4. Confirmation of Exposure

DOI regulations require Assessment Plans to confirm that:

> at least one of the natural resources identified as potentially injured in the preassessment screen has in fact been exposed to the released substance [43 CFR § 11.37(a)].

A natural resource has been exposed to hazardous substances if "all or part of [it] is, or has been, in physical contact with . . . a hazardous substance, or with media containing the . . . hazardous substance" [43 CFR § 11.14(q)]. The regulations also state that "whenever possible, exposure shall be confirmed using existing data" from previous studies of the assessment area [43 CFR § 11.37(b)(1)].

This chapter first discusses transport pathways, which are the routes or media through which hazardous substances are or were transported from the source of the release to the injured resource [43 CFR § 11.14 (dd)]. At the Arsenal, most of the hazardous substances were deposited on soils or in waste basins. Section 4.2 then confirms that soils, air, sediments, surface and groundwater, as well as aquatic and terrestrial biota and their supporting habitats, have been exposed to hazardous substances. The conclusions in this chapter rely solely on pre-existing data.

4.1 Contaminant Pathways

CERCLA allows Trustees to recover NRDs for injuries that have resulted from releases of hazardous substances. To make the link between release and injury, Trustees examine pathways through which hazardous substances travel. Pathways may be direct, such as a release into surface water causing injury to that water body. Pathways may also be indirect, such as a release to the ground surface that enters the bodies of earthworms, then into small birds that eat the worms, finally causing injury to the eagles that eat the small birds. In the second example, the soils, worms, and small birds are all pathway resources.

Pathways are determined using information about the nature and transport of the hazardous substances, and data documenting the presence of the hazardous substance in the pathway resource. As part of the assessment, the Trustees will use existing data to confirm that resources have been exposed to hazardous substances directly or through contaminant pathways. Specifically, to determine pathways of hazardous substances, the Trustees consider:

- The chemical and physical characteristics of the released hazardous substance when transported by natural processes or while present in natural media [43 CFR § 11.63(a)(1)(i)]
- The rate or mechanism of transport by natural processes of the released hazardous substance [43 CFR § 11.63(a)(1)(ii)]
- Combinations of pathways that, when viewed together, may transport the released hazardous substance to the resource [43 CFR § 11.63(a)(1)(iii)].

The pathway may be determined by either demonstrating the presence of the hazardous substance in sufficient concentrations in the pathway resource or by using a model that demonstrates that the conditions existed in the route and in the hazardous substance such that the route served as the pathway [43 CFR § 11.63(a)(2)]. Data presented in this chapter show sufficient concentrations in pathway resources. Also included is a discussion of a contaminant uptake model that demonstrates how hazardous substances in contaminated soils can injure wildlife resources. Chapter 6 discusses the model in more detail.

Figure 4.1 is a simplified diagram showing pathways by which hazardous substances are transported from hazardous substance sources at the Arsenal to natural resources of the State. In general, hazardous substances were released directly into surface water, sediments, and soil. Plants and invertebrates accumulate the hazardous substances. Biota that ingest these plants and invertebrates accumulate and sometimes “biomagnify” the hazardous substances, such that tissue concentrations (and adverse effects) of the hazardous substances can be greater in higher-level predators. To reach groundwater, hazardous substances in soil, surface water, and sediment either infiltrate the underlying unsaturated zone or are transferred to groundwater via a direct hydrologic connection. The following sections describe these pathways in more detail.

4.1.1 Groundwater pathways

In general, the sources of hazardous substances in groundwater are chemical spills on the ground or disposal into waste trenches, sewers, ditches, lagoons, and basins. Ebasco Services et al. (1989), contractors for the Army, describe the following mechanisms by which contaminants migrate from source areas to groundwater:

- Direct contact with source areas that are below the water table
- Percolation from soils downward through the unsaturated zone
- Hydraulic interchange with contaminated surface water/sediments
- Downward migration along an improperly constructed well bore.

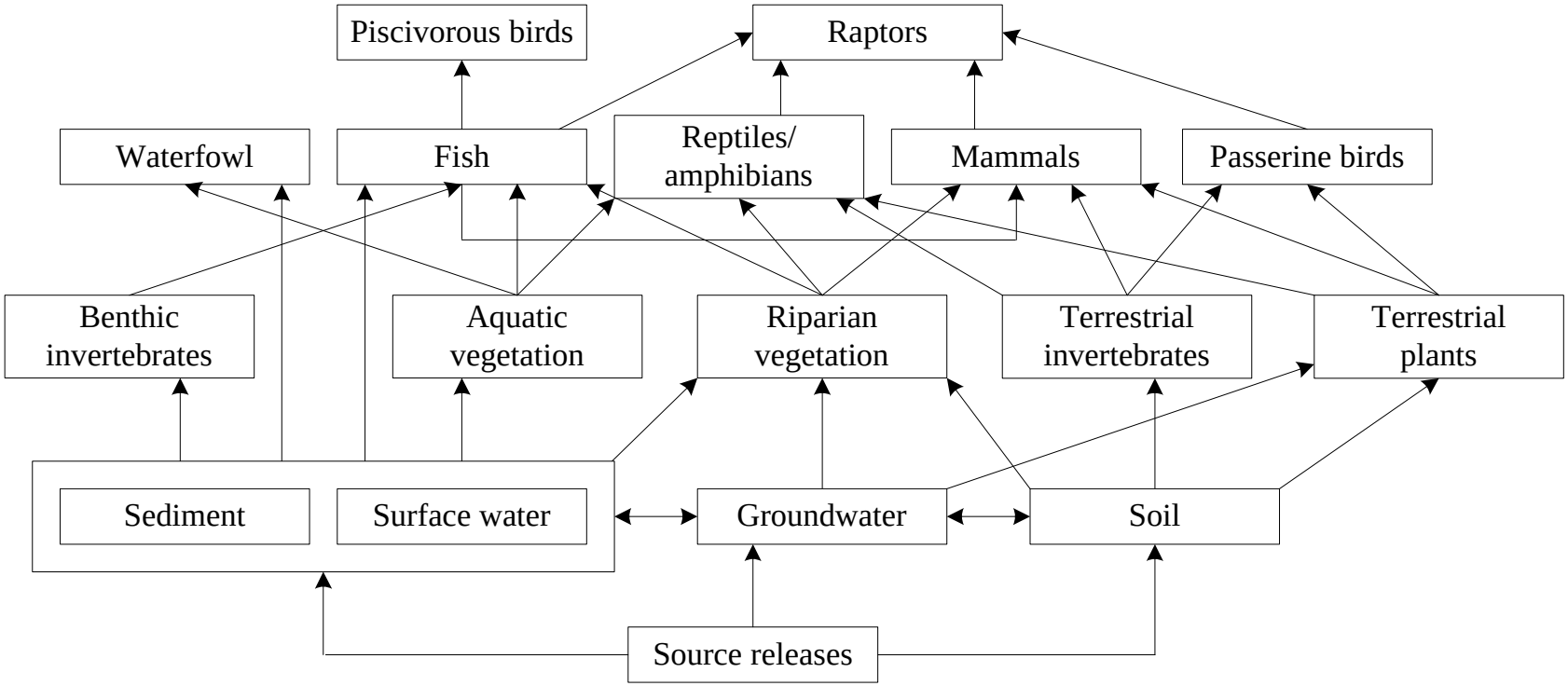

Figure 4.1. Simplified pathways by which hazardous substances are transported from the hazardous substances sources at the Arsenal to natural resources of the State. Pathways to air resources (not shown) include direct releases from source areas and soils.

Stormwater and snowmelt can dissolve contaminants in soils, carrying the contaminants downward through the unsaturated zone to the water table. In addition, large spills of liquid contaminants may percolate through the unsaturated zone and enter the groundwater undiluted. Direct percolation of contaminants may also occur from the waste disposal basins, sewers, and ditches that transported and accumulated industrial wastes at the site (Ebasco Services et al., 1989).

The RI Summary Report (Ebasco Services et al., 1992a) contains the following confirmations of the pathways to groundwater:

- "There are 14 basin and lagoon sites containing approximately 4.3 million bcy of contaminated material. Basins and lagoons formerly used for liquid waste disposal are among the most contaminated sites at the Arsenal . . . contaminant concentrations in soils at several of these sites exceed levels detected elsewhere at the Arsenal, and groundwater contaminant plumes are observed to originate below these sources. The continuous presence of contaminant occurrences throughout the unsaturated soil column below many of these sites supports the conclusion that the more contaminated basins and lagoons are sources of groundwater contamination" (Ebasco Services et al., 1992a, p. 2-12).

- "Like the disposal basins, burial trenches contain a wide variety of contaminants, most notably Army agent breakdown products, volatile organic compounds, and metals . . . These trenches have been identified as sources of pesticides, agent breakdown products, and volatile organics in groundwater" (Ebasco Services et al., 1992a, p. 2-14).

- "Leakage from faulty joints and fractures [of chemical sewers] historically allowed infiltration of wastewater into subsurface soils . . . Several portions of the chemical sewer are characterized by a wide variety of contaminants at moderate to high concentrations . . . [The chemical sewers] are significant because of their potential to contribute large volumes of contaminants to soil and groundwater" (Ebasco Services et al., 1992a, p. 2-19).

Pathways by which contaminants reach deeper aquifers are either through direct contact with the contaminated shallow aquifer, or through improper well construction. The Denver aquifer underlies the shallow aquifer; the upper Denver aquifer includes some weathered sandstone and fractures that have a direct hydraulic connection to the upper alluvium. Chapter 5 discusses the aquifers underlying the Arsenal and the extent of any downward migration of contamination in more detail.

For a period between 1962 and 1966, the Arsenal liquid wastes were directly injected into a well that was over 12,000 ft deep, thousands of feet below all usable deep aquifers underlying the Arsenal. This well was sealed in 1985 (Foster Wheeler, 1996). The direct injection of contaminants into this well served only as a pathway to Precambrian basement rock; these deep contaminants are unlikely to affect any of the usable overlying aquifers.

4.1.2 Surface water/sediment pathways

The banks, beds, and suspended sediments of water bodies are considered part of surface water resources, according to the DOI regulations [43 CFR § 11.14 (pp)].

Hazardous substances were released directly into surface water resources through chemical sewers and ditches, as well as indirectly via groundwater. Some example releases of hazardous substances to surface water resources include:

- Releases directly from the South Plants Complex to Lower Derby Lake and the Sand Creek Lateral (Ebasco Services et al., 1989)
- Releases from the North Plants Complex to ditches that could transport the hazardous substances to First Creek during storm events (Ebasco Services et al., 1989)
- Releases from the Arsenal wastewater treatment plant directly to First Creek (Ebasco Services et al., 1989)
- Releases from contaminated groundwater to First Creek at the northern boundary of the Arsenal (Harding Lawson Associates, 1992).

Hazardous substances may also have been transported to surface water resources from soils through aerial deposition from wind. Most of the contaminants of concern at the Arsenal are hydrophobic and thus are likely to sorb to sediment rather than remain dissolved in surface water.

4.1.3 Soil pathways

Most of the hazardous substances in soils were released directly onto the soils. Some of the waste disposal basins were under water at the time of contaminant disposal; the contaminated sediment in the basins subsequently became contaminated soil when the basins were dewatered.

4.1.4 Biota pathways

Exposure pathways include direct contact of biota with hazardous substances in air, soil, surface water, and sediments, and exposure through aquatic and terrestrial food web pathways (Figure 4.1). Biota comes in direct contact with hazardous substances through dermal contact, inhalation, and ingestion of contaminated soil, sediment, and surface water (Figure 4.1).

Organochlorine pesticides, including dieldrin and aldrin, are primary hazardous substances of concern at the Arsenal. These contaminants are used as an example to discuss the pathways by which these persistent pesticides affect biota. Many of the other hazardous substances released at the Arsenal follow similar pathways. The Trustees' assessment will include an analysis of these pathways for several of the primary contaminants of concern.

Soils and sediments often contain organic matter in which organochlorine pesticides accumulate. Plant roots, and to a lesser extent plant green tissues, also accumulate pesticides (International Programme on Chemical Safety, 1992). Higher trophic-level organisms, such as earthworms, insects, birds, or mammals, ingest contaminated soils, sediments, or lower-order biota (Figure 4.1). The transfer of contamination from media such as soils to animal tissue is called bioaccumulation.

Wildlife that ingest the bioaccumulated hazardous substances in prey may have higher contaminant tissue concentrations through the process of biomagnification, which is an increase in tissue residue concentration in predators compared to the concentration in prey (Schwarzenbach et al., 2003). Organochlorine pesticides become concentrated in fats and lipid membranes of soil-dwelling earthworms or sediment-dwelling aquatic macroinvertebrates (Beyer and Gish, 1980). These organisms can have very high body burdens of toxic compounds because they have direct contact with contaminated soils and are often insensitive to pesticide toxicity. Consumers of these worms accumulate and biomagnify the pesticides in fat and in fatty tissues such as the brain and liver, with organochlorine pesticide concentrations in these tissues increasing by 3–10 times the ingested concentrations (Klaassen, 2001). As a result, predatory birds and mammals at the top of the food web generally have the highest levels of persistent pesticides in their tissues and thus are the most likely species to be injured by releases of organochlorine pesticides and similar hazardous substances.

4.2 Confirmation of Exposure

Hazardous substances released from the Arsenal include organic contaminants and metals (see Chapter 2). The following sections present data confirming exposure of groundwater, surface water and sediment, geologic resources (soil), biota, and air resources to hazardous substances.

Additional natural resources beyond those discussed in this chapter may also be exposed to hazardous substances released from the Arsenal.

4.2.1 Groundwater

According to DOI regulations, groundwater resources are:

> water in a saturated zone or stratum beneath the surface of land or water and the rocks or sediments through which ground water moves. It includes ground water resources that meet the definition of drinking water supplies [43 CFR § 11.14 (t)].

Drinking water supplies are defined as:

> any raw or finished water sources that may be used by the public or by one or more individuals [43 CFR § 11.14 (o)].

The Arsenal RI confirms that contaminants released at the Arsenal have migrated into the groundwater. According to the RI Summary Report (Ebasco Services et al., 1992b, p. 2-12), the principal contaminants in groundwater are relatively mobile volatile compounds (volatile halogenated organics, volatile hydrocarbon compounds, and volatile aromatic organics) and less mobile contaminants, including organochlorine pesticides and arsenic.

The RI found exposure of both the alluvial aquifer and the Denver formation aquifer below it. Data evaluated in the Water RI were primarily collected during the third quarter of 1987 from a total of 296 alluvial wells and 176 wells screened in the Denver formation (Ebasco Services et al., 1989). Table 4.1 presents a summary of the results of these samples for selected contaminants. These concentrations are elevated above background conditions as described in the RI Summary Report (Ebasco Services et al., 1992b, Table RISR B.2-1). Chloroform and dieldrin were found in over 100 different alluvial wells. Chloroform was also found in over half of the wells in the unconfined Denver formation (Table 4.1).

Table 4.1. Summary of groundwater data from the Arsenal Water RI

Analyte	Detections	Wells sampled	Range (µg/L)	Median (µg/L)
Alluvium				
Dieldrin	102	262	0.062–3.48	0.245
Endrin	35	262	0.064–1.51	0.321
Oxathiane	37	230	1.66–68.6	6.610
Dithiane	47	232	1.25–498	19.300

Table 4.1. Summary of groundwater data from the Arsenal Water RI (cont.)

Analyte	Detections	Wells sampled	Range (µg/L)	Median (µg/L)
Chlorophenylmethyl sulfide	74	231	0.68–748	5.345
Chlorophenylmethyl sulfoxide	44	230	2.16–148	11.750
Chlorophenylmethyl sulfone	61	231	2.83–1,390	11.000
Benzene	31	296	1.49–25,000	3.250
Chlorobenzene	49	297	0.582–31,200	6.910
Chloroform	109	297	0.54–38,800	16.500
Methylene chloride	6	295	6.63–5,780	13.735
1,1,1-Trichloroethane	24	297	0.8–102	8.935
1,1-Dichloroethane	9	297	1.2–9.74	3.270
1,2-Dichloroethene	26	297	0.636–143	5.635
1,1-Dichloroethene	14	297	2.28–35.6	8.210
Trichloroethene	90	297	0.71–2,840	5.285
Tetrachloroethene	57	297	0.82–926	8.760
DBCP	55	264	0.146–278	0.586
DCPD	25	262	10.7–1,200	152.000
DIMP	102	259	11.9–12,100	203.500
Arsenic	66	257	2.56–315	5.270
Fluoride	179	259	1,000–13,400	2,290
Chloride	260 [sic]	259	25,700–6,230,000	187,000
Denver unconfined				
Dieldrin	13	35	0.103–8.92	0.221
Endrin	8	35	0.115–1.22	0.234
Oxathiane	10	35	1.79–1,950	8.100
Dithiane	9	35	3.16–7,760	34.800
Chlorophenylmethyl sulfide	10	35	3.38–94.3	7.845
Chlorophenylmethyl sulfoxide	7	35	8.97–392	47.300
Chlorophenylmethyl sulfone	9	35	3.28–520	16.500
Benzene	5	35	2.15–16,000	7.470
Chlorobenzene	3	35	1.74–1,170	55.900
Chloroform	19	35	1.99–16,500	24.500
Methylene chloride	3	32	11.7–7,340	58.900
1,1,1-Trichloroethane	0	35		
1,1-Dichloroethane	3	35	1.57–3.77	2.110
1,2-Dichloroethene	8	35	2.62–474	34.100

Table 4.1. Summary of groundwater data from the Arsenal Water RI (cont.)

Analyte	Detections	Wells sampled	Range (µg/L)	Median (µg/L)
1,1-Dichloroethene	2	35	1.70–4.41	3.055
Trichloroethene	11	35	1.2–175	4.380
Tetrachloroethene	13	35	2.31–184	15.500
DBCP	8	35	0.609–5.57	1.335
DCPD	6	35	16.6–256	128.700
DIMP	19	35	11.9–5,230	322.000
Arsenic	8	34	4.59–410	17.685
Fluoride	32	35	1,200–223,000	2,410
Chloride	35	35	5,730–28,200,000	246,000
Denver confined				
Dieldrin	10	140	> 0.05–1.23	0.123
Endrin	4	140	< 0.057–0.162	0.060
Oxathiane	5	140	3.09–49.5	12.800
Dithiane	6	140	1.68–263	56.500
Chlorophenylmethyl sulfide	5	140	1.25–4.09	2.50
Chlorophenylmethyl sulfoxide	0	140		
Chlorophenylmethyl sulfone	3	140	3.16–9.58	3.650
Benzene	27	141	1.63–73.8	4.500
Chlorobenzene	24	141	0.79–74.7	16.050
Chloroform	19	141	1.71–194	8.790
Methylene chloride	1	138	6.76	6.760
1,1,1-Trichloroethane	0	141		
1,1-Dichloroethane	2	141	5.21–8.82	7.015
1,2-Dichloroethene	2	141	0.97–2.61	1.759
1,1-Dichloroethene	0	141		
Trichloroethene	11	141	1.24–8.68	2.550
Tetrachloroethene	3	141	1.54–6.67	3.060
DBCP	5	141	0.191–0.779	0.370
DCPD	0	139		
DIMP	11	136	17.0–5,350	127.000
Arsenic	16	138	2.57–26.7	6.460
Fluoride	80	139	913–7,870	1,675
Chloride	132	139	5,520–7,290,000	57,450

µg/L = micrograms per liter.

Source: Ebasco Services et al., 1989, Table 4.2-5.

4.2.2 Surface water/sediment

According to DOI regulations, surface water resources are defined as:

> the waters of the United States, including the sediments suspended in water or lying on the bank, bed, or shoreline and sediments in or transported through coastal and marine areas [43 CFR § 11.14 (pp)].

The Arsenal RI confirmed that surface water, when present, was exposed to hazardous substances. Contamination is primarily introduced during precipitation and runoff events, which were not targeted for sampling (Ebasco Services et al., 1992b). Table 4.2 presents a summary of detected contaminants in samples collected from fall 1985 through fall 1987 (Ebasco Services et al., 1989).

Few analytes were detected in samples entering the Arsenal along the south boundary. Contaminants, including DBCP, aldrin, dieldrin, chloroform, and arsenic, were detected sporadically in samples collected along First Creek, the only continuous surface water drainage through the Arsenal (Ebasco Services et al., 1989, 1992b). Sewage treatment plant effluent discharged to First Creek contained detectable levels of the same contaminants. Very few constituents were detected in RI samples from Lower Derby Lake, Lake Ladora, and Lake Mary. However, historically, organochlorine pesticides, including dieldrin, were detected frequently in the lakes (Ebasco Services et al., 1989). When they contained water, Basin A and a pond near the South Plants Water Tower had elevated levels of organic contaminants, arsenic, and chloride (Table 4.2).

Sediment samples from 36 ditch, lake, and pond sites, including the three major lakes on the Arsenal (Upper and Lower Derby Lakes and Lake Ladora), were collected for the Arsenal RI (Ebasco Services et al., 1992b). These samples confirmed that sediment was exposed to hazardous substances. Table 4.3 presents a summary of selected contaminants in samples from these ditch, lake, and pond sites. Sediments contained elevated concentrations of pesticides, arsenic, and mercury. The highest contaminant concentrations were observed in samples collected from depths of less than 5 ft.

4.2.3 Soils

According to DOI regulations, geologic resources are defined as:

> those elements of the Earth's crust such as soils, sediments, rocks, and minerals, including petroleum and natural gas, that are not included in the definitions of ground and surface water resources [43 CFR § 11.14 (s)].

Table 4.2. Summary of surface water data from the Arsenal Water RI

Location description	Sample site	Detections	Number of samples	Analyte	Arithmetic mean (µg/L)[a]	Range (µg/L)
South boundary the Arsenal – water entering the Arsenal						
First Creek at East Boundary entering the Arsenal	08-001	1	10	Aldrin	0.200	< 0.070–0.20
Peoria Interceptor entering the Arsenal	11-001	1	5	Aldrin	0.200	< 0.070–0.200
		1	2	Benzothiazole	12.0[b]	< 1.70–2.93
		2	5	1,1,1-Trichloroethene	2.430	–
Havana Interceptor entering the Arsenal	11-002	1	2	Arsenic	2.56	–
Havana Pond outlet	11-003	1	1	Benzothiazole	2.06	–
South Boundary ditch – surface drainage entering the Arsenal	12-004	1	1	Arsenic	3.79	–
First Creek						
First Creek at 6th Avenue	05-001	1	2	Arsenic	3.79	–
Sewage Treatment Plant effluent to First Creek	24-001	1	5	DBCP	0.15	< 0.13–0.15
		5	5	Aldrin	0.853	0.080–2.98
		4	5	Dieldrin	0.332	< 0.060–0.936
		2	5	Chloroform	8.1	< 1.40–11.4
		2	2	Arsenic	33.7	–
First Creek at North boundary exiting the Arsenal	24-002	1	6	Aldrin	0.200	< 0.070–0.200
Ponds and lakes						
Lake Ladora and Lake Mary overflows	02-004	1	4	Chloroform	18.1	< 1.40–18.1
		1	1	Arsenic	10.5	–

Table 4.2. Summary of surface water data from the Arsenal Water RI (cont.)

Location description	Sample site	Detections	Number of samples	Analyte	Arithmetic mean (µg/L)[a]	Range (µg/L)
Other locations						
Pond south of South Plants Water Tower	01-002	2	4	DBCP	0.708	< 0.130–1.08
		1	4	Aldrin	0.530	< 0.083–0.530
		3	4	Dieldrin	0.571	< 0.055–0.913
		1	1	Benzothiazole	18.4	
		4	4	Chlorophenylmethyl sulfone	198.7	85.8–298
		3	4	Chlorophenylmethyl sulfoxide	89	< 4.20–204
		2	4	Chlorophenylmethyl sulfide	27.5	< 1.30–52.9
		2	4	Toluene	4.94	< 1.21–8.37
		1	4	Benzene	1.98	< 1.34–1.98
		1	1	Arsenic	11.5	–
Basin A – South Plants surface water/groundwater discharges	36-001	4	5	DBCP	3.8	> 2.2–140
		4	5	DCPD	32.8	< 9.31–70.2
		5	5	Methylisobutyl ketone	1,048	> 104–2,800
		2	4	Hexachlorocyclopentadiene	1.85	< 1.40–2.45
		2	5	Aldrin	2.03	< 0.700–3.07
		4	5	Dieldrin	6.7	3.75–> 20.8
		3	5	Endrin	2.70	< 1.04–5.16
		1	5	DIMP	32.0	< 10.5–32.0
		1	5	Dimethylmethyl phosphonate	17.3	< 15.2–17.3
		5	5	Chlorophenylmethyl sulfone	1,389	> 110–1,870
		5	5	Chlorophenylmethyl sulfoxide	58.3	26.0–87.1
		1	5	1,4-Dithiane	1.46[b]	< 1.10–< 1.59
		4	5	Toluene	25	< 12.1–41.2
		5	5	Benzene	53.8	1.72–176

Table 4.2. Summary of surface water data from the Arsenal Water RI (cont.)

Location description	Sample site	Detections	Number of samples	Analyte	Arithmetic mean (µg/L)[a]	Range (µg/L)
Basin A – South Plants surface water/groundwater discharges (cont.)		4	5	Ethylbenzene	54.0	< 1.28–102
		5	5	o- and p-xylenes	214	18.1–286
		5	5	Chloroform	432	188–641
		5	5	Chlorobenzene	1101	15.8–1,700
		1	5	Methylchloride	7.85	< 5.00–7.85
		5	5	Tetrachloroethylene	83.0	43.1–130
		4	5	Trans 1,2-Dichloroethene	4.38	< 1.10–5.70
		3	5	1,1,1-Trichloroethane	2.87	< 1.70–3.25
		4	5	1,1,2-Trichloroethane	4.01	< 1.00–5.93
		4	5	Trans 1,2-Dichloroethene	8.93	1.20–12.2
		5	5	Trichloroethene	45.5	19.7–62.0
Basin A central pool	36-003	1	2	Aldrin	4.98	4.98–< 8.30
		2	2	Dieldrin	45.6	43.3–47.9
		1	2	DIMP	27.6	< 10.5–27.6
		2	2	Chlorophenylmethyl sulfone	172	125–208
		1	2	1,4-Dithiane	3.57	< 1.10–3.57
		1	2	Chloroform	2.14	< 1.40–2.14
		1	2	Chlorobenzene	3.82	< 0.580–382
		1	2	1,1,2-Trichloroethane	7.85[b]	< 1.00–6.85
		1	2	1,2-Dichloroethane	6.14	< 0.610–6.14
		1	1	Arsenic	1,240	–
		1	1	Chloride	252,000	–

Note: Organic contaminants from samples collected fall 1985 to fall 1987; arsenic and chloride from samples collected in spring of 1987.

a. Arithmetic means are based solely on values above the certified reporting limit (CRL).
b. As reported in source. Mean outside of range.

Source: Ebasco Services et al., 1989, Table 4.1-3.

Table 4.3. Summary of ditch, lake, and pond sediment samples from the Arsenal Summary RI

Analyte	Detected	Samples	Detected concentration range (µg/g)	Median of detected samples (µg/g)
Volatile halogenated organics				
Methylene chloride	16	321	0.64–170	1.7
Tetrachloroethene	6	327	0.30–1.0	0.40
Volatile aromatic organics				
Toluene	4	322	0.30–4.0	0.70
Organophosphorous compounds – GB-agent related				
DIMP	23	687	0.19–5.0	3.2
DBCP	31	1,236	0.0068–0.65	0.036
Organochlorine pesticides				
Aldrin	164	1,041	0.0022–1,100	0.14
Chlordane	48	995	0.026–800	0.13
DDE	95	1,041	0.0012–6.6	0.014
DDT	67	1,041	0.0025–10.0	0.041
Dieldrin	263	1,041	0.0015–3,000	0.19
Endrin	96	1,041	0.0020–20	0.040
Isodrin	68	1,041	0.0013–500	0.024
Arsenic	139	601	2.5–190	7.5
Mercury	187	833	0.052–18	0.16

µg/g = micrograms per gram.

Source: Ebasco Services et al., 1992b, Table RISR A3.1-2.

The Arsenal RI identified 178 sites of soil contamination on the Arsenal (Ebasco Services et al., 1992b, p. A3-4). Contaminated soils were found in source areas, including basins and lagoons; ditches, lakes, ponds, and pits (discussed in Section 4.2.2); ordnance testing and disposal areas; solid waste burial sites; building, equipment, and storage sites; spill sites; sewer sites; surficial soils; and other isolated areas. Contamination was also found in soils collected from nonsource areas.

Soils collected from 14 disposal basins and lagoons[1] had the highest rate of detection and the greatest number of detected analytes (Table 4.4). Soils from waste trenches, buildings, equipment and storage sites, spill sites, and sewer sites also contained a wide range of analytes [not presented; see Ebasco Services et al. (1992b) for summary]. Soils collected from 12 ordnance-testing sites used for testing, burning, or disposal of incendiary devices and munitions were associated with elevated metals concentrations, but few organic contaminants (Table 4.5). Soils from 18 solid waste burial sites, which received contaminated solid and liquid waste materials, contained a wide range of contaminants at relatively high concentrations (Table 4.6). Contamination in surficial soils is characterized by widespread, low levels of contamination indicative of windblown transport of contaminants from poorly vegetated soils, such as the dewatered basins.

Table 4.4. Summary of soil samples from basin and lagoon sites. Selected analytes only.

Analyte	Detected	Samples	Detected concentration range (µg/g)	Median of detected samples (µg/g)
Volatile halogenated organics				
Chlorobenzene	9	508	0.34–5.0	1.7
Chloroform	22	538	0.12–70	1.8
Methylene chloride	58	422	0.27–6.7	1.0
Tetrachloroethene	19	537	0.20–40	2.8
Trichloroethene	4	538	0.14–1.0	0.51
Volatile hydrocarbons				
2,2-Oxybisethanol	36	36	0.6–8	2
2-Pentanone	9	9	1–20	10
Bicycloheptadiene	16	541	0.95–5,100	9.7
DCPD	58	1,079	0.35–22,000	24
Volatile aromatic organics				
Benzene	17	552	0.24–6.0	1.2
Ethylbenzene	11	552	0.14–9.3	1.6
m-Xylene	15	552	0.14–12	1.0
o- and p-Xylene	9	553	0.15–12	2.0
Toluene	18	550	0.13–1,000	0.95

1. These included Basins A, B, C, D, E, and F, and other smaller basins and lagoons.

Table 4.4. Summary of soil samples from basin and lagoon sites (cont.).
Selected analytes only.

Analyte	Detected	Samples	Detected concentration range (µg/g)	Median of detected samples (µg/g)
Organosulfur compounds – mustard-agent related				
Chloroacetic acid	23	242	43–7,900	140
Dithiane	8	1,065	0.47–370	0.70
Thiodiglycol	11	242	6.0–120	25
Organosulfur compounds – herbicide related				
Chlorophenylmethyl sulfide	18	1,070	0.50–700	5.4
Chlorophenylmethyl sulfone	83	1,070	0.34–300	2.5
Chlorophenylmethyl sulfoxide	25	1,067	0.58–70	2.6
Dimethyldisulfide	3	760	2.0–70	10
Organophosphorous compounds – GB-agent related				
DIMP	119	968	0.12–10	1.3
Dimethylmethyl phosphonate	9	767	3.0–70	6.0
Isopropylmethyl phosphonic acid	34	234	4.6–3,700	39
Methylphosphonic acid	24	122	3.1–400	16
Phosphoric acid, triphenyl ester	33	33	1–20	10
DBCP	14	1,099	0.0061–20	0.019
Fluoroacetic acid	25	124	3.4–200	8.5
Polynuclear aromatic hydrocarbons (PAHs)				
Fluoranthene	4	4	4–8	5
Pyrene	3	3	1–100	4
Semivolatile halogenated organics				
Hexachlorocyclopentadiene	24	1,121	0.0040–2,600	0.018
Organochlorine pesticides				
Aldrin	169	1,249	0.0024–18,000	2.0
Chlordane	56	1,125	0.072–660	0.44
DDE	79	1,256	0.0014–28	0.038
DDT	56	1,251	0.0028–60	0.030
Dieldrin	401	1,247	0.0014–2,100	0.60
Endrin	217	1,246	0.0011–1,100	0.085
Isodrin	108	1,251	0.0014–11,000	1.5

Table 4.4. Summary of soil samples from basin and lagoon sites (cont.). Selected analytes only.

Analyte	Detected	Samples	Detected concentration range (µg/g)	Median of detected samples (µg/g)
Arsenic	531	1,253	2.4–110,000	12
Mercury	313	1,099	0.050–35,000	0.27
Metals				
Cadmium	163	1,047	0.63–3,900	1.3
Chromium	768	1,047	6.9–110	14
Copper	919	1,047	4.8–2,300	12
Lead	305	1,039	10–1,100	25
Zinc	969	1,047	11–910	44

Source: Ebasco Services et al., 1992b, Table RISR A3.1-1.

Table 4.5. Summary of soil samples from ordnance testing sites. Selected analytes only.

Analyte	Detected	Samples	Detected concentration range (µg/g)	Median of detected samples (µg/g)
Volatile hydrocarbons				
2,2-Oxybisethanol	12	12	0.6–2	0.9
Volatile aromatic organics				
Benzene	4	74	0.31–0.47	0.35
PAHs				
Methyl naphthalene	4	4	0.5–1	0.6
Organochlorine pesticides				
Dieldrin	3	315	0.0029–2.8	0.35
Arsenic	56	303	2.8–32	5.8
Mercury	43	310	0.061–0.32	0.084
Metals				
Cadmium	35	313	0.63–59	2.5
Chromium	261	313	7.8–56	17
Copper	306	314	5.0–340	17
Lead	89	313	11–3,400	28
Zinc	295	313	15–57,000	59

Source: Ebasco Services et al., 1992b, Table RISR A3.1-3.

Table 4.6. Summary of soil samples from solid waste disposal sites. Selected analytes only.

Analyte	Detected	Samples	Detected concentration range (µg/g)	Median of detected samples (µg/g)
Volatile halogenated organics				
1,1,1-Trichloroethane	8	510	0.50–3.0	0.79
Carbon tetrachloride	5	510	1.0–8.7	1.0
Chloroform	20	510	0.15–8.8	1.1
Methylene chloride	55	496	0.17–760	0.80
Tetrachloroethene	29	510	0.19–120	1.0
Trichloroethene	11	510	0.11–25	1.0
Volatile hydrocarbons				
Bicycloheptadiene	6	450	0.91–56	5.9
DCPD	15	1,196	1.0–450	37
Methylcyclohexane	4	4	5–100	40
Methylisobutyl ketone	3	459	8.8–20	14
Volatile aromatic organics				
Benzene	25	437	0.12–26	0.74
Ethylbenzene	11	437	0.43–9.9	0.98
m-Xylene	14	437	0.18–13	2.2
o- and p-Xylene	13	437	0.16–14	3.2
Toluene	24	437	0.12–370	3.9
Organosulfur compounds – mustard-agent related				
Dithiane	9	898	0.46–12	3.20
Organosulfur compounds – herbicide related				
Benzothiazole	3	125	1.9–130	60
Chlorophenylmethyl sulfide	10	899	0.50–100	2.7
Chlorophenylmethyl sulfone	8	899	0.68–20	1.3
Chlorophenylmethyl sulfoxide	6	899	1.0–4.2	3.6
Dimethyldisulfide	8	501	0.39–100	13
Organophosphorous compounds – GB-agent related				
DIMP	38	889	0.16–36	1.7
Dimethylmethyl phosphonate	5	569	0.19–0.65	0.2
Isopropylmethyl phosphonic acid	3	61	3.7–17	8.3
Methylphosphonic acid	5	61	2.8–220	3.9
DBCP	51	1,344	0.0076–670	0.15
Fluoroacetic acid	14	58	2.7–27	7.5

Table 4.6. Summary of soil samples from solid waste disposal sites (cont.).
Selected analytes only.

Analyte	Detected	Samples	Detected concentration range (µg/g)	Median of detected samples (µg/g)
PAHs				
Pyrene	4	4	0.7–10	2
Semivolatile halogenated organics				
Hexachlorocyclopentadiene	33	871	0.0037–53,000	1.1
Organochlorine pesticides				
Aldrin	109	978	0.0033–670	1.0
Chlordane	46	861	0.18–100	2.0
DDE	32	979	0.0026–1.9	0.015
DDT	29	979	0.0033–26	0.022
Dieldrin	212	978	0.0021–360	0.83
Endrin	98	968	0.0018–370	0.38
Isodrin	62	979	0.0026–870	0.11
Arsenic	184	823	2.0–1,200	7.2
Mercury	219	980	0.053–40	0.17
Metals				
Cadmium	75	830	0.64–1,100	1.6
Chromium	590	829	5.9–4,900	13
Copper	699	829	4.8–27,000	11
Lead	224	829	10–7,100	20
Zinc	798	829	11–12,000	41

Source: Ebasco Services et al., 1992b, Table RISR A3.1-4.

4.2.4 Biota

According to DOI regulations, biological resources (biota) are defined as:

> those natural resources referred to in section 101(16) of CERCLA as fish and wildlife and other biota. Fish and wildlife include marine and freshwater aquatic and terrestrial species; game, nongame, and commercial species; and threatened, endangered, and State sensitive species. Other biota encompass shellfish, terrestrial and aquatic plants, and other living organisms not listed in this definition [43 CFR § 11.14 (f)].

The Arsenal RI confirmed that the contaminants released at the Arsenal followed the pathways described in Section 4.1.4 from sources to predators at the top of the food web. Samples were taken from key terrestrial and aquatic species collected from contaminated sites at the Arsenal and at on- and off-post control areas. Biota were grouped into trophic level categories to develop an analysis of biomagnification of contaminants. Terrestrial trophic levels and representative species were:

- **Primary producers**: morning glory, sunflower
- **Herbivores**: grasshopper, black-tailed prairie dog, cottontail, mule deer, mourning dove
- **Omnivores**: ring-necked pheasant, mallard, blue-winged teal, redhead, American coot
- **Carnivores**: American kestrel, red-tailed hawk, ferruginous hawk, golden eagle, great horned owl, coyote, badger
- **Detritivores**: earthworms.

Aquatic trophic levels and representative species were:

- **Primary producers**: aquatic macrophytes (plants)
- **Primary consumers**: plankton
- **Omnivores**: black bullhead
- **Primary carnivores**: bluegill
- **Top carnivores**: northern pike, largemouth bass.

The RI Summary Report (Ebasco Services et al., 1992b) found elevated concentrations of organochlorine pesticides in terrestrial primary producers (plants) and in wildlife tissue samples compared to plants and wildlife in control sites. Elevated concentrations generally correlated with locations of higher concentrations of organochlorine pesticides in the Arsenal soils. In addition, a pattern of increasing dieldrin biomagnification up the food web was evident. Table 4.7 presents a summary of contaminant concentrations in terrestrial trophic levels. Regarding terrestrial biota, Ebasco Services et al. (1992b) concluded the following:

- Dieldrin was detected in all trophic levels, with higher concentrations in higher trophic-level organisms due to biomagnification
- Aldrin was detected in herbivores
- Endrin was detected in terrestrial herbivores and omnivores
- DDE was detected in terrestrial omnivores and carnivores
- Arsenic was detected most frequently in detritivores and primary producers
- Mercury showed some tendency to bioaccumulate and was most often detected in omnivores.

Table 4.7. Summary of terrestrial biota samples from the Arsenal Summary RI

Analyte	Trophic level	Detections	Samples	Minimum (µg/g)[a]	Maximum (µg/g)	Mean[b]
Dieldrin	Producers	2	19	< 0.044	0.08	0.028
	Herbivores	39	94	< 0.031	56.3	1.2
	Omnivores	55	78	< 0.031	5.38	0.55
	Carnivores	43	73	< 0.031	27.7	2.3
	Detritivores	2	8	< 0.031	5.3	0.92
Aldrin	Herbivores	6	94	< 0.02	5.8	0.1
Endrin	Producers	1	20	< 0.04	0.19	0.029
	Herbivores	5	94	< 0.04	3.74	0.12
	Omnivores	2	73	< 0.04	0.14	0.022
	Detritivores	1	9	< 0.04	0.91	0.12
DDE	Omnivores	10	71	< 0.094	0.92	0.09
	Carnivores	10	72	< 0.094	5.5	0.59
Arsenic	Producers	5	20	< 0.025	4.5	0.46
	Herbivores	7	94	< 0.025	6.6	0.31
	Omnivores	3	59	< 0.025	1.82	0.17
	Detritivores	8	9	< 0.025	1.53	0.93
Mercury	Herbivores	5	94	< 0.05	0.36	0.034
	Omnivores	34	72	< 0.05	1.77	0.25
	Carnivores	16	78	< 0.05	0.405	0.058
	Detritivores	2	9	< 0.05	0.25	0.072

a. Minimum presented as CRL.
b. Mean calculated using one-half the CRL where analyte not detected. Therefore, in some cases where there are many non-detects, the mean will be lower than the minimum.

Source: Ebasco Services et al., 1992b, Table RISR A3.5-1.

Unlike terrestrial biota, a pattern of biomagnification was not generally observed in aquatic biota from the Arsenal lakes. Table 4.8 presents a summary of contaminant concentrations in aquatic trophic levels. Regarding aquatic biota, Ebasco Services et al. (1992b) concluded the following:

- Dieldrin was detected in omnivores, primary carnivores, and top carnivores.
- Aldrin and DDE were detected in top carnivores, in about 20–30% of samples.[2] DDE concentrations were higher than aldrin concentrations.
- Arsenic was detected in primary producers.[3]
- Mercury was detected in primary carnivores and top carnivores.

Table 4.8. Summary of aquatic biota samples from the Arsenal Summary RI

Analyte	Trophic level	Detections	Samples	Minimum (µg/g)[a]	Maximum (µg/g)	Mean[b]
Dieldrin	Omnivores	3	3	0.0851	0.209	0.14
	Top carnivores	16	21	< 0.031	0.161	0.082
	Primary carnivores	15	27	< 0.031	0.86	0.15
Aldrin	Top carnivores	5	27	< 0.020	0.0527	0.015
DDE	Omnivores	1	3	< 0.094	0.098	0.064
	Top carnivores	9	27	< 0.094	0.839	0.2
Arsenic	Primary consumers	1	9	< 0.025	0.432	0.16
	Producers	2	6	< 0.025	0.782	0.29
Mercury	Omnivores	1	3	< 0.050	0.0516	0.034
	Primary carnivores	11	21	< 0.050	0.137	0.058
	Top carnivores	23	27	< 0.050	0.550	0.22

a. Minimum presented as CRL.
b. Mean calculated using one-half the CRL where analyte not detected. Therefore, in some cases where there are many non-detects, the mean will be lower than the minimum.
Source: Ebasco Services et al., 1992b, Table RISR A3.5-2.

DDT and endrin were not detected in any off-post samples. Arsenic, mercury, and dieldrin were detected more frequently and in significantly higher concentrations in on-post specimens than in off-post specimens. DDE was detected more frequently in off-post samples.

2. DDE was also detected in one omnivore sample.

3. Arsenic was also detected in one primary consumer sample.

4.2.5 Air

According to DOI regulations, air resources are defined as:

> those naturally occurring constituents of the atmosphere, including those gasses essential for human, plant, and animal life [43 CFR § 11.14 (b)].

Monitoring data from 1988, the year of the Basin F IRA, indicate that air at the Arsenal has been exposed to hazardous substances and other contaminants (R.L. Stollar & Associates, 1990).

The annual mean concentrations of total suspended particulates (TSP) at 12 air monitoring stations throughout the Arsenal ranged from 40 to 97 micrograms per cubic meter ($\mu g/m^3$) (R.L. Stollar & Associates, 1990, p. 53). R.L. Stollar & Associates (1990, p. 53) reported that the secondary 24-hour ambient air quality standard for TSP of 150 $\mu g/m^3$ was violated 9 times and the primary standard of 260 $\mu g/m^3$ was exceeded twice. Elevated TSP concentrations were most likely influenced by remedial cleanup activity at Basin F because the monitoring stations with the highest TSP levels were immediately adjacent to or downwind of Basin F operations. A peak value of 591 $\mu g/m^3$ TSP was measured in the vicinity of Basin F during remediation (R.L. Stollar & Associates, 1990, p. 57). R.L. Stollar & Associates (1990) concluded that disturbances at Basin F, the Borrow Pit, and Basin A, and general TSP from the Denver metropolitan area, were contributing sources.

Metals above background conditions were also detected in air samples collected during remedial activities in 1988 (Table 4.9). Copper and zinc concentrations decreased with distance from Basin F. The highest arsenic concentrations were measured at a location between the South Plants and Basin A, suggesting that Basin A may have been a source of arsenic emissions. The highest average lead values were observed at sites along the western boundary of the Arsenal, and may be associated with Denver traffic activity. The highest cadmium concentrations were observed along the southern boundary of the Arsenal, and may either be associated with Basin A and the South Plants or various industrial activities to the south of the Arsenal (R.L. Stollar & Associates, 1990).

Monitoring in 1988 also identified volatile organic compounds (VOCs) in air samples (R.L. Stollar & Associates, 1990) (Table 4.9). Remedial activities at Basin F appeared to release bicycloheptadiene, methylene chloride, dimethyl disulfide, benzene, ethylbenzene, and toluene to air. Concentrations of these VOCs were highest in the vicinity of Basin F and decreased with distance. Chloroform was frequently identified in air samples collected from near the South Plants. The Denver urban area may also contribute to many of the VOCs identified in air samples at the Arsenal.

Table 4.9. Maximum detected concentrations in air samples collected at the Arsenal in 1988 (mg/m^3)

Analyte	Maximum long-term average	Maximum 24-hour
Metals		
Arsenic	0.0014	0.0041
Cadmium	0.0015	0.0253
Chromium	0.0175	0.2083
Copper	0.1158	0.5671
Lead	0.0270	0.0576
Zinc	0.0745	0.5054
VOCs		
1,1-Dichloroethane	0.139	0.271
1,2-Dichloroethane	0.135	0.358
Bicycloheptadiene	7.153	25.430
Benzene	10.532	44.293
Carbon tetrachloride	0.858	2.609
Methylene chloride	25.201	185.140
Chloroform	6.010	14.520
Chlorobenzene	0.472	2.527
DBCP	2.902	17.039
DCPD	5.392	29.38
Dimethyl disulfide	12.173	159.3
Ethylbenzene	2.394	13.041
Toluene	25.422	91.379
Methyl isobutyl ketone	0.099	0.326
Dimethylbenzene	0.349	0.755
Tetrachloroethene	5.607	23.500
Trichloroethene	0.497	5.500
Xylene	9.604	50.62
Semivolatile organic compounds (SVOCs)		
Aldrin	0.378	2.829
Chlordane	0.004	0.004
Dieldrin	0.397	2.296
Endrin	0.138	0.902
Isodrin	0.112	0.861
p,p-DDE	0.039	0.039
p,p-DDT	0.035	0.058
Parathion	0.131	0.210

mg/m^3 = milligrams per cubic meter.

Source: R.L. Stollar & Associates, 1990, Tables 4.2-15, 4.2-23, and 4.2-34.

SVOCs, including pesticides such as aldrin, endrin, and dieldrin, were also detected in air samples during monitoring at the Arsenal in 1988. The highest levels of pesticides were clustered around Basin F. Pesticide concentrations at locations more distant from Basin F were negligible.

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