Taken from the Natural Resource Damage Assessment Plan (NRDA) 2007

2. Site Description

The Arsenal, a 27 square-mile Army facility located 10 miles northeast of downtown Denver, formerly was used for the production of munitions, chemical warfare agents, nerve agent, industrial and agricultural chemicals, and the blending of rocket fuel. The Arsenal property is adjacent to Commerce City to the north and west, Montbello to the south, and Denver International Airport to the north and east (Figure 2.1) (EPA, 2007a).

Climate

The Arsenal is situated within a temperate grassland region of the High Plains and is part of a broad transition zone between mountain and plains habitats. The land surface slopes from southeast to northwest, with a total change of altitude of 220 ft. Prevailing winds are from the south and southwest. The average annual precipitation is approximately 15 inches, with 50% of that falling between April and July. Snow accounts for about 30% of the average precipitation. Localized summer thunderstorm activity results in large spatial variations in precipitation (Ebasco Services et al., 1989b).

Hydrology

Surface water at the Arsenal follows several small tributaries to the South Platte River, which flows to the northwest approximately 2 miles from the northwest boundary and 3 miles from the north boundary of the Arsenal (Figure 2.2). The drainages within the Arsenal include First Creek in the northeast, and Irondale Gulch in the southwest. A series of ditches, culverts, sewers, retention basins, and constructed lakes have greatly modified surface water flow, particularly in Irondale Gulch.

First Creek is a natural intermittent stream with few diversions. The Creek generally loses water as it crosses the Arsenal. In the mid-1980s, the average flow entering the Arsenal was 1.36 cubic feet per second (cfs), and the average flow leaving was 1.15 cfs (Ebasco Services et al., 1989b). Extended periods with little or no flow are common. First Creek discharges to O'Brian Canal approximately 0.5 miles north of the Arsenal boundary.

Irondale Gulch is a poorly defined topographic feature on the western side of the Arsenal and in the Irondale community northwest of the site (Figure 2.2). Surface water in Irondale Gulch does not follow a defined stream channel. Various lakes, ditches, and retention basins capture the surface water, which subsequently enters shallow groundwater or evaporates. Located in the southern section of the Arsenal, Lower Derby Lake and Lake Ladora were irrigation reservoirs prior to the construction of the Arsenal and were subsequently enlarged by the Army. The Army constructed Upper Derby Lake as an additional water storage area, and constructed Lake Mary for recreational fishing (Ebasco Services et al., 1989b).

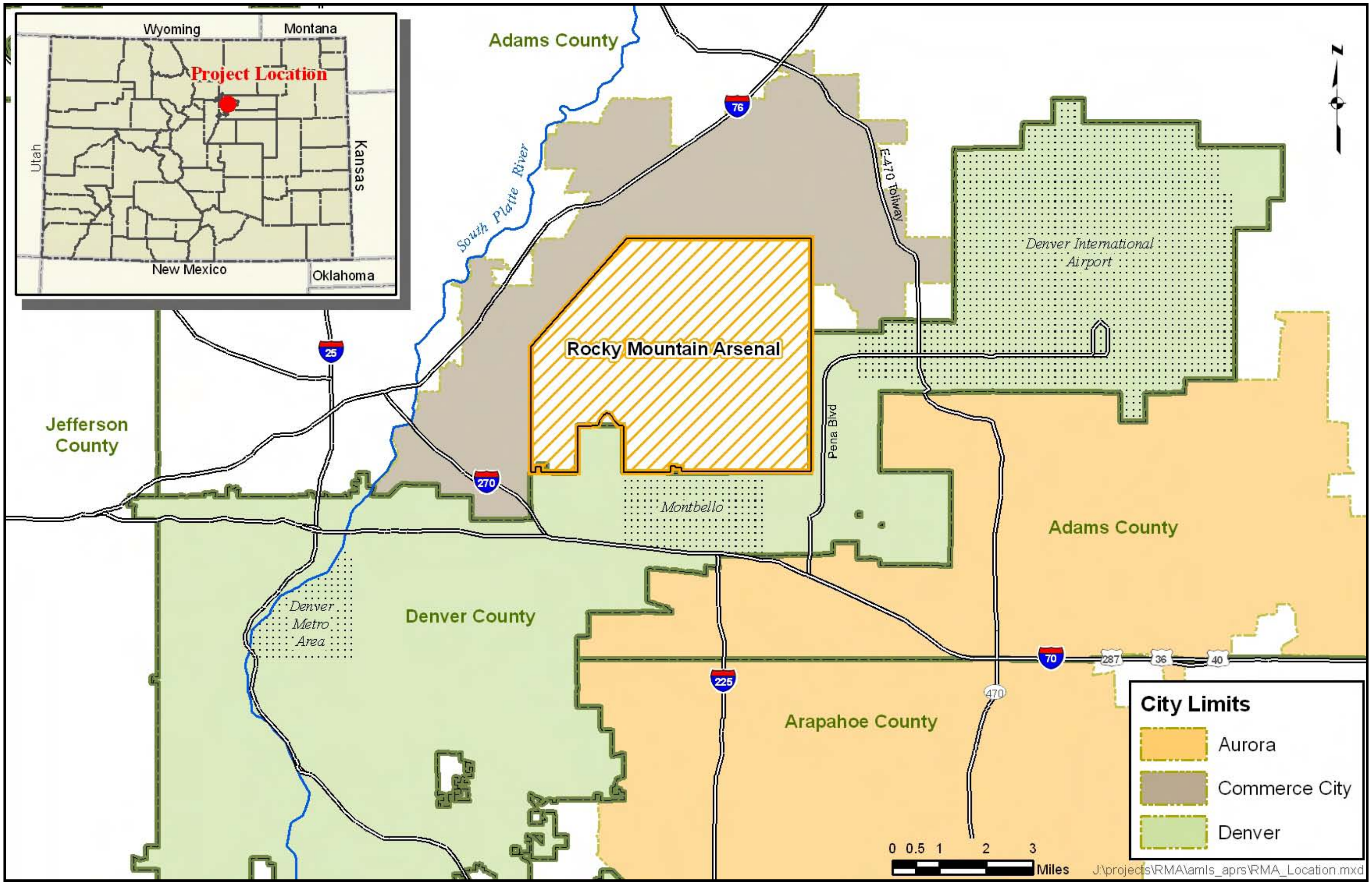

Figure 2.1. General location of the Rocky Mountain Arsenal in the Denver area.

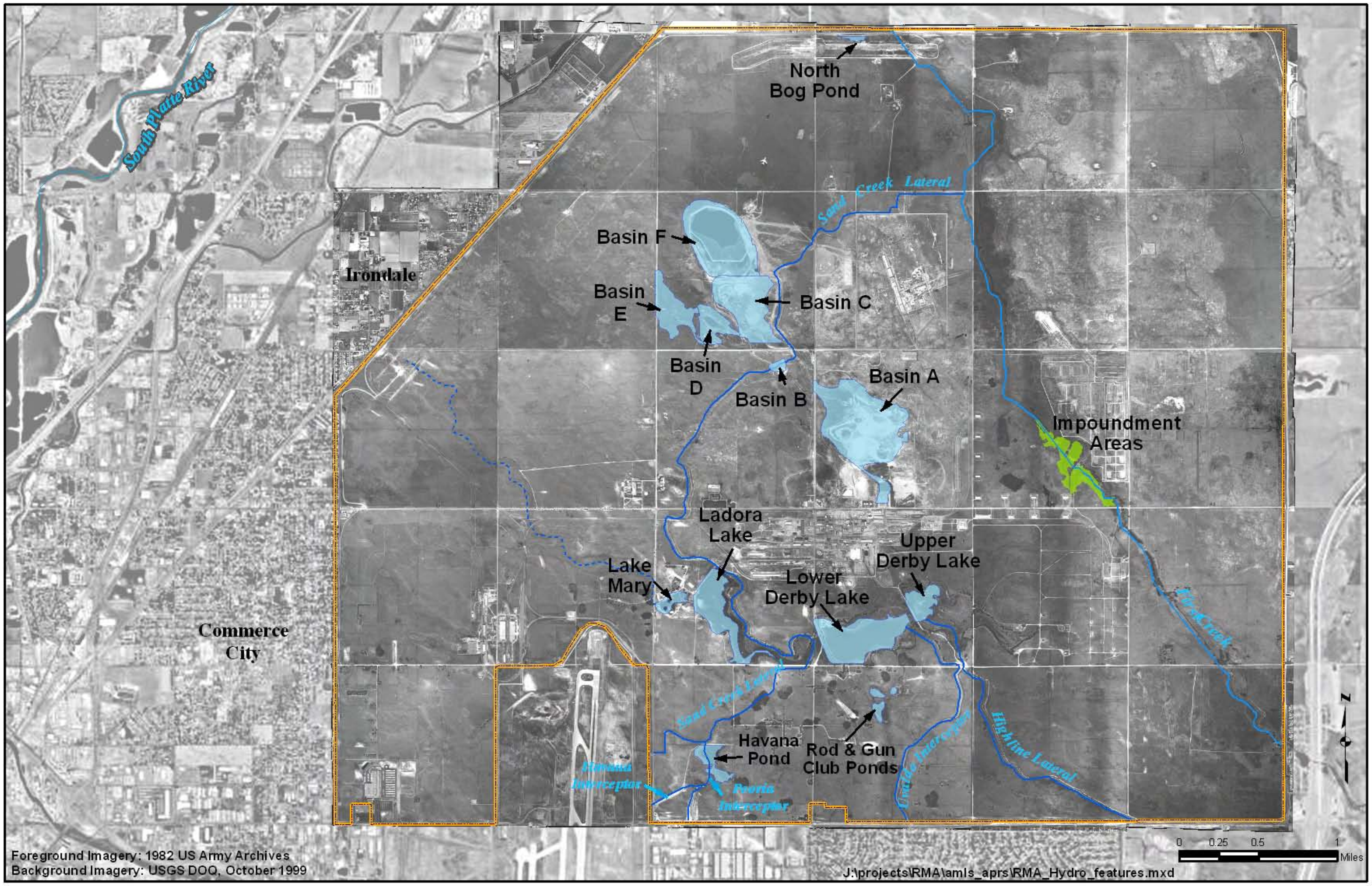

Figure 2.2. Past and present hydrologic features at the Arsenal. Most of the ditches and basins no longer hold surface water.

The Army also maintained six basins, Basin A through Basin F, for retention of stormwater, process water, and process waste (Figure 2.2). Basins A through E were unlined natural depressions, modified with berms and connecting overflow ditches. Basin F was constructed by the Army Corps of Engineers and lined with 3/8-inch thick asphalt (Environmental Science & Engineering and Harding Lawson Associates, 1988d). Liquids in these basins either evaporated or percolated to groundwater. Groundwater was often in direct contact with the bottom of Basin A (Ebasco Services et al., 1989b). The basins are no longer used for water retention and no longer contain surface water.

Groundwater

The groundwater at the Arsenal is part of the regional Denver Basin. Bedrock below the Arsenal is part of the Denver Formation. Sandy deposits known as alluvium overlie the bedrock, with thick deposits ranging from 50 to 130 ft found in ancient channels, and thinner deposits of approximately 20 ft found outside of these channels.

Shallow groundwater tends to follow these ancient alluvial channels, flowing to the north and northwest. The depth to groundwater and the thickness of the alluvial aquifer vary considerably across the site. From the 1950s through the 1980s, the groundwater levels near the manufacturing plants and the Basin A waste disposal basin were close to the surface (Ebasco Services et al., 1989b). Groundwater levels have dropped since manufacturing ended at the site (Foster Wheeler, 2000a).

Chapter 5 discusses the groundwater underlying the Arsenal in more detail.

Biota

Native vegetation at the Arsenal consists primarily of open semiarid grasslands, with some areas of shrubland, patches of yucca, riparian woodlands, cattail marshes and other wetland types, locust and wild plum thickets, upland groves of deciduous trees, and ornamental plantings. Parts of the Arsenal were planted with crested wheatgrass in the 1930s and 1940s to stabilize land susceptible to erosion. Societal changes in the region have altered the landscape to a mosaic of agricultural, developed (industrial and residential), and native habitats (Ebasco Services et al., 1994).

When ecological surveys were conducted in the 1970s and 1980s, 26 species of mammals were found at the Arsenal, including all of the common mammals that inhabit the prairie grasslands of the Colorado Front Range, as well as 176 species of birds and at least 17 species of reptiles and amphibians. The species richness of birds at the Arsenal was found to be high. Ground-nesting songbirds and other birds preferring open habitat are common in the primary Arsenal habitats of open grassland and weedy plains (Ebasco Services et al., 1994).

Ebasco Services et al. (1994) state that the larger lakes at the Arsenal (Figure 2.2) support viable aquatic communities, but benthic invertebrates are largely absent. Fish in the lakes are stocked.

Chapter 6 describes the biota at the Arsenal in more detail.

The remainder of this chapter describes the industrial activities and the waste disposal practices that occurred at the Arsenal. Section 2.1 provides a brief operational history of the Arsenal. Section 2.2 describes some of the manufacturing and disposal sites that became sources of hazardous substance releases to natural resources, followed by references cited in the text. Chapter 3 discusses the investigation and remediation of these releases.

2.1 Site History

Prior to World War II, the land where the Arsenal sits was shortgrass prairie that had been converted to agriculture. In May 1942, the Army purchased over 17,000 acres for manufacturing chemical and incendiary weapons (Army, 2004). After World War II, the Arsenal was placed on standby status, but with the start of the Korean conflict in 1950, the Army resumed operations. Production continued through 1957 as Cold War tensions heightened (Army, 2004). In the late 1950s into the 1960s, Army activities at the Arsenal included the manufacturing of nerve agent and weapons, demilitarization of chemical weapons, and the blending of rocket fuel for the Air Force (Army, 2004). In the 1970s, the Army used the Arsenal primarily for the demilitarization of chemical weapons. These activities ceased in the early 1980s (Army, 2004).

In addition to Army activities, private industries used the Arsenal for manufacturing. Julius Hyman and Company (Hyman) began producing pesticides at the Arsenal in 1946, followed by Colorado Fuel and Iron (CF&I) in 1947. In 1952, Shell acquired Hyman and continued to produce agricultural pesticides on-site until 1982 (EPA, 2007a).

Since the early 1980s, site investigation and remediation have been the primary activities at the Arsenal (Army, 2004; EPA, 2007a). The remainder of this section describes the industrial facilities and the products manufactured at the site. Chapter 3 then discusses cleanup activities in more detail.

2.1.1 Army manufacturing

Chemical agents, nerve agents, and munitions

The majority of the manufacturing at the Arsenal occurred at the South Plants Complex (Figure 2.3), which covered approximately 500 acres with buildings, roads, parking lots, railroad tracks, sewer lines, culverts, steam pipes, manholes, water mains, and some open space (Ebasco Services et al., 1989c). Chemical agents produced within the complex included mustard, lewisite, and phosgene (Table 2.1). Incendiary munitions were mainly napalm, white phosphorous, and a mixture of potassium chlorate, red phosphorous and glass known as “button bombs” and “sandwich button bombs” (DOJ, 1986; Ebasco Services et al., 1988b).

From 1942 to 1943, over 3.5 million tons of mustard were produced. Of this, over 334 tons were determined to be off-specification and ultimately treated and disposed of on-site (DOJ, 1986). In total, the Army produced about 1.6 million nerve gas munitions, including cluster bombs, shells, bomblets, rockets, and warheads at the Arsenal (Goldstein, 2001).

Napalm was produced from 1943 to 1945, with a total output of over 2.6 million bombs (Environmental Science & Engineering et al., 1988d). White phosphorous-filled munitions, including white phosphorous cups, igniters, grenades, and 105 mm shells, followed from 1945 until 1970 (DOJ, 1986). By the end of World War II, the Arsenal had created more than 100,000 tons of incendiary munitions (Army, 2004). By 1968, over 1.7 million button bombs and 7 million sandwich button bombs had been manufactured at the Arsenal (DOJ, 1986). White phosphorous and burned incendiary device casings were disposed of in the Army Section 36 Complex Disposal Trenches (Foster Wheeler, 2001) (Figure 2.3).

The Army constructed the 90-acre North Plants Complex (Figure 2.3) from 1950 to 1952. From 1952 to 1957, the Army used the North Plants Complex to manufacture Sarin nerve agent (Table 2.1), fill munitions with Sarin, and assemble cluster bombs, as well as to store Sarin, feedstock chemicals, and munitions. The facility was later used for the demilitarization of chemical warfare agents. The Army stored Sarin in one-ton containers and in underground tanks (DOJ, 1986; RVO, 2004).

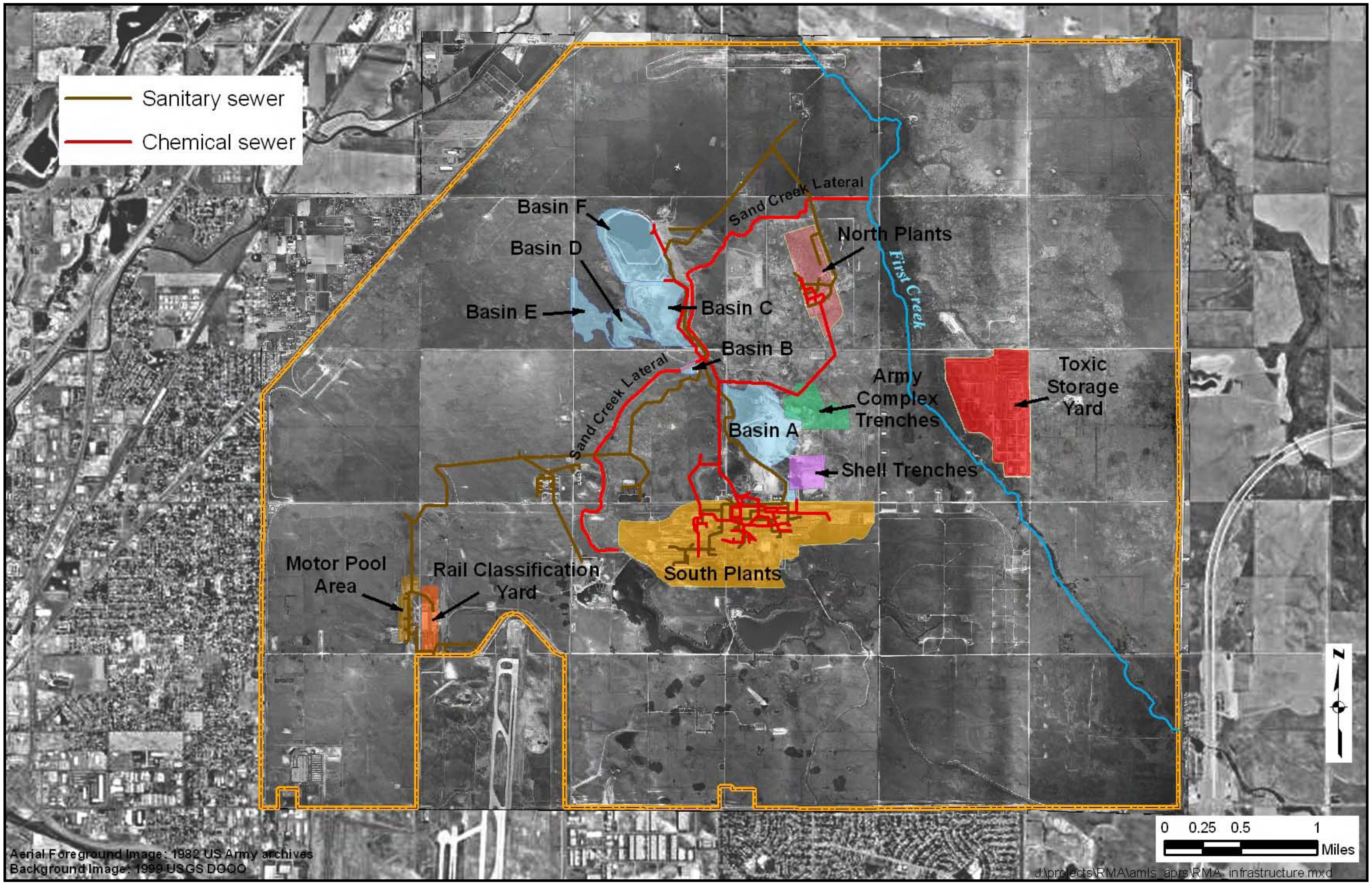

Figure 2.3. Manufacturing, storage, waste transit, and waste disposal sites at the Arsenal. Background image from 1982.

Table 2.1. Chemical agents and munitions manufactured or handled at the Arsenal

Product	Description	Sources
Mustard [bis (2-chloroethyl) sulfide; H; HS; Levinstein mustard]	Mustard is a vesicant, or blistering agent. Raw materials used in the production of mustard were ethyl alcohol, Freon 114, sulfur monochloride, calcium chloride, bleaching powder, coke, kerosene, fuel oil, caustic soda, and hexamine. Mustard and mustard-filled munitions were manufactured at the Arsenal in 1943 and from 1950 to 1957. Between 1945 and 1946, the Army reprocessed mustard into distilled mustard.	Ebasco Services et al., 1988b
Lewisite [2-chlorovinyl dichloro arsine]	Lewisite is a vesicant, sometimes used in combination with mustard. Raw materials associated with lewisite production included acetylene, arsenic trichloride, thionyl chloride, hydrochloric acid and mercuric chloride, many of which were manufactured at the Arsenal. The Army produced lewisite from April through November 1943.	Kuznear and Trautmann, 1980
Phosgene [carbonyl chloride]	Phosgene is a choking agent. The phosgene bomb-filling plant at the Arsenal operated from January 1944 to December 1944.	Kuznear and Trautmann, 1980; Army, 2004
Napalm	Napalm is a powdered thickening agent added to gasoline to produce the incendiary mixture called NP gel. This thickened fuel was used in incendiary bombs and flamethrowers. The incendiary oil plant, which mixed the napalm thickener and gasoline, operated from April 1943 to August 1945.	Ebasco Services et al., 1988b
White and red phosphorus	White phosphorus was used for production of incendiary bombs. Red phosphorus was used as a chemical constituent in button bombs and sandwich button bombs. The phosphorus plant operated in 1944–1945, 1952, 1953, and 1958–1960.	Ebasco Services et al., 1988b
Sarin [GB; isopropyl methylphosphono-fluoridate]	Sarin is an extremely toxic nerve agent. Raw materials included methylphosphonic dichloride, hydrofluoric acid, isopropyl, tributylamine, methanol, carbon tetrachloride, ethyl ether, methylene chloride, and calcium chloride. Sarin was manufactured at the North Plants from July 1952 through March 1957.	Ebasco Services et al., 1988b
VX [O-ethyl-S-(2-diisopropylaminoethyl) methylphosphonothiolate]	VX is an extremely toxic nerve agent. VX was not manufactured at the Arsenal, but VX bombs were decommissioned along with Sarin bombs at the site in the 1960s, and byproducts of the process were disposed of at the site.	Ebasco Services et al., 1988b

Demilitarization of munitions

After manufacturing these chemical agents and munitions, the Army subsequently demilitarized many of the same munitions at the facility (Figure 2.4). Beginning in 1947, obsolete and deteriorating mustard-filled munitions were disassembled at the Arsenal. The mustard was incinerated in a furnace located in the South Plants, and the casings were decontaminated in an acid bath and/or burned (DOJ, 1986). Other mustard demilitarization activities at the site included:

- *1958 to 1959*: 30,000 mustard-filled munitions
- *1964 to 1969*: more than 58,000 mustard-filled munitions
- *1973 to 1976*: 3,407 mustard-filled one-ton containers incinerated (DOJ, 1986).

Figure 2.4. Technician deactivating fuses in cluster bombs at the Arsenal.

Source: Army (2004).

Demilitarization of Sarin munitions began in the 1950s, primarily on munitions that were off-specification. From 1955 to 1970, over 204,000 Sarin-filled munitions were demilitarized. In 1969, the Army initiated "Project Eagle" to demilitarize excess stocks of toxic agent at the Arsenal. From 1973 to 1976, over 21,000 stored M34 cluster bombs, each containing 76 bomblets filled with 2.6 pounds of Sarin, were demilitarized. The Army drained the bomblets, mixed the Sarin with caustic in a reactor chamber, and spray-dried the brine. Approximately 450,000 gallons of Sarin from over 21,000 munitions were deactivated as part of Project Eagle, resulting in almost 6.25 million pounds of contaminated spray-dried salt. The salt was stored in more than 18,000 steel and fiberboard drums in the Toxic Storage Yard (Army, 1978; DOJ, 1986).

In 1968, the Army began the demilitarization of the nerve agent VX, which was "the deadliest nerve agent ever created" (Council on Foreign Relations, 2006). VX was not produced at the Arsenal, but from 1964 to 1969, 2.3 million pounds were transported to the site and stored in steel containers, spray tanks, rockets, and mines. Approximately 3,600 pounds of VX munitions were neutralized at the Arsenal (DOJ, 1986).

Demilitarization of chemical weapons halted in 1984, essentially ending industrial operations at the site (Ebasco Services et al., 1988g).

Rocket fuel

In 1959, in coordination with the Air Force, the Army constructed the Hydrazine Blending and Storage Facility (HBSF) to blend anhydrous hydrazine with unsymmetrical dimethylhydrazine to produce Aerozine 50 (Ebasco Services et al., 1988c). Aerozine 50 is a hypergolic fuel (ignites spontaneously) when used with nitrogen oxidizers. It was primarily used in the Titan and Delta missile programs (NASA KSC, 2005). Blending of Aerozine 50 began in 1961 and continued through 1982 (Ebasco Services et al., 1988c).

2.1.2 Other chemical manufacturing

CF&I manufactured dichlorodiphenyltrichloroethane (DDT) in the South Plants area in 1947 and 1948 (Ebasco Services et al., 1988d). CF&I also produced monochlorobenzene, a precursor of DDT, at a benzene plant in the South Plants complex in 1947 (Army, 2001). During the 1950s, CF&I manufactured chlorobenzene, DDT, naphthalene, and chlorine (Ebasco Services et al., 1988a).

Hyman developed the pesticides aldrin, dieldrin, and chlordane, and produced those pesticides as well as endrin at the Arsenal between 1947 and 1952 (Army, 2004). In 1950, Hyman took over caustic soda and chlorine production facilities formerly operated by CF&I. In 1948, Shell merged with Hyman, and in 1952, Shell assumed Hyman's leases at the Arsenal.

Shell manufactured a wide variety of pesticides, insecticides, and herbicides at South Plants (Table 2.2), producing aldrin and dieldrin until 1974 and other pesticides until the 1980s (Ebasco Services et al., 1988b; Army, 2001, 2004). Hazardous substance waste streams associated with the production of aldrin/dieldrin included: acetic acid, benzene, cyclopentadiene, dicyclopentadiene (DCPD), hexachlorocyclopentadiene, hydrogen, toluene, and xylene (Ebasco Services et al., 1988b).

Table 2.2. Herbicides and pesticides produced by Shell at the Arsenal

Substance	Years produced	Description
Aldrin/dieldrin	1947–1974	An organochlorine pesticide used on cotton and corn, among others. Use now banned or severely restricted.
Chlordane	1947–1952	A pesticide used on corn and citrus crops and on home lawns and gardens. Use now banned or severely restricted.
Endrin	1952–1965	A chlorinated hydrocarbon pesticide used to control insects, rodents, and birds. Use now banned or severely restricted.
Isodrin	1952–1965	A process intermediate of endrin with insecticidal properties similar to those of aldrin.
Methyl parathion	1957–1967	An insecticide for farm crops, especially cotton. Use now banned or severely restricted.
Ethyl parathion	1964–1966	An organophosphate insecticide used primarily on row crops and fruit.
Vapona	1960–1982	An insecticide used in Shell “No Pest Strips.”
Supona	1963–1969	A pesticide used to kill parasites in sheep and cattle. No longer used in the United States.
Bidrin	1962–1979	A pesticide used to control aphids, mites, thrips, fleahoppers, grasshoppers, boll weevils, and other insects on cotton, ornamental trees, and fruit crops.
Dibrom	1962–1970	An organophosphate pesticide used for, among other things, mosquito control.
Ciodrin	1962–1976	An organophosphate insecticide.
Azodrin	1965–1977	An insecticide used to control a broad spectrum of pests. Use now banned or severely restricted.
Atrazine	1977–1987	An agricultural herbicide.
Gardona	1967–1968	An insecticide used to control flies.
Akton	1952–1974	An organophosphate insecticide.
Landrin	1969–?	An insecticide.
Nudrin	1973–1977	An insecticide included on EPA’s Superfund Extremely Hazardous Substances list.
Nemagon[a]	1955–1977	A soil fumigant used to control soil-inhabiting nematodes. Use now banned or severely restricted.
Bladex	1970–1971, 1974–1975	A restricted use herbicide used to control weeds and invasive grasses.
Planavin	1966–1975	A herbicide used to control weeds and grass.
Nemafere	Unknown	A nemacide used to control nematodes.
Phosdrin	1956–1973	An insecticide used on vegetables, alfalfa, fruits, and nuts. Use now banned or severely restricted.

a. Nemagon is the trade name for dibromochloropropane (DBCP).

Sources: DOJ, 1986; Ebasco Services et al., 1988b; MK-Environmental Services, 1993; ATSDR, 2003; EPA, 2007b; Scorecard.org, 2007.

2.2 Sources of Hazardous Substances

In 1984, the Army developed a map that identified over 100 potentially contaminated sites. These included 15 basins and lagoons; 14 ditches, lakes, and ponds; 13 contaminated sewers; 38 solid waste burial sites; and 8 ordnance testing and disposal sites (Ebasco Services, 1985). Each of these sites may have released hazardous substances into the environment. A detailed assessment of each of the sources of hazardous substances is beyond the scope of this report. The Trustees instead provide a list of contaminants that are known to have been released at the Arsenal (Table 2.3), and then describe some of the primary manufacturing, waste transport, and waste disposal sites that are, or were, sources of hazardous substances and other contaminants (Figure 2.3). Table 2.3 is a partial list of contaminants released at the Arsenal; a complete compendium is beyond the scope of this document.

Table 2.3 lists over 160 contaminants, including over 100 hazardous substances, released at the Arsenal (DOJ, 1986; Ebasco Services et al., 1988b). Shell released an estimated 150,112 tons of contaminants into the environment, and the Army an estimated 26,405 tons (DOJ, 1986).

Table 2.3. Documented contaminants released at the Arsenal

Contaminant	Use	Contaminant	Use
Acetic acid	Used in the production of dieldrin, endrin, and bidrin	Ammonium nitrate	Waste product from Shell manufacturing
Acetone	Used in the production of azodrin and planavin	Ammonium nitrite	Waste product from Shell manufacturing
Acetonitrile	Waste product from Shell manufacturing	Ammonium sulfite	Waste product from Shell manufacturing
Acetophenone	Breakdown product of ciodrin	Antimony	Used in the production of lewisite
Acetylene tetrachloride	Used in laundry and clothing operations	Antimony compounds	Antimony chloride was used in the production of lewisite
Aldrin	Shell product manufactured at the Arsenal	Antimony hydroxide	Used in the production of lewisite
Allyl alcohol	Used in the production of Nemagon	Arsenic	Used in the production of lewisite
Allyl chloride	Used in the production of Nemagon	Arsenic trichloride	Used in the production of lewisite
Aminoisobutyronitrile	Process intermediate in the production of Bladex	Arsenic trioxide	Used in the production of lewisite
Ammonia	Used in the production of azodrin, bladex, and planavin	Asbestos	Insulation of pipes and buildings
Ammonium chloride	Fire retardant	Benzene	Used in the production of aldrin, dieldrin, and endrin

Table 2.3. Documented contaminants released at the Arsenal (cont.)

Contaminant	Use	Contaminant	Use
Bidrin	Shell product manufactured at the Arsenal	Copper	Used in pesticide manufacture
Cacodylic acid	Possibly used in the production of lewisite or as an herbicide	Copper compounds	Used in the production of azodrin and white phosphorous cups
Cadmium	Purpose of use not documented	Cyanide	Purpose of use not documented
Calcium arsenide	Used in the production of lewisite	Cyanogen chloride	Used in the production of phosgene
Calcium arsenite	Used in the production of lewisite	Cyclohexane	Purpose of use not documented
Calcium carbide	Used in the production of aldrin, dieldrin, and acetylene	Cyclohexanone	Purpose of use not documented
Carbon tetrachloride	Used in the production of Dibrom and as a cleaning solvent	Cyclopentadiene	Used in the production of aldrin, dieldrin, and heptachlor
Chlordane	Used in the production of heptachlor	DBCP	Shell product manufactured at the Arsenal
Chlorinated phenols	Use not documented	D-D soil fumigant	Shell product manufactured at the Arsenal
Chlorine	Used in the production of lewisite, azodrin, bidrin, heptachlor, and nudrin	DDT	Product manufactured at the Arsenal
Chloroacetic acid	Purpose of use not documented	Dibromoethane	Purpose of use not documented
Chlorobenzene	Used in the production of lewisite	Dichlorobenzene	Used in the production of akton
Chloroethylbenzene	Shell process intermediate	Dichlorodiphenylethane (DDE)	Decomposition product of DDE
Chloroform	Used in the production of azodrin and bidrin	1,1 dichloroethane	Used in the production of acetylene
Chlorophenylmethyl sulfide	Process intermediate in the production of Planavin	1,2 dichloroethane	Purpose of use not documented
Chlorophenylmethyl sulfone	Process intermediate in the production of Planavin	1,1-dichloroethylene	Purpose of use not documented
Chlorothiophenol	Purpose of use not documented	Dichloromethane	Used in the production of dichlor
Chromic acid	Used in the production of acetylene	Dichloropropane	Used in the production of D-D soil fumigant for nematodes
Chromium	Purpose of use not documented	Dichloropropene	Used in the production of D D soil fumigant for nematodes

Table 2.3. Documented contaminants released at the Arsenal (cont.)

Contaminant	Use	Contaminant	Use
Dichlorotrichlorophenyl urea	Used in laundry and clothing operation	Hexachlorocyclopenta-diene	Used in the production of aldrin, dieldrin, and endrin
Dichlorvos	Shell product manufactured at the Arsenal; also used in the production of bidrin	Hexane	Used in the production of ciodrin and nudrin
Dicyclopentadiene	Used in the production of aldrin and endrin	Hydrazine	Used in the production of Aerozine 50
Dieldrin	Shell product manufactured at the Arsenal	Hydrochloric acid	Used in the production of lewisite, phosgene, and landrin
Diketene	Used in the production of azodrin and ciodrin	Hydrofluoric acid	Used in the production of Sarin
Dimethylamine	Used in the production of bidrin	Hydrogen cyanide	Used in the production of Bladex
Dimethylhydrazine	Used in the production of Aerozine 50	Hydrogen peroxide	Used in the production of dieldrin, endrin, and planavin
Dipropylamine	Used in the production of Planavin	Hydrogen sulfide	Decomposition product of akton, parathion, and nudrin
Endrin	Shell product manufactured at the Arsenal	Isodrin	Process intermediate in the production of endrin
Ethylbenzene	Purpose of use not documented	Isopropanol	Used in the production of Sarin, endrin, and planavin
Ferric chloride	Purpose of use not documented	Lead	Purpose of use not documented
Fluoroacetic acid	Purpose of use not documented	Malathion	Used in military training
Freon	Used in the production of button and sandwich button bombs	Mercuric compounds	Mercuric chloride was used in the production of lewisite
Heptachlor	Julius Hyman product manufactured at the Arsenal	Mercury	Purpose of use not documented
Heptachlor epoxide	Degradation product of heptachlor	Methanethiol	Process intermediate associated with the production of nudrin
Heptachlorobicyclohep-tadiene	Process intermediate in the production of endrin	Methanol	Used in the manufacture of Sarin and akton
Heptane	Purpose of use not documented	Methomyl	Shell product manufactured at the Arsenal
Hexachlorobenzene	Purpose of use not documented	Methyl disulfide	Used in the production of nudrin
Hexachlorobicyclopent-adiene	Metabolite of heptachlor	Methyl isobutyl ketone	Used in the production of nudrin

Table 2.3. Documented contaminants released at the Arsenal (cont.)

Contaminant	Use	Contaminant	Use
Methyl isocyanate	Used in the production of landrin and nudrin	Phenol	Purpose of use not documented
Methyl mercaptan	Used in the production of nudrin	Phosdrin	Shell product manufactured at the Arsenal
Methyl parathion	Shell product manufactured at the Arsenal	Phosgene	A choking agent used in bombs at the Arsenal; a decomposition product of dibrom
Methylhydrazine	Used in the production of Aerozine 50	Phosphoric acid	A decomposition product of azodrin, bidrin, ciodrin, and gardona
Methylthioacetaldoxime	Used in the production of nudrin	Phosphorous (red)	Used in the production of button and sandwich button bombs
Mixed oleum and nitric acid	Used in the production of mustard	Phosphorus (white)	Used in the production of white phosphorous cups
Mustard	Army product manufactured at the Arsenal	Potassium chlorate	Used in the production of button and sandwich button bombs
Naled	Shell product manufactured at the Arsenal	Pyrene	Purpose of use not documented
Nitric acid	Used in the production of planavin and mustard demilitarization	Sarin	Army product at the Arsenal
Nitro sodium phenolate	Hydrolysis product of methyl and ethyl parathion	Sodium	Byproduct and decomposition product of Sarin
4-nitrophenol	Product of parathion hydrolysis	Sodium chlorate	Used in the production of Sarin and chlorine
N-nitrosodimethylamine (NDMA)	Impurity of dimethyl hydrazine; used in the production of Aerozine 50	Sodium fluoride	Byproduct of production; filling and demilitarization of Sarin munitions
Octachlorocyclopenta-diene	Purpose of use not documented	Sodium hydroxide	Used in the manufacture of caustic, chlorine, Sarin scrubber effluent, akton, and nudrin
Parathion	Shell product manufactured at the Arsenal	Sodium hypochlorite	Used to decontaminate equipment and work areas
Pentachlorobenzene	Purpose of use not documented	Sodium methylate	Used in the production of akton
Phenanthrene	Purpose of use not documented	Sodium nitrate	Used in M-74 incendiary munitions

Table 2.3. Documented contaminants released at the Arsenal (cont.)

Contaminant	Use	Contaminant	Use
Sodium nitrite	Used in M-74 incendiary munitions and a Shell waste	Trichlorobenzene	Used in the manufacture of gardona
Sulfur monochloride	Used in the production of mustard	1,1,1 trichloroethane	Solvent used by Shell
Sulfuric acid	Used in the production of nudrin and planavin; used in chlorine production and mustard distillation	1,1,2 trichloroethane	Purpose of use not documented
Sulfuryl chloride	Used in the production of ciodrin, heptachlor, and phosdrin	Trichloroethylene (TCE)	Used in laundry and M-74 bomb filling
Tetrachloroethane	Purpose of use not documented	Trimethyl phosphite	Used in the production of azodrin, bidrin, ciodrin, phosdrin, and vapona
Tetrachloroethylene (or perchloroethylene, PCE)	Used in laundry and clothing operations	TX	Army biological agent processed at the Arsenal
Tetrahydrofuran	Solvent used by Shell for unreported purposes	Vinyl chloride	Used in the manufacture of endrin
Thiodiglycol	Used in the production of mustard	Xylene	Used in the production of dieldrin, endrin, and gardona
Toluene	Used in the production of aldrin dieldrin and endrin	Zinc	Purpose of use not documented
Trichloroacetaldhyde	Used in the production of dibrom and dichlorovos	Zinc oxide	Used in laundry and clothing operations

Sources: DOJ, 1986; Ebasco Services et al., 1988b.

2.2.1 South Plants Complex

The South Plants Complex (Figure 2.3) was the site of the first manufacturing operations at the Arsenal and ultimately contained between 165 and 197 structures (Ebasco Services et al., 1988d). The Army initially used South Plants for the production, filling, and storage of bombs containing mustard, lewisite, phosgene, white phosphorus, chlorine, incendiary mixtures, and explosives (Ebasco Services et al., 1988d). Beginning in 1957 and continuing into the 1980s, the Army also demilitarized chemical weapons in the South Plants area. Demilitarization included emptying, burning, neutralizing, and disposing of nerve agents, nerve agent munitions, and nerve agent-contaminated items (Environmental Science & Engineering et al., 1988b). As discussed above, a succession of companies, primarily Shell, manufactured pesticides, insecticides, and herbicides at South Plants beginning in 1946 and continuing until 1982.

The South Plants Complex released hazardous substances to the environment through direct disposal of wastes into, among other locations, Basins A through F, Lime Settling Basins, Army Complex Trenches, Shell Trenches, sewers, ditches, and lakes (Figure 2.3). In addition, numerous spills associated with Army and Shell activities were reported. From the late 1940s to the end of manufacturing activities in the early 1980s, over 87,000 gallons of solvents, pesticides, metals, and other process intermediates leaked or spilled in the South Plants manufacturing area (DOJ, 1986; Ebasco Services et al., 1988b, 1988d).

In 1966, Shell constructed an incinerator in South Plants to decontaminate and dispose of their wastes. The incinerator was shut down in 1970 due to high particulate emission levels (Ebasco Services et al., 1992).

Numerous small waste pits and lagoons were located in and around the South Plants Complex, including the Liquid Storage Pool, Hex Pits, M1 Pits, South Plants Lime Pits, South Plants Lagoon, the Test Site, and the Insecticide/Pesticide Pits. Each of these has been identified as a source of hazardous substances (Ebasco Services et al., 1989c). A description of each is beyond the scope of this document, but all of these sites are within or adjacent to the South Plants and therefore the entire complex should be considered a source of hazardous substances.

South Plants Tank Farm

The South Plants Tank Farm was another source of hazardous substances located within the South Plants Complex. The Army, CF&I, Hyman, and Shell used the tanks for liquid storage (Ebasco Services et al., 1987). The tanks were constructed of dismantled salvage material, and they contained fuel, alcohol, benzene, bicycloheptadiene bottoms, DCPD, water, D-D soil fumigant, DBCP, and sulfuric acid (Ebasco Services et al., 1987). The overall capacity of the tanks was 2.3 million gallons (Ebasco Services et al., 1987). As reported in Ebasco Services et al. (1987), some of the numerous releases to the environment via spills and tank leakage included:

- 100,000 gallons of benzene in 1947
- 17,000 gallons of DCPD in 1963
- 1,548 gallons of DCPD and oil in 1976
- 58,864 gallons of DCPD in 1978.

In addition, sediments and DCPD bottoms were routinely removed from the tanks during cleaning and buried at unreported locations, possibly in pits adjacent to the tanks (Ebasco Services et al., 1987).

South Plants Chemical Sewers

The South Plants sewer system carried chemical wastewaters from production units to Basin A, the M-1 Pits, the Lime Settling Basins, the Sand Creek Lateral (via the storm sewer), ditches, and Basin F (Ebasco Services et al., 1988a). The sewers were originally constructed to dispose of wastewater generated at the South Plants Complex (Ebasco Services et al., 1988a). These sewers released hazardous substances, including acetic acid, aldrin, caustic soda, dieldrin, endrin, xylene, acids, and tetrachloroethylene, to South Plants groundwater (Ebasco Services et al., 1988a).

Sand Creek Lateral

Farmers originally constructed the Sand Creek Lateral (Figures 2.2 and 2.3) in the early 1900s for flood irrigation (Foster Wheeler, 2000b). As part of Arsenal operations, it served as a chemical sewer conveying wastes from the South Plants. The Sand Creek Lateral originally discharged liquid waste from the chlorine plants and South Plants stormwater runoff directly into First Creek. When sodium chloride concentrations in the waste reached 20,000 parts per million (ppm), flows from the Lateral were redirected to Basins D and E (Tetra Tech EC, 2005).

In 1951, the waste from the White Phosphorus Plant and the M-74 Bomb Filling Operations were redirected from Basin A to the Sand Creek Lateral (Tetra Tech EC, 2005). In 1953, the Sand Creek Lateral was incorporated into the liquid waste disposal system to convey overflow wastes from Basins A and B downstream to Basin C and subsequently into Basins D and E (Tetra Tech EC, 2005). The Sand Creek Lateral was used until the Basin F chemical sewer system was brought online in late 1956 (Tetra Tech FW, 2004; Tetra Tech EC, 2005).

The use of the Sand Creek Lateral for storm water runoff and discharge from the South Plants resulted in releases of hazardous substances, including aldrin, copper, dieldrin, TCE, trichloroethane arsenic, mercury, lead, sulfate, white phosphorous, various salts, caustics, and acids, to groundwater, surface water, and sediments (Tetra Tech FW, 2004; Tetra Tech EC, 2005).

North Plants Complex

The Army constructed the North Plants Complex (Figures 2.3 and 2.5) in the early 1950s to produce Sarin nerve gas, create the Sarin delivery systems (bombs), and subsequently to demilitarize Sarin bombs and other chemical warfare and incendiary munitions (Ebasco Services et al., 1989a; RVO, 2004). The manufacturing process resulted in the release of hazardous substances into, among other locations, Basins A and F, Army Complex Trenches, the Toxic Storage Yard, sewers, trenches, pits, and ditches, as well as directly to the ground from leakage and overflow of underground tanks and sumps within the North Plants (Ebasco Services et al., 1989a).

Figure 2.5. North Plants Complex.

Source: Army archives.

Floor drains from 18 buildings in the North Plants were connected to the Building 1727 Sump, an 80,000-gallon wastewater repository (Ebasco Services et al., 1989a). Wastes in the sump were neutralized with caustic, then pumped into Basin A or Basin F (Ebasco Services et al., 1989a).

Between 1953 and 1982, waste liquids from sump overflow migrated through ditches into First Creek. Leakage from the sump, in addition to spills and leakage from other areas of the North Plants, resulted in the release of benzene, 1,1 dichloroethane, 1,2 dichloroethane, carbon tetrachloride, 1,1,1 trichloroethane, TCE, chloroform, methylisobutyl ketone, arsenic, mercury, cadmium, chromium, copper, lead, zinc, pyrene, chloroacetic acid, aldrin, and dieldrin (Ebasco Services et al., 1989a). Soil samples taken adjacent to the North Plant sewers showed releases of dieldrin, arsenic, cadmium, chromium, and lead (Ebasco Services et al., 1989a).

2.2.2 Basins

Lime Settling Basins

The Lime Settling Basins (Figure 2.3) comprised three, one-acre unlined basins originally used during World War II to precipitate arsenic and metals from lewisite production wastewater (Environmental Science & Engineering et al., 1987e). All South Plants wastewater, including pesticide waste and byproducts, was reportedly channeled through the Lime Settling Basins to Basin A and, later, Basin B (Environmental Science & Engineering et al., 1987e). In addition, over 150 drums of mustard may have been disposed in these basins from 1959 to 1960 (Environmental Science & Engineering et al., 1987e). When their use was discontinued, the Army estimated that 80,000 cubic yards of sludge were contained in the Lime Settling Basins, with an additional 26,000 cubic yards located adjacent to them (Ebasco Services et al., 1990). Discharge of liquids into the Lime Settling Basins resulted in the release of numerous hazardous substances, including aldrin, dieldrin, endrin, isodrin, DDT, DDE, chlorophenylmethyl sulfide, arsenic, mercury, lead, cadmium, and chromium (Ebasco Services et al., 1990).

Basin A

Basin A was an unlined natural depression and the primary disposal area for liquid chemical waste from the South Plants from the time production of mustard was initiated in the early 1940s until the mid-1950s when the construction of Basin F was completed. Liquids were discharged to Basin A primarily through the chemical sewers. At maximum capacity, Basin A covered 125 acres (Environmental Science & Engineering, 1987; Figure 2.6).

In 1943, approximately 10% of the mustard produced was determined to be off-specification (DOJ, 1986). Each batch of off-specification mustard was neutralized with caustic and discharged through a toxic waste sewer into Basin A (Ebasco Services et al., 1988d). The treatment of mustard with caustic was not always successful, and high levels of mustard were often found in the water of Basin A near the sewer outlet (Kuznear and Trautmann, 1980). Mustard neutralization also produced 514,000 pounds of the hazardous substance thiodiglycol, which was also disposed of in Basin A (DOJ, 1986).

In addition, the Army flushed the mustard storage tanks with a mixture of carbon tetrachloride and fuel oil, and then a 10% solution of caustic and chlorinated water. Other parts of the mustard complex were rinsed using approximately 20,000 gallons of 98% sulfuric acid. All rinsate was discharged through the sewer into Basin A (DOJ, 1986).

During munitions filling operations, approximately 500 gallons of distilled mustard leaked from a corroded storage tank and was discharged untreated into Basin A (DOJ, 1986).

Figure 2.6. Basin A in June 1950.

Source: Army archives.

White phosphorous was shipped to the Arsenal in specialized railroad cars. The phosphorous was covered with water to avoid auto-ignition. The "phossy water," as it was called, was discharged to Basin A via the chemical sewers until 1951 (DOJ, 1986).

Documented disposal of hazardous substances to Basin A from pesticide and herbicide manufacturing include (Ebasco Services et al., 1988b):

- > 170,000 pounds of aldrin mixtures
- 11,000 pounds of endrin manufacturing wastes
- 17,000 pounds of isodrin manufacturing wastes
- 406 pounds of nemafere manufacturing wastes.

Basin B

Basin B was a two-acre, unlined natural depression that was used until 1956 as an intermediate containment reservoir for excess Basin A liquids directed to Basin C (Figure 2.3) (Environmental Science & Engineering et al., 1987d). Disposal of waste liquids into Basin B resulted in the release of numerous hazardous substances, including dieldrin, arsenic, mercury, lead, cadmium, and chromium (Environmental Science & Engineering et al., 1987d; Environmental Science & Engineering and Harding Lawson Associates, 1988e).

Basin C

Basin C was a 77-acre unlined natural depression (Figure 2.3) that the Army reportedly first used in the early 1950s as a repository for an unknown amount of white phosphorous waste considered to be incompatible with Basin A fluid (Environmental Science & Engineering et al., 1987a). The Army constructed dikes in 1953 to create a waste repository with an estimated capacity of 190 million gallons (Environmental Science & Engineering et al., 1987a). All waste liquids flowing into the basin were derived from two sources: (1) overflow from Basins A and B, and (2) surface drainage ditches in the South Plants that led into the Sand Creek Lateral (see Figure 2.2). Basin C was hydraulically connected to groundwater and thus served as a direct source of hazardous substance to groundwater (Environmental Science & Engineering et al., 1987a). Disposal of liquids into Basin C resulted in the release of numerous hazardous substances, including xylene, aldrin, dieldrin, DDE, chlorophenylmethyl sulfide, arsenic, mercury, copper, lead, cadmium, and chromium (Environmental Science & Engineering et al., 1987a; Environmental Science & Engineering and Harding Lawson Associates, 1988a).

Basin D

Basin D was a 21-acre unlined natural depression (Figure 2.3) that originally received Army waste from the chlorine plant and white phosphorous filling operations in the South Plants Complex via the Sand Creek Lateral prior to 1946 (Environmental Science & Engineering et al., 1987b). In 1952, the Army opened a spillway from Basin A, allowing 113 million gallons of Shell and Army waste to flow to Basin D over a three-month period (Environmental Science & Engineering et al., 1987b). From 1953 to 1956, all aqueous wastes entering Basin D were Basin A overflows from Shell manufacturing in the South Plants and the Army's Sarin manufacturing in the North Plants (Environmental Science & Engineering et al., 1987b). Disposal of liquids into Basin D resulted in the release of numerous hazardous substances, including aldrin, dieldrin, chlorophenylmethyl sulfide, arsenic, mercury, copper, lead, cadmium, and chromium (Environmental Science & Engineering et al., 1987b; Environmental Science & Engineering and Harding Lawson Associates, 1988b).

Basin E

Basin E was a 29-acre unlined natural depression (Figure 2.3) that, like Basin D, was a disposal site for wastewater overflow from Basin A (Environmental Science & Engineering et al., 1987c). Basin E began receiving overflow from Basin A and discharge from the chlorine plant in the South Plants in 1953 and continued to be used as additional storage capacity for overflow from Basin A until 1956 (Environmental Science & Engineering et al., 1987c). Disposal of liquids into Basin E resulted in the release of numerous hazardous substances, including aldrin, dieldrin, arsenic, mercury, lead, and chromium (Environmental Science & Engineering et al., 1987c; Environmental Science & Engineering and Harding Lawson Associates, 1988c).

Basin F

Basin F was a 93-acre, asphalt-lined evaporative disposal basin with a capacity of 240,000,000 gallons constructed in 1956 (Figure 2.3). By December 1956, the majority of contaminated liquid waste streams at the Arsenal were discharged into Basin F. On three occasions, Basin F filled to capacity: in 1962, 1965, and between 1975 and 1976. Shell disposed of liquid wastes in Basin F until 1978, and the Army until 1981. In 1981, the Army installed an aeration system that sprayed Basin F liquids into the air. While this accelerated evaporation of Basin F liquids, it also resulted in considerable contamination to surface soils around the exterior of the basin (Tetra Tech EC, 2005).

Repairs and modifications to Basin F's liner and dikes occurred several times during its use. The asphalt liner in Basin F did not prevent the release of hazardous substances to underlying soils and groundwater. Discharge of liquid wastes into Basin F resulted in the release of numerous hazardous substances, including aldrin, dieldrin, endrin, isodrin, toluene, trichloroethane, TCE, DBCP, ethyl benzene, xylene, DDE, arsenic, mercury, lead, and chromium (Environmental Science & Engineering et al., 1988a).

Specific documented disposal of hazardous substances from Shell's pesticide and herbicide manufacturing to Basin F includes (DOJ, 1986; Ebasco Services et al., 1988b):

- 44,000 pounds of endrin manufacturing wastes
- 50,000 pounds of isodrin manufacturing wastes
- 60,000 pounds per year (~10 years) of methyl parathion salts
- 140,000 pounds of methyl parathion manufacturing wastes
- 120,000 pounds of ethyl parathion manufacturing wastes
- 150,000 pounds of bidrim manufacturing wastes
- 12,000 pounds of dibrom manufacturing wastes
- 28,000 pounds of ciodrin manufacturing wastes
- 2,000 pounds of azodrin manufacturing wastes

- 8,600 pounds of nudrin manufacturing wastes
- 238,400 pounds of DBCP manufacturing wastes
- 9,300 pounds of bladex manufacturing wastes
- 1,360,000 pounds of planavin manufacturing wastes
- 1,300 pounds of phosdrin manufacturing wastes.

2.2.3 Trenches

Army Complex Trenches

The Army Complex Trenches (Figure 2.3) was a solid waste disposal site covering over 100 acres. The Army used the trenches from the 1940s to the early 1970s to dispose of wastes that included potentially contaminated tools, equipment, unwanted containers, rejected incendiaries, vehicles, empty munitions casings, chemical warfare agent, and chemical agent-filled unexploded ordnance (Foster Wheeler, 2001). Because of the lack of disposal records, and the Army's fear that an intrusive investigation could result in exposure to unexploded ordnance and chemical agent, the nature of waste disposed in discrete portions of the site is undetermined. Hazardous substances identified in some trench contents or trench soils include aldrin, dieldrin, endrin, chlordane, DDT, DBCP, fluoroacetic acid, arsenic, mercury, cadmium, chromium, and lead (Harding Lawson Associates, 1993). Additional hazardous substances identified in groundwater downgradient of the trenches include chlorobenzene, dichloroethane, dichloroethene, tetrachloroethane, TCE, trichloroethane, xylene, and cyanide (Harding Lawson Associates, 1993).

Shell Section 36 Trenches

The Shell Section 36 Trenches (Figure 2.3), also known as the Shell Trenches, covered an eight-acre area that Shell used from 1952 to 1965 for land disposal of liquid and solid hazardous substances from the production of pesticides. Approximately 31 unlined trenches were excavated 10 to 20 ft wide and between 5 and 10 ft below the surface. The trenches were used to dispose of organic and inorganic compounds, process intermediates, and off-specification products. The use of these trenches for disposal resulted in the release of hazardous substances, including aldrin, dieldrin, endrin, isodrin, benzene, chlorobenzene, chloroform, DBCP, dicyclopropane, ethylbenzene, hexane, toluene, xylene, 1.1-dichloroethane, 1,2-dichloroethane, 1.2-dichloroethene, methylene chloride, tetrachloroethylene, and trichloroethene (Environmental Science & Engineering et al., 1987f, 1988c; Environmental Science & Engineering and Harding Lawson Associates, 1988f, 1988g; MK-Environmental Services, 1993).

Whereas the basins were used to dispose of the hazardous byproducts of pesticide and herbicide manufacturing, the Shell Trenches were used to dispose of unused pesticide and herbicide products. Documented products disposed in the Shell Trenches include (DOJ, 1986; Ebasco Services et al., 1988b; MK-Environmental Services, 1993):

- 842,000 pounds of endrin
- 5,990,000 pounds of isodrin and isodrin impurities
- 13,000 pounds of methyl parathion
- 13,000 pounds of vapona
- 6,100 pounds of bidrin
- 10,000 pounds of dibrom
- 45,000 pounds of azodrin
- 9,800 pounds of DBCP
- 70,000 pounds of planavin and planavin impurities
- 4,000 pounds of phosdrin.

2.2.4 Motor Pool/Rail Classification Yard

The Motor Pool (Figure 2.3) was constructed in the 1940s to service heavy equipment, vehicles, locomotives and rail cars, and for storing fuel, road oil, and flammable liquids (Ebasco Services et al., 1988e). Various wastes may have been discharged into drainage ditches, including solvents, petroleum products, strong caustics, dilute wastes from the motor pool wash bay, and detergents (Ebasco Services et al., 1988e). A 1984 Compliance Order by the Colorado Department of Health halted the use of degreasing solvents at the Motor Pool. The wastes discharged by activities associated with the Motor Pool resulted in releases of hazardous substances, including benzene, chloroform, 1,1-dichloroethane, ethylbenzene, methylene chloride, tetrachloroethylene, toluene, 1,1,1-trichloroethane, TCE, m-, o- and p-xylene, aldrin, DBCP, arsenic, mercury, cadmium, chromium, and lead (Ebasco Services et al., 1988e; Foster Wheeler, 2000a).

The Rail Classification Yard (Figure 2.3), adjacent to the Motor Pool, was built in the late 1940s for the storage of pesticides, solvents, and acids. In addition, the area was used as open storage for tanks, trailers, crates, and for the temporary storage of railcars, including railcars holding DBCP. There were several reported spills in the Rail Classification Yard, resulting in a groundwater plume emanating from the site. DBCP is the only identified hazardous substance released from the Rail Classification Yard (Ebasco Services et al., 1988h, 1989d).

2.2.5 Toxic Storage Yard

The Toxic Storage Yard (Figure 2.3) was originally constructed in 1952 as a 16-acre storage site for lewisite, mustard, phosgene, Sarin, VX, and decontamination agents. The site was later expanded to the south and west to provide additional storage capacity. By April 1953, the Army had constructed four 10,000 square-foot open storage pads as support facilities for Sarin production in the North Plants Complex. In August 1954, 625 one-ton containers, likely containing Sarin, were in the yard. In the early 1960s, the Army discovered that containers and cluster bombs in the Toxic Storage Yard were leaking Sarin. In the early 1970s, the Army stored 76,000 drums of demilitarized Sarin salts in the Toxic Storage Yard as part of Project Eagle (Ebasco Services et al., 1988f, 1988i).

Spills from leaking containers and bombs are the primary source of contaminants in the toxic storage areas (Ebasco Services et al., 1988f). The use of the Toxic Storage Yard to store lewisite, mustard, phosgene, Sarin, VX, and decontamination agents resulted in the release of hazardous substances, including, but not limited to, chloroacetic acid, arsenic, chromium, and lead (Ebasco Services et al., 1988f, 1988h).

2.2.6 Other areas

The Army identified over 178 different contaminant source areas (Ebasco Services et al., 1992). Not all have been discussed in this Plan. The majority of these sources are in the South Plants and in Section 36, where Basin A and the Army and Shell Trenches, among other sites, are located (Figure 2.3). Some sources not discussed above are addressed in the next chapter that summarize cleanup activities at the site.

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