of the river. Under good ecological conditions, biological measures for controlling purple loosestrife are effective; however, widely fluctuating water levels along the Columbia River destroy the biological control organisms as they attempt to over-winter soil at the base of the plants. Winter mortality prevents effective population control agents from developing. No control measures were applied in 2016 for purple loosestrife.

Russian Knapweed (Acroptilon repens). Biological controls for Russian knapweed are limited, and their success has been poor in the semi-arid climate of the Hanford Site. Chemicals and other control techniques are being developed that promise to be effective with this difficult-to-control species.

Saltcedar (Tamarix spp.). Several individual plants of saltcedar were found at the Hanford Site in years past. Most are the remainders from ornamental plantings near homes in the early part of the previous century. A few populations are the result of natural seed dispersal. Most individual plants south and west of the Columbia River have been eliminated. Those remaining continue to be treated with herbicide and will be monitored until they are eradicated.

Saltcedar roots are very deep and store a great deal of energy, making control of the species difficult. A few trees that were treated with herbicide in 2014 began to show new green growth in 2016. Effective control of weeds often depends on the plant having sufficient green-leaf area for herbicide to enter the plant. The small amount of green growth found in 2016 was not sufficient for effective herbicide application. It is expected that these trees will be sprayed with herbicide in 2017.

Spotted Knapweed (Centaurea maculosa). Spotted knapweed at the Hanford Site has been controlled so that sprouts or seedlings are rare. In 2016, no sprouts or seedlings were found. The Hanford Site will continue to be monitored for several years to ensure that viable seeds and roots have been eliminated from the soil. Cooperative efforts with neighboring landowners continue to eliminate spotted knapweed near the Hanford Site. The root-feeding weevil *Cyphocleonus achates* has been released specifically to help eradicate spotted knapweed at Hanford; however, it is expected that the population is too small and scattered to sustain a biological control population. *Cyphocleonus* is known to use diffuse knapweed; it is hoped that this weevil will establish in diffuse knapweed and cross over to control spotted knapweed when it appears. Most biological controls for diffuse knapweed also are effective for spotted knapweed.

10.4 Waste Site Remediation and Revegetation

RC Roos, JM Rodriguez

In 2016, only 2 ac (0.8 ha) across the Hanford Site were planted with grass seed to stabilize areas where traffic and erosion had damaged the grass cover on waste sites. Waste sites in the 200-East and 200-West Areas were designed and constructed with a cap of perennial grass essential to performance of engineered waste sites. However, soil used as backfill and cover on waste sites was often sandy, which provides a poor medium for growth of the grass. Over the years, poor soil combined with lack of maintenance has resulted in degradation and decreased function of the vegetative caps on many waste sites. Integrated Biological Control has been actively restoring vegetative caps on waste sites.

Vegetative caps on waste sites perform three primary functions:

- **Prevent Erosion.** A well-designed and maintained grass cap stabilizes soil on waste sites by physically covering the soil surface and serves as a windbreak, reducing wind velocity at the soil surface.

- **Exclude Tumbleweed Growth.** Tumbleweeds are the main biological vector of contamination spread on the Hanford Site. They are deep-rooted annual plants that quickly invade and establish on disturbed soil. The deep roots readily absorb radionuclides buried in the soil and transport them to the aboveground portions of the plant. At the end of the 1-year lifecycle, dead tumbleweeds detach from the roots and become mobile, transporting radioactive contamination from posted and monitored disposal areas.

  A well-designed and maintained grass cap excludes tumbleweeds by direct competition for space and nutrients (primarily water). Stabilized soil forms a crypto-biotic crust composed of moss, lichen, algae, and other organisms that provide a poor surface for germination of tumbleweed seeds. The combination of competition for resources and prevention of germination effectively excludes tumbleweeds from establishing on waste sites.

- **Prevent Water Percolation through the Soil Column.** Waste sites were designed with vegetative caps to prevent natural precipitation moving through the soil column and washing radioactive or hazardous materials downward toward groundwater.

  The 6- to 7-in. (15- to 18-cm) average precipitation received at the Hanford Site typically percolates 2 to 4 ft (0.6–1.2 m) into the soil during the winter. Evaporation during summer months removes some moisture from the soil. However, as surface soil dries, it acts as a mulch, which inhibits further evaporation. Evaporation alone does not remove all the natural precipitation from the soil. Water remaining in the soil from the previous year has an additive effect during the subsequent wet season, allowing water to percolate to increasing depth.

Vegetative caps on waste sites were designed so that in addition to evaporation from the soil surface, plant roots would mine water from deeper in the soil profile, transporting it to leaves where it is lost through evaporation. The process of water moving from soil into plant roots, through the plant, and out the leaves to the atmosphere is transpiration. The combination of evaporation and transpiration removes sufficient moisture from the soil so that precipitation during subsequent wet seasons falls on dry soil, yielding no net increase in depth of percolation. Effective containment of waste in burial grounds depends on the combination of evaporation and transpiration drying the soil, preventing additive percolation and transport of contaminants to groundwater.

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