Table 5.4-10 Soil Exceedance Categories, Medium Groups, and Subgroups

Human Health Exceedance Category

- Basin A Medium Group
- Basin F Medium Group
  - Basin F Wastepile Subgroup
  - Former Basin F Subgroup
- Secondary Basins Medium Group
- Sewer Systems Medium Group
  - Chemical Sewers Subgroup
  - Sanitary/Process Water Sewers Subgroup
- Disposal Trenches Medium Group
  - Complex Trenches Subgroup
  - Shell Trenches Subgroup
  - Hex Pit Subgroup
- Sanitary Landfills Medium Group
- Lime Basins Medium Group
  - Section 36 Lime Basins Subgroup
  - Buried M-1 Pits Subgroup
- South Plants Medium Group
  - South Plants Central Processing Area Subgroup
  - South Plants Ditches Subgroup
  - South Plants Balance of Areas Subgroup
- Buried Sediments/Ditches Medium Group
  - Buried Sediments Subgroup
  - Sand Creek Lateral Subgroup
- Undifferentiated Medium Group
  - Section 36 Balance of Areas Subgroup
  - Burial Trenches Subgroup

Biota Exceedance Category

- Surficial Soil Medium Group
- Lake Sediments Medium Group
- Ditches/Drainage Areas Medium Group

Potential Agent Presence Category

- Agent Storage Medium Group
  - North Plants Subgroup
  - Toxic Storage Yards Subgroup

Potential UXO Presence Category

- Munitions Testing Medium Group

Table 5.4-11 Summary of Soil Medium Groups and Subgroups

Medium Groups	Subgroup	Description
Munitions Testing	—	This group is comprised of sites having similar histories and uses. The sites, considered potential HE-filled UXO presence areas and predominantly located in the eastern portions of RMA, were used for testing or destruction of nonchemical munitions. These sites typically contain slag, debris, and potential UXO in the uppermost 1 ft of soil and therefore present physical hazards. The mortar impact area in Section 30 may contain UXO at depths as deep as 6 ft. COC concentrations were not detected above human health SEC at any of the sites.
Agent Storage	North Plants	Sites in this subgroup have potential agent presence but do not contain human health exceedances except as isolated detections. They are located in the North Plants GB manufacturing area. These sites are presumed to contain agent based on use histories and detections of agent breakdown products. Isolated detections of arsenic exceed the human health SEC. Portions of the sites in this subgroup potentially pose risks to biota.
	Toxic Storage Yards	Sites in this subgroup (including the New and Old Toxic Storage Yards) are located in the storage areas in the eastern portion of RMA and are considered to potentially contain agent based on use histories and detections of agent breakdown products. However, sampling has not indicated the presence of agent at these sites. The Old Toxic Storage Yards were retained as sites presumed to contain agent. Isolated detections of chloroacetic acid and arsenic exceed the human health SEC.
Lake Sediments	—	Sites within this medium group include sediments from lakes located in the southern portion of RMA and sediments from the North Bog. They were grouped together based on the potential risk they present to ecological receptors. Contamination has resulted from the influx of suspended solid- or dissolved-phase contaminants transported to the lakes by surface water or groundwater. Isolated exceedances of human health SEC include chlordane and chromium and acute exceedances of aldrin and dieldrin. Water is not currently allowed to pond in Upper Derby Lake, and portions of Upper Derby Lake contain soil that poses a potential risk to biota.
Surficial Soil	—	This medium group consists of areas of shallow soil contamination (including Basin F Exterior) posing risk to biota that are not included as sites in other medium groups/subgroups. Portions of this group contain OCPs above human health SEC. This group also contains the pistol and rifle ranges.
Ditches/Drainage Areas	—	Exceedance sites within this medium group have various disposal and release histories and contain low levels of contaminants, primarily OCPs, that pose risks to biota.

Medium Groups	Subgroup	Description
Basin A	—	This medium group is comprised of two sites within the Basin A high-water line. Basin A contains soil and sediment that were contaminated by organic and inorganic chemicals from manufacturing wastewater discharged to the basin. The medium group is also characterized by the potential presence of agent and agent-filled UXO. Agent was detected in the southern portion of Basin A. COCs detected above the human health SEC include primarily OCPs; soil near the center of the basin exceeds the principal threat criteria.
Basin F	Basin F Wastepile	This subgroup consists of the Basin F Wastepile that was formed as a result of the Basin F IRA. The IRA has included incineration of Basin F liquids in the SQI, excavation of Basin F soil from below the original asphalt liner and the final grading, capping, and revegetation of the excavated area. The Basin F Wastepile consists of excavated sediment and soil that are contaminated with organic compounds, arsenic, and metals at concentrations exceeding human health SEC and principal threat criteria. The total concentrations of organics are inferred to be on the order of 1,000 to 10,000 ppm. This material also contains elevated levels of salts due to the high chloride content in the wastewater stored in the former Basin F.
	Former Basin F	The former Basin F site consists of the former basin area, including the area beneath the Basin F Wastepile. Basin F received wastewaters through the chemical sewer system, and the site is expected to contain somewhat elevated levels of salts due to the high chloride content in the wastewater. COCs remaining in the soil exceeding human health SEC include OCPs and chloroacetic acid; large portions of the former basin exceed principal threat criteria. The Basin F IRA included the installation of a soil cover.
Secondary Basins	—	Sites within this subgroup consist of four liquid disposal basins (Basins B, C, D, and E) that collected overflow water from Basin A and the former deep disposal well. These sites are expected to contain somewhat elevated levels of salts that are a result of the storage of wastewater with high chloride content. COCs detected in the soil above human health SEC include OCPs, although the majority of contamination potentially poses risks to biota only.
Sewer Systems	Sanitary/ Process Sewers	Sites within this subgroup consist of sanitary and process water sewers. Soil around these sewer lines does not exceed human health SEC and does not pose risks to biota based on the depth of the sewer lines; however, these sewer lines potentially serve as conduits for the migration of groundwater contamination.
	Chemical Sewers	Sites within this subgroup consist of chemical sewers. COCs in the soil exceeding human health SEC and principal threat criteria in portions of South Plants include OCPs, volatile organics, and chloroacetic acid. These sewers are further characterized by the potential presence of agent.

Table 5.4-11 Summary of Soil Medium Groups and Subgroups

Medium Groups	Subgroup	Description
Disposal Trenches	Complex Trenches	This subgroup is characterized by trenches or pits that were filled with trash and manufacturing/military wastes. Wastes are suspected to consist of drums of solid and liquid material, wood, glass, metal, laboratory and manufacturing equipment, and miscellaneous material. This subgroup is further characterized by the potential presence of agent and agent-filled UXO.
	Shell Trenches	This subgroup is characterized by trenches or pits that were filled with trash and manufacturing/military wastes in the area of the Shell Trenches. Wastes are suspected to consist of drums of solid and liquid material. IRA activities at this site have consisted of the placement of a soil cap across the entire site and a vertical barrier surrounding the site.
	Hex Pit	This site was historically used for disposal of hex bottoms, a tarry, chlorinated wastestream resulting from the production of HCCPD. The soil at this site is contaminated with these resinous materials. This material was buried in thin-gauge caustic barrels and in bulk.
Sanitary Landfills	—	This medium group consists of sanitary landfills and inferred trenches that are predominantly located in the eastern and western portion of RMA. These sites contain trash and rubbish, but are not anticipated to contain drums of hazardous material, agent, or UXO.
Lime Basins	Section 36 Lime Basins	The Section 36 Lime Basins, used for the neutralization of process wastes related to agent production, are characterized by soil/sludge mixtures with high pH levels and the potential presence of agent. COCs in the soil/sludge exceeding human health SEC include primarily OCPs; low-level inorganic contamination is also present. IRA activities at this site involved placing a soil cover across the entire site.
	M-1 Pits	The Buried M-1 Pits, used for the neutralization of process wastes related to agent production, are characterized by soil/sludge mixtures with high pH levels and the potential presence of agent. COCs in the soil/sludge exceeding human health SEC and principal threat criteria primarily consist of arsenic and mercury. This subgroup is distinguished by percentage levels of arsenic and mercury.

Table 5.4-11 Summary of Soil Medium Groups and Subgroups

Medium Groups	Subgroup	Description
South Plants	South Plants Central Processing Area	This subgroup consists of the main processing area within the South Plants. Contamination has resulted from manufacture, storage, and disposal of chemicals and from the demilitarization of agent-filled ordnance. A wide range of COCs in the soil exceeding human health SEC and principal threat criteria include volatiles, OCPs, and arsenic. The soil in this area potentially contains agent.
	South Plants Ditches	This subgroup consists of the drainage ditches within South Plants. Contamination has resulted from manufacture, storage, and disposal of chemicals and from the demilitarization of agent-filled ordnance. COCs in the soil exceeding human health SEC and principal threat criteria include primarily OCPs. Also, contaminated soil in these ditches potentially poses risk to biota.
	South Plants Balance of Areas	The remainder of the sites within South Plants were placed in this subgroup. Contamination at these sites has resulted from manufacture, storage, and disposal of chemicals and from the demilitarization of agent-filled ordnance, and from windblown dispersion of contaminants from the Central Processing Area. COCs in the soil exceeding the human health SEC and principal threat criteria primarily consist of OCPs and ICP metals. Most of the contaminated soil in the balance of South Plants potentially poses risks to biota. This subgroup is also characterized by the potential presence of high explosives-filled UXO and agent.
Buried Sediments/ Ditches	Buried Sediments	This subgroup consists of two sites that contain contaminated sediments that were dredged from the adjacent lakes (Lake Ladora and Derby lakes), deposited in unlined ditches at their current locations, and covered with clean soil. COCs exceeding human health SEC include OCPs.
	Sand Creek Lateral	This subgroup consists of the northern and southern segments of the Sand Creek Lateral that transported runoff from the South Plants Central Processing Area during storm events and snowmelt, and of the drainage ditches used to transport water to and from the Secondary Basins and to drain the South Plants and North Plants process areas. COCs in the soil exceeding Human Health SEC primarily consist of OCPs.
Undifferentiated	Section 36 Balance of Areas	Sites within this subgroup are located in the southern area of Section 36. They do not have unique site-type characteristics or contamination patterns. COCs in the soil exceeding human health SEC include OCPs and chloroacetic acid. This subgroup is also characterized by the potential presence of agent and agent-filled UXO.
	Burial Trenches	Sites within this subgroup consist of trenches that are located in Sections 30 and 32 related to munitions testing and disposal. COCs in the soil exceeding human health SEC include chromium and lead. The sites are also characterized by the potential presence of HE-filled UXO.

Table 5.4-12 Summary of Contaminant Concentrations Within the Soil Exceedance Volumes

Medium Group/ Subgroup	Contaminants of Concern	Range of Concentrations Within Exceedance Volume[1] (ppm)	Average Concentration Within Exceedance Volume[1] (ppm)	Exceedance Depth (ft)[2]
North Plants				
Human Health	Arsenic	312–10,000	2,800	1
Biota	Dieldrin	0.01–2.9	0.13	1
	Endrin	0.003–0.09	0.01	
	Arsenic	2.8–260	41	
	Mercury	0.05–2.9	0.32	
Toxic Storage Yards				
Human Health	Chloroacetic	80–134	115	6
	Acid	270–4,000	1,600	
	Arsenic			
Biota	Arsenic	BCRL–140	3.6	1
	Mercury	BCRL–30	0.15	
Lake Sediments				
Human Health	Aldrin	BCRL–31	11.8	3
	Dieldrin	BCRL–3.4	0.7	
	Chlordane	BCRL–57	1.8	
Biota	Aldrin	BCRL–2.7	0.060	1
	Dieldrin	BCRL–2.9	0.069	
	Chlordane	BCRL–9.3	0.056	
	DDE	BCRL–1.3	0.018	
	DDT	BCRL–3.0	0.35	
	Mercury	BCRL–18	0.43	
	Arsenic	BCRL–16	0.69	
Surficial Soil				
Human Health	Aldrin	0.048–390	17	1
	Dieldrin	0.001–560	27	
	Lead (firing ranges)	Not Available	Not Available	
Biota	Aldrin	BCRL–3.0	0.016	1
	Dieldrin	BCRL–3.5	0.057	
	Endrin	BCRL–13	0.039	

Table 5.4-12 Summary of Contaminant Concentrations Within the Soil Exceedance Volumes

Medium Group/ Subgroup	Contaminants of Concern	Range of Concentrations Within Exceedance Volume[1] (ppm)	Average Concentration Within Exceedance Volume[1] (ppm)	Exceedance Depth (ft)[2]
Ditches/Drainage Area				
Biota	Aldrin	BCRL–0.094	0.005	1
	Dieldrin	BCRL–2.2	0.27	
	Endrin	BCRL–2	0.053	
	DDE	BCRL–0.78	0.027	
	DDT	BCRL–0.32	0.01	
	Arsenic	BCRL–50	6.6	
	Mercury	BCRL–1.9	0.16	
Basin A				
Human Health	Aldrin	BCRL–720	42	8
	Dieldrin	BCRL–2,600	150	
	Endrin	BCRL–3,200	110	
	Isodrin	BCRL–160	9	
	Chlordane	BCRL–2,900	100	
	Arsenic	BCRL–28,000	350	
	Chromium	BCRL–98	13	
	DDT	BCRL–105	3	
	DDE	BCRL–21	1.4	
	Mercury	BCRL–11,000	140	
Biota	Aldrin	BCRL–1.9	0.04	1
	Dieldrin	BCRL–3.6	0.53	
	Endrin	BCRL–3.0	0.10	
	Arsenic	BCRL–230	25	
	Mercury	BCRL–54	0.67	
	DDT	BCRL–0.73	0.01	
	DDE	BCRL–0.71	0.01	
Basin F Wastepile				
Human Health[3]	Aldrin	0.1–3,100	Not Available	NA
	Dieldrin	0.1–700	Not Available	
	Endrin	9.2–900	Not Available	
	Isodrin	3.16–3,000	Not Available	
	Chloroacetic	110–760	Not Available	
	Acid	3,4–110	Not Available	
	1,2-Dichloroethane DCPD	1,500–2,000	Not Available	

Table 5.4-12 Summary of Contaminant Concentrations Within the Soil Exceedance Volumes

Medium Group/ Subgroup	Contaminants of Concern	Range of Concentrations Within Exceedance Volume[1] (ppm)	Average Concentration Within Exceedance Volume[1] (ppm)	Exceedance Depth (ft)[2]
Former Basin F				
Human Health	Aldrin	BCRL–2,900	260	10
	Dieldrin	BCRL–1,100	130	
	Endrin	BCRL–710	47	
	Isodrin	BCRL–10,000	360	
	Chloroacetic	BCRL–7,000	960	
	Acid	BCRL–20,000	670	
	DCPD			
Secondary Basins				
Human Health	Aldrin	BCRL–180	21.6	1
	Dieldrin	BCRL–120	28.2	
	Chlordane	BCRL–3.0	0.68	
	Endrin	BCRL–8.4	2.1	
	Chromium[4]	BCRL–120	–	
	Arsenic	BCRL–140	9.8	
	Mercury	BCRL–1.6	0.17	
Biota	Aldrin	BCRL–2.7	0.08	1
	Dieldrin	BCRL–3.4	0.69	
	Endrin	BCRL–0.57	0.07	
	DDE	BCRL–1.0	0.006	
	Arsenic	BCRL–56	10	
	Mercury	BCRL–0.23	0.086	
Chemical Sewers				
Human Health	Aldrin	BCRL–20,000	Not Available	10
	Dieldrin	BCRL–200	Not Available	
	Isodrin	BCRL–1,000	Not Available	
	DDT	BCRL–500	Not Available	
	Chloroacetic	BCRL–230	Not Available	
	Acid	BCRL–32,000	Not Available	
	DBCP	BCRL–4,000	Not Available	
	HCCPD	BCRL–200	Not Available	
	Carbon	BCRL–400	Not Available	
	Tetrachloride	BCRL–740	Not Available	
	Chloroform			
	Arsenic			

Table 5.4-12 Summary of Contaminant Concentrations Within the Soil Exceedance Volumes

Medium Group/ Subgroup	Contaminants of Concern	Range of Concentrations Within Exceedance Volume[1] (ppm)	Average Concentration Within Exceedance Volume[1] (ppm)	Exceedance Depth (ft)[2]
Complex Trenches[5]				
Human Health	Aldrin	BCRL–40	Not Available	14
	Isodrin	BCRL–27	Not Available	
	Chlordane	BCRL–150	Not Available	
	DBCP	BCRL–6.7	Not Available	
	Chromium	BCRL–5,200	Not Available	
	Lead	BCRL–10,000	Not Available	
	Mercury	BCRL–860	Not Available	
	Arsenic	BCRL–4,500	Not Available	
Biota	Aldrin	BCRL–0.19	Not Available	1
	Dieldrin	BCRL–3	Not Available	
	Endrin	BCRL–4.7	Not Available	
	DDE	BCRL–2.9	Not Available	
	DDT	BCRL–0.18	Not Available	
	Arsenic	BCRL–98	Not Available	
	Mercury	BCRL–70	Not Available	
Shell Trenches[5]				
Human Health	Aldrin	BCRL–1,000	Not Available	10
	Dieldrin	BCRL–500	Not Available	
	Endrin	BCRL–400	Not Available	
	Isodrin	BCRL–1,000	Not Available	
	Chlordane	BCRL–70	Not Available	
	DBCP	BCRL–700	Not Available	
	HCCPD	BCRL–40,000	Not Available	
Hex Pit[5]				
Human Health	Aldrin	BCRL–1,000	Not Available	10
	Dieldrin	BCRL–500	Not Available	
	Endrin	BCRL–400	Not Available	
	Isodrin	BCRL–1,000	Not Available	
	Chlordane	BCRL–70	Not Available	
	HCCPD	BCRL–40,000	Not Available	

Table 5.4-12 Summary of Contaminant Concentrations Within the Soil Exceedance Volumes

Medium Group/ Subgroup	Contaminants of Concern	Range of Concentrations Within Exceedance Volume[1] (ppm)	Average Concentration Within Exceedance Volume[1] (ppm)	Exceedance Depth (ft)[2]
Sanitary Landfills				
Human Health	Aldrin	BCRL–420	2.5	12
	Dieldrin	BCRL–300	3.0	
	Endrin	BCRL–38	0.31	
	Isodrin	BCRL–27	0.16	
	Chlordane	BCRL–3.1	0.02	
	DDT	BCRL–61	0.44	
	Chromium	BCRL–1,800	18	
	Lead	BCRL–8,600	65	
	Cadmium	BCRL–1,100	5.8	
Biota	Aldrin	BCRL–3.2	0.09	1
	Dieldrin	BCRL–2.6	0.17	
	DDE	BCRL–5.6	0.19	
	DDT	BCRL–61	1.3	
	Endrin	BCRL–20	0.39	
	Arsenic	BCRL–120	5.5	
	Mercury	BCRL–3.5	0.11	
Section 36 Lime Basins				
Human Health	Aldrin	BCRL–1,700	190	10
	Dieldrin	BCRL–780	90	
	Endrin	BCRL–400	41	
	Isodrin	BCRL–400	48	
	Chlordane	BCRL–240	25	
	DDE	BCRL–13	1.9	
	DDT	BCRL–2.6	0.06	
	Arsenic	BCRL–900	100	
	Mercury	BCRL–56	5.4	
Buried M-1 Pits				
Human Health	Aldrin	BCRL–27	0.55	10
	Dieldrin	BCRL–36	0.82	
	Isodrin	BCRL–7.1	0.099	
	HCCPD	BCRL–1,300	44	
	DCPD	BCRL–7,800	195	
	Cadmium	BCRL–2,400	320	
	Arsenic	27–100,000	17,000	
	Mercury	1.3–83,000	4,300	

Table 5.4-12 Summary of Contaminant Concentrations Within the Soil Exceedance Volumes

Medium Group/ Subgroup	Contaminants of Concern	Range of Concentrations Within Exceedance Volume[1] (ppm)	Average Concentration Within Exceedance Volume[1] (ppm)	Exceedance Depth (ft)[2]
South Plants Central Processing Area				
Human Health	Aldrin	BCRL–15,000	580	10
	Dieldrin	BCRL–6,300	210	
	Endrin	BCRL–3,700	67	
	Isodrin	BCRL–300	19	
	Chlordane	BCRL–1,500	15	
	Chloroacetic	BCRL–350	13	
	Acid	BCRL–300	7.5	
	DDT	BCRL–5,300	28	
	HCCPD	BCRL–14,000	275	
	DBCP	BCRL–140	1.9	
	Carbon	BCRL–40,000	580	
	Tetrachloride	BCRL–970	6.7	
	Chloroform	BCRL–14,000	230	
	DCPD	BCRL–540	5.1	
	Arsenic	BCRL–280	20	
	Cadmium	BCRL–7,100	310	
	Chromium	BCRL–17,000	300	
	Lead			
	Mercury			
Biota	Aldrin	BCRL–3.4	0.19	1
	Dieldrin	BCRL–3.4	0.73	
	Endrin	BCRL–1.2	0.029	
	DDE	BCRL–1.6	0.023	
	DDT	BCRL–8.6	0.03	
	Arsenic	BCRL–289	11	
	Mercury	BCRL–56	2.04	
South Plants Ditches				
Human Health	Aldrin	0.60–4,400	270	5
	Dieldrin	0.71–805	58	
	Isodrin	BCRL–23	2.3	
	Chlordane	BCRL–6.3	0.4	
	Chromium	BCRL–62	12	
	Endrin	BCRL–3.4	0.17	
	DDE	BCRL–2.1	0.20	
	DDT	BCRL–10	0.4	
	Arsenic	BCRL–6.1	0.42	
	Mercury	BCRL–15	0.30	
Biota	Aldrin	BCRL–2.3	0.11	1
	Dieldrin	BCRL–2.7	0.69	
	Endrin	BCRL–0.31	0.038	
	DDE	BCRL–3.2	0.12	
	DDT	BCRL–0.81	0.047	
	Mercury	BCRL–2.5	0.10	

Table 5.4-12 Summary of Contaminant Concentrations Within the Soil Exceedance Volumes

Medium Group/ Subgroup	Contaminants of Concern	Range of Concentrations Within Exceedance Volume[1] (ppm)	Average Concentration Within Exceedance Volume[1] (ppm)	Exceedance Depth (ft)[2]
South Plants Balance of Areas				
Human Health	Aldrin	BCRL–6,900	14	10
	Dieldrin	0.67–1,500	33	
	Endrin	BCRL–46	1.6	
	Isodrin	BCRL–390	18	
	Chlordane	BCRL–370	4.2	
	DDE	BCRL–9.7	0.53	
	DDT	BCRL–140	1.4	
	HCCPD	BCRL–2,000	23	
	Chromium	BCRL–2,200	62	
	Lead	BCRL–4,900	340	
	Mercury	BCRL–8,600	500	
Biota	Aldrin	BCRL–3.5	0.037	1
	Dieldrin	BCRL–3.6	0.32	
	Endrin	BCRL–1.17	0.011	
	DDE	BCRL–1.02	0.006	
	DDT	BCRL–1.7	0.15	
	Arsenic	BCRL–180	0.73	
	Mercury	BCRL–41	0.065	
Buried Sediments				
Human Health	Dieldrin	26.1–53	40	10
	Chlordane	BCRL–8.9	0.8	
Sand Creek Lateral				
Human Health	Aldrin	BCRL–400	27.8	2
	Dieldrin	BCRL–140	18.5	
	Isodrin	BCRL–4.0	0.24	
	Chlordane	BCRL–9.7	0.42	
	Chloroacetic Acid	230	Not Applicable	
	Chromium	BRCL–490	180	
	Lead	BCRL–2,000	800	
	DDE	BCRL–4.7	0.04	
	DDT	BCRL–6.0	1.0	
Biota	Aldrin	BCRL–3.7	0.30	1
	Dieldrin	BCRL–3.6	0.44	
	Endrin	BCRL–3.8	0.087	
	DDE	BCRL–4.7	0.095	
	DDT	BCRL–6.0	0.10	
	Arsenic	BCRL–190	5.8	
	Mercury	BCRL–2.3	0.13	

Table 5.4-12 Summary of Contaminant Concentrations Within the Soil Exceedance Volumes

Medium Group/ Subgroup	Contaminants of Concern	Range of Concentrations Within Exceedance Volume[1] (ppm)	Average Concentration Within Exceedance Volume[1] (ppm)	Exceedance Depth (ft)[2]
Section 36 Balance of Areas				
Human Health	Aldrin	BCRL–120	11	10
	Dieldrin	BCRL–140	24	
	Endrin	BCRL–46	5.3	
	Isodrin	BCRL–37	1.6	
	Chlordane	BCRL–140	2.2	
	Chloroacetic	BCRL–320	52	
	Acid	BCRL–1.8	0.10	
	DDE	BCRL–23	0.20	
	DDT	BCRL–16	2.4	
	Arsenic	BCRL–50	0.46	
	Mercury			
Biota	Aldrin	BCRL–2.2	0.061	1
	Dieldrin	BCRL–3.5	0.010	
	Endrin	BCRL–3.1	0.12	
	Chlordane	BCRL–11	0.84	
	DDE	BCRL–1.6	0.010	
	DDT	BCRL–8.6	0.028	
	Arsenic	BCRL–39	3.85	
	Mercury	BCRL–56	0.5	
Burial Trenches				
Human Health	Chromium	BCRL–39	20	10
	Lead	BCRL–3,400	190	

1 Concentrations listed are based on the samples present within the respective exceedance volumes only. For modeled sites, the range and average represent estimated contaminant concentrations for the modeled exceedance volume. See Section 7.1.4 for more discussion on soil contaminant modeling.

2 Human health exceedance depths represent the maximum depth of any detected human health exceedances.

3 Concentrations inferred from remedial investigations sampling at Former Basin F prior to interim response action.

4 Present above human health SEC in one sample in NCSA-4a.

5 Concentrations for these sites represent samples taken throughout the site. Limited information is available for soil concentrations within the disposal trenches proper.

6.0 Summary of Site Risks

A risk assessment is a scientific procedure used to estimate the potential adverse effects on human health and the environment from exposure to chemicals. At a CERCLA site, a baseline risk assessment is prepared and serves as the basis for evaluating risks posed from contamination if no remedial actions are taken. The resulting level of risk is called the baseline risk, i.e., an estimate of risk that might exist if no remediation or institutional controls were applied at a site. At RMA, a risk assessment called the Integrated Endangerment Assessment/Risk Characterization (IEA/RC) was performed and used as the baseline risk assessment. In this instance, the IEA/RC defined baseline to include the completion of the soil-related IRAs (e.g., Basin F, Lime Basins) and enforcement of the FFA's use restrictions. The FFA prohibits residential development; potable use of groundwater and surface water; agricultural activities for the purpose of raising livestock, crops, or vegetables; and the consumption of fish and game taken from RMA. Therefore, these uses were not considered during the IEA/RC. The relevant IRAs (Table 2.4-1) were implemented in accordance with the FFA to prioritize the selection of some of the more highly contaminated sites for remedial action and reduce or eliminate the risk for exposure to contaminated soil prior to the selection of the final remedial action. The risk assessment methodology used during the IEA/RC was initiated prior to the publication of EPA risk assessment guidance (OERR-EPA 1989). However, this methodology does incorporate the exposure assumptions and toxicity assessment methods specified in EPA guidance and fulfills EPA's requirement of estimating risk based on a reasonable maximum exposure (RME).

The IEA/RC was the result of a progressive series of endangerment assessment analyses initiated by the Biota RI (ESE 1989), the Human Health Exposure Assessment (HHEA), and the HHEA Addendum. These initial evaluations served as screening assessments for the protection of human health and preliminary estimations of biota risk, and provided the basic building blocks of the IEA/RC report, which is divided into two evaluations, the Human Health Risk Characterization (HHRC) and the Ecological Risk Characterization (ERC). Both of these evaluations are summarized in the final report.

The general methodology of the risk assessment process involves the following steps: identify the COCs, perform the exposure and toxicity assessments, and perform the risk characterization. The more than 50,000 groundwater, surface water, sediment, soil, air, and biota samples collected during the past decade were used to evaluate which chemicals were of concern to human health and the environment and to develop the risk assessment.

6.1 Human Health Risk Characterization

Soil at RMA is the primary medium by which humans can be exposed to contamination on post, due to land-use restrictions and/or limitations on the uses of other environmental media specified in the FFA and the Rocky

Mountain Arsenal National Wildlife Refuge Act of 1992. Remedial measures for on-post groundwater will augment the soil remedy and facilitate long-term remediation of groundwater. Risk-based criteria for groundwater established by the ROD for the Off-Post Operable Unit are used for the on-post boundary treatment systems.

The objectives of the HHRC were to develop risk-based soil criteria protective of people who might visit or work at RMA, evaluate the uncertainty associated with these criteria, characterize the potential risks to these people, and evaluate where these risks exist at RMA to guide the remedial decisions. Two types of health effects were evaluated, potential cancer (carcinogenic) risks and potential health effects other than cancer. The context for interpreting cancer risk estimates is provided by EPA in CERCLA regulations and guidance: Acceptable exposure levels for a carcinogenic compound are those levels that result in an increased cancer risk between 1 in 10,000 (or 1×10^{-4}) and 1 in 1,000,000 (or 1×10^{-6}). These estimated carcinogenic risks are usually termed "excess lifetime cancer risks," which means there is an increased chance of an individual developing cancer over 30 years of exposure over a 70-year life span to the carcinogenic chemicals in "excess" of the normal cancer rate. (The normal cancer rate determined by the American Cancer Society is about one in three persons.)

Noncancer (noncarcinogenic) risk estimates are expressed in terms of a hazard index (HI) for **chronic, subchronic, and acute exposure durations.** A concern for adverse health effects may occur when an HI value, the sum of chemical-specific hazard quotients (HQs), exceeds 1.0. However, the value of any given HI does not provide an estimate of the probability of any adverse effects that may occur (unlike a cancer risk estimate). An HI of 1.0 represents the highest level of chronic exposure that is unlikely to result in adverse effects. For values of HI greater than 1.0, the potential for adverse effects to occur increases as the HI value increases.

6.1.1 Identification of Contaminants of Concern

Contaminants in the RI and Endangerment Assessment programs were selected as target analytes if they satisfied all of the following criteria:

- Quantities handled or disposed at RMA
- Acute toxicity and carcinogenic potential
- Persistence in the environment
- Identification as a breakdown product from Army surety agents
- The presence of the chemical in other monitoring or investigatory programs ongoing at RMA

A total of 64 contaminants were identified as target analytes from a list of more than 650 chemical constituents. These target contaminants were subsequently evaluated in the HHEA report. The HHEA served as a basis for identifying COCs that would become the focus of a more detailed evaluation of risk during the IEA/RC.

Based on the evaluation conducted during the HHEA, 27 soil COCs were ultimately selected for evaluation in the HHRC (Table 6.1-1). These chemicals, which are expected to contribute the majority of projected risks at RMA, were identified based on pre-established selection criteria as follows:

1. Include all COCs designated as Category A (Exposure Index >10) in the HHEA.
2. Include all COCs with carcinogenic weight of evidence classifications designations A or B.
3. Include all COCs with carcinogenic weight of evidence classification designation C and potency factors.
4. Consider treatability to exclude chemicals from the COC list.
5. Consider isolated detections to exclude chemicals.
6. Include all COCs listed on the Land Ban Disposal Restriction List.
7. Include all COCs with RCRA soil criteria.
8. Consider the state's request to include DIMP and isopropylmethyl phosphonate (IMPA). (DIMP and IMPA are predominantly groundwater contaminants and were therefore not included on the final COC list.)
9. Group by chemical class to reduce COCs.
10. Consider frequency of detection.
11. Consider essential nutrients.
12. Consider concentration and toxicity.
13. Consider historical information.
14. Consider special exposure routes.
15. Consider Army agent degradation products.
16. Consider co-occurrence with other COCs to exclude chemicals.
17. Consider bioconcentration, mobility, and persistence.
18. Consider detections in laboratory blanks in comparison to concentrations detected on site. (Fluoroacetic acid, which was considered a COC in drafts of the IEA/RC report, was removed as a COC in this analysis because on-post detections of this chemical were similar in concentration to detections in laboratory blanks.)

6.1.2 Exposure Assessment

The objective of the human health exposure assessment is to estimate the type and magnitude of exposure to COCs by human populations through the characterization of the exposure setting (i.e., potential land uses) and current and future potentially exposed populations, identification of exposure pathways, and estimation of the exposure point concentrations.

6.1.2.1 Characterization of Exposure Setting and Potentially Exposed Populations

The identification of potentially exposed populations at RMA required consideration of potential site land uses. The FFA indicates the Parties' goal that significant portions of RMA will be available for open space for public benefit, including, but not limited to, wildlife habitat(s) and park(s). By the enactment of the Rocky Mountain

Arsenal National Wildlife Refuge Act of 1992, future land-use options will involve an open space scenario dominated by the formation of a nature preserve and wildlife refuge that includes parks and recreational areas.

Given the land-use projections identified above, two land-use options were identified that formed the basis for defining target receptor populations: open space, which includes nature preserve, wildlife refuge, and recreational park scenarios, and economic development, which includes commercial and industrial scenarios. Following passage of the Rocky Mountain Arsenal National Wildlife Refuge Act, economic development would only apply in limited areas along the western boundary of RMA. Based on the open space land-use projection, three receptor populations were evaluated in the HHRC, biological workers, regulated/casual visitors, and recreational visitors. Based on the economic development land-use projection, two worker populations, industrial and commercial workers, were selected for evaluation. Figure 6.1-1 is a diagram showing the land-use scenarios and the potentially exposed populations associated with them. For both open space and economic development land-use options, risks were calculated assuming that exposure would occur at a given site or, in the case of the boring-by-boring analysis, at an individual soil boring.

6.1.2.2 Identification of Exposure Pathways

An exposure pathway describes the course a chemical or physical agent takes from the contaminant source to the exposed receptor. A complete exposure pathway includes a source area, a means of transport in the environment, an exposure point, and a receptor. At RMA, direct and indirect exposure pathways were evaluated. The direct pathways included ingesting contaminated soil (ingestion), coming into contact with contaminated soil (dermal absorption), or breathing contaminated dust particles (inhalation). The indirect pathways included inhalation of contaminated vapors in open areas (e.g., during work performed outdoors) and enclosed spaces (e.g., in basements). Dermal contact with metals in soil was not evaluated for any receptor population due to negligible contaminant absorption through this exposure pathway.

The five potentially exposed populations/subpopulations and their respective current and future exposure pathways included the following:

- Biological Worker, e.g., a wildlife biologist working on the refuge – All direct pathways and open space vapor inhalation
- Regulated/Casual Visitor, e.g., someone (adult or child) visiting the wildlife refuge – All direct pathways and open space vapor inhalation
- Recreational Visitor, e.g., someone (adult or child) jogging or playing on areas of the wildlife refuge – All direct pathways and open space vapor inhalation
- Commercial Worker, e.g., a person working inside a building on the wildlife refuge – All direct pathway and enclosed space vapor inhalation
- Industrial Worker, e.g., a person working outside and potentially exposed to soil – All direct and indirect pathways

Figure 6.1-2 depicts the potential exposure pathways for each human receptor population and Table 6.1-2 lists the soil horizons (soil depth interval) for each exposure pathway evaluated.

6.1.2.3 Estimation of Exposure Point Concentrations

The chemical concentration to which an individual could be exposed is known as the exposure point concentration. To characterize potential chronic (long-term risk, i.e., 7 to 70 years) human health risks at RMA, both location-specific (i.e., 178 discrete sites on RMA) and sample-specific (boring-by-boring) risks were quantified. The complete data set used for the estimation of these exposure point concentrations was issued on computer diskettes and distributed with the IEA/RC report.

Human health risks were estimated for the location-specific analysis using representative contaminant concentrations calculated for each of the 178 sites evaluated in the HHRC. The concentration term used to estimate exposure was calculated by several different methods to give a range of potential risks. A mean exposure concentration term ($C_{rep,mean}$) was calculated as the simple arithmetic mean of the samples as representative of a potential average exposure for each of the 178 locations. (This method is no longer recommended by EPA.) The 95 percent upper confidence limit (95% UCL) on the site sample arithmetic mean ($C_{rep,upper}$) was calculated to establish the RME risks. The 95% UCL was calculated in accordance with EPA guidance (OSWER-EPA 1992) and this represents EPA's preferred method to calculate concentration terms.

For the location-specific analysis, concentrations based on **composited samples** (i.e., samples collected from borings from the 0-ft to 1-ft interval mixed with samples from a deeper interval). These concentrations were estimated by doubling the concentration detected in the 0-ft to 1-ft interval, using the conservative assumption of 50 percent dilution by clean soil collected from the deeper samples. Concentrations reported for samples that were not composited (i.e., samples collected from the 0-ft to 1-ft interval and analyzed without the addition of deeper soil) were not doubled because these concentrations were not potentially diluted by deeper, clean soil.

For the boring-by-boring analysis, potential risks were evaluated using the maximum contaminant concentration (C_{max}) at a given boring for a specific depth interval or at a given surficial soil sample location. Surficial soil sample results were included in the boring-by-boring analysis to supplement results from the deeper sample intervals. The objective of the surficial soil sampling program was to identify any contamination that may have occurred as a result of windblown contamination from source areas using composited samples from randomly selected sample locations at the 0-inch to 2-inch depth interval. Because the samples were composited from within this one interval, the effects of dilution caused by mixing soil from deeper intervals was avoided. The inclusion of these results in the boring-by-boring analysis are intended to offer insight into the variability of contamination at RMA and facilitate the identification of contaminant hot spots. The use of

analytical results from composited samples may have reduced the overall conservatism of the boring-by-boring analysis, which assumes that cumulative chronic exposures would occur at any individual boring location and at the specific depths where the maximum concentration occurred. However, the surficial soil results do supplement the subsurface boring evaluation, and may be more relevant to the evaluation of direct contact exposure risks for some receptors (e.g., visitor populations) than corresponding results for deeper soil intervals.

6.1.2.4 Exposure Parameters

Exposure parameters are combined with chemical-specific exposure point concentrations and toxicity data to characterize each of the five potential routes of human exposure to COCs at RMA. Some exposure parameters, such as body weight and frequency of exposure, are applicable to all exposure pathways. Other parameters, however, such as soil ingestion rate and molecular diffusivity, are used only for specific exposure routes. The probabilistic analysis developed for the IEA/RC assumes chronic exposures (greater than 7 years). However, potential risks associated with shorter-term exposures (i.e., acute exposures occurring on a single day or subchronic exposures lasting more than 1 day but less than 7 years) were calculated during the HHEA using deterministic methods (i.e., using fixed exposure parameters).

The exposure parameters used in this evaluation are fixed or probabilistic (Tables 6.1-3 through 6.1-5). Probabilistic parameters are characterized by a distribution of values, while the fixed parameters are represented by a single value. Probability distributions and the fixed numerical estimates are defined based on an extensive literature search and data review. A detailed description of the individual exposure parameters and the development of their specific distributions is contained in Appendix B of the IEA/RC report. The deterministic exposure parameters used for the development of the acute and subchronic **preliminary pollutant limit values (PPLVs)** are presented in Tables 6.1-6 and 6.1-7, respectively. A detailed description of these parameters is provided in the HHEA Addendum report.

6.1.3 Toxicity Assessment

The objective of the toxicity assessment is to derive toxicological criteria that can be used in the calculation of potential risk from exposure to COCs in terms of carcinogenic and noncarcinogenic effects.

Carcinogenic effects result, or are suspected to result, in the development of different types of cancer. EPA assumes a nonthreshold mechanism for carcinogens; accordingly, any amount of exposure to a carcinogenic chemical is assumed to have a potential for producing a carcinogenic response in the exposed individual. EPA has a carcinogenic-classification system that uses weight of evidence to classify the likelihood that a chemical is a human carcinogen. The classifications are as follows:

A Human Carcinogen

B1 Probable human carcinogen; limited human data are available

B2 Probably human carcinogen; sufficient evidence in animals and inadequate or no evidence in humans

C Possible human carcinogen

D Not classified as to human carcinogen

E Evidence of noncarcinogenicity for humans

Carcinogenic toxicity values used in the HHRC were developed by the EPA Cancer Assessment Group and obtained from EPA-derived sources that include the Integrated Risk Information System database and the Health Effects Summary Table. These values are based on cancer slope factors. Slope factors are chemical-specific, experimentally derived potency values that are used to calculate the risk of cancer resulting from exposure to carcinogenic chemicals. A higher value implies a more potent carcinogen. Slope factors and carcinogenic doses based on a 1×10^{-6} excess cancer risk for the COCs are summarized in Table 6.1-8 for both oral and inhalation routes.

Noncarcinogenic effects, or any health impact other than cancer, may result from short-term (i.e., acute and subchronic), or long-term (chronic) exposures. For most noncarcinogenic effects, protective mechanisms within an individual are assumed to exist that must be overcome before there is an adverse effect. The level above which effects may occur is called a threshold level. In developing dose-response values for noncarcinogenic effects, i.e., the reference dose (RfD), EPA's goal is to identify the highest no observed adverse effect level (NOAEL), the upper bound of the tolerance range (generally regarded as safe), or the lowest observed adverse effect level (LOAEL) from well-designed human or animal studies. In general, the RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. To account for uncertainty associated with the toxicity studies, uncertainty factors (UFs) are incorporated to adjust this level. The RfDs for COCs at RMA are summarized in Table 6.1-9 for both the oral and inhalation exposure routes for chronic exposures. (Acute and subchronic exposures from RMA media were evaluated in the HHEA Addendum report.)

The chronic reference doses listed in Table 6.1-9 pertain to lifetime or other long-term exposures (i.e., 7 years to lifetime). However, for noncarcinogenic chemicals, chronic exposure is not a prerequisite for toxicity to be manifested; even a single exposure or shorter-duration exposure may be sufficient to produce adverse effects. More recently, EPA has begun developing acute and subchronic reference doses, which are useful for characterizing potential noncarcinogenic effects associated with shorter-term exposures (i.e., acute and subchronic). Acute and subchronic reference doses are used to evaluate the potential noncarcinogenic effects of exposure periods lasting 1 day or more than 1 day but less than 7 years.

Development of acute and subchronic reference doses parallels the development of chronic reference doses; the distinction is one of exposure duration. If acute or subchronic data are not available and a chronic RfD derived from chronic data exists, the chronic RfD is adopted as the acute or subchronic RfD. There is no application of an uncertainty factor to account for differences in exposure duration in this instance. The critical toxicity factors (D_T values) used for the acute and subchronic PPLVs are listed in Table 6.1-10.

Toxicity profiles for each of the COCs were published in the HHEA. Toxicity profiles for each RMA target contaminant were generated from current toxicological literature and include considerations of dose, routes of exposure, types of adverse effects manifested, transport, and fate and a quantitative evaluation of a D_T value. Each profile is composed of seven sections that address the following elements:

- Summary
- Chemical and physical properties
- Transport and fate
- Health effects
- Toxicity to wildlife and domestic animals
- Regulations and standards
- D_T value

The toxicity factors contained in the toxicity profiles were revised if current values contained in the Integrated Risk Information System or the Health Effects Summary Table differed from those contained in the HHEA toxicity profile. Tables 6.1-8 and 6.1-9 list the toxicity factors used in the IEA/RC.

6.1.4 Risk Characterization

PPLVs, which are risk-based concentrations of chemicals in soil that are considered protective of human health given a defined set of exposure and toxicity assumptions, were used to estimate risks to human health. For noncarcinogens, PPLVs are defined as soil concentrations unlikely to pose adverse health effects. For carcinogens, PPLVs are defined as soil concentrations protective of human health at a specified cancer risk level. PPLVs are a function of media intake rates, exposure frequencies and durations, partition coefficients, physiological parameters (e.g., breathing rates, body rates, skin surface areas), pharmacokinetic parameters (e.g., contaminant absorption fractions), and toxicity data.

6.1.4.1 Calculation of PPLVs

Probabilistic PPLVs were computed for each of the five potentially exposed populations via the direct and indirect exposure pathways. In addition, because exposure to contaminants may occur from a number of exposure routes, cumulative direct and indirect PPLVs were also calculated over all the single pathways. Acute/subchronic deterministic and chronic probabilistic approaches differ in their use of exposure assumptions. The exposure parameters used in the estimation of probabilistic PPLVs are characterized by a

distribution of values or ranges of exposures potentially occurring within the population. It is assumed that some individuals have a high level of exposure and others have a lower level. The exposure parameters used in the estimation of deterministic PPLVs (i.e., nonprobabilistic) are the fixed numerical estimates that correspond to a reasonable maximally exposed individual (RME). EPA defines the RME as the highest exposure that is reasonably expected to occur at a site and in practice is estimated by combining upper bound fixed values for some but not all exposure parameters.

During the HHRC, both 5th and 50th percentile cumulative direct PPLVs (Tables 6.1-11 and 6.1-12, respectively) were calculated for each of the five receptor populations. The 5th percentile defines the RME PPLV (i.e., there is 95 percent confidence that the PPLV will be protective at the specified risk level), and the 50th percentile represents the median PPLV estimate (i.e., there is 50 percent confidence that the PPLV will not exceed the specified risk level). The remediation decisions are based on the 5th percentile PPLV, which corresponds to a reasonable maximum exposure (and risk) evaluation. The lowest (more protective) cumulative direct PPLVs were generally derived for the biological worker. The only exceptions are related to the PPLVs calculated for certain volatile organic compounds (i.e., benzene, carbon tetrachloride, chloroacetic acid, chlorobenzene, and toluene); for these compounds, the lowest PPLVs were derived for the industrial worker.

The single-pathway PPLVs used to derive the cumulative PPLVs are summarized in Tables 6.1-13 through 6.1-17. As shown in these tables, the majority of the cumulative direct PPLVs were derived based on a carcinogenic endpoint. The dermal absorption pathway accounts for the majority of the cumulative risk for most of the organic COCs. The only exceptions are aldrin, dieldrin, DDE, endrin, isodrin, chlordane, DDT, and DCPD, for which soil ingestion is the driver exposure pathway, and DCPD and HCCPD, for which soil particulate inhalation is the driver exposure pathway for some populations/subpopulations.

For aldrin, soil ingestion is the driver exposure pathway for the biological worker, recreational visitor, regulated/casual visitor, and commercial worker subpopulations. For dieldrin, soil ingestion is the driver exposure pathway for the biological worker, regulated/casual visitor, and commercial worker subpopulations. For DDE, endrin, and isodrin, soil ingestion is the driver exposure pathway for the biological worker and commercial worker subpopulations. For chlordane, DDT, and DCPD, soil ingestion is the driver exposure pathway for the commercial worker subpopulation.

For DCPD, inhalation is the driver exposure pathway for all populations/subpopulations except the commercial worker, for which ingestion is the driver exposure pathway. For HCCPD, inhalation is the driver exposure pathway for all populations except the recreational visitor, for which dermal exposure is the driver exposure pathway.

Soil ingestion and particulate inhalation are the driver pathways for metals. (As explained in Section 6.1.2.2, dermal absorption was not quantified for metals.) Soil ingestion represents the driver pathway for arsenic, lead, and mercury, and particulate inhalation represents the driver pathway for cadmium and chromium.

6.1.4.2 Determination of Carcinogenic and Noncarcinogenic Risks

Once PPLVs were calculated, they were combined with exposure point concentrations to calculate excess lifetime carcinogenic risks and noncarcinogenic HIs. As noted in Section 6.1, these excess lifetime cancer risks are probabilities that are generally expressed in scientific notation (e.g., 1×10^{-6}). An excess lifetime cancer risk of 1×10^{-6} indicates that, as a plausible upper bound, an individual has a 1 in 1 million chance of developing cancer as a result of site-related exposure to a carcinogen over 30 years of exposure over a 70-year life span under the specific exposure conditions at a site.

Potential concern for noncarcinogenic effects of a single contaminant in a single medium is expressed as the HQ (or the ratio of the estimated intake derived from the contaminant concentration in a given medium to the contaminant's RfD). By adding the HQs for all contaminants within a medium or across all media to which a given population may reasonably be exposed, the HI can be generated. The HI provides a useful reference point for gauging the potential significance of multiple contaminant exposures within a single medium or across media.

For carcinogens, cumulative risks (representing all exposure pathways and COCs) were compared to an acceptable risk range that is no greater than 1×10^{-6} to 1×10^{-4}. For carcinogens causing health effects in addition to cancer and for noncarcinogens, potential adverse health effects were identified where HI values exceeded 1.0, below which is considered the safe, or benchmark, level. As stated by EPA (OSWER-EPA 1991b), where the cumulative site risk to an individual based on the RME for both current and future land-use scenarios is less than 1×10^{-4}, and the HQ is less than 1.0, action generally is not warranted; however, when risk reduction is warranted, the remediation goals should be towards 1×10^{-6} risk-based concentrations.

Location-Specific Risks and HIs

RME risks were calculated for each of the 178 sites using $C_{rep,upper}$ concentrations and PPLVs. During the HHRC, site risks were calculated for Horizon 0 (0-ft to 1-ft depth interval), Horizon 1 (0-ft to 10-ft depth interval), and Horizon 2 (>10 ft to groundwater). Because Horizon 0 results were not graphically displayed in the IEA/RC report, this section mainly focuses on the results for that horizon. More information on site risks for Horizons 1 and 2, as well as results for surficial soil (0 inches to 2 inches), can be found in the IEA/RC report.

PPLVs were derived for each of the five potentially exposed populations/subpopulations evaluated in the risk characterization. Table 6.1-18 lists the number of site $C_{rep,upper}$ values exceeding the corresponding PPLV for

Horizon 0. As shown in this table, only five carcinogenic contaminants have $C_{rep,upper}$ estimates exceeding a 1 x 10^{-4} cancer risk PPLV: aldrin, chlordane, dieldrin, arsenic, and DBCP. For noncarcinogens, only chloroacetic acid, endrin, isodrin, and chromium have $C_{rep,upper}$ values exceeding the corresponding PPLV (assuming an HI of 1.0 as the target criterion).

The results of the HHRC indicate that site-specific cancer risks and HIs were highest in Horizons 0 and 1 for the biological worker (open space option) and industrial worker (economic development land-use option). Given these findings, and the fact that the biological worker exposure setting is most reflective of anticipated future land uses at RMA, the following summary is based on results obtained for the biological worker. These results indicate that potential cancer risks are highest in the following areas, which are generally located in the central portions of RMA:

- Chemical Sewers (site SP10)
- Lime Basins, including sites SP1E (Buried M-1 Pits) and NC1B (Section 36 Lime Basins)
- South Plants, with sites SP3A (ditch), SP1A (Central Processing Area), and SP3B (concrete salt storage pad) exhibiting the highest risks
- Former Basin F (site NC3)
- Sanitary/Process Water Sewers (site NC8A)
- Basin A (site NC1A)
- Shell Trenches (site C1A)

The generalized locations of these sites are depicted on Figure 6.1-3. Exceedances of 1 x 10^{-4} cancer risk levels are limited to the sites listed above (the Basin F Wastepile was not evaluated separately, but would fall into this category) (Figure 6.1-4). The results for noncarcinogenic endpoints (HIs) exhibit similar trends; however, more sites exceed an HI of 1.0 than those identified above (e.g., one sanitary landfill and additional sites in South Plants [Figure 6.1-5]).

Summary of Principal Chemical Risk Drivers

Figures 6.1-6 and 6.1-7 summarize cancer risks and HIs associated with the $C_{rep,\ upper}$ concentrations for Horizon 0. As shown in these figures, the number of exceedances shown for the biological worker at Horizon 0 is larger than for any of the other populations; however, the cumulative direct PPLVs (summarized in Table 6.1-11) are generally lower (and are thus drivers) for the biological worker. As indicated in Section 3 of the IEA/RC report, Horizon 1 C_{rep} concentrations show slightly higher cancer risks and HIs than for Horizon 0, probably because the indirect soil vapor inhalation pathways were not evaluated for shallow depth intervals. As is also indicated in the IEA/RC report, Horizon 2 C_{rep} concentrations revealed far lower cancer risks and HIs (relative to results for Horizons 0 and 1). No site exceedances of a 10^{-4} cancer risk level were identified for either the biological or

industrial workers. Only 2.2 percent (four sites) of Horizon 2 site cancer risks calculated for the industrial worker exceed 10^{-6}; similar trends are exhibited for HI endpoints.

For cancer risk endpoints, DBCP, aldrin, arsenic, and dieldrin are the primary contributors to the total estimated risks for the biological worker at Horizon 1. It should be noted, however, that the apparent major contribution of DBCP stems in large part from the elevated observation at the Chemical Sewers (site SP10), where the DBCP cancer risk was 7.6×10^{-3} and the HI was 0.016. The influence of arsenic on total cancer risks for Buried M-1 Pits (site SP1E) and some North Plants agent storage sites (sites NP5 and NP6) is expected as arsenic is a component of the agent compounds that were stored or disposed in these areas. For noncarcinogenic risk endpoints, DBCP, aldrin, and arsenic account for the majority of the total estimated HIs.

No cancer risk estimates exceed 10^{-4} at Horizon 2. However, for those sites with Horizon 2 cancer risks exceeding 10^{-6}, chloroform and benzene are the major contributors to the total estimated risks. For those sites with HIs exceeding 1.0, DBCP, DCPD and HCCPD account for the majority of the total estimated HIs.

Detailed data regarding the contribution of individual chemicals to total site risks and HIs are provided in the additivity reports, which can be accessed using the HHRC software provided in Appendix D of the IEA/RC report.

Summary of Pathway Risk Drivers

Carcinogenic and noncarcinogenic risks estimated for the biological worker and other open space land-use option receptors were attributed primarily to the direct soil exposure pathways (soil ingestion and dermal absorption; see Tables 6.1-13 through 6.1-17). In contrast to trends identified for the biological worker, the soil vapor inhalation pathway was the dominant exposure pathway for the driver COCs identified for industrial (and commercial) workers.

A sensitivity analysis was conducted for the HHRC to rank the influence of several distributed input parameters on the variability of the cumulative direct PPLVs for aldrin, dieldrin, DBCP, arsenic, and chlordane. These chemicals were chosen because of their strong contributions to overall risk at RMA. The sensitivity analysis considered both biological and industrial worker receptors (representing open space and economic development land-use options, respectively) for both cancer risk and HI endpoints. Standardized regression coefficients and full-model partial correlation coefficients were computed for each input parameter to provide two separate measures of a parameter's influence on the variability of the direct exposure pathway PPLVs.

The eight distributed input parameters used for the direct PPLV calculations included the following:

TE	Exposure duration (years) (for carcinogens only)
DW	Annual frequency of exposure (days/year)

TM	Daily exposure rate (hours/day)
RAF_{dermal}	Relative absorption factor for dermal absorption (unitless)
$RAF_{ingestion}$	Relative absorption factor for ingestion (unitless)
CSS	Dust loading factor ($\mu g/m^3$)
SC	Skin soil covering (mg/cm^3)
SI	Soil ingestion (mg/day)

The results of this analysis indicate that variability in exposure duration is consistently the dominant contributor to variability in the direct carcinogenic PPLV, followed by soil ingestion. Soil ingestion is also a dominant contributor to variability in the direct noncarcinogenic PPLV. Other influential parameters include RAF_{dermal}, $RAF_{ingestion}$, and soil covering.

Risks for the boring-by-boring analysis were characterized using the following sampling data:

- Surficial soil results (samples collected from a 0- to 2-inch soil-depth interval in areas outside of designated sites)
- Boring-by-boring results (maximum contaminant concentrations detected in each soil-depth interval for individual borings located within designated sites)

Surficial Soil Results

Figure 6.1-8 shows the incremental cancer risks estimated for the biological worker using surficial soil (0-inch to 2-inch depth interval) results. This map indicates only three surficial soil locations with incremental cancer risks exceeding 10^{-4}: one occurs east of Basin C, one occurs in Basin A, and one occurs in the southern area of Section 36. Similar trends are apparent for HIs; of the 493 non-zero observations, only three surficial soil locations have incremental HIs exceeding 1.0. The surficial soil results supplement the subsurface boring evaluation discussed below, and may be more relevant to the evaluation of direct contact exposure risks for open space land-use option receptors than corresponding results for deeper soil intervals (in particular, the recreational and regulated/casual visitor subpopulations).

Boring-Specific Risks and HIs

The findings of the boring-specific evaluation for Horizons 0 and 1 basically parallel those described for the site analysis summarized above in that exceedances of a 1×10^{-4} cancer risk level (Figures 6.1-9 and 6.1-10) or an HI of 1.0 (Figures 6.1-11 and 6.1-12) at individual borings are generally limited to the following areas located in the central portions of RMA: South Plants, Sewer Systems, Lime Basins, Former Basin F, Basin A, and the Complex Trenches located in Section 36. Isolated exceedances of a 1×10^{-4} cancer risk were also identified at borings located in Basin C, Sand Creek Lateral, the North Plants Agent Storage Areas, and the sanitary landfill near the Rail Yard (located in the western portion of RMA). The boring-specific HI results exhibit similar trends.

Figures 6.1-13 and 6.1-14 show the composite of carcinogenic and noncarcinogenic chronic risk exceedances, as well as acute risk exceedances.

For all receptors evaluated in the HHRC, the major contaminants contributing to potential cancer risks were aldrin, DBCP, arsenic, and dieldrin. For noncancer risk endpoints, DBCP, aldrin, and arsenic account for the majority of the total estimated HIs.

Acute and Subchronic Risk Evaluation

In the probabilistic evaluation, PPLVs were calculated to be protective of chronic (long-term) exposures. However, it is possible that exposures to COCs at RMA could be short term, such as exposures occurring only on a single day (acute), or exposures lasting more than 1 day but less than 7 years (subchronic). These PPLVs, originally calculated for the HHEA Addendum, are summarized in Tables 6.1-19 and 6.1-20. The cumulative direct acute and subchronic PPLVs are protective of exposure via three pathways, soil ingestion, particulate inhalation, and dermal contact with soil. The PPLVs presented in these tables are the same as those originally calculated, with two exceptions: PPLVs for aldrin and dieldrin were recalculated during the HHRC to reflect updated toxicity criteria and the dermal relative absorption factor (all receptor scenarios) and soil covering factor (visitor populations only) were revised.

In general, and particularly for the biological and industrial worker populations, the acute and subchronic PPLVs shown in Tables 6.1-19 and 6.1-20 are higher than the corresponding chronic noncarcinogenic 5th percentile PPLVs (Tables 6.1-13 through 6.1-17). This finding is expected because the body can generally tolerate a higher contaminant dose over a short (e.g., acute) duration than over a long (chronic) duration for a given dose rate. However, for the recreational and regulated/casual visitor exposure settings, acute/subchronic PPLVs for some chemicals are lower than corresponding chronic noncarcinogenic 5th percentile PPLVs. Figure 6.1-15 shows sample locations exceeding an HI of 1.0 for all COCs having acute PPLV values.

6.2 Ecological Risk Characterization

Ecological risk characterization focuses on chemicals that, because of their toxicity, may adversely affect biota populations, individuals of threatened or endangered species, or the species diversity in a community. For these effects to occur, toxic chemicals must be present in the environment, potential biota receptors must be present and they must be engaged in activities that would expose them to chemicals that are not only present, but bioavailable (Figure 6.2-1). The sections below summarize the steps of the ERC at RMA, which are similar to the HHRC steps.

6.2.1 Identification of Contaminants of Concern

Fourteen chemicals detected on RMA were selected as of concern to biota: aldrin, dieldrin, chlordane, endrin, DDT, dichlorodiphenyldichloroethene (DDE), mercury, arsenic, cadmium, chlorophenylmethylsulfide (CPMS), chlorophenylmethylsulfone ($CPMSO_2$), copper, DBCP, and DCPD. The biota COCs were selected on the basis of criteria (toxicity, persistence, amount used or produced at RMA, and areal extent of contamination) developed collectively by the Army, EPA, USFWS, and Shell to focus on the potential main risk drivers.

Of the 14 biota COCs considered in the ERC, six (aldrin, dieldrin, endrin, DDT, DDE, and mercury) are known to biomagnify substantially, and seven do not biomagnify substantially or at all (arsenic, cadmium, CPMS, $CPMSO_2$, copper, DBCP, and DCPD). Chlordane can biomagnify (usually in the form of its metabolites), but was not treated quantitatively as such because no tissue sample data were available for this chemical. Biomagnification means that each successive organism in the food chain (e.g., from plant to insect, mouse, and hawk) will have a higher concentration of the chemical in its body tissue.

6.2.2 Exposure Assessment

Numerous ecological studies have been performed at RMA, particularly by USFWS in the 1960s, the Army in the 1970s to mid-1980s, and by Shell, USFWS, and the Army in the late 1980s and 1990s to identify the ecological receptors that may be exposed to the biota COCs and to determine the effects of this exposure. Using the data from these studies, several food webs were constructed to represent the biota food chains present at RMA. For the purposes of the IEA/RC, a food web is a collection of food chains that all culminate in a single top predator. Five such food webs were evaluated for RMA, each headed by different predators:

- Bald eagle
- American kestrel
- Great horned owl
- Great blue heron
- Shorebird

The following types of biota were selected to represent the various feeding levels (trophic boxes) in these RMA food webs and were evaluated from past varied studies where tissues were collected for analysis of COC concentrations:

- Earthworms
- Insects (represented by grasshoppers and ground beetles)
- Small birds (represented by vesper sparrows, western meadowlarks, and mourning doves)
- Small mammals (represented by deer mice and 13-lined ground squirrels)
- Medium mammals (represented by desert cottontails and black-tailed prairie dogs)
- Water birds (represented by mallards, blue-winged teal, and American coots)

- Shorebirds (represented by killdeer)
- Large fish (represented by northern pike and largemouth bass)
- Small fish (represented by channel catfish, black/brown bullheads, and bluegills)
- Aquatic invertebrates
- Plankton
- Terrestrial and aquatic plants

The data on tissue concentrations of contaminants were used to both document the nature and extent of contamination in biota and to provide tissue data that could be used in the ERC process described in Section 6.2.4. The exposure assessment included the estimation of exposure area soil concentrations; the estimation of species- and chemical-specific biomagnification factors (BMFs) based on bioaccumulation factors (BAFs) that describe the amount of COC transfer from food to consumers; and the identification of dietary items, fraction of items consumed, and feed rates. Exposure area soil concentrations were calculated based on an area-wide average (i.e., an arithmetic mean) concentration, an "area" being defined as an organism's estimated foraging or exposure area. The area-averaged concentration was computed from spatially interpolated soil concentrations in the 0-ft to 1-ft depth interval (except for the prairie dog's exposure area, which incorporated a vertical average for the 0-ft to 20-ft depth interval). The interpolated soil concentrations were calculated on a square grid with 100-ft spacing using surrounding actual soil sample concentration data and the inverse distance-squared algorithm. Before the soil data were interpolated, values that were below certified reporting limits (BCRL) were replaced with estimated values based on nearby detections when the surrounding data were sufficient using the inverse distance-squared algorithm. Because the spatial interpolation of BCRL data proceeded iteratively, a previously estimated BCRL value may have been included with nearby detections to estimate a replacement value for a BCRL at a different location (see Appendix C of the IEA/RC report for a detailed description of the spatial interpolation of BCRL data). Specifically, exposure area soil concentrations were estimated in three steps: spatial interpolation of BCRL data, interpolation of soil concentrations onto an RMA-wide grid, and averaging of interpolated data within an exposure area to compute exposure area soil concentrations. A best estimate of the exposure range of each receptor was obtained from the literature and represented by a circle (to facilitate the modeling of average risk) within which an individual receptor was assumed to be exposed. By centering the exposure range circle for a given receptor on a grid block and averaging the soil values within grid blocks that fell half or more within the circle, an average exposure concentration was estimated. This process was repeated for each grid block over the entire RMA area.

The BMF used at RMA represents a ratio between the concentration of a chemical in biota tissue (generally represented as the "whole-body concentration," which includes the whole animal for small mammals, such as deer mice, and the skinned/eviscerated carcass for medium mammals, such as prairie dogs) and that in soil. Three different methods of calculating the BMF were used in evaluating potential risk at RMA, which yielded

differing BMF values for four COC categories (Table 6.2-1). The differences reflect the uncertainties associated with the data as well as the alternate methods used to derive the BMFs. Because the BMFs resulted in varying risk estimations, the SFS (see Section 6.2.4.3) will attempt to resolve uncertainties about the spatial extent of potential excess exposure and resulting subpopulation risk to biota compared to the three ranges of risk derived from the three BMFs.

Once a BMF was developed for a particular chemical/receptor combination, it was multiplied by the estimated exposure soil concentration in each block to obtain an estimated tissue concentration for the ecological receptor centered on that grid block. Data on dietary fractions and feed rates were obtained from the literature and from studies conducted at RMA. Where appropriate, the RMA-specific dietary data were used instead of literature values; however, if RMA data were not available, preference was given to literature dietary information from geographic and habitat types most similar to those at RMA. The exposure assessment parameters (Table 6.2-2) were based on best estimates of averages and were used to calculate potential tissue concentrations and dosages based on ingestion of contaminated soil and prey.

6.2.3 Toxicity Assessment

Literature data on chemical toxicity that include biota COC concentrations associated with some type of adverse health effect were used as numerical thresholds against which risk was evaluated. Reported effects on reproduction were preferred because these have the most obvious connection with detrimental population impacts; however, nonreproductive effects, such as behavioral toxicity, may also be important, but these effects are more difficult to evaluate and quantify. Other such toxicological endpoints were considered from a qualitative perspective. For all of the receptors evaluated, both tissue-based (i.e., maximum allowable tissue concentrations, or MATCs) and dose-based (i.e., toxicity-reference values, or TRVs) threshold values were sought in the literature. Each of the values found in the literature was evaluated as to its appropriateness for use as a threshold value (NOAELs and no observed effects levels, or NOELs, were the preferred endpoints). UFs were applied to the final literature-based pre-UF MATCs and pre-UF TRVs to help ensure adequate protection of biota populations. UFs were developed for the MATC and the TRV (Table 6.2-3) approaches in parallel (i.e., it was decided to apply the same rationale and values for each derivation process).

UFs were developed for four categories as follows:

- Intertaxon variability in toxicological responses to contaminants when extrapolating from the species used in an experimental study to a target species at RMA
- Extrapolation from the duration of an experimental study to the chronic exposure being assessed at RMA

- Extrapolation from a toxicity endpoint in an experimental study to the desired no adverse effects endpoint for the ecological risk assessment at RMA
- Modifying factors to account for additional sources of uncertainty

The final UF, the product of the results of these four categories, is divided into the pre-UF MATC or pre-UF TRV critical value to determine a final MATC or TRV (Table 6.2-4). The total uncertainty (final UF) applied for the derivation of TRVs ranged from 4 to 7,500 and the total uncertainty for MATCs ranged from 1.5 to 375. However, if the final UF exceeded 400, a final UF of 400 was used. The total uncertainty ranges for the main risk driver, aldrin/dieldrin, was much tighter: 4 to 30 for the aldrin/dieldrin TRVs (Table 6.2-5) and 1.5 to 30 for the aldrin/dieldrin MATCs (Table 6.2-6).

The MATCs represent maximum whole-body concentrations of bioaccumulative chemicals that are unlikely to cause harmful effects to specific receptors. The MATCs, expressed as the weight of contaminant per unit of body weight (mg/kg-bw), were derived from literature data on tissue concentrations associated with the presence or absence of observed toxicological effects in biological test species (to produce pre-UF MATCs), and then adjusted with the COC/receptor-specific UF to produce final MATCs.

The final TRVs represent estimates of a daily dose (mg/kg-bw-day) that are likely to be without an appreciable risk of harmful effects to target receptors. The TRVs computed for the IEA/RC follow an approach that is different from that described in the Off-Post Operable Unit Endangerment Assessment/FS for RMA (Harding Lawson Associates 1992); however, both RMA approaches are similar to the methodology used by EPA to compute RfDs for assessing risks to human health.

The final toxicological threshold values, MATCs and TRVs, are compared to the site-specific exposure measurements (i.e., population mean contaminant tissue concentrations and doses) to estimate potential risk to biota populations (Section 6.2.4.1). The toxicological threshold values are intended to be protective of biota populations and individual bald eagles at RMA.

The final tissue- and dose-based threshold values selected for the characterization of risk are shown in Table 6.2-4. When both tissue-based and dose-based threshold values were available, the value with the lower UF was selected. When the uncertainty was equal, the TRV was selected because it avoided the use of a BMF, which introduced uncertainty of its own. Where two values were calculated, the value that is shown in bold face was used to estimate risk.

6.2.4 Risk Characterization

6.2.4.1 Methods

The characterization of potential risk from the biota COCs to terrestrial receptors was performed by integrating the exposure assessment and the toxicity assessment with a Geographic Information System (GIS) to produce a series of maps that display areas of potential risk (i.e., HQs or HIs greater than 1.0).

For the tissue-based approach, estimated tissue concentrations were compared directly with a tissue-based toxicity threshold value to calculate an HQ, which represented an estimate of potential risk in a grid block for the chemical/receptor combination being investigated. This approach is represented by the following equation:

$$HQ = \frac{\text{Tissue Concentration}}{MATC}$$

Alternatively, if the dose-based approach was used, the dose to the receptor being investigated was estimated and compared to a dose-based toxicity threshold value to calculate an HQ. The dose-based approach is represented by the following equation:

$$HQ = \frac{\text{Dose}}{TRV}$$

The HQ equations presented above are a generalized representation of those actually used in the ERC. Appendix C of the IEA/RC report contains a detailed description of the equations used. The risk characterization processes were repeated for all grid blocks and for all chemical/receptor combinations for which biomagnification factors were calculated. There were variations from these approaches for chemicals having no tissue data, for predators that were not sampled for nonbioaccumulative COCs, and for aquatic food chains. These variations are also described in Appendix C of the IEA/RC report.

An HQ greater than 1.0 indicated a potential risk from a particular chemical. The sum of all HQs for a single receptor resulted in an HI, which indicates the potential risk from all biota COCs to that receptor. HQs and HIs were mapped using GIS to show the geographic extent of areas having potential risk (Figures 6.2-2 through 6.2-5).

The degree to which the results of the risk characterization were consistent with the ecological measurement endpoints on observable field effects identified within the ecological database available for RMA was also evaluated. Ecological measurement endpoints were selected at the community, population, and individual levels of ecosystem organization. The community-level measurement endpoints considered were species richness and trophic diversity; these provide information on the assessment endpoint of biological structural

diversity of the RMA and regional ecosystem. Population-level measurement endpoints were relative abundance, reproductive success, and morbidity; these provide information on the assessment endpoint of population robustness. Selected biomarkers (i.e., acetylcholinesterase inhibition and eggshell thinning) were examined at the individual level, but evaluated as measurement endpoints for extrapolation to population effects. Endpoints at the individual level are appropriate for evaluating adverse effects on individuals of threatened or endangered species (e.g., bald eagle), which by definition have populations reduced to the level where individuals are important.

6.2.4.2 Results

Quantitative results were calculated for all five of the predators (bald eagle, American kestrel, great horned owl, great blue heron, and shorebird) heading the food webs developed for RMA and for four of the trophic boxes in their food webs (small bird, small mammal, medium mammal, and water bird). Other trophic boxes, including all strictly aquatic organisms in the RMA lakes, were not evaluated quantitatively because toxicity threshold values for these biota COCs/trophic box combinations were not available in the literature. The results of the terrestrial risk characterization are presented primarily in maps, which best show the spatial variability of the estimated potential risk. Figures 6.2-2 and 6.2-3, which illustrate the number of receptors having potential risk, are based on the Shell BMF because Shell BMF results were intermediate between the Army and EPA BMF results. Many other such maps are available in the IEA/RC report (Section 4 and Appendix C.3). In viewing these maps, it should be remembered that a small hot spot (identified by only a few borings) or a large relatively clean area can affect the soil concentrations interpolated for several surrounding grid blocks. These grid blocks in turn can affect the estimated exposure soil concentrations for many grid blocks, particularly for receptors with large exposure ranges such as raptors. Such species are likely to have sizable areas of potential risk because very high contaminant concentrations in hot spots around the manufacturing plants and basins were averaged over large exposure ranges. If the high contaminant concentrations in just these hot spots were reduced, then the areal extent of potential risk, as well as the magnitude of HQs and HIs, would be reduced. Conversely, if large relatively clean areas are included in the estimation of exposure soil concentrations, the effect could be a dilution of concentration attributed to hot spots.

Potential risk varied depending on the BMF used, the chemical or chemical group being considered, and receptor (trophic box) being evaluated. Differences in risk among receptors for a given chemical were partly due to differences in the toxicity threshold values, and especially due to differences in the exposure range size. Figure 6.2-2 shows the number of representative trophic boxes that have HIs greater than 1.0 in various parts of RMA. This figure shows that the areas of potential risk to the greatest number of species tend to be smaller and located toward the center of RMA, even though the specific receptors subject to potential risk in one area may be different from those subject to potential risk elsewhere. Terrestrial areas where all trophic boxes are expected to be at potential risk (based on cumulative risk from all of the COCs combined) are most of the

central sections of RMA, including South Plants; Basins A, B, C, D, and F; and the northernmost upland areas adjacent to the South Lakes area. Pesticides (especially aldrin/dieldrin) are the primary biota COCs contributing to biota risk at RMA, as shown in Figure 6.2-3. This figure shows the number of trophic boxes having an HI greater than 1.0 for aldrin/dieldrin, DDT/DDE, and endrin based on soil exposure and the Shell BMF approach. Metals are also significant contributors to biota risk.

The degree to which potential risk predicted by the EPA, Shell, and Army BMFs differed for a single COC/receptor combination based on the TRV (dose-based) approach is shown for aldrin/dieldrin in Figure 6.2-4 for the great horned owl and in Figure 6.2-5 for the small mammal. The effect of the small mammal's much smaller exposure range can be seen by comparing Figure 6.2-4 with Figure 6.2-5. Receptors with larger exposure ranges generally show greater areas of potential risk, and receptors with smaller exposure areas tend to show smaller areas of potential risk that more directly reflect specific areas of higher soil contamination. The areas depicted in the maps do not necessarily denote the extent of magnitude or severity of potential risks to biota, nor do they depict the ecological relevance of the potential risks to local populations. The ecological relevance of the potential risks will be addressed as part of remedial design and incorporate the ongoing USFWS biomonitoring program, as well as the SFS and other evaluations being performed by the BAS (see Section 6.2.4.3). EPA defines ecological relevance generally in terms of "population sustainability and community integrity" for both current and future exposure and risk.

The potential risk to predators at the top of food webs having aquatic food chains is shown in Table 6.2-7. These risks are tabulated because a single risk value was calculated for all the lakes combined. In combining measured tissue concentrations from the various lakes, feeding was assumed to be proportional to the size of the lake. Table 6.2-7 shows that potential risk from aquatic food chains is greatest to the great blue heron.

The results of the quantitative ERC were also compared with the results of evaluating potential ecological effects such as impacts on reproduction, species abundance, and species diversity. No strong trends in any of these data indicated populational effects. However, because sampling was concentrated in contamination areas, average tissue concentrations exceeded the MATC (which represents the tissue-based toxicity threshold value) for dieldrin, mercury (for this COC, the detection limit also exceeded the MATC), and DDE. Likely adverse effects of RMA contamination have been observed in individual animals collected at RMA, but these effects were not apparent in the available data collected for wildlife populations as a whole at RMA. The available data were obtained from studies that had varying purposes and degrees of ability to discern contaminant effects on local populations. It should be noted that the state and EPA disagreed with the ability to draw conclusions on wildlife populations or on the effects of RMA contaminants to individual animals from the available data. In accordance with the Conceptual Remedy, all Parties, through their representatives on the BAS, will continue

to evaluate the SFS and USFWS biomonitoring studies and provide information to risk managers on the status and health of biota at RMA in terms of the need to refine design boundaries to include additional locations where biota risks were deemed to be excessive. This process will continue during the remedial design after the ROD is signed (see Section 6.2.4.3).

The potential risk from all COCs combined covered most of RMA for at least one species. However, a number of considerations should be taken into account when evaluating this risk. For example, the risk from mercury is overestimated for RMA because all mercury was assumed to be in its most toxic and bioavailable form, methyl mercury, although this is not the most prevalent form at RMA. Conversely, because chlordane was not quantitatively modeled as a bioaccumulative COC, its risks to biota may be underestimated. For terrestrial and aquatic receptors, there are uncertainties inherent in the toxicity threshold values used and in the estimated tissue concentrations that were compared to these threshold values. The uncertainties in threshold values are mostly reflected in the magnitude of UFs used to derive each TRV or MATC. For terrestrial receptors, uncertainties in estimated tissue concentrations result primarily from uncertainties in the estimates of the exposure soil concentration and the BMF.

The available ecological data used to evaluate ecological effects were also subject to uncertainty resulting from the short-term nature of many of the studies, lack of sufficient precision of the results, and study designs that were not always oriented toward correlating ecological parameters with contaminant concentrations. As noted previously, not all the Parties agreed with the appropriateness of the ecological data used in this comparison.

6.2.4.3 Continuing Biological Studies

Generally, the results of the ERC showed that the areas of highest potential risk are located in the central portions of RMA and are associated with major chemical manufacturing processes or a disposal area that contains the greatest concentration of contaminants. Although the Army, Shell, and EPA approaches all agree regarding excessive risk (i.e., HQ or HI greater than 1.0) to wildlife in the central areas of RMA, they differ in their estimates of areas and magnitudes of potential ecological risk in other parts of RMA. The major variation is due to the use of different BMFs (as calculated by the Army, EPA, and Shell) to estimate exposure. Because of the scientific differences of opinion concerning the best approach to determine field BMFs at RMA, the SFS was established. Phase I of the SFS is designed to determine whether unacceptable levels of exposure (i.e., risk) exist within the Area of Dispute (Figure 6.2-6). The Area of Dispute is defined as the difference in the areas of potential aldrin/dieldrin risk (HQ greater than 1.0, based on MATC) to small mammals based on the Army and EPA approaches and was delineated for the primary purpose of sample collection in Phase I of the SFS. It may or may not reflect the area of uncertainty in terms of excessive risk to biota, although this is also coincidentally the ROD Area of Contamination (AOC) boundary. If Phase I of the SFS indicates that unacceptable risks to biota are likely,

the SFS may proceed with Phase II under RMA Council direction to collect additional tissue and soil data to estimate field BMFs for selected species.

The goal of biota remediation is to achieve appropriate remediation such that it is protective of biota health (i.e., sustainability of local subpopulations and individuals of threatened or endangered species). HIs were used in the IEA/RC to provide a semiquantitative characterization of predicted risks to biota at RMA. In general, HIs less than 1.0 denote the absence of excessive risk to biota populations. HIs greater than 1.0 may indicate potential adverse risks to biota populations; the greater the HI, the greater the potential risk.

To demonstrate spatial representation of biota risk, a series of additional risk maps (pre- and post-remediation) are presented for the American kestrel and great horned owl using the Army and EPA BMF approaches (Figures 6.2-7 through 6.2-14). These residual risk maps show locations and relative magnitudes of estimated biota risks due to exposure to the bioaccumulative COCs (excluding mercury) following proposed remediation. Residual risk areas will be evaluated by the BAS as potential locations for additional ecotoxicological studies.

Mean HIs for the American kestrel and great horned owl were estimated within the pre-remediation areas identified as having an HI greater than 1.0 using the Army and EPA BMF approaches based on a semiquantitative analysis of the pre- and post-remediation risk maps (Figure 6.2-7 through 6.2-14). Several general conclusions about the pre- and post-remediation risks to biota and associated uncertainty can be made from this semiquantitative analysis as follows:

- EPA mean HI estimates were an average of about 3 times higher than the Army mean HI estimates based on differences in the BMFs (ranging from about 2 to 4 times higher; American kestrel had the highest difference).
- Pre-remediation mean HIs ranged from about 2 to 120 using Army BMFs and about 7 to 270 using EPA BMFs (bald eagle was the highest in both cases).
- Post-remediation mean HIs ranged from 1 to 7 using Army BMFs and about 4 to 16 using EPA BMFs (bald eagle was the highest in both cases). The residual risk maps show that in general residual risks remain adjacent to the ROD's biota remediation areas (shown as the shaded areas in Figure 6.2-6) and that the highest ranges of residual risk are located adjacent to the southwest section of the green-shaded areas.
- In general, both the Army and EPA methods show at least a 10-fold reduction in risk for all species of concern following remediation of the shaded areas shown in Figure 6.2-6.

While the SFS is being conducted, certain areas of more highly contaminated surficial soil, which represent the areas in which all three BMF approaches yielded HQs greater than 1.0 (using the MATC approach) for aldrin/dieldrin for small mammals, as well as some additional areas north of Former Basin F and areas identified by USFWS as priority areas (i.e., known areas of high contamination and posing a threat to wildlife based on field observations), have been identified as candidates for initial focused remediation and are identified as the green-

shaded areas in Figure 6.2-6. The process outlined in the Conceptual Remedy and summarized below permits the further investigation of other identified areas of potential residual risk outside the green-shaded areas in order to more accurately characterize actual biota risk and impacts and to refine design boundaries if warranted. This process includes the following:

- The BAS of technical experts (e.g., ecotoxicologists, biologists, range/reclamation specialists) from the Parties will focus on the planning and conduct of both the USFWS biomonitoring programs and the SFS/risk assessment process. The BAS will provide interpretation of results and recommendations to the Parties' decision makers.
- The ongoing USFWS biomonitoring programs and the SFS/risk assessment process will be used to refine design boundaries for surficial soil and aquatic contamination to be remediated.
  - Phase I and the potential Phase II of the SFS will be used to refine the general areas of surficial soil contamination concern. The field BMFs from Phase II will be used to quantify ecological risks in the Area of Dispute, identify risk-based soil concentrations considered safe for biota, and thus refine the area of excess risks (Figure 6.2-6).
  - Pursuant to the FFA process, USFWS will conduct detailed site-specific exposure studies of contaminant effects and exposure (tissue levels and Army-provided abiotic sampling) on sentinel or indicator species of biota (including the six key species identified in the IEA/RC report as appropriate). These studies will address both the aquatic resources and at least the surficial soil in and around the Area of Dispute. These site-specific studies will be used in refining contamination impact areas in need of further remediation.
  - Results from both the SFS/risk assessment process and the site-specific studies will be considered in risk-management decisions, which may further refine the areas of surficial soil and aquatic contamination to be remediated. (In the event of a conflict between management of RMA as a wildlife refuge and performance of remedial response actions, the Rocky Mountain Arsenal National Wildlife Refuge Act indicates that response actions will take priority.)
- The BAS will serve as a technical resource to the Parties' decision makers by using technical expertise in analyzing, and potentially collecting, data sufficient to support design refinement for surficial soil areas and aquatic resources that will break unacceptable exposure pathways in consideration of minimizing habitat disturbance. Further, it will assess through monitoring the efficacy of remedies in breaking unacceptable pathways to biota. If any additional sites are identified, the remedy will be implemented as follows:
  - It will be staged to allow habitat recovery.
  - It will be performed first on locations selected through a balance of factors such as:
    - The Parties agree an area has a negative impact on or excessive risk to fish or wildlife.
    - The effort will not be negated by recontamination from other remediation activities.
    - The existing fish and wildlife resource value.
  - It will include revegetation of a type specified by USFWS; if the initial revegetation is not successful, the appropriate adjustments will be made and revegetation again implemented.
  - It will provide that the locations and timing of remediation are to be determined with consideration of and in coordination with USFWS refuge management plans and activities.

6.3 Uncertainty Analysis

Several sources of uncertainty must be considered in the evaluation of the HHRC and ERC results. Model parameter distributions were developed based on empirical data, and in instances where empirical data were

lacking, best professional judgment was incorporated. In addition, when uncertainty in the empirical data for a given parameter warranted conservative assumptions, these assumptions were incorporated into the exposure and risk estimations.

6.3.1 Human Health Risk Characterization

6.3.1.1 Chemical Database

Contributing to the chemical database uncertainty are the different analytical techniques used by the RI Phase I and Phase II programs for some of the organic chemicals. Phase I employed **gas chromatography/mass spectrometry (GC/MS)**, and Phase II employed more precise GC methods. The Phase I techniques made use of higher detection limits; thus, chemicals present at lower levels may not have been detected. In a few cases, Phase I samples required dilution to facilitate analysis, and the dilution may have masked the presence of some compounds by raising the effective detection level. When necessary, an expanded suite of Phase II analyses and/or additional GC/MS analyses were used to ensure that all target analytes were evaluated. Some other limitations associated with the chemical database are soil sample collection, tentatively identified compounds, unidentified compounds, and Army agent contamination. Uncertainties associated with soil sample collection can under- or overestimate risk. Tentatively identified and unidentified compounds were not considered in the risk characterization and the detections of Army chemical agent reported in the chemical database were not quantitatively evaluated. Potential risk may have been underestimated based on the exclusion of agent and tentatively identified compounds from the evaluations.

6.3.1.2 Exposure Point Concentration

Uncertainties associated with the exposure point concentrations include the estimation method used to approximate site concentration values used to calculate risk. In accordance with EPA guidance, representative soil concentrations were estimated using the arithmetic mean ($C_{rep,mean}$). The uncertainty in these estimates was characterized by reporting the 95 percent upper and lower confidence limits (95% UCL and 95% LCL, respectively) on the mean. The 95% UCL ($C_{rep,upper}$) was used to estimate the RME risks. Conservative assumptions were also employed to address potential dilution effects when soil boring samples were composited and to calculate the boring-by-boring risk estimates; the highest detected concentration of the COC was used regardless of the depth of the sample.

6.3.1.3 Land-Use and Exposure Scenarios

Uncertainty exists regarding the likelihood that the land uses evaluated will in fact occur under a future development scenario at RMA. Land use at RMA is currently limited to commercial, industrial, recreational, and open space (i.e., nature preserve/wildlife refuge) uses. The land-use designations were based on information obtained from several governmental agencies overseeing and directing land use within their respective jurisdictions surrounding RMA. The FFA restricts the ownership, use, and transfer of property at

RMA now and into the future. Consistent with the FFA, certain future land uses at RMA are not considered foreseeable, such as residential and agricultural development. It is for this reason that certain pathways of exposure (e.g., potable and agricultural use of groundwater, surface water and sediment exposures, and consumption pathways) were not evaluated at RMA. The uncertainties associated with the human health exposure scenarios evaluated in the IEA/RC as related to land use, target receptors, spatial exposure patterns, and exposure pathways could result in an over- or underestimation of risk.

6.3.1.4 Human Health Toxicity Estimates

The toxicity factors (D_T; the dose-response parameter based on the slope factor or RfD) used in the HHRC were designated as a fixed parameter to maintain consistency with established EPA toxicity factors used in CERCLA risk assessments. However, a large degree of uncertainty is known to be associated with the toxicity factors. This uncertainty could lead to an over- or underestimation of risk. The major sources of uncertainty include the following:

- Extrapolation of toxicity factors from effects observed at high doses administered in a laboratory setting to effects observed at relatively low doses expected from human contact with the chemical in environmental media
- Use of short-term toxicity studies to predict the effects of long-term (chronic) exposures and vice versa
- Use of animals to predict the effects of contaminant exposure on humans where adequate human data are lacking
- Use of toxicity data from laboratory animals (homogeneous populations) and healthy humans to predict the effects observed in a general population, which included individuals having a wide range of sensitivities

As indicated in "Guidelines for Carcinogenic Risk Assessment," the cancer slope factors generated from the linearized multistage extrapolation procedure lead to what is considered a "plausible upper limit to the risk that is consistent with some proposed mechanisms of carcinogenesis. Such an estimate, does not necessarily give a realistic prediction of the cancer risk. The true value of the risk is unknown, and may be as low as zero" (EPA 1986). Descriptions of the uncertainties associated with the toxicity factors are contained in Appendix B and Appendix E of the IEA/RC report.

6.3.1.5 Exposure Parameters and PPLVs

The variability and uncertainty in the PPLVs were estimated by developing probabilistic distributions for each of the HHRC model's parameters. The variability in the parameter distribution refers to the real variation in possible parameter values, which may be spatial (e.g., soil density), temporal (e.g., dust loading), physiological (e.g., body weight, skin surface areas) or due to the effects of other factors such as behavior. Uncertainty is that part of the parameter distribution resulting from random sampling variation and other sources of potential error. Uncertainty increases the overall spread of the distribution and may also result in bias, both intentional (e.g., conservative assumptions) and unintentional (unknown). There was substantial uncertainty about the

representativeness of data for parameters describing human exposures (e.g., soil intake parameters, time-dependent exposure parameters). In general, however, conservative assumptions were made. Ages and activities associated with the open space visitor land-use options were characterized using available empirical data and professional judgment. Although survey data were used to characterize time and activity patterns for the refuge worker population and biological worker subpopulation in order to improve the confidence in the analysis, the representativeness of the resulting distributions for current and future exposed populations at RMA remains uncertain. The datasets compiled for these populations or subpopulations may under-represent exposures for some portion of the future RMA population and over-represent for some other portion. It is not possible to determine with certainty whether data representativeness in the risk evaluations imparted a conservative or underconservative bias to the results. Summaries of the major uncertainties associated with the PPLV equation parameters are presented in Tables 6.3-1 through 6.3-3.

The variation in the HHRC model parameters is reflected in the spread of the PPLV distribution. Because the uncertainty and/or variability in many key probabilistic parameters is higher for particular chemicals or for exposed populations, the resulting PPLV distributions corresponding to these chemicals and land uses have a wider spread. A detailed description of the PPLV distribution variability is described in Appendix E of the IEA/RC report.

6.3.1.6 Risk Estimates

The PPLV-based risk estimations were based on a target cancer risk of 1×10^{-6} or an HQ of 1.0 and exposure point concentrations representing the C_{max}, $C_{rep,mean}$, and $C_{rep,upper}$ (the different risk calculation methods are available via the HHRC model). When the cancer risk estimates are based on the 5th percentile PPLV and the $C_{rep,upper}$, the results can be considered as upper bound estimates of potential risk.

In the IEA/RC, both carcinogenic risks and noncarcinogenic HQs are assumed to be additive, consistent with current risk assessment guidance. There are several limitations associated with this assumption. Due to these limitations, the potential to over- or underestimate risk cannot be firmly established. In summing cancer risks, the underlying assumption is that there is an independence of action (i.e., effect to organ, tissue, etc.) by the chemicals involved and that there are no synergistic or antagonistic chemical interactions. Uncertainty is also associated with summing cancer risks for multiple chemicals that have differing weights of evidence for human carcinogenicity (i.e., Group A versus Group C carcinogens; see Section 6.1.3). Because little or no information on antagonistic or synergistic effects was available for the RMA COCs, noncarcinogenic effects from multiple chemicals were also assumed to be additive. A limitation with the additive approach used for the IEA/RC is that the COC-specific HQs were not segregated by major toxic effect prior to summing to derive the HI;

however, this simplifying step may not have introduced large degrees of uncertainty because most of the noncancer effects were attributed to a single COC (dieldrin).

6.3.2 Ecological Risk Characterization

6.3.2.1 Chemical Database

The same uncertainties associated with the chemical database that were identified for the HHRC apply to the ERC. However, the database used for the ERC also included results associated with biota sample collection and analysis. Despite the relative abundance of site-specific field data to characterize ecological risk at RMA, the need to work with data from sampling programs designed for other purposes (e.g., to establish nature and extent of contamination) may have been less than ideal for the estimation of exposure soil concentrations and BMFs. It is difficult to know if the use of these data resulted in an over- or underestimation of potential risks to biota. The biota species sampled on RMA were chosen from species that best represented the uptake of contaminants from environmental media and the subsequent transfer, via food consumption, through food chains to top predators. Uncertainty is associated with the use of these biota samples to derive RMA-specific BMFs. Some uncertainty is also associated with the more scattered peripheral abiotic sampling where heterogeneous soil contamination occurs, and where detection limits, in some cases, exceeded the risk-based concentrations. These factors, along with lesser sampling density and little collocation of tissue and soil samples, added to the uncertainties associated with the chemical database.

6.3.2.2 Exposure Pathways

Exposure pathways were selected to include the predominant pathways of exposure believed to exist at RMA. Those selected for the food-web model included food consumption, dermal exposure to surface water by organisms, ingestion of water by some terrestrial organisms, and sediment and soil ingestion by some aquatic and terrestrial organisms. Exposure pathways excluded from the food-web model included inhalation of contaminant vapors and particulates and dermal exposure to contaminants from soil contact. These exposure pathways are implicitly contained in the BMF because measured tissue concentrations (from sampled biota species) are the result of cumulative exposure by all pathways. Additional uncertainties related to the exposure pathways are presented in Section 6.3.2.4.

6.3.2.3 Exposure Concentrations

Most of the uncertainty regarding exposure concentrations centers on the estimated exposure area concentrations used to calculate terrestrial risk. Aquatic risk was estimated directly from measured tissue concentrations and therefore was not based on quantitative exposure concentrations in aquatic media. Terrestrial tissue concentrations, dose, and risk are theoretically dependent on exposure soil concentrations (ESCs), i.e., the concentration in soil that is bioavailable and accessed by an individual during exposure activity. The ESC is, for all practical purposes, unverifiable in the field; therefore, it is represented by

estimated exposure area soil concentration, i.e., the average soil concentration in a specified depth profile within a circular species-specific exposure area. Two types of uncertainty occur when applying ESC to estimate risk. "Representation uncertainty" refers to the uncertainty in adequately representing spatial and temporal scales of the ESC by exposure area soil concentration, and "estimation uncertainty" refers to the uncertainty in analytically estimating the exposure area soil concentration based on available data. Representation uncertainty explains the difference between true exposure concentration for an individual and the exposure area concentration for a typical (mean) individual. Unfortunately, representation uncertainty is for all practical purposes unquantifiable and irreducible, because the detailed information on individual organisms (and their prey) required for its calculation cannot be practically obtained. Estimation uncertainty explains the differences between the true exposure area soil concentration in a given area or for a given individual, and the estimated exposure area soil concentration based on available sampling and analytical data.

The empirical mathematical constant used to relate exposure area soil concentration to tissue concentration is the BMF. BMF is therefore defined as a correlation based on the variable exposure area soil concentration and not on actual exposure soil concentration. The BMF values determined purely from literature data, rather than site-specific data from RMA, will describe the relationship between tissue concentration and a different dose-based quantity than ESC, and therefore may create more or less bias if used with ESC to predict risk at RMA. Uncertainty is also associated with the BMF based on the use of site-specific information (e.g., RMA-soil and biota data collected at different times and locations and for various purposes). The uncertainty associated with the exposure concentration, including the estimation of BMFs, will be further ascertained by review of the findings gathered from the SFS and the ongoing USFWS biomonitoring studies.

6.3.2.4 Ecological Toxicity Estimates

MATC and TRV uncertainty was incorporated quantitatively by use of UFs as discussed in Section 6.2.3. The UFs were applied to add a margin of safety to the extrapolated toxicity measures. The UF protocol included factors to account for four categories of uncertainty: intertaxon variability, study duration, toxicity effect levels (study endpoints), and other modifying factors (including nine subcategories) that were multiplied to arrive at the total estimated uncertainty.

In addition to the uncertainty incorporated in the UFs are potentially unrecognized or unquantifiable sources of uncertainty. These include the following:

- Representativeness of toxicity endpoint tissue concentration data from one species relative to other species in the trophic box
- Differences in metabolic rate, body size, and physiology between test and target species
- Differences in feeding habits and behavioral patterns in test v. target species
- Differences in the life stage of the organisms tested v. those exposed

- Seasonal differences in response to toxicants (e.g., "fat" versus "lean" times)
- Difficulty in adequately estimating exposure concentrations (including environmental variability in time and space)
- The possibility that exposed organisms may avoid, or be attracted to, contaminated media (e.g., pesticide-debilitated prey) and so may not show effects seen in laboratory tests (Suter 1993)
- Inability to quantify the other stresses that biota may face (e.g., climate, food supplies, background levels of toxicants, habitat disturbance, and other manmade causes)
- The possibility that exposure pathways, in addition to ingestion, are significant
- The fact that there are no standard measures of effect, patterns of dosing, durations of exposure, etc., so comparison across studies/ecosystems is obscured or confounded

6.3.2.5 Risk Estimates

Toxicological effects from multiple chemicals were assumed to be additive, consistent with the risk assessment procedures used for human health. This assumes independence of action, i.e., no net synergistic or antagonistic effects, since these effects are poorly understood with the limited toxicological data available. This practice of additivity without a toxicological basis (i.e., common mechanism of action or target organ effect) is protective but scientifically questionable; however, some means of evaluating the potential cumulative effects of exposure was required and EPA guidance requires such an approach in the absence of site-specific data on additivity. Hence, the individual HQs for each COC were summed to estimate the total risk (HI) for each trophic box. It is difficult to determine whether this procedure over- or underestimated risks to biota. As noted in the IEA/RC report, a range of potential risk was presented for the bioaccumulative COC because three different BMFs were employed. Because of the overall uncertainty associated with each of the parameters incorporated in the food-web model and the toxicity threshold values, it is difficult to state with certainty at this time which of the three BMF approaches best estimated risk to biota at RMA. Additionally, it is possible that actual residual risk to biota of an excessive nature may occur in some cases following remediation based on the uncertainty associated with the food-web risk modeling process and its application to delineated areas proposed for remediation. Again, the uncertainty associated with the risk estimates will be further ascertained by review of the findings gathered from the SFS and the ongoing USFWS biomonitoring studies.

6.3.2.6 Ecological Measurement Endpoints

The presence of potential ecological risk was given further perspective by considering it together with available field data on ecological endpoints. The available data on ecological status and health used to evaluate ecological endpoints are also subject to uncertainty. In this context, uncertainty results from the following:

- The short-term nature of many of the studies relative to the cycles of natural variability
- Estimation of quantitative ecological parameters at levels of precision that may not be biologically and/or statistically significant and/or use of endpoints that may not have been sensitive enough to discern the various potential human health risks to biota

- Study designs that did not precisely and quantitatively correlate ecological parameters with parameters related to contaminant concentrations
- Study designs that did not precisely quantify all parameters that might have positively or negatively affected the ecological data

Appendix E of the IEA/RC report presents a detailed discussion on the assumptions, limitations, and uncertainties associated with each of the uncertainty categories listed above.

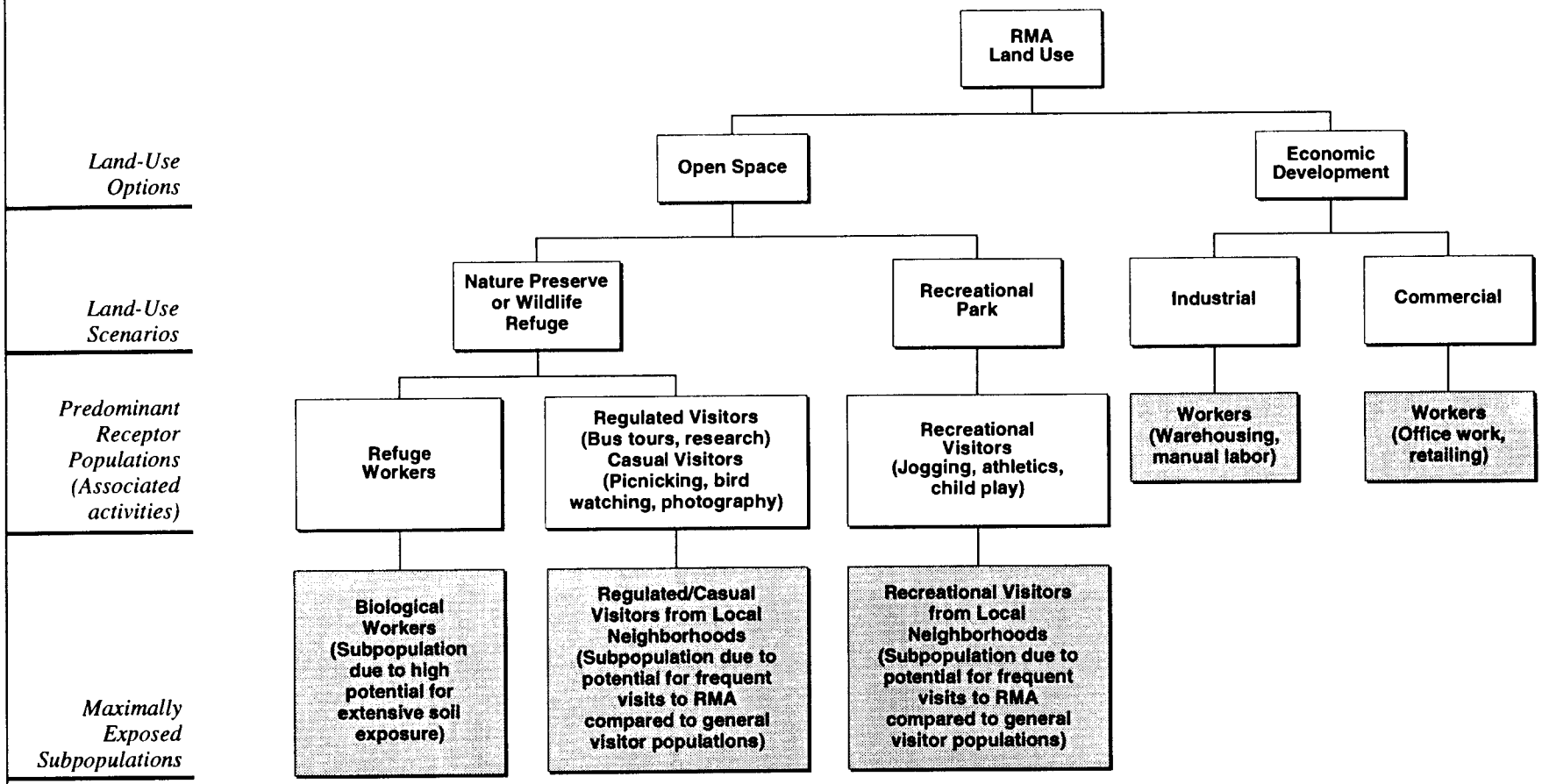
6.4 Conclusions

Both the human health and the ecological risk assessment results are based on probabilistic methodologies. The probabilistic methods account for the variability in literature and field data for the various parameters used to quantify exposure and risk and at least partially reflect the uncertainty associated with these parameters. The use of this methodology and the discussions of uncertainty increases the understanding the risk characterization by clarifying the uncertainties associated with the input values and their implications on estimated risks.

The results of the risk assessment, as presented in the IEA/RC report, indicate that potential risks exist for both human and ecological receptors. The contaminants that are the major contributors to overall potential risks are similar for both receptor groups, i.e., the OCPs. Likewise, the areas that pose the greatest potential risks to both receptor groups are in the central core region of RMA. It is very important to remember that the potential risks presented in this report are based on current and historical contamination evaluated under present or future land-use scenarios. However, data from some of the areas at RMA that have undergone interim remediation (e.g., capping to eliminate possible exposure pathways for receptors) were not revised to reflect the remediation; the actual risks are, therefore, likely to be lower than the risks presented in the IEA/RC report.

Areal extents of biota remediation that are needed to reduce or prevent excessive risks to ecological health are not completely known at present, but will be further refined as part of remedial design and incorporate ongoing ecotoxicological evaluations by the BAS. Recommendations regarding the nature and extent of excessive risks to biota will be presented by the BAS to RMA risk managers for inclusion in soil remedial actions to reduce risks to acceptably healthy levels in accordance with EPA Superfund guidance, the Rocky Mountain Arsenal National Wildlife Refuge Act, and the selected remedy.

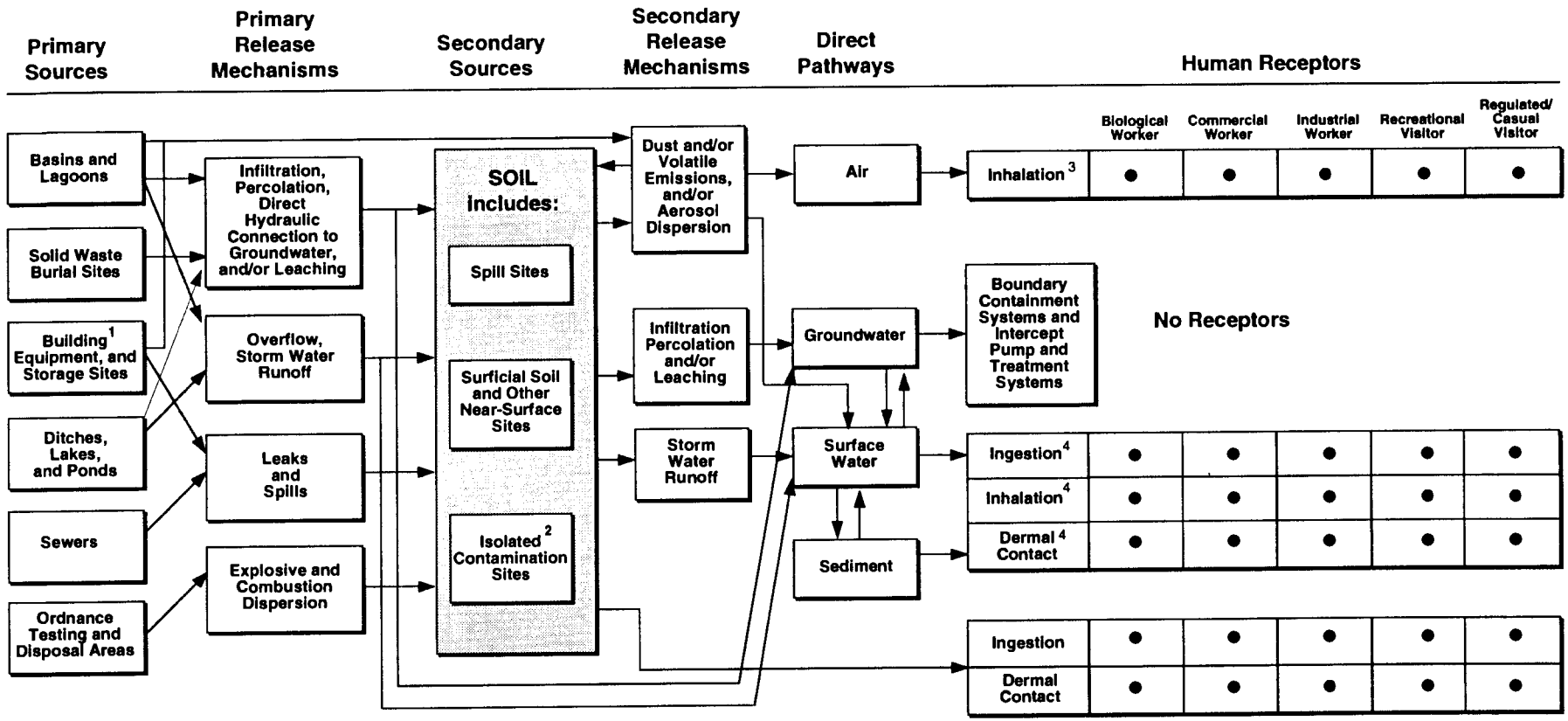
Actual or threatened releases of hazardous substances from this site, if not addressed by implementing the response action selected in this ROD, may present an imminent and substantial endangerment to public health, welfare, or the environment.



1 - Receptor populations/subpopulations shown in shaded boxes were evaluated in this risk assessment

Figure 6.1-1
Projected Land-Use Scenarios for RMA[1]

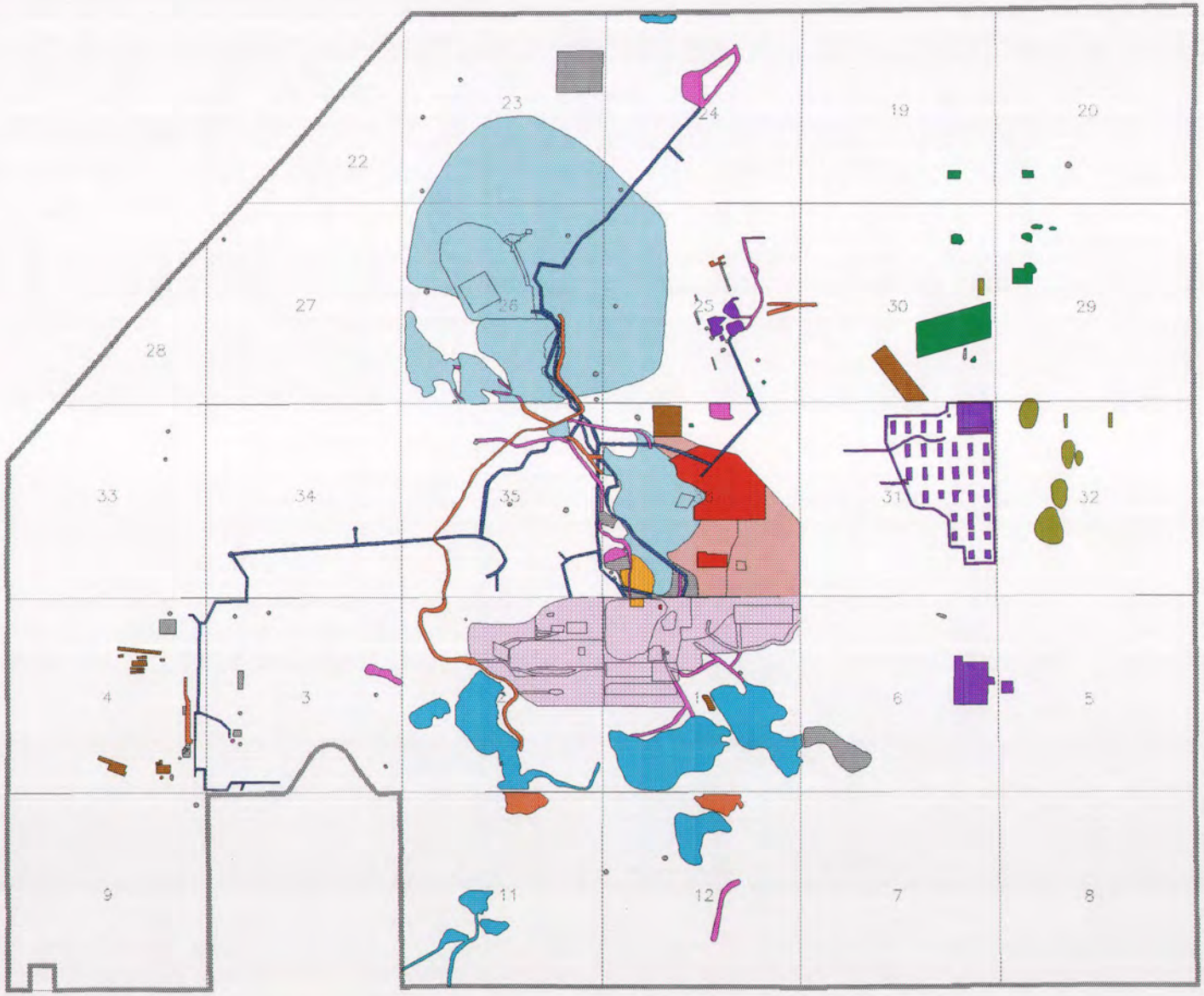
Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corporation



1 - Building, Equipment, and Storage Sites include only the soils present at these sites, not the structures themselves.
2 - Isolated Contamination Sites are not generally considered sources in the sense that they could provide releases to the environment.
3 - Enclosed space vapor inhalation evaluated for commercial and industrial populations only. Open space vapor inhalation evaluated for all populations except commercial workers.
4 - Only ephemeral lake sediments evaluated.

Figure 6.1-2
RMA Site Conceptual Model for Human Receptors

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corporation



Legend

- RMA Boundary
- SAR Site Boundary[1]
- Munitions Testing
- Agent Storage
- Lake Sediments
- Ditches/Drainage Areas
- Basins (A–F)
- Sewer Systems
- Disposal Trenches
- Sanitary Landfills
- Lime Basins
- South Plants
- Buried Sediments/Ditches
- Section 36 Balance of Areas
- Burial Trenches
- RMA Balance of Areas[2]
- 5 Section Number

[1]Study Area Report (see Remedial Investigation Summary Report, Ebasco 1992a).

[2]RMA Balance of Areas site designation includes all RMA areas not shaded.

-N-

1500 0 1500 3000 Feet

Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

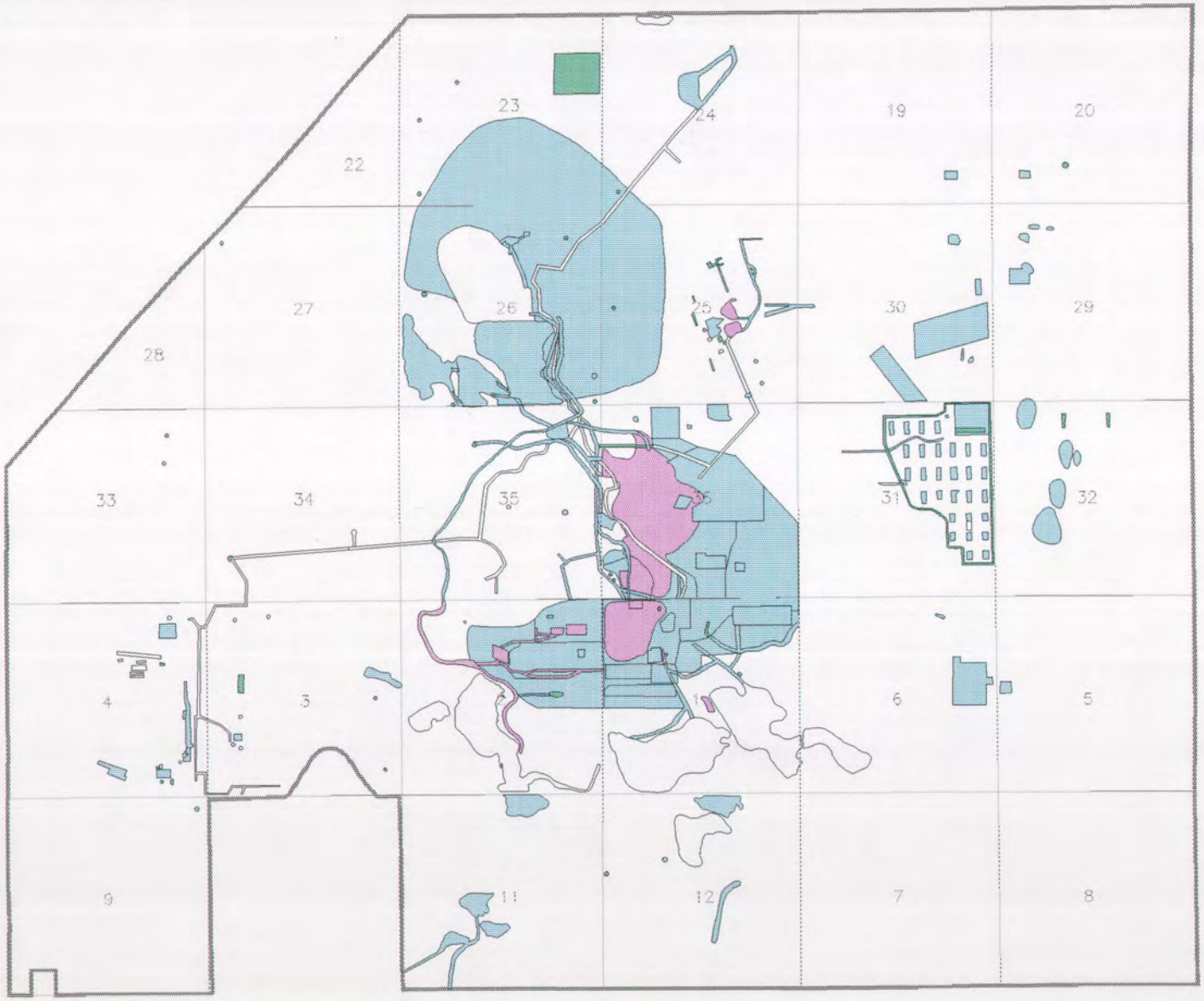
June 1996

Figure 6.1-3

RMA Site Designations used in the HHRC

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corporation

File Name: C:\SOILS\ROD\ROD61-2
Date 6/06/96
Drawn by XG
Checked by SA



Legend

- RMA Boundary
- SAR Site Boundary[1]
- CR > 10^{-4}
- 10^{-6} < CR ≤ 10^{-4}
- CR ≤ 10^{-6}
- COCs Reported Below CRLs
- 5 Section Number

[1]Study Area Report (see Remedial Investigation Summary Report, Ebasco 1992a).

[2]Based on RME exposure parameters and $C_{rep,upper}$ for 0–ft to 1–ft depth interval.

-N-

1500 0 1500 3000 Feet

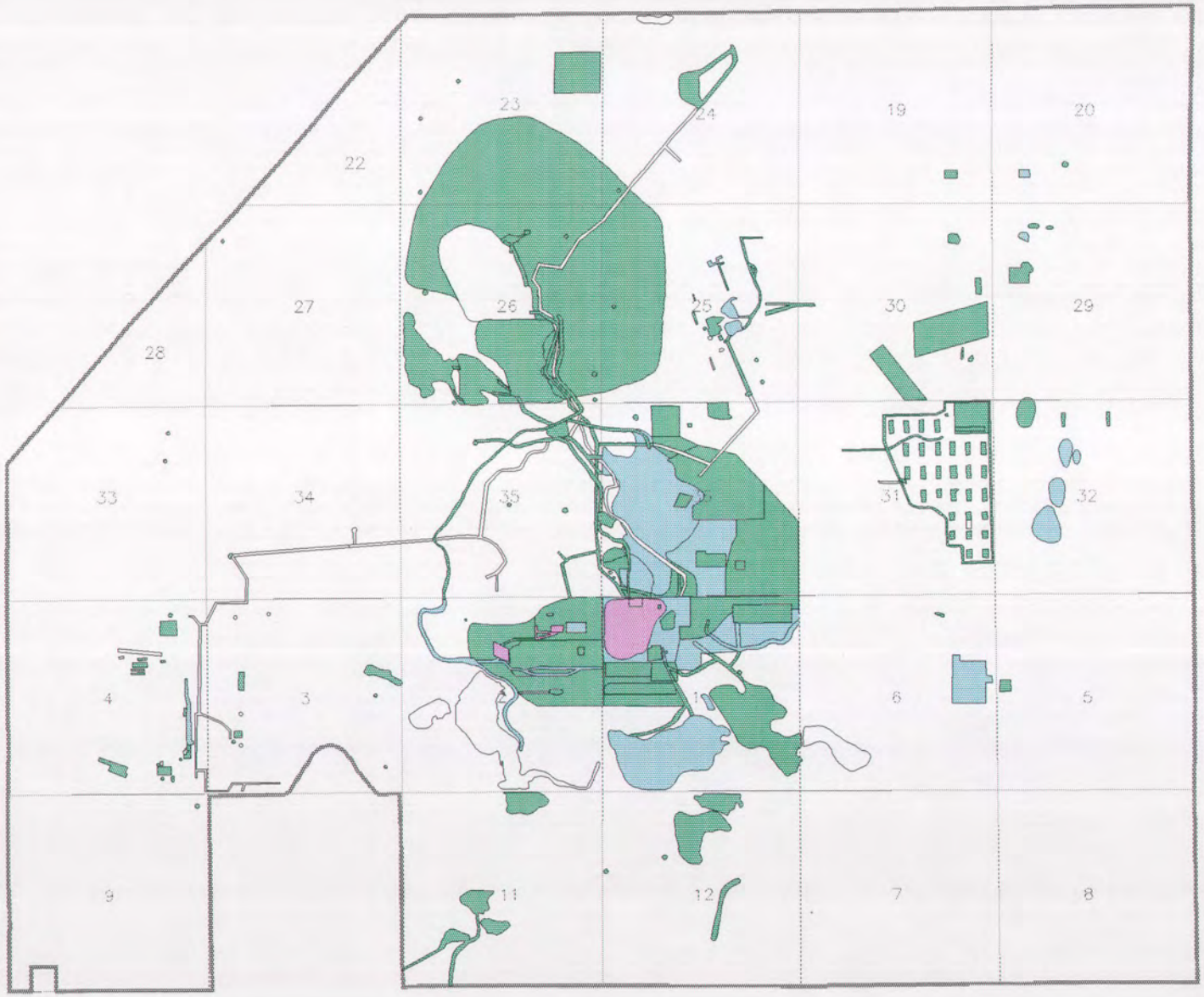
Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

Figure 6.1–4

Total Site Cancer Risks for Biological Worker,[2] Horizon 0

Foster Wheeler Environmental Corporation
June 1996

File Name: C:\SOILS\ROD\EI-HOR1
Date 6/06/96
Drawn by XG
Checked by SA



Legend

- RMA Boundary
- SAR Site Boundary[1]
- HI > 10
- 1 < HI ≤ 10
- HI ≤ 1
- COCs Reported Below CRLs
- 5 Section Number

[1]Study Area Report (see Remedial Investigation Summary Report, Ebasco 1992a).

[2]Based on RME exposure parameters and $C_{rep,upper}$ for 0–ft to 1–ft depth interval.

-N-

1500 0 1500 3000 Feet

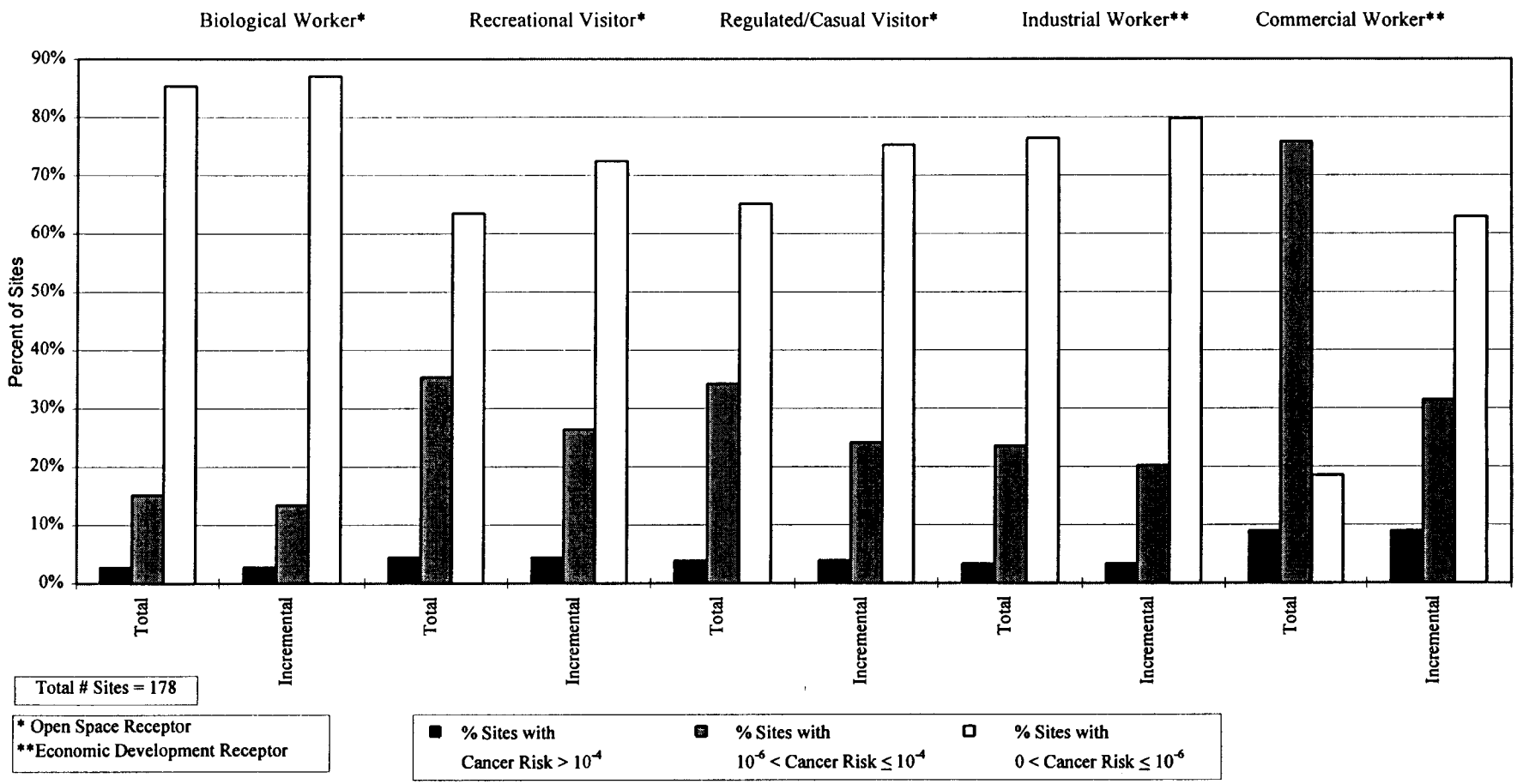
Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

Figure 6.1–5

Total Site Hazard Indices for Biological Worker,[2] Horizon 0

Foster Wheeler Environmental Corporation
June 1996

File Name: C:\SOILS\ROD\HI-HOR1
Date 6/06/96
Drawn by XG
Checked by SA



Note: Incremental risk is equal to the total minus the risk attributable to indicator (background) levels of metal COCs.

Figure 6.1-6

Cancer Risk Summary for All Receptors Based on Site-Specific ($C_{rep,\ upper}$) Results, Horizon 0

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corporation

rma\1603G.XLS

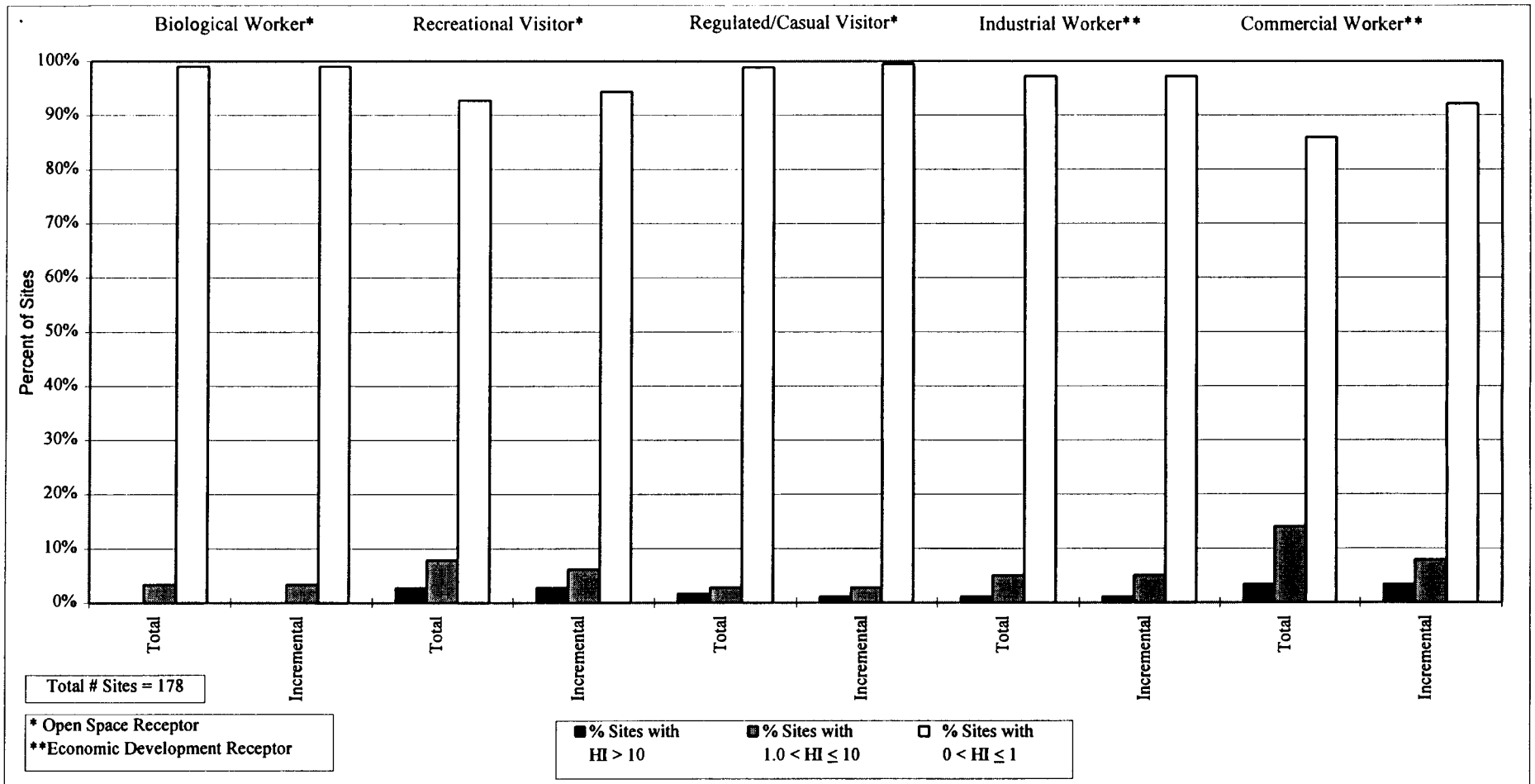
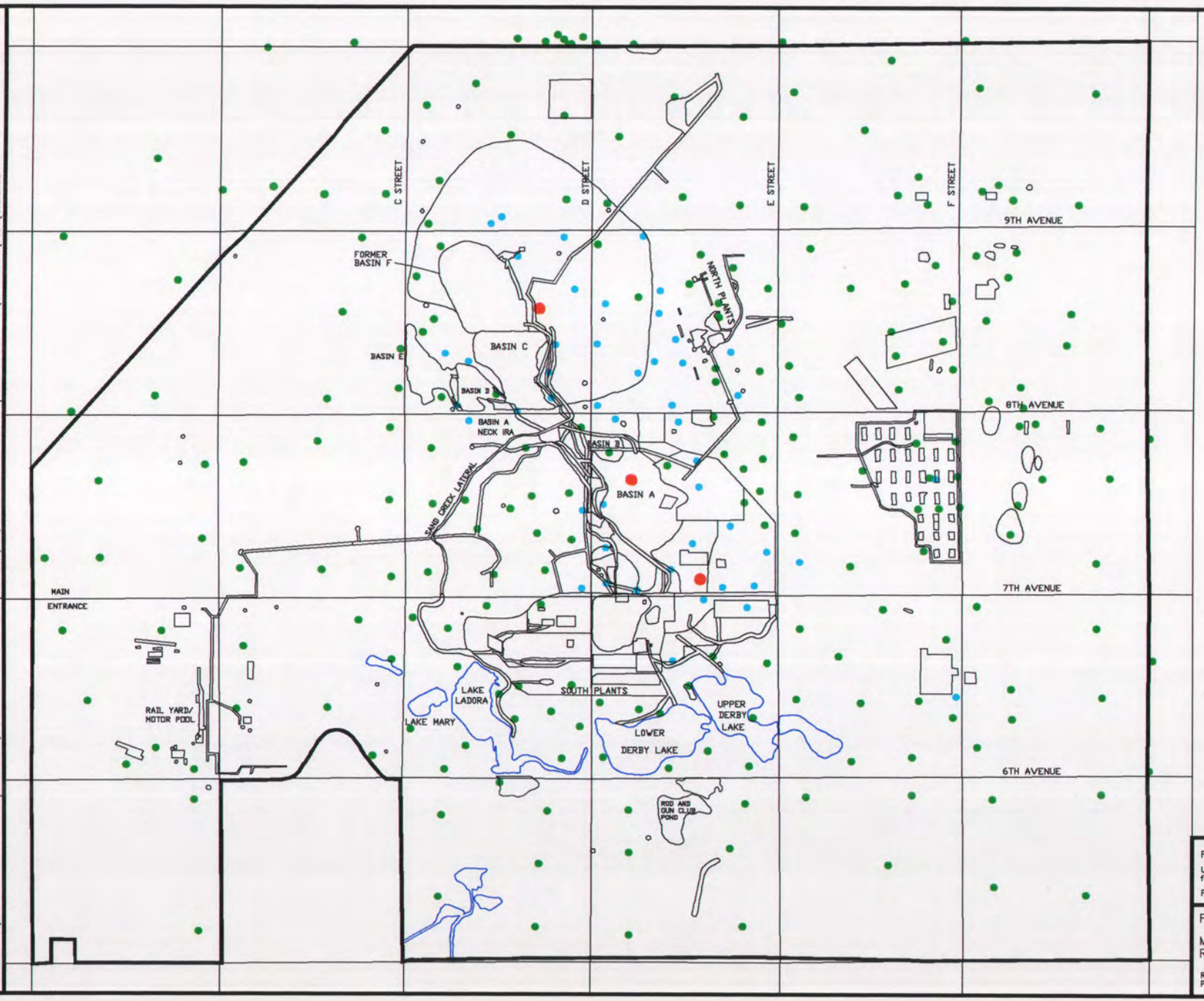


Figure 6.1-7

Hazard Index Summary for All Receptors Based on Site-Specific ($C_{rep,upper}$) Results, Horizon 0

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corporation



LEGEND

- CR > 10^{-4}
- 10^{-6} < CR < 10^{-4}
- CR ≤ 10^{-6}

Prepared for:

U.S. Army Program Manager for Rocky Mountain Arsenal

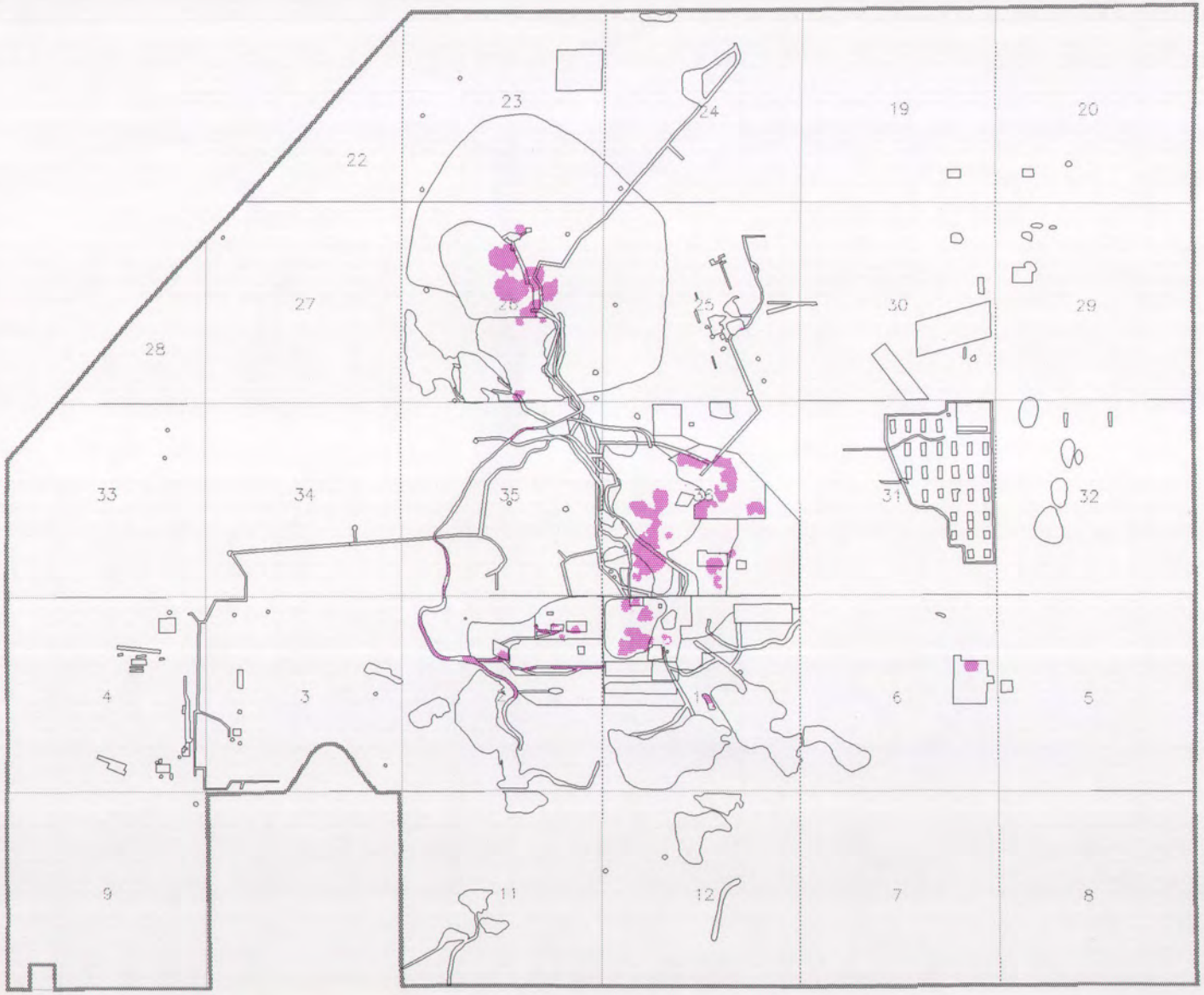
Prepared June 1996

Figure 6.1–8

Map of Surficial Soil Incremental Cancer Risks for the Biological Worker

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corporation

File Name: F:\PROJECTS\RMA\SIC.DWG
Date 5/08/96
Drawn by MAT
Checked by SA



Legend

RMA Boundary

SAR Site Boundary[1]

Human Health Exceedance Area
Cancer Risk ≥ 10E−4

5 Section Number

[1]Study Area Report (see Remedial Investigation Summary Report, Ebasco 1992a).

[2]Based on RME exposure parameters and C_{max} on boring by boring basis for 0−ft to 1−ft depth interval.

N

1500 0 1500 3000 Feet

Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

Figure 6.1−9

Human Health Carcinogenic Exceedance Areas,[2] Horizon 0

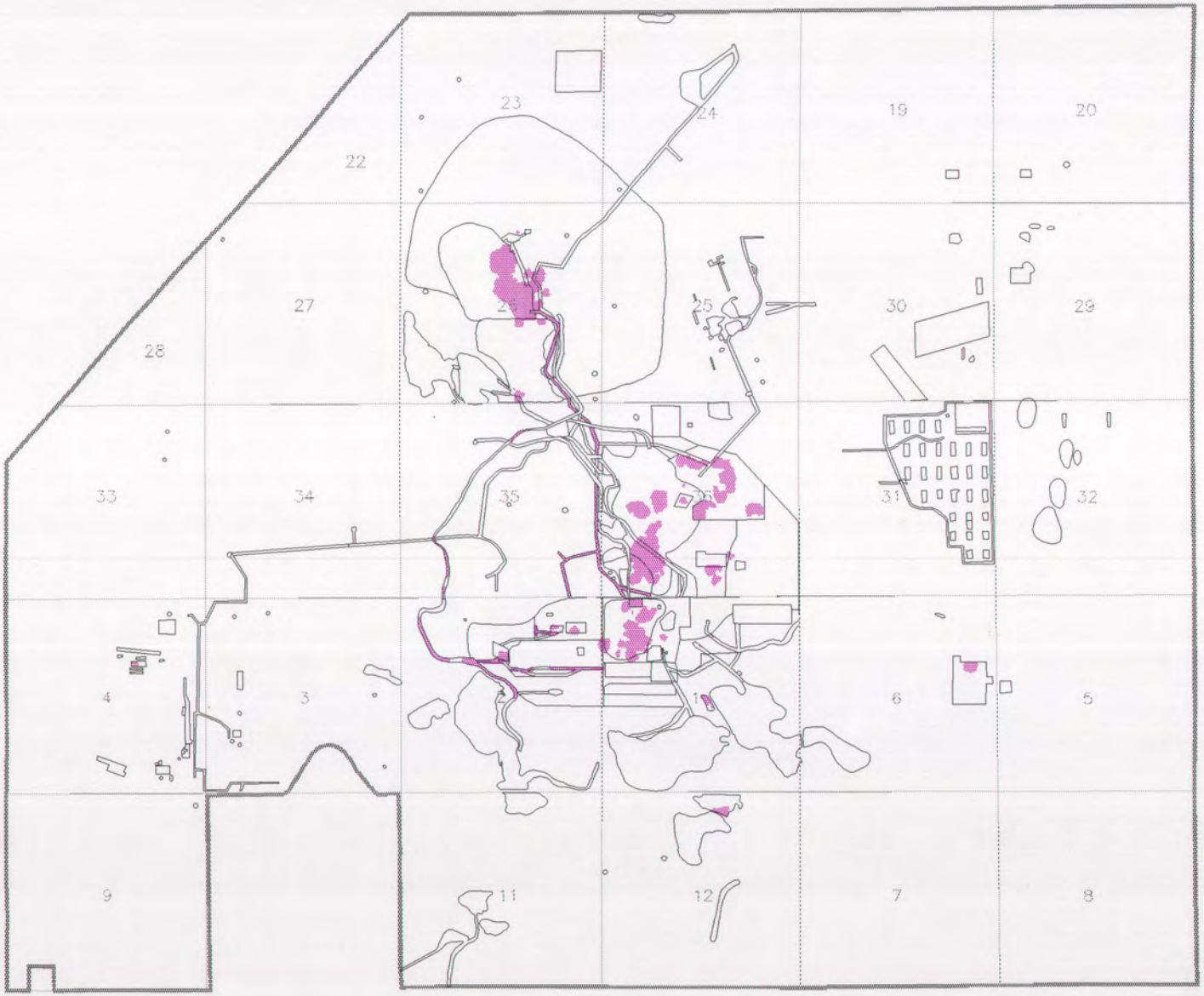
Foster Wheeler Environmental Corporation
June 1996

File Name: C:\SOILS\ROD\EI01

Date 6/06/96

Drawn by XG

Checked by SA



Legend

RMA Boundary

SAR Site Boundary[1]

Human Health Exceedance Area
Cancer Risk ≥ 10E−4

5 Section Number

[1]Study Area Report (see Remedial Investigation Summary Report, Ebasco 1992a).

[2]Based on RME exposure parameters and C_{max} on boring by boring basis for 0−ft to 10−ft depth interval.

-N-

1500 0 1500 3000 Feet

Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

Figure 6.1−10

Human Health Carcinogenic Exceedance Areas,[2] Horizon 1

Foster Wheeler Environmental Corporation
June 1996

File Name: C:\SOILS\ROD\EI

Date 6/06/96

Drawn by XG

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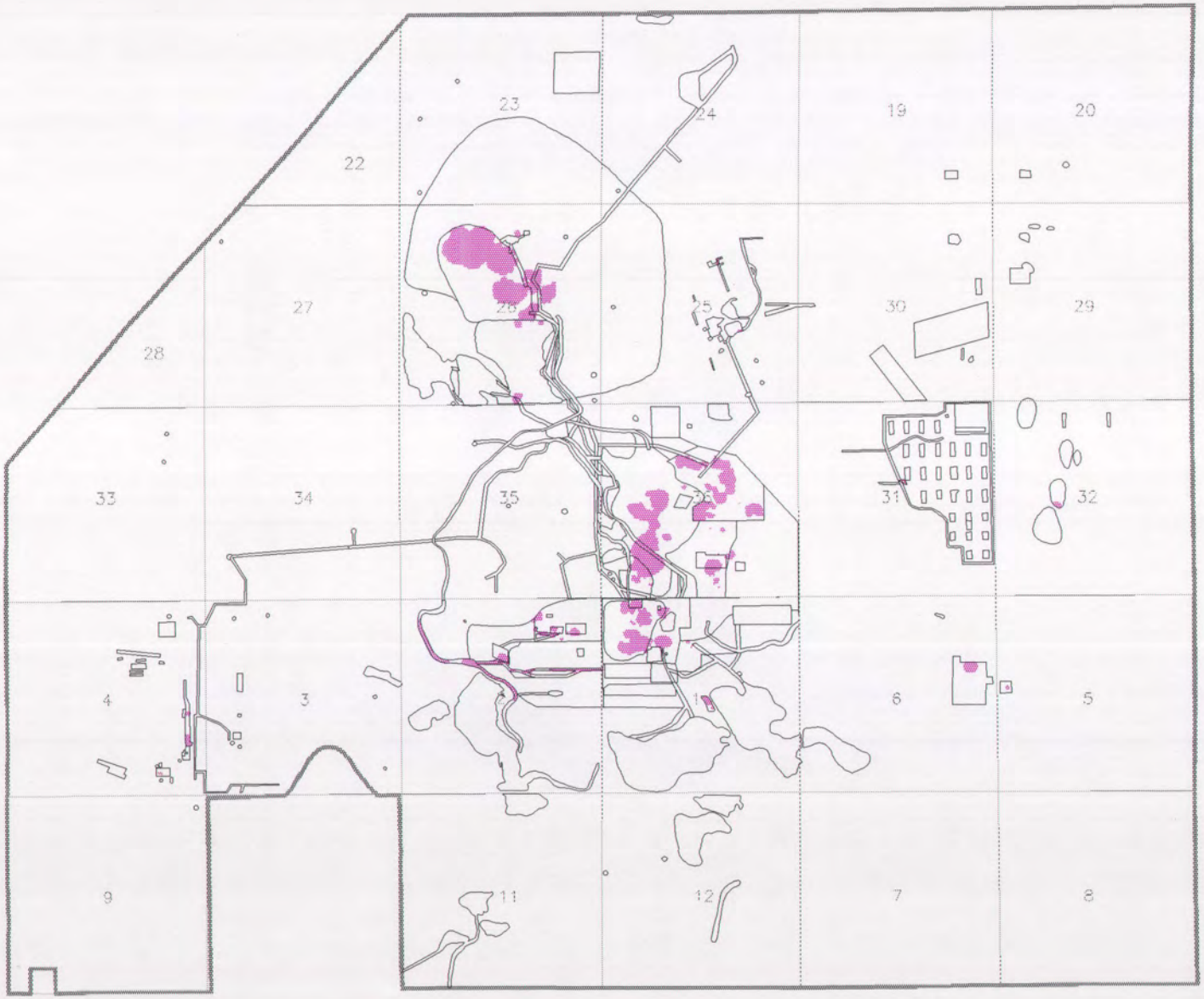


Legend

RMA Boundary

SAR Site Boundary[1]

Human Health Exceedance Area
Chronic HI ≥ 1.0

5 Section Number

[1]Study Area Report (see Remedial Investigation Summary Report, Ebasco 1992a).

[2]Based on RME exposure parameters and C_{max} on boring by boring basis for 0–ft to 1–ft depth interval.

-N-

1500 0 1500 3000 Feet

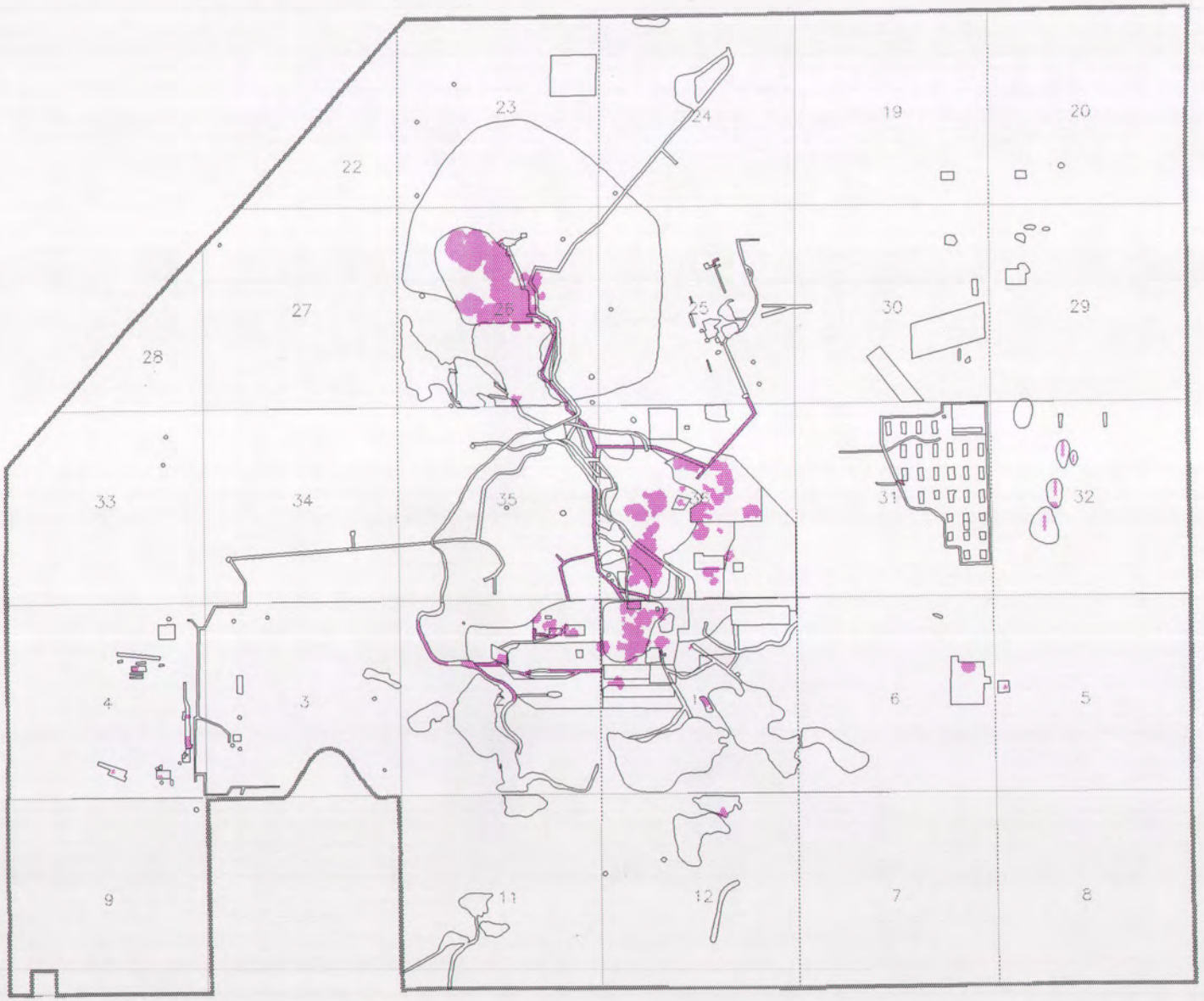
Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

Figure 6.1–11

Human Health Noncarcinogenic Exceedance Areas,[2] Horizon 0

Foster Wheeler Environmental Corporation
June 1996

File Name: C:\SOILS\ROD\HI01
Date 6/06/96
Drawn by XG
Checked by SA



Legend

RMA Boundary

SAR Site Boundary[1]

Human Health Exceedance Area
Chronic HI ≥ 1.0

5 Section Number

[1]Study Area Report (see Remedial Investigation Summary Report, Ebasco 1992a).

[2]Based on RME exposure parameters and C_{max} on boring by boring basis for 0–ft to 10–ft depth interval.

-N-

1500 0 1500 3000 Feet

Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

Figure 6.1–12

Human Health Noncarcinogenic Exceedance Areas,[2] Horizon 1

Foster Wheeler Environmental Corporation
June 1996

File Name: C:\SOILS\ROD\HI

Date 6/06/96

Drawn by XG

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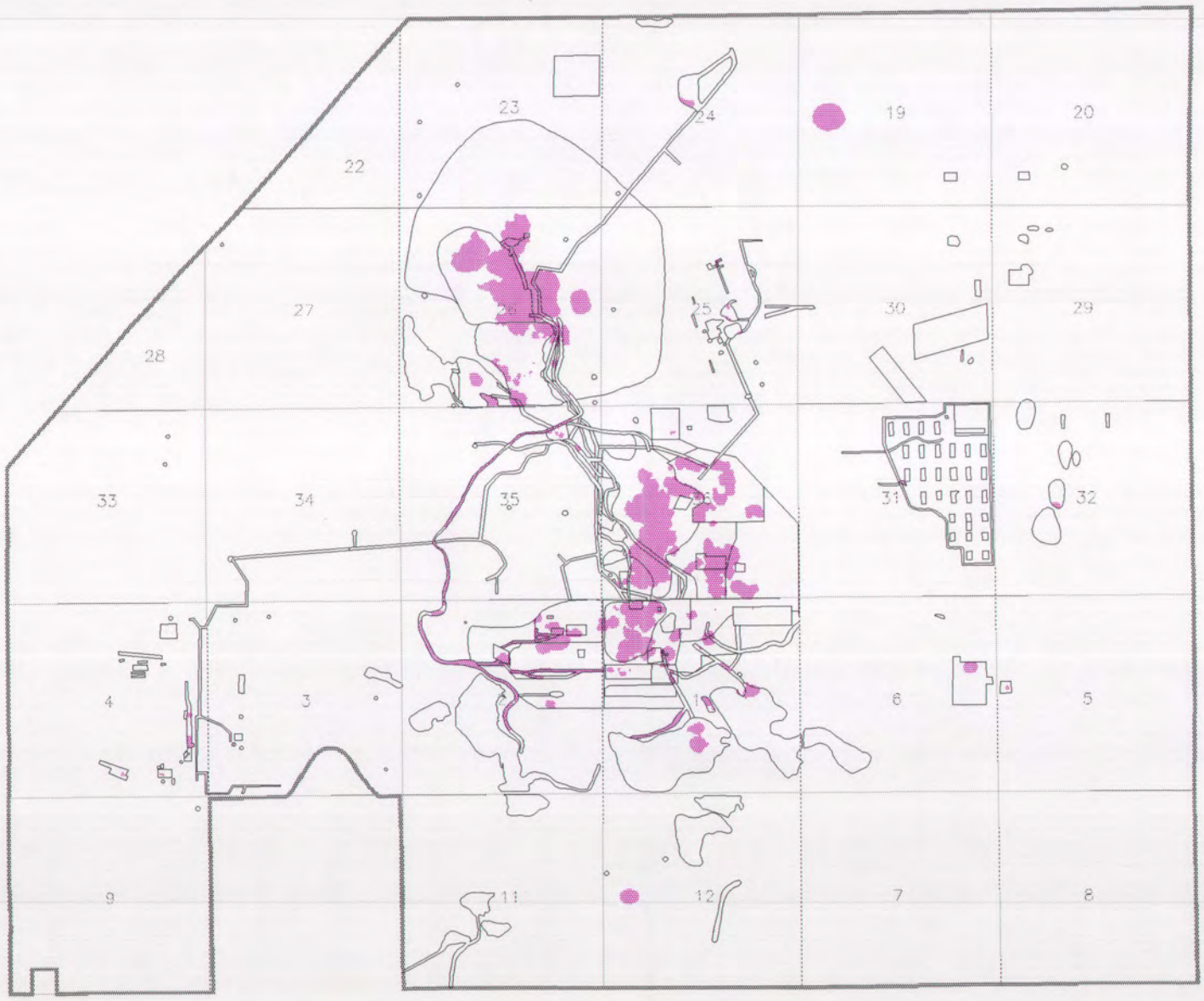


Legend

RMA Boundary

SAR Site Boundary[1]

Human Health Exceedance Area
Cancer Risk ≥ 10E−4,
Chronic HI ≥ 1.0, or Acute HI ≥ 1.0

5 Section Number

[1]Study Area Report (see Remedial Investigation Summary Report, Ebasco 1992a).

[2]Based on RME exposure parameters and C_{max} on boring by boring basis for 0−ft to 1−ft depth interval.

-N-

1500 0 1500 3000 Feet

Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

Figure 6.1−13

Human Health Exceedance Areas,[2] Horizon 0

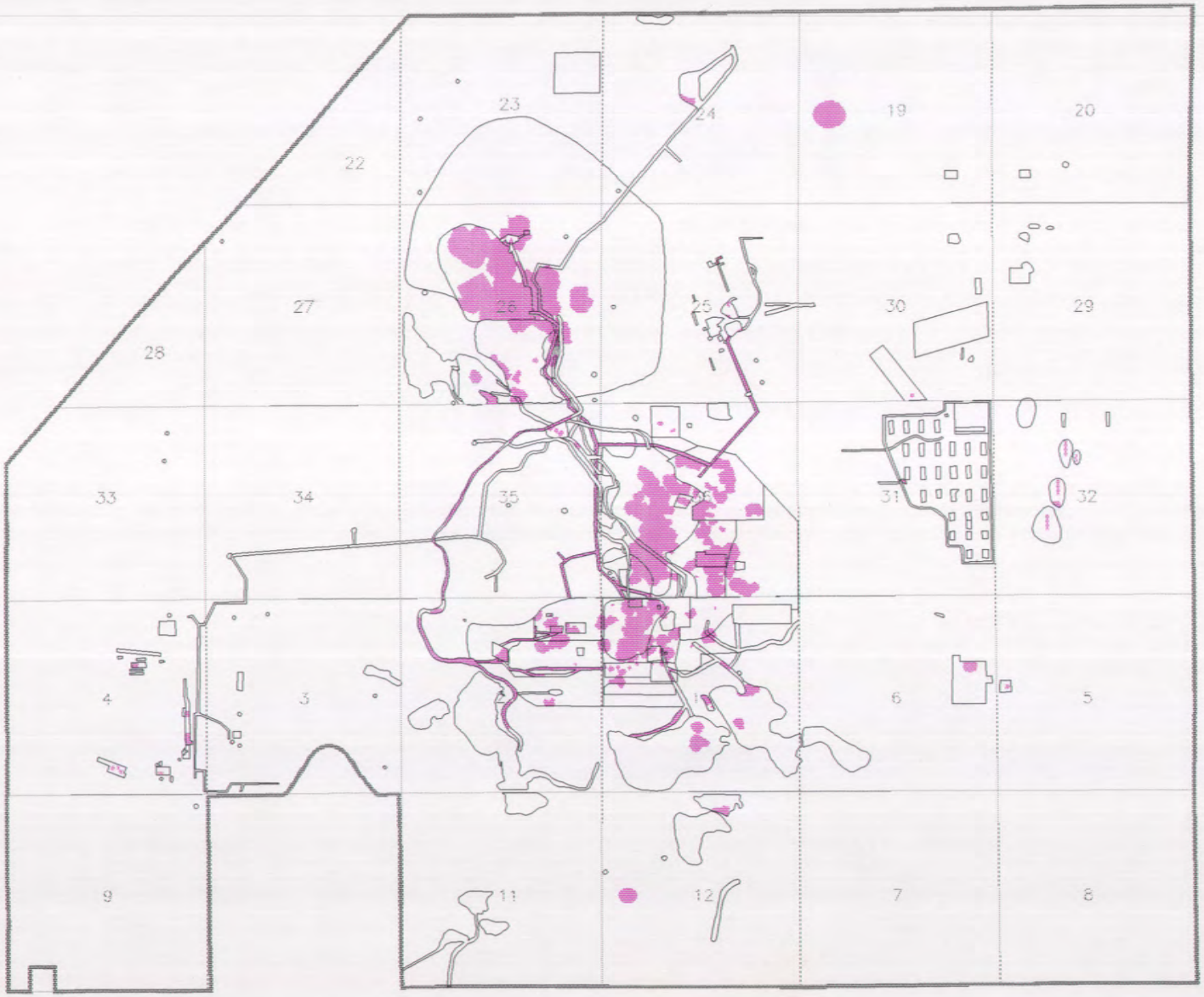
Foster Wheeler Environmental Corporation
June 1996

File Name: C:\SOILS\RODVACT01

Date 6/06/96

Drawn by XG

Checked by SA



Legend

RMA Boundary

SAR Site Boundary[1]

Human Health Exceedance Area
Cancer Risk ≥ 10E−4,
Chronic HI ≥ 1.0, or Acute HI ≥ 1.0

5 Section Number

[1]Study Area Report (see Remedial Investigation Summary Report, Ebasco 1992a).

[2]Based on RME exposure parameters and C_{max} on boring by boring basis for 0−ft to 10−ft depth interval.

-N-

1500 0 1500 3000 Feet

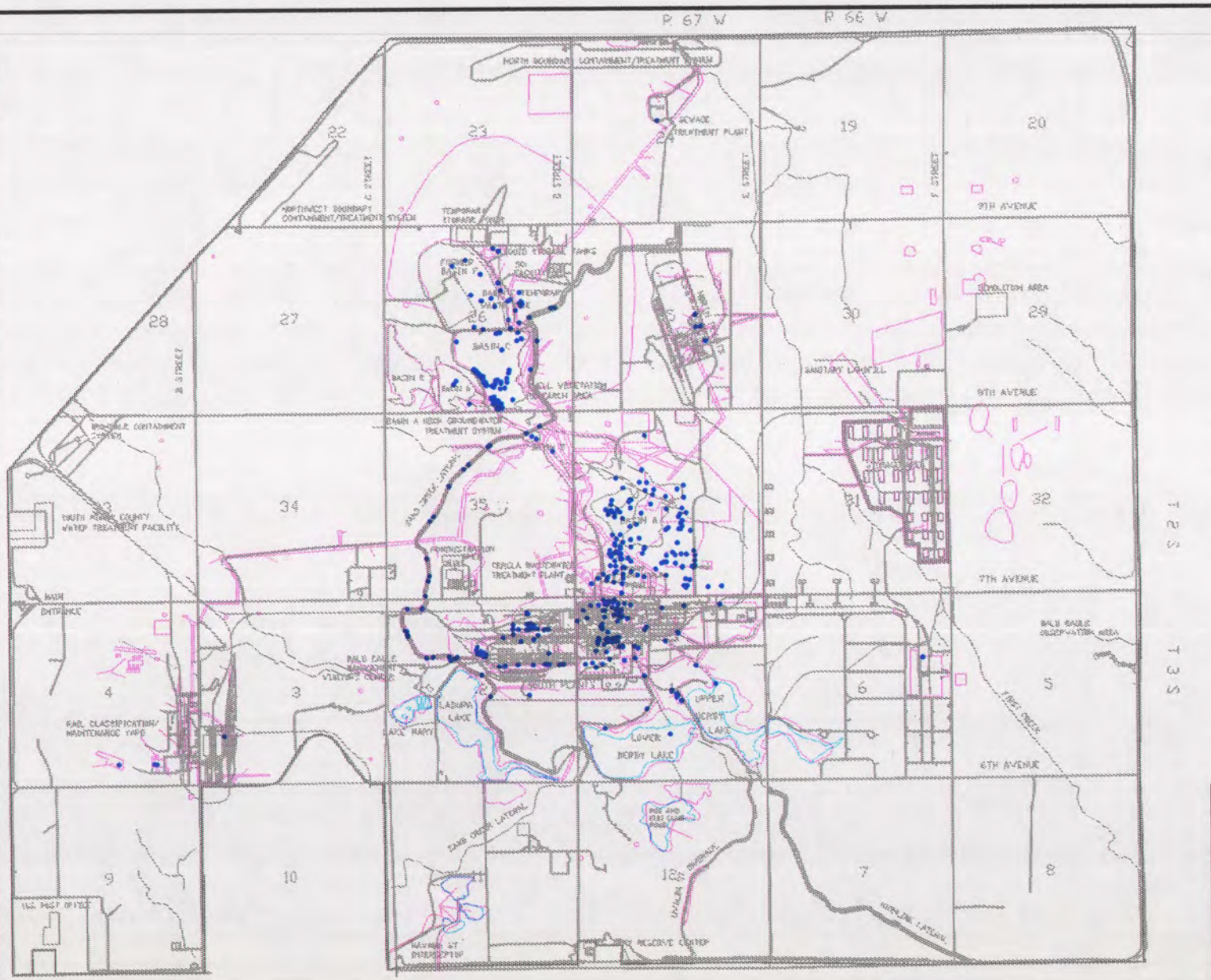
Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

Figure 6.1−14

Human Health Exceedance Areas,[2] Horizon 1

Foster Wheeler Environmental Corporation
June 1996

File Name: C:\SOILS\ROD\AREAS2
Date 6/06/96
Drawn by XG
Checked by SA



Legend

- SAR Site
- 31 Section Number
- Section Line
- Drainage
- Road
- Railroad
- • Sample Exceeds Acute Criteria HI* ≥ 1.0, 0 – 1 foot depth interval

*Cumulative HI developed using deterministic exposure parameters presented in Table 6.1–6 on environmental soil data, for all COCs with acute PPLV values (Table 6.1–19)

N

0 2000 4000
Scale in Feet

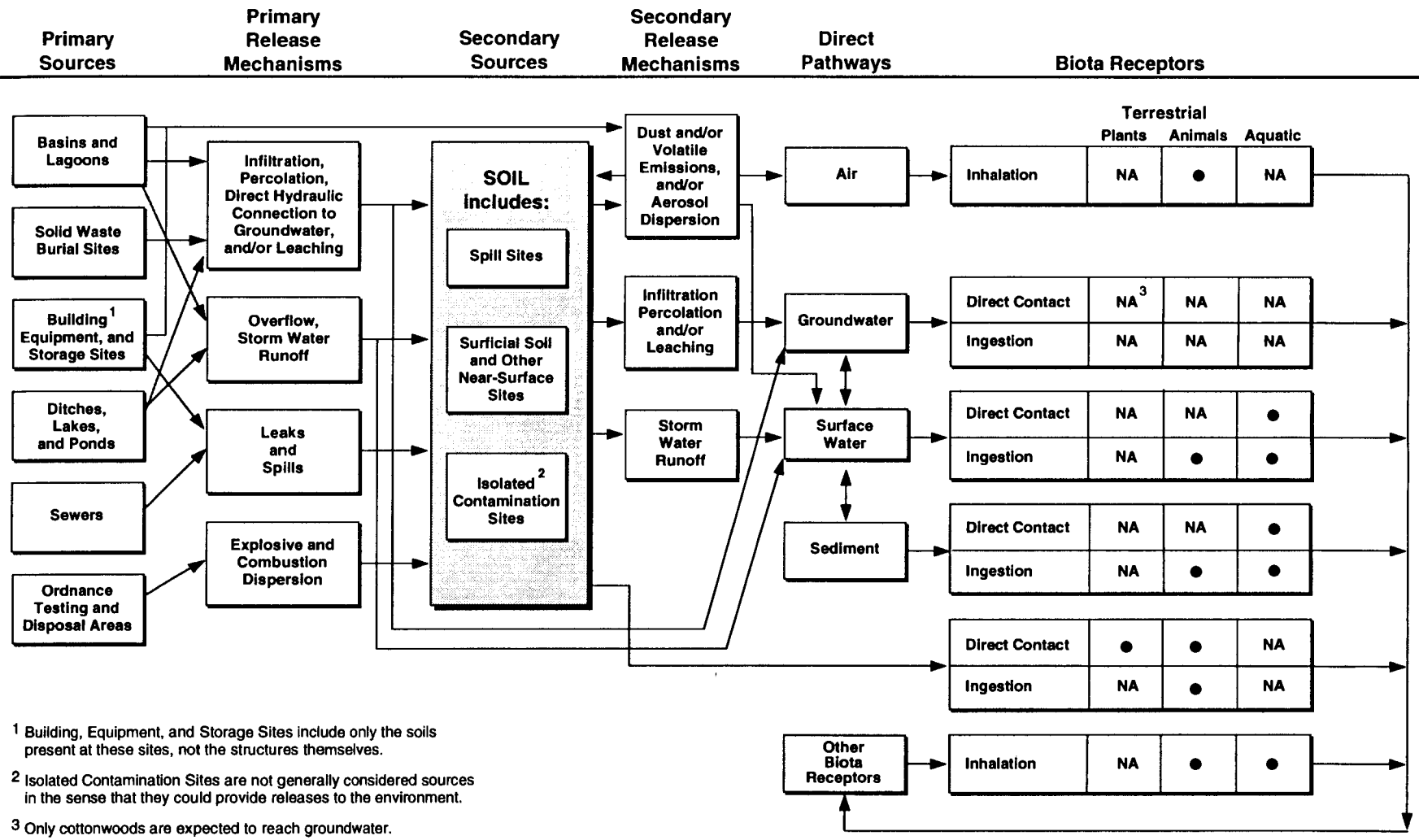
Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal
June 1996

Figure 6.1–15

Acute Exceedance Sample Locations

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

File Name: F:\PROJECTS\ARSENAL\ROD\EXCEED.DWG
Date 6/06/96
Drawn by JLS
Checked by SA



[1] Building, Equipment, and Storage Sites include only the soils present at these sites, not the structures themselves.

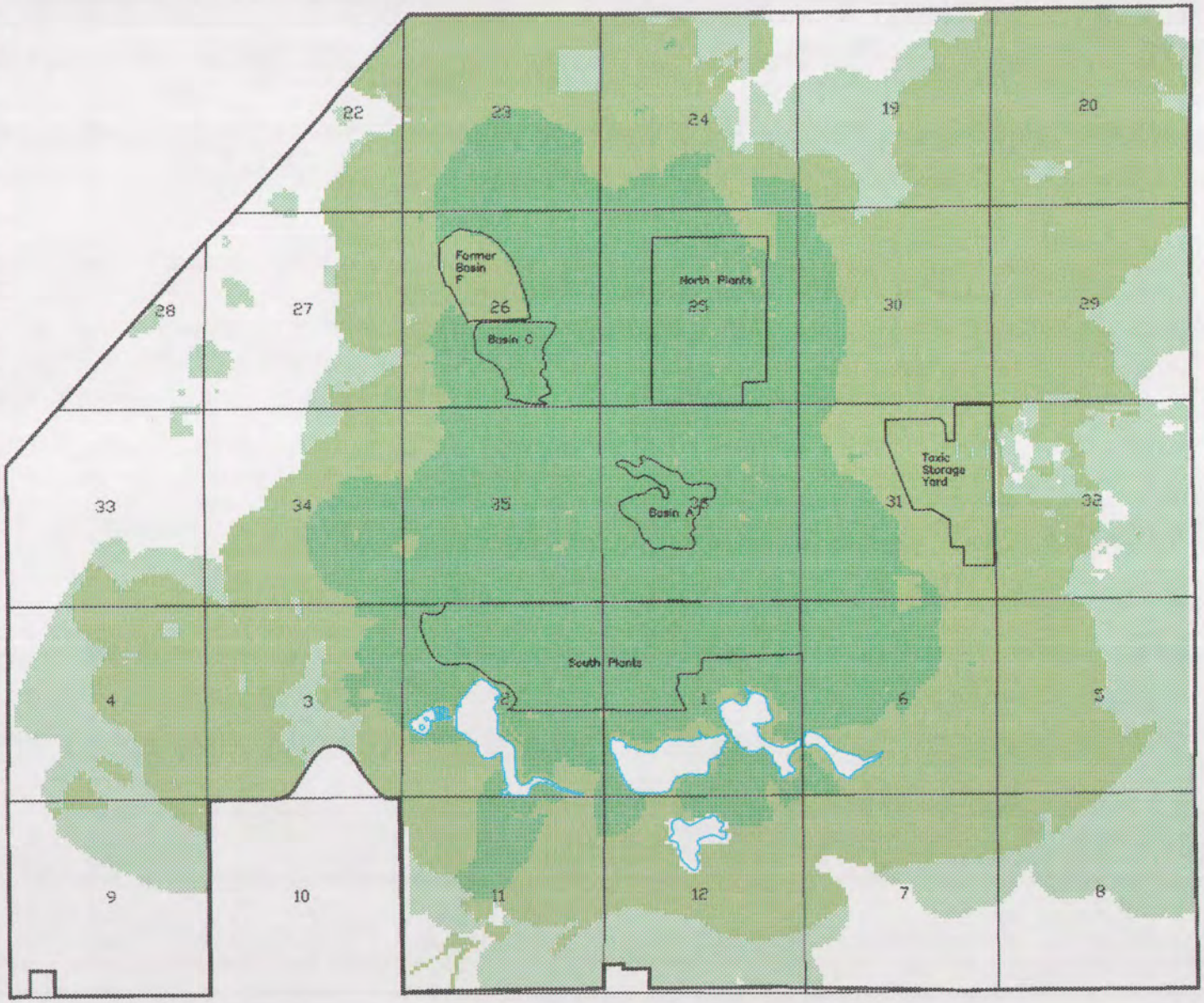
[2] Isolated Contamination Sites are not generally considered sources in the sense that they could provide releases to the environment.

[3] Only cottonwoods are expected to reach groundwater.

NA - Not applicable.

Figure 6.2-1
RMA Site Conceptual Model for Ecological Receptors

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corporation



Legend

- 1 trophic box with HI > 1
- 2-4 trophic boxes with HI > 1
- 5-7 trophic boxes with HI > 1
- Lake
- 31 Section Number
- Section Line

N

0 2000 4000
Scale in Feet

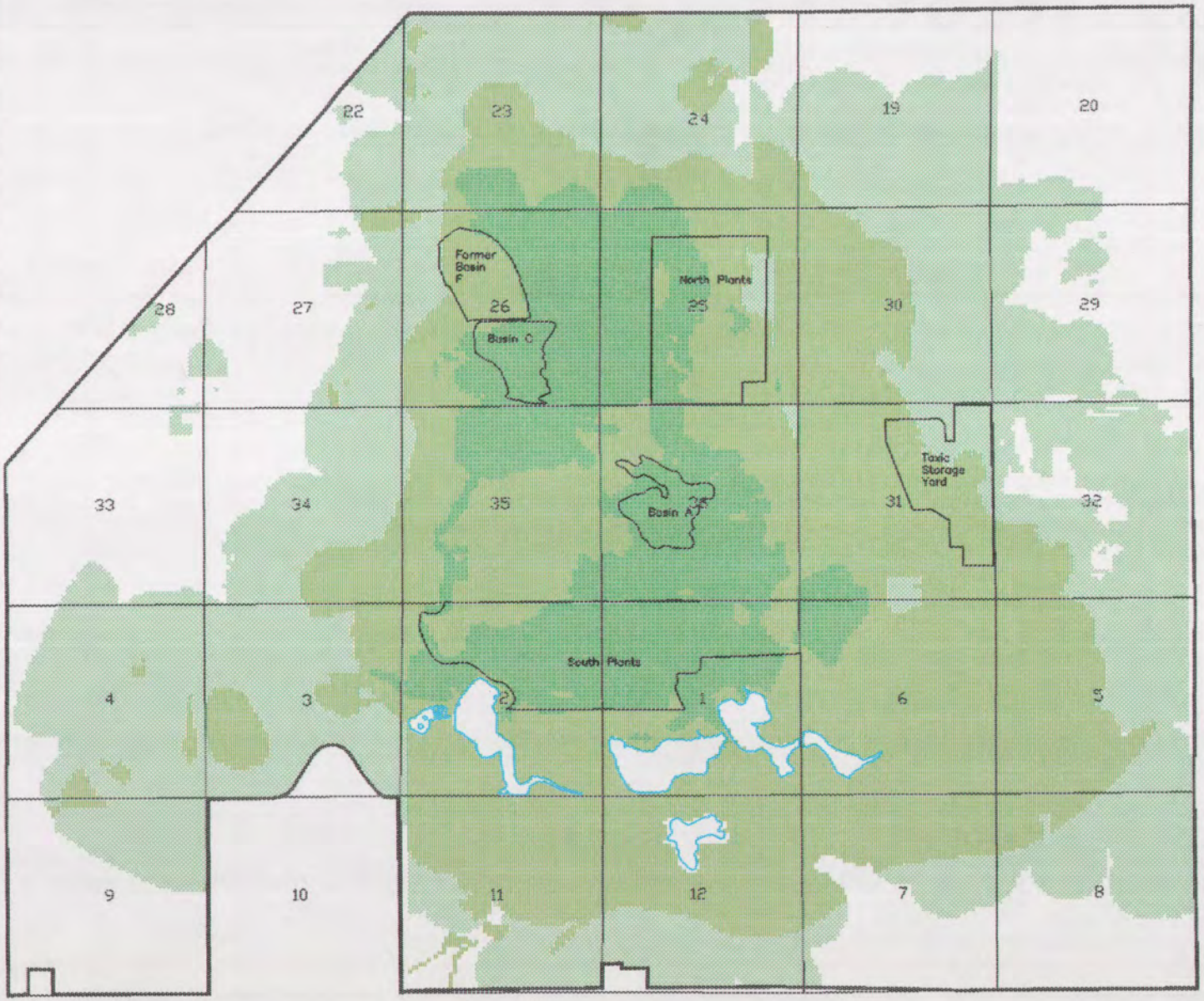
Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

June 1996

Figure 6.2-2
Number of Trophic Boxes with Soil Hazard Indices Greater than 1.0 for All COCs Combined Based on the Shell Approach

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

File Name: F:\PROJECTS\ARSENAL\ROD\ALLCHEM1.DWG
Date 5/14/96
Drawn by JLS
Checked by SA



Legend

1 trophic box with HI > 1

2-4 trophic boxes with HI > 1

5-7 trophic boxes with HI > 1

Lake

31 Section Number

Section Line

N

0 2000 4000

Scale in Feet

Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

June 1996

Figure 6.2-3
Number of Trophic Boxes with Soil Hazard Indices Greater than 1.0 for Aldrin/Dieldrin, DDT/DDE, and Endrin Combined Based on the Shell Approach

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

Checked by SA | Drawn by JLS | Date 5/14/96 | File Name: F:\PROJECTS\ARSENAL\ROD\OCP1.DWG

Legend

- EPA Approach
- Army and EPA Approaches
- Army and Shell and EPA Approaches

Colors show which approaches result in HQ > 1 in the areas indicated

- Lake
- 31 Section Number
- Section Line

N

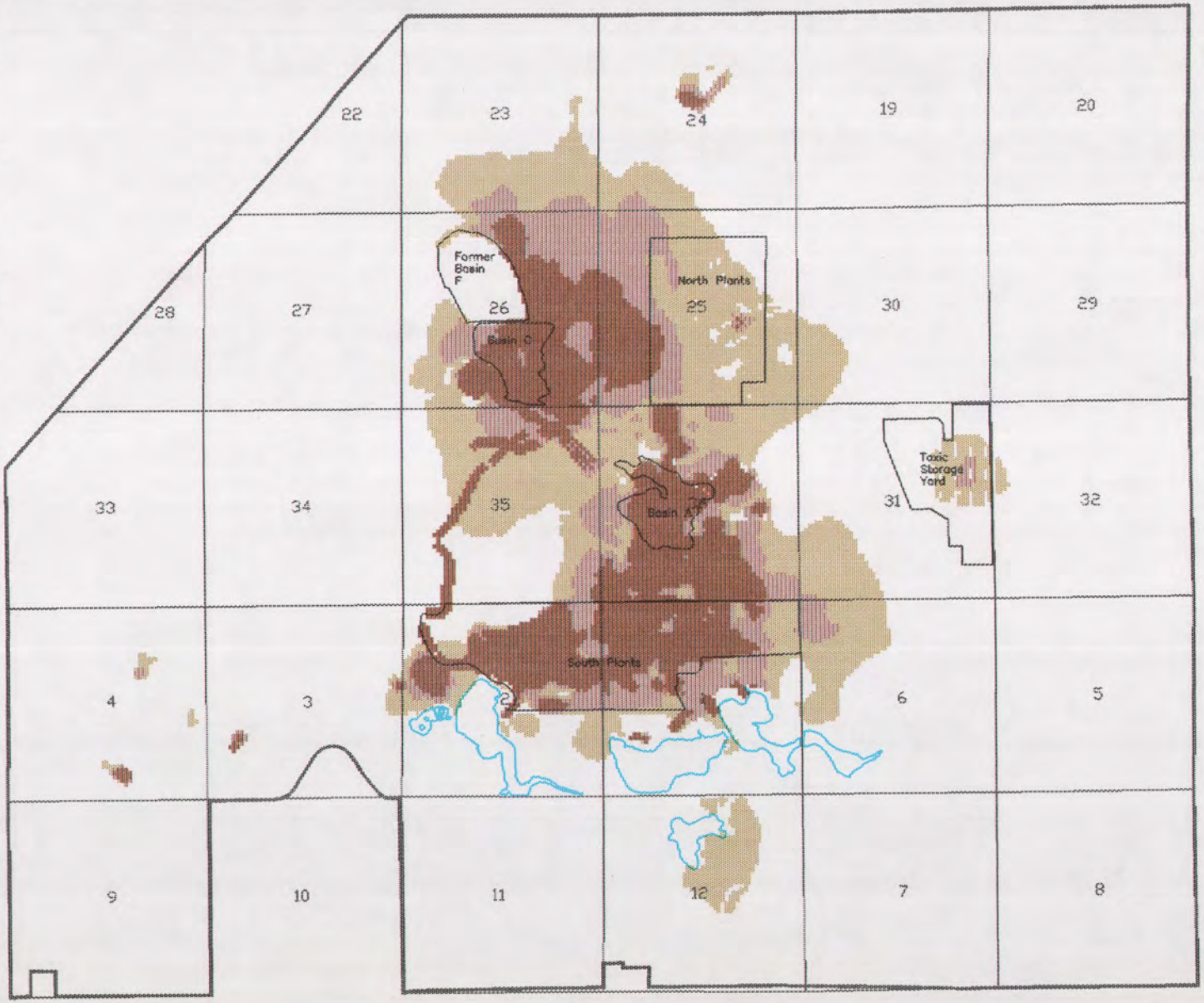
0 2000 4000
Scale in Feet

Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal
June 1996

Figure 6.2–4
Aldrin/Dieldrin Hazard Quotient Map (HQ>1) for the Great Horned Owl Trophic Box Based on Exceedance of TRV and using the Army, EPA, and Shell Approaches

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

Checked by SA | Drawn by JLS | Date 5/14/96 | File Name: F:\PROJECTS\ARSENAL\ROD\OW_DRIN.DWG



Legend

- EPA Approach
- Shell and EPA Approaches
- Army and Shell and EPA Approaches

Colors show which approaches result in HQ > 1 in the areas indicated

- Lake
- 31 Section Number
- Section Line

N

0 2000 4000
Scale in Feet

Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

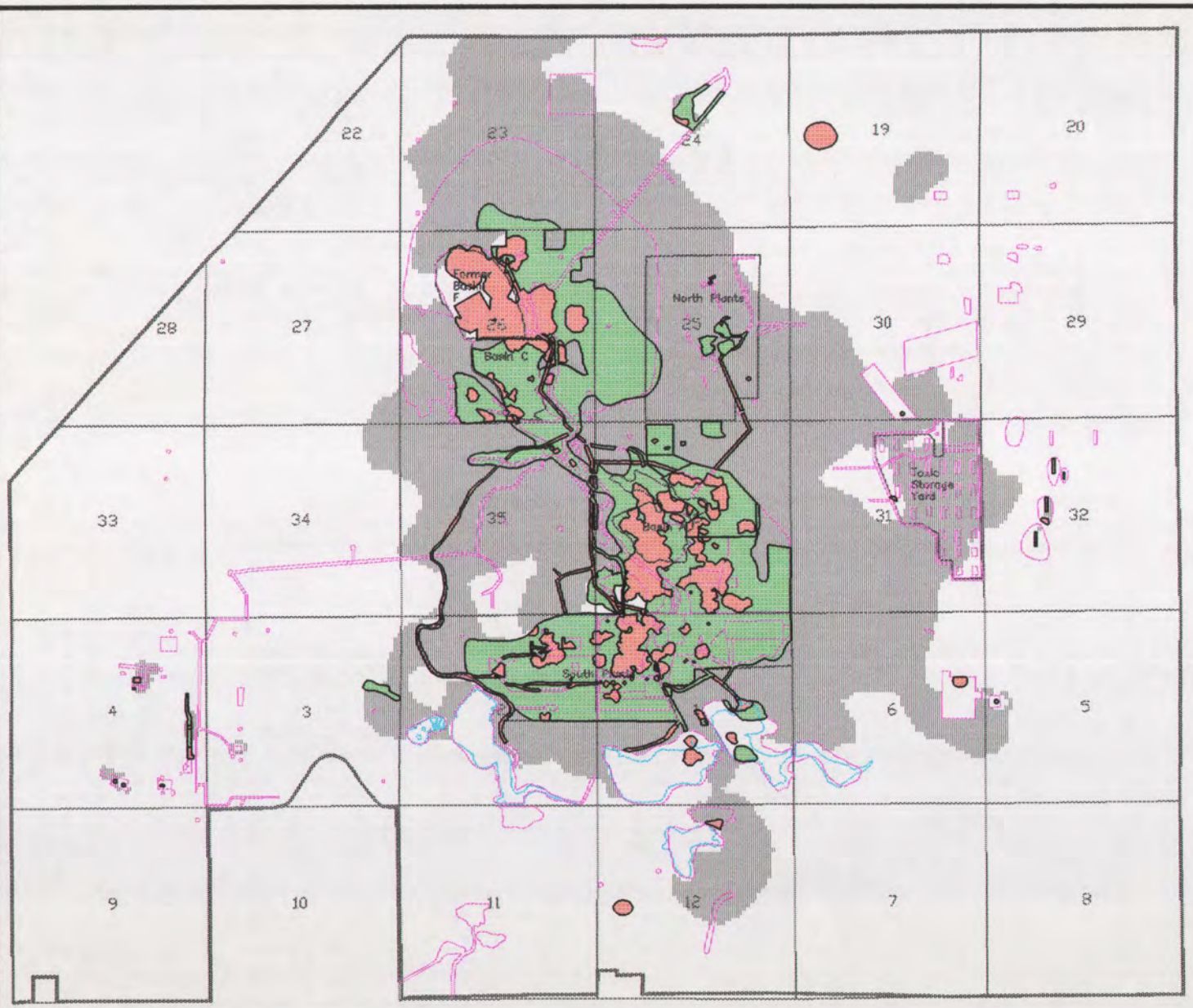
June 1996

Figure 6.2-5

Aldrin/Dieldrin Hazard Quotient Map (HQ>1) for the Small Mammal Trophic Box Based on Exceedance of TRV and using the Army, EPA, and Shell Approaches

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

Checked by SA | Drawn by JLS | Date 5/14/96 | File Name: F:\PROJECTS\ARSENAL\ROD\SHL_DRIN.DWG



Legend

- Area of Dispute and Prey Study Area based on MATC
- Biota Risk Area[1]
- Human Health Exceedance Area (Cancer Risk ≥ 1.0E−4; Chronic or Acute HI ≥ 1.0)
- SAR Site Boundary[2]
- Lake
- 31 Section Number
- Section Line

[1] The area in which EPA, Shell, and Army models all show small mammal HI > 1.0 for aldrin/dieldrin.

[2] Study Area Report (see Remedial Investigation Summary Report, Ebasco 1992a).

-N-

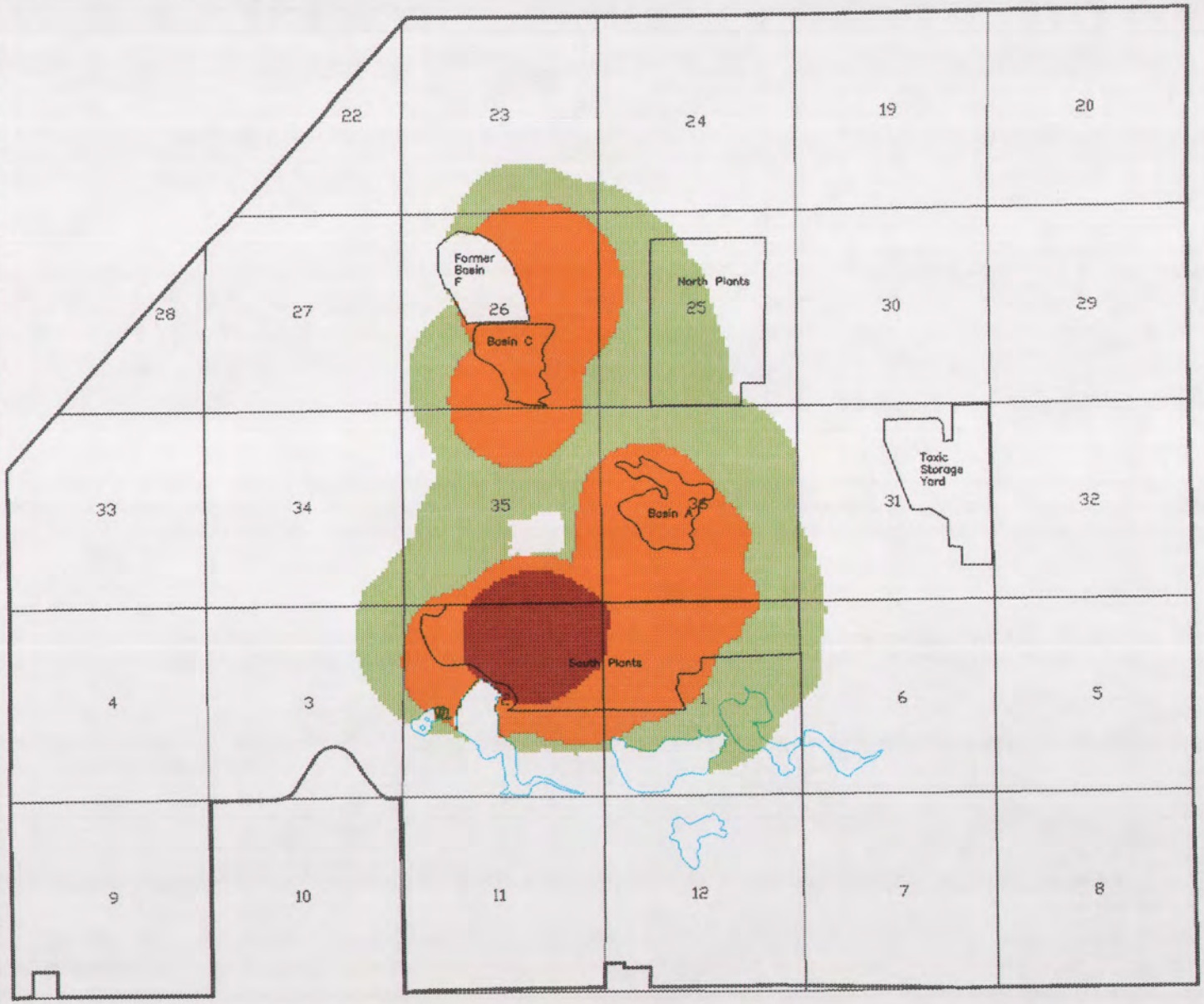
0 2000 4000
Scale in Feet

Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal
June 1996

Figure 6.2–6
Human Health and Biota Risk Areas

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

Checked by SA | Drawn by JLS | Date 6/06/96 | File Name: F:\PROJECTS\ARSENAL\ROD\BIO_REM3.DWG



Legend

- 1 < HI < 10
- 10 ≤ HI < 100
- HI ≥ 100
- Lake
- 31 Section Number
- Section Line

N

0 2000 4000
Scale in Feet

Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

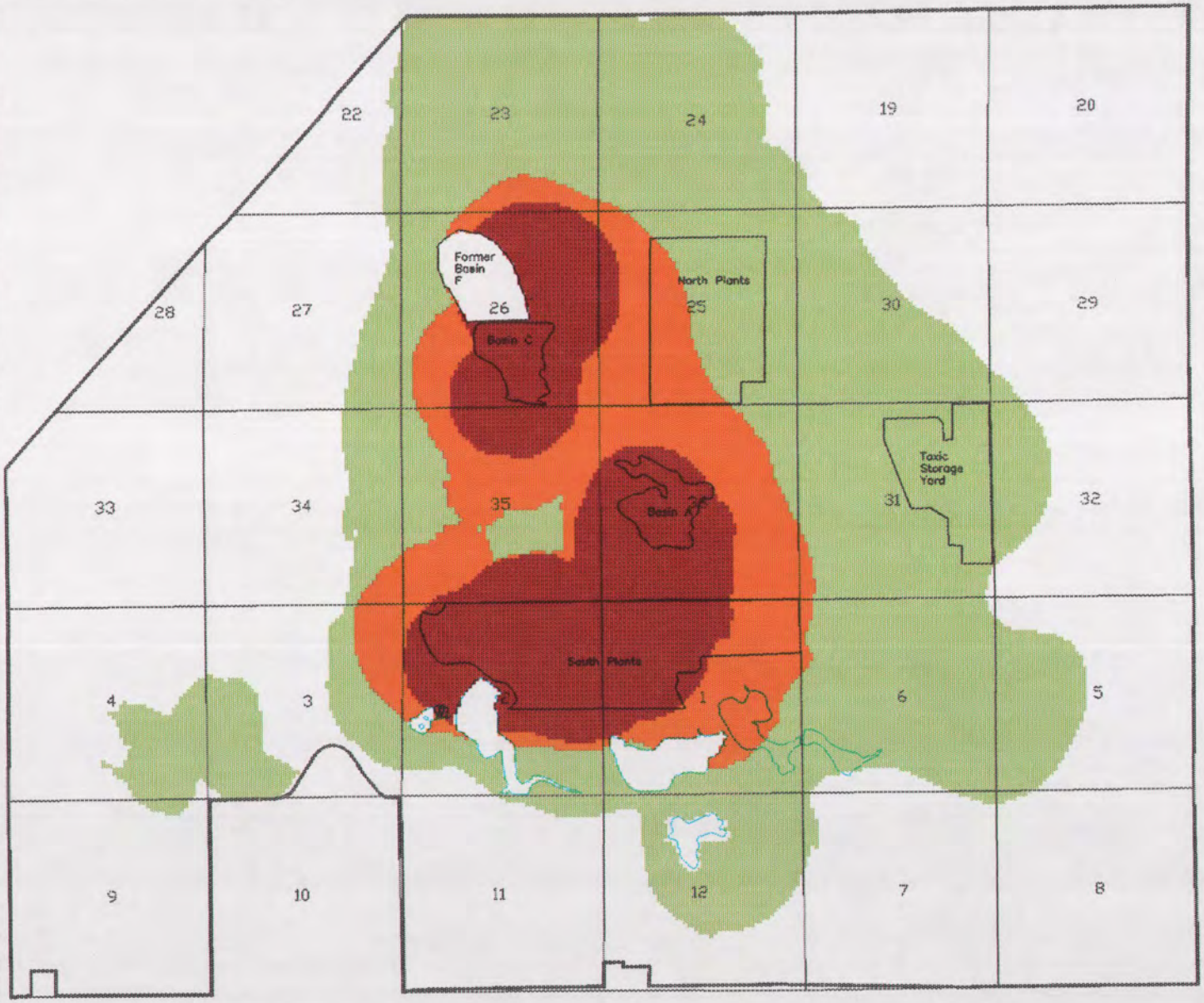
June 1996

Figure 6.2–7

Pre–Remediation Risk Distribution using Army BMF for American Kestrel

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

File Name: F:\PROJECTS\ARSENAL\ROD\KESARMY.DWG
Date 5/10/96
Drawn by JLS
Checked by SA



Legend

- 1 < HI < 10
- 10 ≤ HI < 100
- HI ≥ 100
- Lake
- 31 Section Number
- Section Line

N

0 2000 4000
Scale in Feet

Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

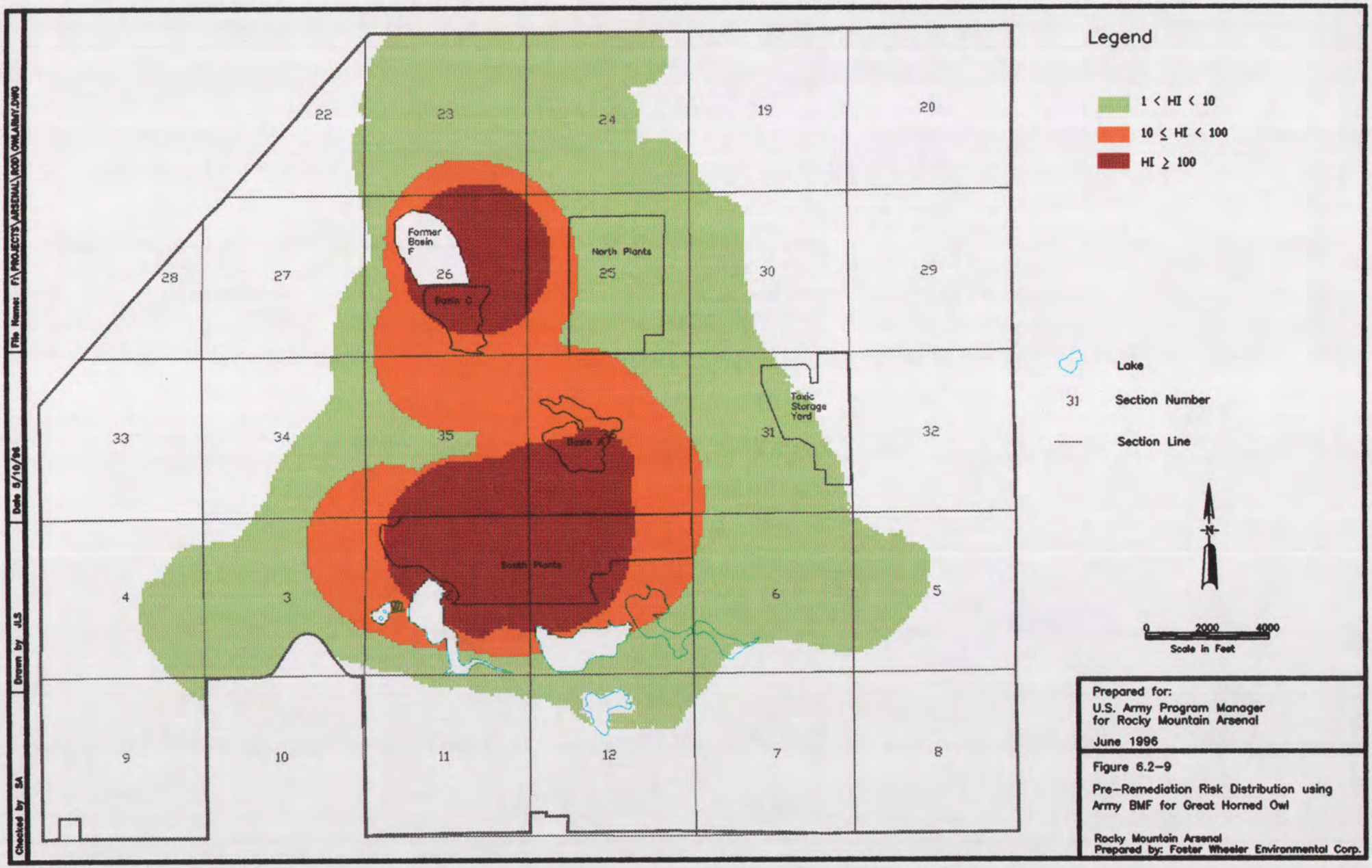
June 1996

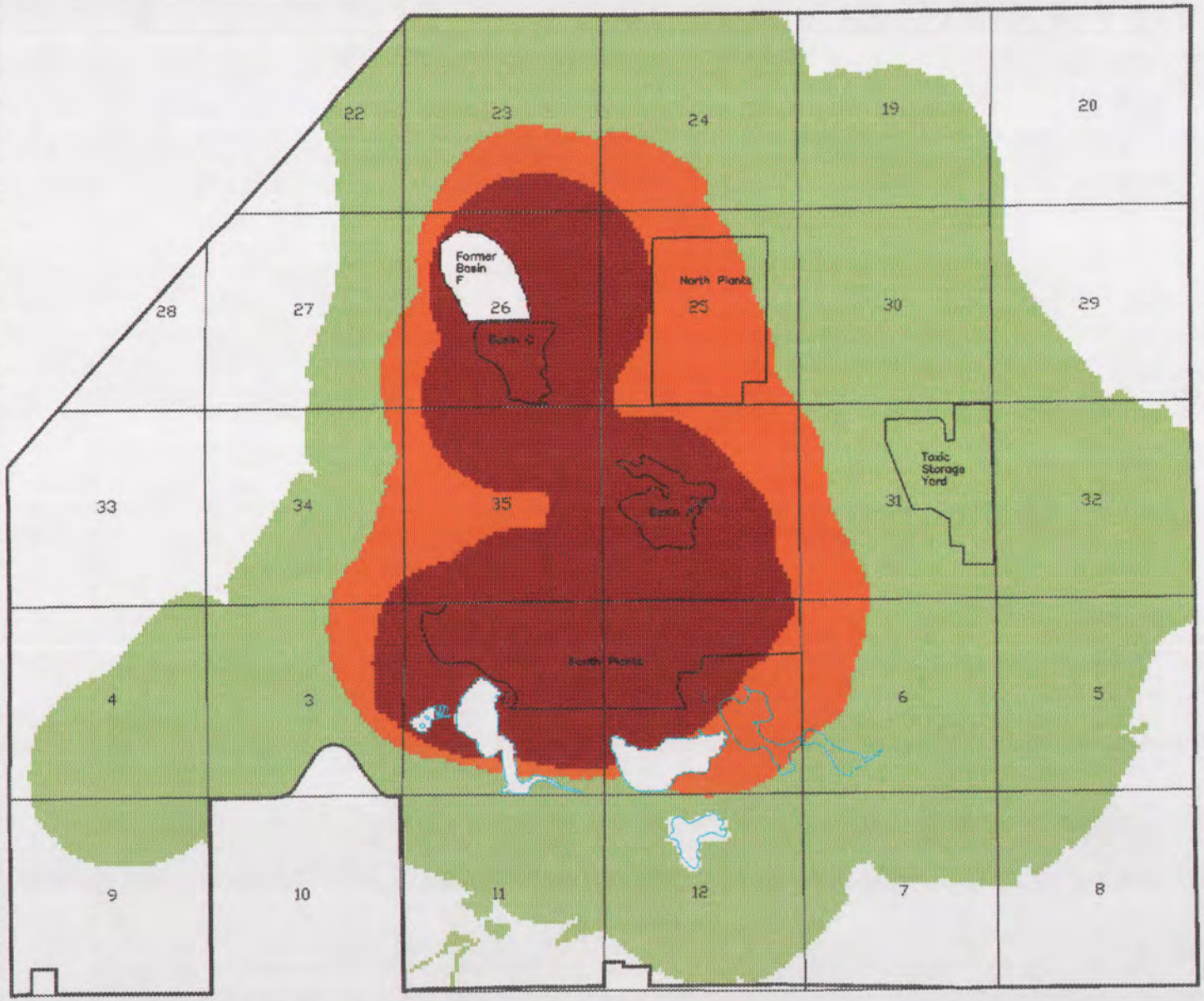
Figure 6.2-8

Pre-Remediation Risk Distribution using EPA BMF for American Kestrel

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

File Name: F:\PROJECTS\ARSENAL\ROD\KESEPA.DWG
Date 5/10/96
Drawn by JLS
Checked by SA


Legend
1 < HI < 10
10 ≤ HI < 100
HI ≥ 100
Lake
31 Section Number
Section Line
N
0 2000 4000
Scale in Feet
Former Basin F
Basin C
North Plants
South Plants
Toxic Storage Yard
22
23
24
19
20
28
27
26
25
30
29
33
34
35
31
32
4
3
6
5
9
10
11
12
7
8
Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal
June 1996
Figure 6.2-9
Pre-Remediation Risk Distribution using
Army BMF for Great Horned Owl
Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.
Checked by SA
Drawn by JLS
Date 5/10/96
File Name: F:\PROJECTS\ARSENAL\ROD\OWLARMY.DWG



Legend

- 1 < HI < 10
- 10 ≤ HI < 100
- HI ≥ 100
- Lake
- 31 Section Number
- Section Line

N

0 2000 4000
Scale in Feet

Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

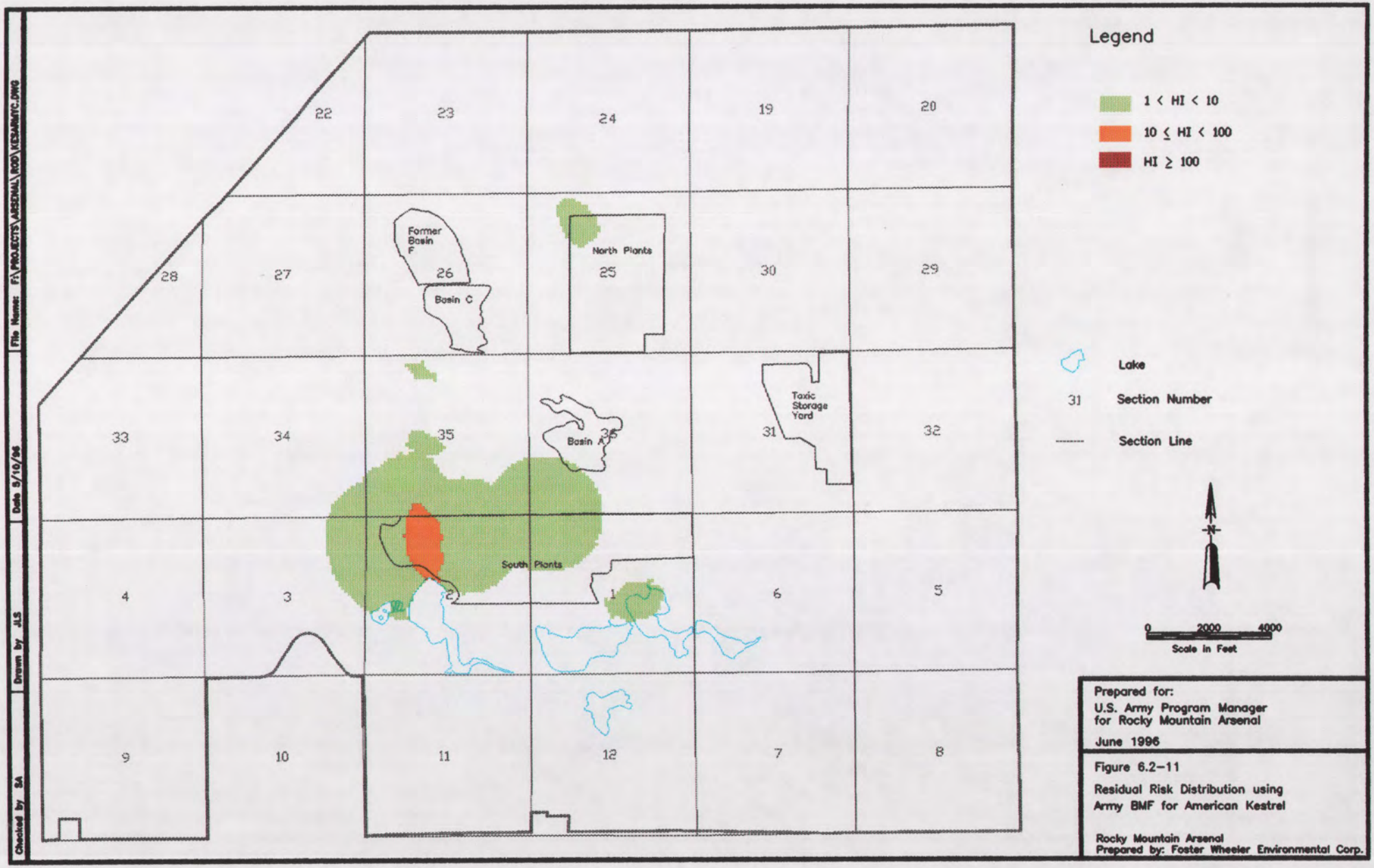
June 1996

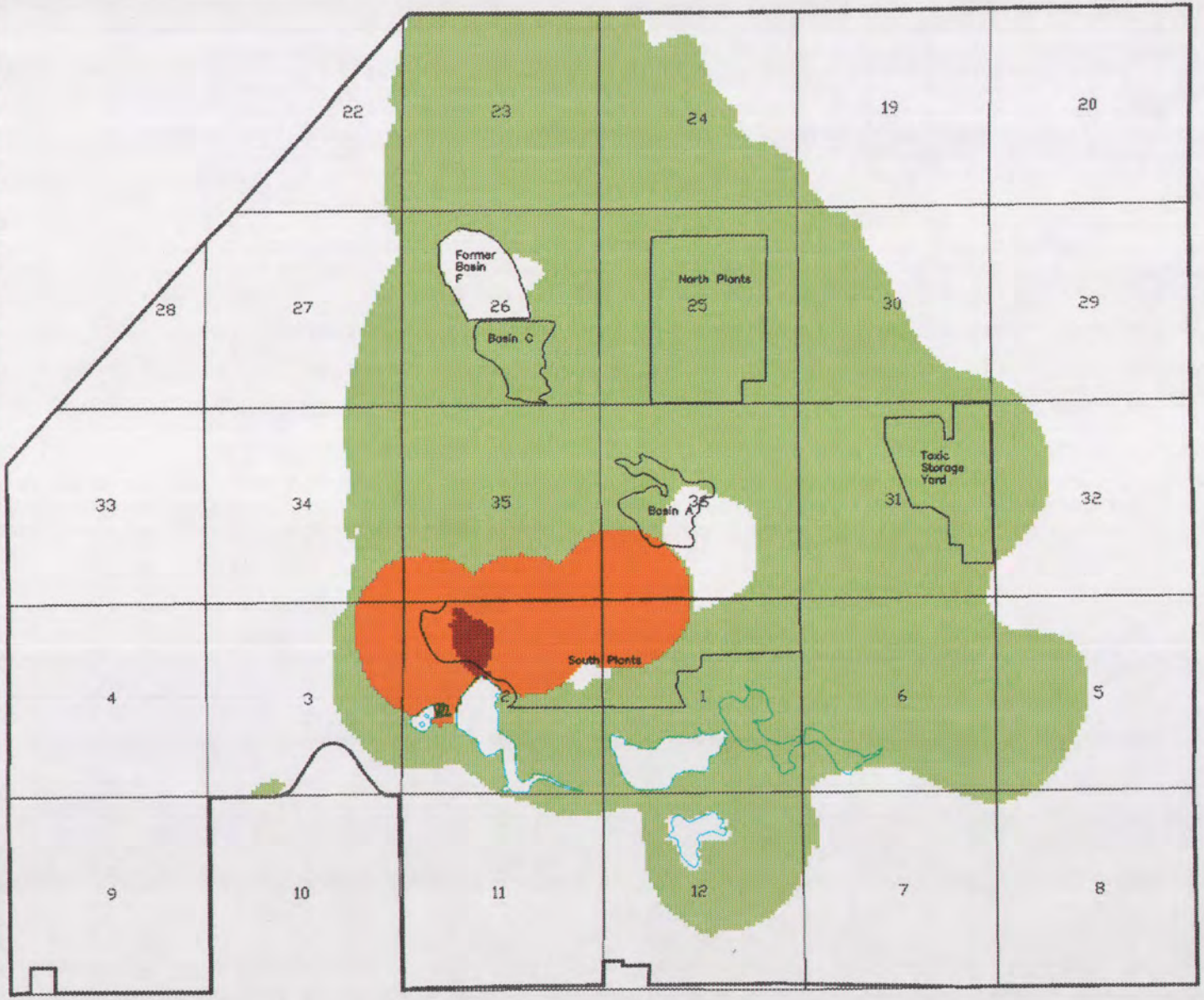
Figure 6.2–10

Pre–Remediation Risk Distribution using EPA BMF for Great Horned Owl

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

Checked by SA | Drawn by JLS | Date 5/10/96 | File Name: F:\PROJECTS\ARSENAL\ROD\OWLEPA.DWG


Legend
1 < HI < 10
10 ≤ HI < 100
HI ≥ 100
Lake
31 Section Number
Section Line
N
0 2000 4000
Scale in Feet
Former Basin F
Basin C
North Plants
Basin A
Toxic Storage Yard
South Plants
22
23
24
19
20
28
27
26
25
30
29
33
34
35
36
31
32
4
3
2
1
6
5
9
10
11
12
7
8
Prepared for:
U.S. Army Program Manager for Rocky Mountain Arsenal
June 1996
Figure 6.2-11
Residual Risk Distribution using Army BMF for American Kestrel
Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.
Checked by SA
Drawn by JLS
Date 8/10/96
File Name: F:\PROJECTS\ARSENAL\ROD\KESARISTC.DWG



Legend

- 1 < HI < 10
- 10 ≤ HI < 100
- HI ≥ 100
- Lake
- 31 Section Number
- Section Line

N

0 2000 4000
Scale in Feet

Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

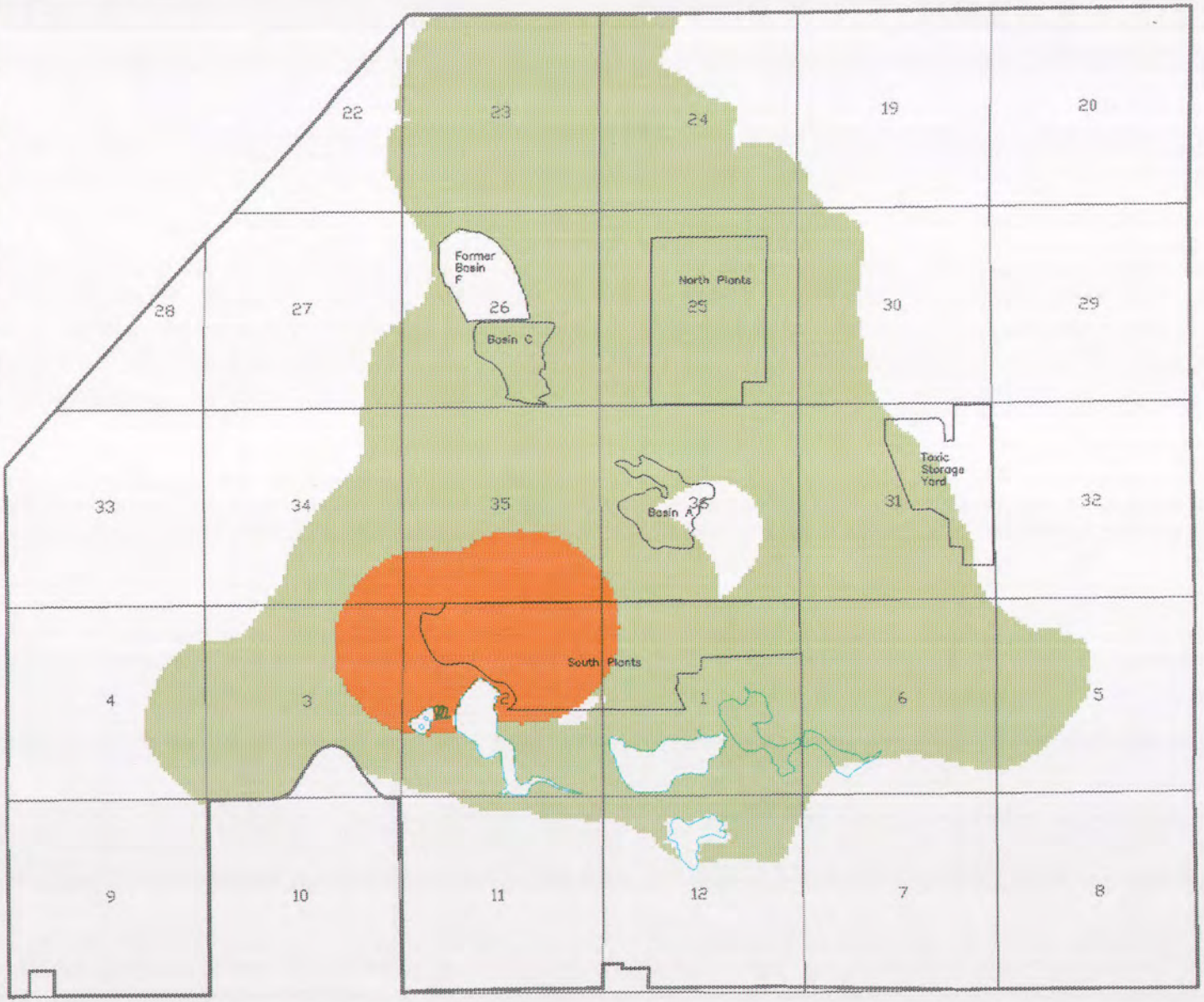
June 1996

Figure 6.2-12

Residual Risk Distribution using
EPA BMF for American Kestrel

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

Checked by SA | Drawn by JLS | Date 5/10/96 | File Name: F:\PROJECTS\ARSENAL\ROD\KESTPAC.DWG



Legend

- 1 < HI < 10
- 10 ≤ HI < 100
- HI ≥ 100
- Lake
- 31 Section Number
- Section Line

N

0 2000 4000
Scale in Feet

Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

June 1996

Figure 6.2–13

Residual Risk Distribution using
Army BMF for Great Horned Owl

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

Checked by SA | Drawn by JLS | Date 5/10/96 | File Name: F:\PROJECTS\ARSENAL\ROD\OWLARMYC.DWG

Legend

- 1 < HI < 10
- 10 ≤ HI < 100
- HI ≥ 100
- Lake
- 31 Section Number
- Section Line

-N-

0 2000 4000
Scale in Feet

Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

June 1996

Figure 6.2–14

Residual Risk Distribution using
EPA BMF for Great Horned Owl

Rocky Mountain Arsenal
Prepared by: Foster Wheeler Environmental Corp.

Checked by SA | Drawn by JLS | Date 5/10/96 | File Name: F:\PROJECTS\ARSENAL\ROD\OWLEPAC.DWG

Aldrin
Arsenic
Benzene
Cadmium
Carbon Tetrachloride
Chlordane
Chloroacetic Acid
Chlorobenzene
Chloroform
Chromium
DBCP
DCPD
DDE
DDT
1,2-Dichlororethane
1,1-Dichloroethylene
Dieldrin
Endrin
HCCPD
Isodrin
Lead
Mercury
Methylene Chloride
1,1,2,2-Tetrachloroethane
Tetrachloroethylene
Toluene
TCE

Table 6.1-2 Soil Horizons and Exposure Pathways Evaluated for the HHRC

		Open Space Option Receptor		Economic Development Option Receptor	
Soil Horizon	Depth Interval	Biological Worker	Local Neighborhood Regulated/Casual and Recreational Visitor	Industrial Worker	Commercial Worker
Surficial Soil	0–2 inches[1]	Dir	Dir	Dir	Dir
Horizon 0	0–1 ft[2]	Dir	Dir	Dir	Dir
Horizon 1	0–10 ft[2]	Dir, Ind (Open Space)	Dir (Open Space)	Dir, Ind (Open and Enc. Space)	Dir, Ind (Enc. Space)
Horizon 2	>10 ft–Groundwater[2]	Ind (Open Space)	Not Evaluated	Ind (Open and Enc. Space)	Ind (Enc. Space)

[1] Risks for this depth horizon were calculated on a boring-by-boring basis using results of surficial soil samples collected in areas peripheral to designated sites. The surficial soil interval (0–2 inches) is not a subset of Horizon 0 (0–1 ft).

[2] Cumulative risks for these soil horizons were calculated on both a site-specific basis (representing both direct and indirect pathway exposures) and a boring-by-boring evaluation (representing direct exposure pathways only).

Dir Denotes direct soil exposure pathway evaluation (soil ingestion, dermal contact, and particulate inhalation). Dermal contact with metals in soil was not evaluated for any receptors due to negligible contaminant absorption from this exposure route.

Ind Denotes indirect vapor inhalation pathway evaluation for open space and/or enclosed space (e.g., enclosed basement structures). Both open and enclosed space soil vapor inhalation exposures were not considered to be significant for shallower depth intervals due to volatilization loss, and therefore were not evaluated for surficial soil and Horizon 0.

Table 6.1-3 Time-Dependent and Other Parameter Values

Parameter	Distribution Family	Mean	Value 50%	95%
Exposure Time (TM) (hours/day)				
Reg/casual visitor	Lognormal	2.47	1.87	6.34
Recreational visitor	Lognormal	1.8	1.38	4.96
Biological worker	Fixed Value	8		
Commercial worker	Normal	7.42	7.42	12.8
Industrial worker	Normal	7.42	7.42	12.8
Exposure Frequency (DW) (days/year)				
Reg/casual visitor	Lognormal	34.9	29.6	76.1
Recreational visitor	Lognormal	63.14	43.3	181
Biological worker	Normal	225	225	242
Commercial worker	Normal	236	236	241
Industrial worker	Normal	236	236	241
Exposure Duration (TE) (years)				
Reg/casual visitor	Lognormal	10.1	5.45	33.8
Recreational visitor	Lognormal	10.1	5.45	33.7
Biological worker	Truncated Normal	7.18	7.18	18.7
Commercial worker	Lognormal	4.38	2.32	14.8
Industrial worker	Lognormal	4.38	2.32	14.8
Basement				
Length (m)	Uniform	10	10	16.3
Width (m)	Uniform	8.5	8.5	13.45
Ventilation Flow Rate (cm^3/sec)	Triangular	617500	617500	1008960
Percent Organic Carbon (fraction) (Aquatic) in Sediments	Lognormal	0.1197716	0.1039339	0.2496338
Percent Organic Carbon (fraction) (Terrestrial) in Sediments	Lognormal	0.0038779	0.003735	0.0058623
Soil Density	Normal	1.45315	1.45315	1.752022
Soil Porosity (fraction)	Normal	0.45164	0.45164	0.5644193
Soil Temperature (celsius)	Fixed Value	9.9		
Soil Moisture (unitless)	Exponential	0.07099	0.04921	0.2126
Respiratory Deposition				
Vapor (fraction)	Fixed Value	1		
Particulate (fraction)	Fixed Value	0.85		

Table 6.1-4 Chemical-Specific Parameter Values

Chemical		Molecular Weight (g/mole)		Molecular Diffusivity (cm^2/sec)		Soil/Water Partition Coefficient (L/kg) Mean	50%	95%		Vapor Pressure (ATM) Mean	50%	95%		Henry's Law Constant (unitless) Mean	50%	95%
Aldrin	F	364.3	F	0.0407	A	298100	151800	1027000	A	5.84E-08	2.78E-08	2.07E-07	D	0.000306	0.0003033	0.0005831
Arsenic	F	74.92	F	NA	A	179.9	55.76	691		NA	NA	NA		NA	NA	NA
Benzene	F	78.11	F	0.0819	A	19034	158.1	461.3	E	0.104	0.107	0.1514207	E	0.00533	0.00533	0.007074
Cadmium	F	112.4	F	NA	A	169.9	59.2	645.2		NA	NA	NA		NA	NA	NA
Carbon Tetrachloride	F	153.8	F	0.0750	A	513	457.1	1007	E	0.124	0.124	0.159	E	0.0237	0.0237	0.0356600
Chlordane	F	409.8	F	0.0404	A	280900	156900	925600	A	1.76E-07	4.14E-08	6.79E-07	A	0.0002760	0.0001186	0.0010061
Chloroacetic Acid	F	94.5	F	NA	A	1.787	1.66	3.125	B	0.0004323	0.0004323	0.0008136	A	1.28E-08	8.36E-09	3.81E-08
Chlorobenzene	F	112.5	F	0.0676	A	611.3	508.9	1378	C	0.0151	0.0151833	0.0166427	E	0.00363	0.00363	0.0044410
Chloroform	F	119.4	F	0.0834	A	86.01	81.29	141.3	E	0.241	0.241	0.3084536	E	0.0031	0.0031	0.0042152
Chromium (VI)	F	52	F	NA	A	20.91	11.16	70.52		NA	NA	NA		NA	NA	NA
DDE	F	318	F	0.00440	A	667800	579500	1392000	E	8.69E-09	8.69E-09	1.07E-08	D	7.35E-04	7.28E-04	1.41E-03
DDT	F	354.5	F	0.0423	A	1425000	653400	5099000	A	4.82E-10	3.41E-10	1.34E-09	D	3.49E-05	3.47E-05	6.03E-05
DBCP	F	236.4	F	0.0600	A	310.2	245.4	756.5	B	0.0053025	0.0053025	0.0099803	A	6.61E-04	6.55E-04	1.27E-03
1,2-Dichloro-ethane	F	98.96	F	0.0856	A	38.45	36.17	64.31	E	0.0825	0.0825	0.122	A	0.0033426	0.0031828	0.0053260
1,1-Dichloro-ethylene	F	96.95	F	0.0744	A	63.13	59.57	104.4	A	0.763	0.763	0.8791	A	0.01598	0.01485	0.02792
DCPD	F	132.2	F	0.0562	A	274300	153300	904200	B	0.009292	0.009292	0.0174892	A	0.0539400	0.0330400	0.168400
Dieldrin	F	380.9	F	0.0416	A	64170	42190	190300	A	3.44E-09	1.38E-09	1.27E-08	D	3.51E-05	3.48E-05	6.85E-05
Endrin	F	380.9	F	0.0416	A	201600	140100	569900	D	2.50E-09	2.48E-09	4.62E-09	D	4.71E-06	4.67E-06	8.81E-06
HCCPD	F	273	F	0.0522	A	274300	153300	904200	E	0.000107	0.000107	0.0001481	A	0.0225900	0.021068	0.0389100

Table 6.1-4 Chemical-Specific Parameter Values

Chemical		Molecular Weight (g/mole)		Molecular Diffusivity (cm^2/sec)		Soil/Water Partition Coefficient (L/kg) Mean	50%	95%		Vapor Pressure (ATM) Mean	50%	95%		Henry's Law Constant (unitless) Mean	50%	95%
Isodrin	F	364.9	F	0.407	A	298100	151800	1027000	A	5.84E-08	2.78E-08	2.07E-07	D	0.000306	0.000304	0.000583
Lead	F	207.2	F	NA	A	6386000	3371	2012000		NA	NA	NA		NA	NA	NA
Mercury	F	200.6	F	NA	A	149.1	115.3	375.8		NA	NA	NA		NA	NA	NA
Methylene Chloride	F	84.94	F	0.0958	A	14.97	14.13	24.75	C	0.3347	0.327	0.5479	E	0.00236	0.00236	0.0035476
1,1,2,2-Tetra-chloroethane	F	167.9	F	0.0958	A	14.97	14.13	24.75	C	0.00725	0.00725	0.0100956	E	0.000415	0.000415	0.0005565
Tetrachloro-ethylene	F	165.9	F	0.00798	A	577.8	457.1	1409	E	0.0207	0.0207	0.0282022	D	0.0185	0.0184	0.0334
Toluene	F	92.13	F	0.0736	A	494.5	417.4	1088	C	0.0323333	0.0328564	0.0399016	C	0.00625	0.0063042	0.0068655
TCE	F	131.4		0.0749	A	455.9	317.4	1287	E	0.0826	0.0826	0.1.27	C	0.0092333	0.0093961	0.0125647

Table 6.1-4 Chemical-Specific Parameter Values

Chemical		RAF Dermal (RfD) Mean	50%	95%		RAF Dermal (CPF) Mean	50%	95%		RAF Oral (RfD) Mean	50%	95%		RAF Oral (CPF) Mean	50%	95%
Aldrin	B	0.00291	0.00291	0.00497	B	0.00291	0.00291	0.00497	B	0.45	0.45	0.63	B	0.45	0.45	0.63
Arsenic		NA	NA	NA		NA	NA	NA	B	0.71	0.71	0.971	B	0.71	0.71	0.971
Benzene	B	0.775	0.775	0.9775	B	0.775	0.775	0.9775	B	0.805	0.805	0.9805	B	0.805	0.805	0.9805
Cadmium		NA	NA	NA		NA	NA	NA	F	1	1	1		NA	NA	NA
Carbon Tetrachloride	B	0.845	0.845	0.9845	B	0.845	0.845	0.9845	B	0.84	0.84	0.984	B	0.84	0.84	0.984
Chlordane	B	0.023	0.023	0.041	B	0.023	0.023	0.041	B	0.805	0.805	0.9805	B	0.805	0.805	0.9805
Chloroacetic Acid	B	0.845	0.845	0.9845		NA	NA	NA	B	0.84	0.84	0.984		NA	NA	NA
Chlorobenzene	B	0.845	0.845	0.9845	B	0.845	0.845	0.9845	B	0.84	0.84	0.984		NA	NA	NA
Chloroform	B	0.75	0.75	0.93	B	0.845	0.845	0.9845	B	0.84	0.84	0.984	B	0.74	0.74	0.92
Chromium (VI)		NA	NA	NA		NA	NA	NA	F	1	1	1	F	1	1	1
DDE	B	0.022	0.022	0.04	B	0.022	0.022	0.04	B	0.805	0.805	0.9805	B	0.805	0.805	0.9805
DDT	B	0.022	0.022	0.04	B	0.022	0.022	0.04	B	0.805	0.805	0.9805	B	0.805	0.805	0.9805
DBCP	B	0.845	0.845	0.9845	B	0.845	0.845	0.9845	B	NA	NA	NA	B	0.84	0.84	0.984
1,2-Dichloro-ethane	B	0.845	0.845	0.9845	B	0.845	0.845	0.9845	B	NA	NA	NA	B	0.84	0.84	0.984
1,1-Dichloro-ethylene	B	0.845	0.845	0.9845	B	0.845	0.845	0.9845	B	0.84	0.84	0.984	B	0.84	0.84	0.984
DCPD	B	0.022	0.022	0.04		NA	NA	NA	B	0.805	0.805	0.9805		NA	NA	NA
Dieldrin	B	0.0056	0.0056	0.00956	B	0.0056	0.0056	0.00956	B	0.8	0.8	0.98	B	0.8	0.8	0.98
Endrin	B	0.022	0.022	0.04		NA	NA	NA	B	0.805	0.805	0.9805		NA	NA	NA
HCCPD	B	0.058	0.058	0.076		NA	NA	NA	B	0.805	0.805	0.9805		NA	NA	NA
Isodrin	B	0.022	0.022	0.04		NA	NA	NA	B	0.805	0.805	0.9805		NA	NA	NA
Lead		NA	NA	NA		NA	NA	NA	B	0.65	0.65	0.964		NA	NA	NA
Mercury		NA	NA	NA		NA	NA	NA	B	0.545	0.545	0.9545		NA	NA	NA

Table 6.1-4 Chemical-Specific Parameter Values

Chemical		RAF Dermal (RfD)				RAF Dermal (CPF)				RAF Oral (RfD)				RAF Oral (CPF)		
		Mean	50%	95%		Mean	50%	95%		Mean	50%	95%		Mean	50%	95%
Methylene Chloride	B	0.845	0.845	0.9845	B	0.845	0.845	0.9845	B	0.84	0.84	0.984	B	0.84	0.84	0.984
1,1,2,2-Tetra-chloroethane	B	0.845	0.845	0.9845	B	0.845	0.845	0.9845	B	0.84	0.84	0.984	B	0.84	0.84	0.984
Tetrachloro-ethylene	B	0.845	0.845	0.9845	B	0.845	0.845	0.9845	B	0.84	0.84	0.984	B	0.84	0.84	0.984
Toluene	B	0.91	0.91	0.991		NA	NA	NA	B	0.88	0.88	0.988		NA	NA	NA
TCE	B	0.845	0.845	0.9845	B	0.74	0.74	0.92	B	0.84	0.84	0.984	B	0.73	0.73	0.91

(A) Lognormal Distribution
(B) Uniform Distribution
(C) Triangular Distribution
(D) Uniform-Triangular Distribution
(E) Normal Distribution
(F) Fixed
(G) The cancer potency factor relative absorption factor differs from the reference dose relative absorption factor.

NA Not Applicable

Table 6.1-5 Summary of Data Sources for PPLV Direct and Indirect Equation Parameters

Parameter	Data Source (s)
Basement Parameters	
Area	Professional Judgment
Volume	Professional Judgment
Volume/Area Ratio	Professional Judgment
Depth	Professional Judgment
Ventilation Rate	Commerce City and Denver 1988 Uniform Building Codes Handbook
Time for Air Exchange	Computed as function of ventilation and basement volume
Body Weight	OHEA-EPA 1989 —Exposure Factors Handbook
Breathing Rate (BR, DINH, RB)	Professional Judgment (EPA 1985)
Density of Arsenal Soils	RMA-Specific —Walsh 1988 —SCS 1987
Dust Loading Factor (CSS)	General Literature RMA-Specific —Comprehensive Monitoring Program
Henry's Law Constant	General Literature
Molecular Weight	General Literature
Percent Organic in Aquatic Sediments	RMA-Specific —Walsh 1988
Fraction Organic Carbon in Soils	RMA-Specific —Walsh 1988

Table 6.1-5 Summary of Data Sources for PPLV Direct and Indirect Equation Parameters

Parameter	Data Source (s)
Refuge Worker Time-Dependent Variables	RMA-Specific (Shell 1991) —Shell/Army Refuge Worker Survey
Relative Absorption Factor (RAF)	
Dermal	General Literature OHEA-EPA 1991 —Interim Guidance for Dermal Exposure Assessment
Oral	General Literature
Respiratory Disposition	General Literature EPA 1982 —Air Quality Criteria for Particulate Matter and Sulfur Oxides (Denver specific data)
Soil Covering	General Literature Professional Judgment OHEA-EPA 1991 —Interim Guidance for Dermal Exposure Assessment
Soil Ingestion	General Literature Professional Judgment OSWER-EPA 1991a —Risk Assessment Guidance (OSWER Directive)
Soil Moisture Content	RMA-Specific —Comprehensive Monitoring Program —Remedial Investigation for RMA
Soil Temperature	Regional Annual Average Temperature
Soil to Water Partition Coefficient (K_{oc}) Normalized to Organic Carbon	General Literature

Table 6.1-5 Summary of Data Sources for PPLV Direct and Indirect Equation Parameters

Parameter	Data Source (s)
Skin Surface Area (SX)	Professional Judgment EPA 1985
Total Soil Porosity	Calculated from soil and particle density
Vapor Pressure	General Literature

Table 6.1-6 RME Estimates For Acute Exposure

Parameter Name	Regulated/Casual Visitors		Recreational Visitors		Commercial Workers	Industrial Workers
Soil Ingestion	2-1/2 yr	250 mg/day	2-1/2 yr	250 mg/day	100 mg/day	100 mg/day
Breathing Rate	2-1/2 yr	4.2 l/min	2-1/2 yr	8.3 l/min	4.8 m^3/day	20 m^3/day
Dust Load Factor		0.042 mg/m^3		0.042 mg/m^3	0.021 mg/m^3	0.042 mg/m^3
Pulmonary Retention		0.75		0.75	0.75	0.75
Pulmonary Absorption		1 (100 percent)		1 (100 percent)	1 (100 percent)	1 (100 percent)
Daily Exposure Period		8 hours		8 hours	8 hours	8 hours
Annual Exposure Frequency		NA	NA	NA	NA	NA
Lifetime Exposure Duration		NA	NA	NA	NA	NA
Skin Surface Area	2-1/2 yr	2,100 cm^2	2-1/2 yr	2,100 cm^2	1,120 cm^2	3,200 cm^2
Soil Covering		0.51 mg/cm^2		0.51 mg/cm^2	0.11 mg/cm^2	1.5 mg/cm^2
Soil Matrix Factor		1.0		1.0	1.0	1.0
Dermal Absorption		0.01 (metals)	0.01 (metals)		0.01 (metals)	0.01 (metals)
		0.10 (organics)	0.10 (organics)		0.10 (organics)	0.10 (organics)
Body Weight		Child: 10th percentile(M&F)[1]	Child: 10th percentile(M&F)[1]		Adult: 70 kg	Adult: 70 kg

NA Not Applicable.
[1] Determined from the average of the male and female 10th percentile bodyweights as summarized in OHEA-EPA (1989).

Table 6.1-7 RME Estimates For Subchronic Exposure

Parameter Name	Regulated/Casual Visitors		Recreational Visitors		Commercial Workers	Industrial Workers
Soil Ingestion	2-1/2 yr 6 yr	250 mg/day 250 mg/day	2-1/2 yr 6 yr	250 mg/day 250 mg/day	100 mg/day	100 mg/day
Breathing Rate	2-1/2 yr 6 yr	4.2 l/min 13.3 l/min	2-1/2 yr 6 yr	8.3 l/min 20.3 l/min	4.8 m^3/day	20 m^3/day
Dust Load Factor		0.042 mg/m^3		0.042 mg/m^3	0.021 mg/m^3	0.042 mg/m^3
Pulmonary Retention		0.75		0.75	0.75	0.75
Pulmonary Absorption		1 (100 percent)		1 (100 percent)	1 (100 percent)	1 (100 percent)
Daily Exposure Period		8 hours		8 hours	8 hours	8 hours
Annual Exposure Frequency		108 day/year		108 days/year	253 days/year	253 days/year
Lifetime Exposure Duration		7 years		7 years	7 years	7 years
Q-Factor		7 years		7 years	7 years	7 years
Skin Surface Area	2-1/2 yr 6 yr	2,100 cm^2 2,500 cm^2	2-1/2 yr 6 yr	2,100 cm^2 2,500 cm^2	1,120 cm^2	3,200 cm^2
Soil Covering		0.51 mg/cm^2		0.51 mg/cm^2	0.11 mg/cm^2	1.5 mg/cm^2
Soil Matrix Factor		1.0		1.0	1.0	1.0
Dermal Absorption		0.01 (metals) 0.10 (organics)		0.01 (metals) 0.10 (organics)	0.01 (metals) 0.10 (organics)	0.01 (metals) 0.10 (organics)
Body Weight		Child: 10th percentile(M&F)[1]		Child: 10th percentile(M&F)[1]	Adult: 70 kg	Adult: 70 kg

NA Not Applicable.
[1] Determined from the average of the male and female 10th percentile bodyweights as summarized in OHEA-EPA (1989).

Table 6.1-8 Carcinogenic Dose-Response Data

Chemical	Weight of Evidence Classification[1]	Exposure Route	Cancer Slope Factor (mg/kg/day)	Carcinogenic Dose for 10^{-6} risk (mg/kg-day)
Aldrin	B2	Oral	1.7E+01	5.90E-08
		Inhalation	1.7E+01	5.90E-08
Arsenic	A	Oral	1.75E+00	5.70E-07
		Inhalation	1.5E+01	6.70E-08
Benzene	A	Oral	2.90E-02	3.40E-05
		Inhalation	2.90E-02	3.40E-05
Cadmium	B1	Oral	NA[2]	NA
		Inhalation	6.30E+00	1.60E-07
Carbon Tetrachloride	B2	Oral	1.30E-01	7.70E-06
		Inhalation	5.25E-02	1.90E-05
Chlordane	B2	Oral	1.30E+00	7.70E-07
		Inhalation	1.30E+00	7.70E-07
Chloroacetic Acid	NE[3]	Oral	NA	NA
		Inhalation	NA	NA
Chlorobenzene	D			
Chloroform	B2	Oral	6.10E-03	1.60E-04
		Inhalation	8.00E-02	1.20E-05
Chromium (VI)	A	Oral	NA	NA
		Inhalation	4.20E+01	2.40E-08
DBCP	B2	Oral	1.40E+00	7.10E-07
		Inhalation	2.40E-03	4.20E-04
DCPD	NE	Oral	NA	NA
		Inhalation	NA	NA
DDE	B2	Oral	3.40E-01	2.90E-06
		Inhalation	3.40E-01[4]	2.90E-06
DDT	B2	Oral	3.40E-01	2.90E-06
		Inhalation	3.40E-01	2.90E-06
1,2-Dichloroethane	B2	Oral	9.10E-02	1.10E-05
		Inhalation	9.10E-02	1.10E-05
1,1-Dichloroethylene	C	Oral	6.00E-01	1.70E-06
		Inhalation	1.80E-01	5.70E-06
Dieldrin	B2	Oral	1.60E+01	6.20E-08
		Inhalation	1.60E+01	6.20E-08
Endrin	D			
HCCPD	D			
Isodrin	NE	Oral	NA	NA
		Inhalation	NA	NA
Lead	B2	Oral	NA	NA
		Inhalation	NA	NA
Mercury	D			
Methylene Chloride	B2	Oral	7.50E-03	1.30E-04
		Inhalation	1.60E-03	6.10E-04
1,1,2,2-Tetrachloroethane	C	Oral	2.00E-01	5.00E-06
		Inhalation	2.00E-01	5.00E-06
Tetrachloroethylene	B2	Oral	5.10E-02	2.00E-05
		Inhalation	1.80E-03	5.50E-04

Table 6.1-8 Carcinogenic Dose-Response Data

Chemical	Weight of Evidence Classification[1]	Exposure Route	Cancer Slope Factor (mg/kg/day)	Carcinogenic Dose for 10^{-6} risk (mg/kg-day)
Toluene	D			
TCE	B2	Oral	1.10E-02	9.10E-05
		Inhalation	5.90E-03	1.70E-04

1 A = Human carcinogen.
B1/B2 = Probable human carcinogen.
B1 = Indicates limited human data are available.
B2 = Indicates sufficient evidence in animals and inadequate or no evidence in humans.
C = Possible human carcinogen.
D = Not classifiable as a carcinogen.

2 NA denotes Not Applicable.

3 NE denotes no Weight of Evidence Classification Assigned.

4 Inhalation cancer slope factor for DDE not available. Value shown is direct extrapolation from oral pathway.

Table 6.1-9 Chronic Noncarcinogenic Dose-Response Data

Chemical	Route of Exposure	Chronic RfD (mg/kg-day)
Aldrin	Oral	3.00E-05
	Inhalation	3.00E-05[1]
Arsenic	Oral	3.00E-04
	Inhalation	3.00E-04[1]
Benzene	Oral	NA[2]
	Inhalation	NA
Cadmium	Oral, water	5.00E-04
	Oral, food	1.00E-03
Carbon Tetrachloride	Oral	7.00E-04
	NA	7.00E-04[1]
Chlordane	Oral	6.00E-05
	Inhalation	6.00E-05[1]
Chloroacetic Acid	Oral	2.00E-03
	Inhalation	2.00E-03[1]
Chlorobenzene	Oral	2.00E-02
	Inhalation	5.00E-03
Chloroform	Oral	1.00E-02
	Inhalation	1.00E-02[1]
Chromium (VI)	Oral	5.00E-03
	Inhalation	6.00E-07
DBCP	Oral	2.00E-04
	Inhalation	6.00E-05[3]
DCPD	Oral	3.00E-02
	Inhalation	6.00E-05
DDE	Oral	NA
	Inhalation	NA
DDT	Oral	5.00E-04
	Inhalation	5.00E-04[1]
1,2-Dichloroethane	Oral	NA
	Inhalation	NA
1,1-Dichloroethylene	Oral	9.00E-03
	Inhalation	9.00E-03[1]
Dieldrin	Oral	5.00E-05
	Inhalation	5.00E-05 [1]
Endrin	Oral	3.00E-04
	Inhalation	3.00E-04[1]
HCCPD	Oral	7.00E-03
	Inhalation	2.00E-05
Isodrin	Oral	7.00E-05
	Inhalation	7.00E-05

Table 6.1-9 Chronic Noncarcinogenic Dose-Response Data

Chemical	Route of Exposure	Chronic RfD (mg/kg-day)
Lead	Oral	1.40E-03
	Inhalation	4.30E-04
Mercury	Oral	3.00E-04
	Inhalation	9.00E-05 [3]
Methylene Chloride	Oral	6.00E-02
	Inhalation	8.60E-01
1,1,2,2-Tetrachloroethane	Oral	NA
	Inhalation	NA
Tetrachloroethylene	Oral	1.00E-02
	Inhalation	1.00E-02 [1]
Toluene	Oral	2.00E-01
	Inhalation	1.10E-01 [3]
TCE	Oral	NA
	Inhalation	NA

1 Inhalation RfD for chemical not available. Value shown is direct extrapolation from oral pathway.
2 NA denotes Not Available.
3 Inhalation RfD extrapolated from RfC, assuming inhalation of 20 cubic meters/day and body weight of 70 kg.

Table 6.1-10 D_T Values For Acute and Subchronic Exposure

Contaminant	Acute		Subchronic	
	D_TING (mg/kg-day)	D_TINH (mg/kg-day)	D_TING (mg/kg-day)	D_TINH (mg/kg-day)
Aldrin	1.0E-04	1.0E-04	1.0E-04	1.0E-04
Arsenic	8.0E-03	2.9E-04	1.0E-03	2.9E-04
Atrazine	1.0E-02	1.0E-02	5.0E-03	5.0E-03
Benzene	NA	NA	NA	NA
Benzothiazole	NA	NA	NA	NA
BCHPD	NA	NA	NA	NA
Cadmium	4.0E-03	1.4E-01	5.0E-04	5.0E-04
Carbon tetrachloride	4.0E-01	1.8E-01	7.0E-03	2.7E-02
Chlordane	6.0E-03	6.0E-03	6.0E-05	1.4E-04
Chloroacetic acid	NA	NA	2.0E-02	2.0E-02
Chlorobenzene	2.0E-01	2.0E-01	2.0E-01	5.0E-02
Chloroform	1.8E-01	4.3E-01	1.0E-02	6.8E-03
CPMS	NA	NA	NA	NA
Chlorophenylmethyl sulfoxide	NA	NA	NA	NA
$CPMSO_2$	NA	NA	NA	NA
Chromium VI	1.0E-01	1.0E-01	2.0E-02	5.7E-06
Copper	NA	NA	NA	NA
DBCP	5.0E-03	5.0E-03	NA	NA
DDE	NA	NA	NA	NA
DDT	5.0E-04	5.0E-04	5.0E-04	5.0E-04
1,1-Dichloroethane	NA	NA	1.0E+00	1.0E+00
1,2-Dichlorethane	NA	NA	NA	NA
1,1-Dichlorethylene	2.0E+00	1.0E+00	9.0E-03	2.3E-02
1,2-Dichloroethylene	NA	NA	1.0E-01	1.0E-01
DCPD	NA	NA	3.0E-01	6.0E-04
Dieldrin	1.0E-04	1.0E-04	1.0E-04	1.0E-04
DIMP	8.0E-01	8.0E-01	8.0E-01	8.0E-01
Dimethyl disulfide	NA	NA	NA	NA
Dimethylmethyl phosphonate	NA	NA	NA	NA