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February 5, 2007

Mr. Eric Williams
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601 D Street, NW
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Dear Mr. Williams:

Enclosed please find the expert report of Mr. Douglas Beltman and Mr. Mark Stackhouse on the risks to the environment posed by the U.S. Magnesium facility in Rowley, Utah.

For the preparation of the report Mr. Stackhouse is compensated \$95 per hour, and Stratus Consulting is compensated \$220 per hour for Mr. Beltman's time. The cost of preparing the report is approximately \$100,000.

Sincerely,

A handwritten signature in black ink, appearing to read 'Doug Beltman', written in a cursive style.

Douglas Beltman
Executive Vice President



STRATUS CONSULTING

Environmental Endangerment at the U.S. Magnesium Facility, Rowley, Utah Expert Report Final

Prepared for:

U.S. Department of Justice
601 D Street, NW
PO Box 7611
Washington, DC 20044-7611

**Environmental Endangerment
at the
U.S. Magnesium Facility, Rowley, Utah
Expert Report**

Final

Prepared for:

U.S. Department of Justice
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February 5, 2007
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Environmental Endangerment at the U.S. Magnesium Facility,
Rowley, Utah

Expert Report

February 5, 2007

Prepared by:



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Environmental Endangerment at the U.S. Magnesium Facility, Rowley,
Utah

Expert Report

January 30, 2007

Prepared by:

A handwritten signature in black ink, appearing to read 'Mark Stackhouse', written over a horizontal line.

Mark Stackhouse

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1. Introduction and Summary of Opinions

This report presents the expert opinions of Douglas Beltman and Mark Stackhouse on the threat to the environment posed by contamination at the US Magnesium (USM) facility, Rowley, Utah (formerly known as the MagCorp facility). Our overall conclusion is that the contamination at and from the facility poses a substantial threat to ecological resources in the area.

We based our conclusions on the following:

1. The Great Salt Lake is a critical habitat for migrating and resident birds, attracting millions of birds every year. The USM facility is adjacent to the lake and is located in an area where many birds of many different species are found. The facility is also located within a natural area that supports many kinds of plants and animals. Many individuals of many different wildlife species have been observed at and near the facility, demonstrating that wildlife are exposed to contaminants at and near the facility.
2. USM produces, disposes of, and releases organochlorine chemicals into the environment. Because of this, the environment at and near the facility is highly contaminated with these chemicals. Organochlorine chemicals are environmentally persistent (meaning that they degrade very slowly), biomagnify up food chains (meaning that they reach their highest concentrations in predators), and are highly toxic. These chemicals include chlorinated dioxins, chlorinated furans, polychlorinated biphenyls (PCBs), and hexachlorobenzene. Concentrations of these chemicals are many thousands of times greater in the soil, sediment, and surface water at the facility than at reference areas. Data show that this contamination has caused plants, terrestrial and aquatic invertebrates, mice, and bird eggs at the facility to become highly contaminated with these chemicals, and other animals are probably contaminated as well.
3. Chemical analysis was performed to determine the concentrations of dioxins, furans, PCBs, and hexachlorobenzene at the facility in (1) soil, sediment, and surface water; (2) food eaten by wildlife (plants, invertebrates, and mice); and (3) bird eggs. This chemical characterization enabled us to assess the environmental threat posed by the contamination at the facility. Chemical concentrations at the facility are many thousands of times greater than environmentally safe levels, and hundreds of times greater than severe effect levels. The adverse environmental effects expected at these elevated chemical concentrations include mortality, decreased ability of wildlife to survive in the wild, and decreased reproduction. The highest concentrations and most severe threat are at the sanitary lagoon, active waste pond, gypsum pile, and the area of the old waste pond near the former inlet.

4. The water in the facility's active waste pond frequently has a pH of less than 1.0, making it more acidic than battery acid. Birds have been observed standing in, landing on, and drinking from the pond, and many of these birds have exhibited signs of distress soon after coming into contact with the pond water. Studies using water collected from USM's active waste pond showed that the water is corrosive to bird tissue, and that birds avoid drinking the water, even when they are dehydrated.

The organochlorine chemicals at the facility can remain in the environment for many decades. For example, the bed of the old waste pond is still highly contaminated with organochlorine chemicals even though the facility stopped discharging its contaminated wastewater to the pond over 20 years ago. Furthermore, if actions are not taken to clean up the contamination, resources in the Great Salt Lake itself are at risk because of the possibility of the failure of the old waste pond dike in the future, as already occurred in 1984.

We recommend the following actions be implemented to address the environmental risks at the USM facility:

1. Waste areas with the highest concentrations of chlorinated hydrocarbon chemicals should be cleaned up to reduce or eliminate wildlife exposure to the chemicals in these areas. These areas are the sanitary lagoon, gypsum pile, active waste pond, and the inlet area of the old waste pond where facility wastewater entered the pond.
2. The ongoing discharge of highly acidic wastewater into the active wastewater pond should be stopped, and actions should be taken to increase the pH of the active wastewater pond and to make it less acidic and dangerous.

The authors' credentials are presented in Appendix A.

1.1 Information Considered

To prepare this report we relied on data and information collected by various investigators, including the USM facility, the federal and Utah state governments, contractors hired by the government, and academic researchers. The data and information, which are contained in USM facility documents, government agency reports, published scientific literature, and unpublished reports, include the following:

- ▶ Physical and chemical characterization of the facility's wastewater ponds and their operational history
- ▶ Environmental contaminant, ecological characterization, and other relevant data collected from areas at and near the facility

- ▶ Results of studies reported in the literature on the effects of contaminants at the facility to wildlife (birds and mammals)
- ▶ A bird survey conducted at the USM facility in 2002 by one of the authors of this expert report (Mr. Stackhouse)
- ▶ Available reports on bird surveys from around the Great Salt Lake
- ▶ Results of a laboratory study conducted for U.S. Environmental Protection Agency (U.S. EPA) on the effects of water from USM's active waste pond on mallards and finches.

The data and information that we considered for this report are the kinds of data and information normally relied on by scientists to evaluate the environmental threats posed by contamination. All of the data and information sources are specifically identified in the reference section of this report.

1.2 Description of the USM Facility

The USM facility is located on the southwestern shore of the Great Salt Lake (Figure 1.1). The primary chemical process conducted at the USM facility is the extraction of magnesium from Great Salt Lake brine. First, a concentrated brine solution is obtained by evaporating Great Salt Lake water. Then, through a chemical and electrolytic process, magnesium (and other products) are extracted from the brine. The magnesium manufacturing process also yields additional materials, including chlorine gas, various chlorinated hydrocarbon chemicals, metals, and hydrochloric acid (URS Operating Services, 2002b; NEIC, 2003). For example, the USM facility reported the release of 1,107,146 pounds of hydrochloric acid into the atmosphere in 2005 (U.S. EPA, 2006a).

The USM facility produces liquid wastes that are highly acidic, as described in Chapter 3. These acidic wastes are discharged into several ditches which join to form the Main Ditch (also known as the "Red River" ditch) (Figure 1.2). The Main Ditch carries the acidic wastewater into the active waste pond where the waste solution is allowed to evaporate and percolate into the soil (URS Operating Services, 2002b). Initially, the Main Ditch carried facility wastewater into the large, old waste pond that was separated from the Great Salt Lake by an earthen dike (Olafson, 1988). The current active pond was constructed between the facility and the old waste pond in 1986, which was soon after the dike separating the old waste pond from the Great Salt Lake was breached by high water (Olafson, 1988; URS Operating Services, 2002b). The active pond has remained in use since 1986. The old waste pond currently varies in water level depending on the precipitation/evaporation cycle. No bottom liner was used in the construction of either of the ponds.

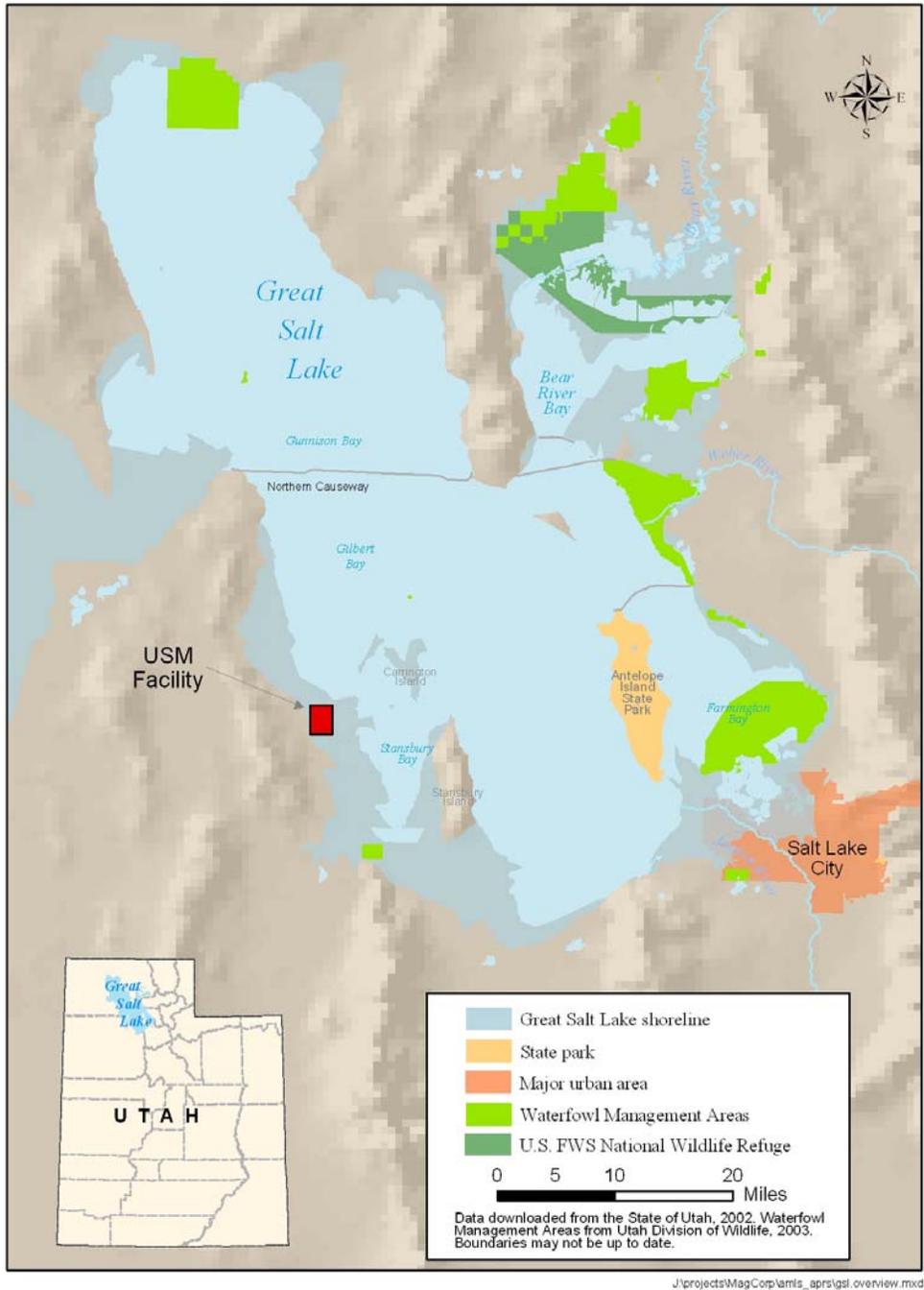


Figure 1.1. The general location of the USM facility.

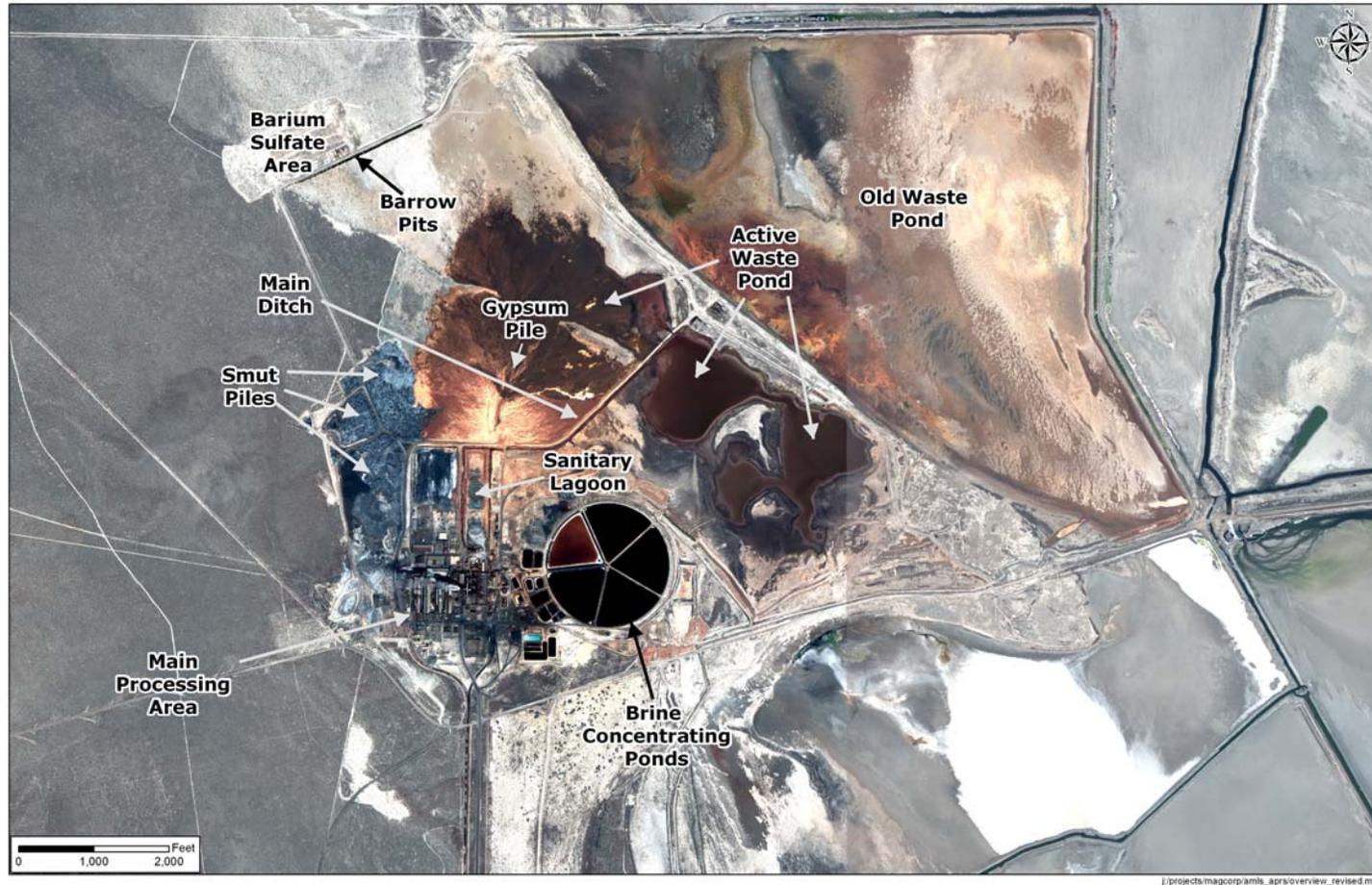


Figure 1.2. Satellite image of the USM facility with primary waste disposal areas identified.

In addition to highly acidic wastewater, the USM facility also produces, disposes of, and releases chlorinated hydrocarbons, including dioxins, furans, PCBs, and hexachlorobenzene. These chemicals are highly toxic to wildlife, and concentrations of a few parts per billion in food can cause toxicity. The toxic effects of these compounds, which are described in more detail in Chapter 4, include death, cancer, reduced reproduction (e.g., reduced number of offspring, reduced number of offspring that survive), deformities in embryos or young, and decreased ability to resist diseases. These chemicals are also environmentally persistent, which means that once in the environment, they remain there for many decades (Carey et al., 1998). They also biomagnify up food chains, which means that their concentrations tend to increase from one trophic level to the next, reaching their highest concentrations in top-level predators (Carey et al., 1998). Because of their toxicity, persistence, and biomagnification, the chlorinated compounds produced at the USM facility are of particular environmental concern.

Chlorinated hydrocarbons are released into the environment at and from the USM facility in plant stack emissions, in solid waste that is disposed of at various locations at the facility, and in liquid wastes discharged to the waste pond via ditches (Western Environmental Services and Testing, 1998; MagCorp, 2001; URS Operating Services, 2002b; NEIC, 2003). Figure 1.2 identifies the primary waste disposal areas at the USM facility.¹ The waste disposal areas identified in the figure are the active and old waste ponds, the smut piles, the gypsum pile, the barium sulfate area, the barrow pits, and the sanitary lagoon. The information presented in Chapter 3 shows that these waste piles and wastewater ponds are contaminated with high concentrations of chlorinated hydrocarbon compounds and that the active wastewater pond is very acidic. Chapter 4 and Chapter 5 demonstrate that the organochlorine chemical contamination and the acidic wastewater, respectively, at the facility pose a substantial threat to the environment.

1. The terms used for the waste disposal areas at the facility were taken from the facility's designations (Parametrix, 2004).

2. Birds and Wildlife at and Near the Facility

The environmental setting of the USM facility is important to consider in evaluating the environmental risks posed by contamination at the facility. This chapter describes the ecological setting of the facility, and provides details on birds and wildlife that have been documented at or near the facility.

From the information presented in this chapter, I (Mark Stackhouse) conclude that the location of the facility in a natural habitat setting next to the Great Salt Lake means that wildlife activity at the site is high, and the wildlife at the facility come in contact with and are exposed to contaminants at the facility.

2.1 The Birds of the Great Salt Lake Area

The Great Salt Lake is one of the great habitats for birds in the western United States. It has an abundant food supply of brine shrimp and brine flies, and many miles of gradual shoreline edges where birds can feed. It is an important habitat for both migratory birds that use the lake as a vital refueling stop and for the many thousands of birds that use the shores of the lake as breeding grounds.

The Great Salt Lake lies on the western boundary of the Central Flyway, which is one of the major migratory routes for waterfowl and shorebirds in North America (Birdnature, 2003). The Great Salt Lake supports up to five million waterfowl each year during spring and fall migration (Utah Division of Wildlife Resources, 1999; Utah Department of Natural Resources, 2000; USGS, 2001). The highly abundant brine shrimp (*Artemia franciscana*) and brine flies (*Ephydra* spp.) in the lake supply migratory birds with the caloric intake needed to complete their migration (Utah Department of Natural Resources, 2000). Birds banded at the Bear River National Wildlife Refuge on the north shore of the Great Salt Lake have been recovered as far away as Russia, Central America, and the Pacific Islands (U.S. Fish & Wildlife Service, 2003b). Over 250 avian species have been counted at the Great Salt Lake, and some of the world's largest colonies of several species are found along its shores during migration (Utah Department of Natural Resources, 2000).

Up to 80% of the world's population of Wilson's phalarope (*Phalaropus tricolor*) use the Great Salt Lake during their fall migration. The Great Salt Lake is their last staging site before they continue on to South America (Jehl, 1988, 1998; as cited in Paul et al., 2000). More than

500,000 phalaropes visit the Great Salt Lake annually (Utah Division of Wildlife Resources, 1999). The world's largest documented staging population of Wilson's phalarope (600,000 individuals) occurred at the Great Salt Lake in 1991 (Utah Division of Wildlife Resources, 1999).

The second largest population in North America of eared grebes (*Podiceps nigricollis*) uses the Great Salt Lake as a staging area during migration. Over one million grebes were tallied in the 1997, 1999, and 2000 Utah Division of Wildlife Resources annual surveys (Paul et al., 2001). Over 75% of the western population of tundra swans (*Cygnus columbianus*) use the Great Salt Lake as a staging area during migration (Utah Department of Natural Resources, 2000), and 10,000 migrating snowy plovers (*Charadrius alexandrinus*), the world's largest documented assemblage, congregated at the Great Salt Lake (WHSRN, 2003). Other species documented at the Great Salt Lake in substantial numbers during migration include 250,000 American avocet (*Recurvirostra americana*); 65,000 black-necked stilts (*Himantopus mexicanus*); 280,000 red-necked phalaropes (*Phalaropus lobatus*); 30,000 marbled godwits (*Limosa fedoa*); and 30,000 long-billed dowitchers (*Limnodromus scolopaceus*) (Utah Department of Natural Resources, 2000).

Many bird species also breed in the Great Salt Lake area in the summer months. Examples include California gull (*Larus californicus*), peregrine falcon (*Falco peregrinus*), Canada goose (*Branta canadensis*), American avocet (Figure 2.1), black-necked stilt, snowy plover, and western grebe (*Aechmophorus occidentalis*) (USGS, 2001; U.S. Fish & Wildlife Service, 2003b, 2003c). The world's largest colony of California gulls, 160,000, and the world's largest breeding population of white-faced ibis (*Plegadis chihi*), have been recorded at the Great Salt Lake (USGS, 2001). One of the three largest American white pelican (*Pelecanus erythrorhynchos*) colonies in western North America breeds on Gunnison Island in the Great Salt Lake (USGS, 2001; WHSRN, 2003).



Figure 2.1. An American avocet on a nest near the USM facility.

Because of its importance to birds, the Great Salt Lake has been designated a Hemispheric Reserve of the Western Hemisphere Shorebird Reserve Network, and it is being considered for nomination as a Wetland of International Importance by the Ramsar Convention Bureau (Utah Department of Natural Resources, 2000; WHSRN, 2003). In addition, the Utah Division of Wildlife Resources has designated numerous Waterfowl Management Areas along the shores of the Great Salt Lake, including Farmington Bay, Howard Slough, Ogden Bay, Harold Crane, Locomotive Springs, Timpie Springs, Salt Creek, Public Shooting Grounds, and Willard Bay.

The Bear River Migratory Bird Refuge is a National Wildlife Refuge located on the northern tip of the Great Salt Lake (Utah Department of Natural Resources, 2000; U.S. Fish & Wildlife Service, 2003a).

Among the species supported by the Great Salt Lake are several that have been listed as sensitive, threatened, or endangered by state or federal agencies. Utah has placed the Caspian tern (*Sterna caspia*), black tern (*Chlidonias niger*), American white pelican (*Pelicanus erythrorhynchos*), and long-billed curlew (*Numenius americanus*) on the state list of sensitive species because of declining populations. One of the largest concentrations in the contiguous United States of bald eagles (*Haliaeetus leucocephalus*), a federally listed threatened species, occurs at the Great Salt Lake (Utah Division of Wildlife Resources, 1998; Utah Department of Natural Resources, 2000). The peregrine falcon, a State of Utah endangered species (Utah Division of Wildlife Resources, 1998), is also a year-round resident at the Great Salt Lake (U.S. Fish & Wildlife Service, 2003c).

The brine shrimp and brine flies that provide an abundance of food for birds that use the Great Salt Lake as a migratory stop are also found at the USM facility. Brine shrimp were observed in the barrow pits in the northwestern portion of the facility, and brine shrimp cysts (or eggs) and adult and larval brine flies were observed at the barrow pits and the old waste pond (although very few brine shrimp cysts, brine fly larvae, or brine fly larval casings were observed in the old waste pond) (Parametrix, 2004).

2.2 Surrounding Ecosystem

The facility exists within a relatively undisturbed area of very little urban or industrial development other than the facility itself. The facility is surrounded by the Great Salt Lake to the northeast and natural habitat on all other sides, and there are very few other buildings or developments for many miles in any direction.

The vegetation type in the area around the USM facility is the saltbush-greasewood community, sometimes termed “salt-desert shrub” or “salt-desert scrub” (Thomson, 1983; Halford et al., 1999; West and Young, 2000). This plant community is dominated by the shrubs greasewood (*Sarcobatus* spp.) and saltbush or shadscale (*Atriplex* spp.), which generally grow to less than 50 cm in height (West and Young, 2000).

This plant community supports many individuals of many species of mammals, birds, and reptiles, as documented in the facility wildlife surveys that are described in the next section.

2.3 Wildlife Activity Documented at the Facility

This section presents data and information on wildlife activity observed at the USM facility, with an emphasis on the Main Ditch and the active and old waste ponds. Section 2.3.1 presents the methods and results of a bird survey we conducted at the facility in 2002, and Section 2.3.2 presents a summary of observations of wildlife reported by other observers.

2.3.1 2002 bird survey

In the summer and fall of 2002, I (Mark Stackhouse) and my assistants conducted an observational study of bird use at the USM facility wastewater ponds and Main Ditch. The purpose of the study was to determine whether birds used the wastewater ponds at the facility and to characterize qualitatively the nature of any use (Stratus Consulting, 2002). Before this study, there was little information available on bird activity at USM's wastewater ditches and ponds. A small number of incidental observations have been reported by regulatory agency personnel during facility visits (see following section).

I conducted the study in two phases. In Phase 1, which took place from May 19, 2002 through June 10, 2002, I made observations from two remote locations (Figure 2.2), on eight days (Table 2.1). I used high-powered spotting scopes that were powerful enough to make bird observation at the ponds possible. In the second phase, from July 24, 2002 through November 7, 2002, we (I and my assistants) observed from several locations immediately adjacent to both the active and the old waste ponds (Figure 2.2). The proximity of the observation locations to the wastewater ponds allowed for detailed observations of bird locations and behavior during their pond usage. We conducted observations on 16 days during Phase 2 (Table 2.1).

Because many of the birds using the Great Salt Lake are migratory, they are present only at certain times of the year. Waterfowl begin to arrive in the area in late March, and shorebird migration lasts from early April through mid-May (U.S. Fish & Wildlife Service, 2003b). Since Phase 1 of the study was from mid-May through early June, it most likely missed the peak of spring migration in the area, instead capturing only the trailing end of the migratory period. Phase 2 was designed to capture the fall migration, which typically begins in July and peaks in mid-August for many of the shorebird species (U.S. Fish & Wildlife Service, 2003b).

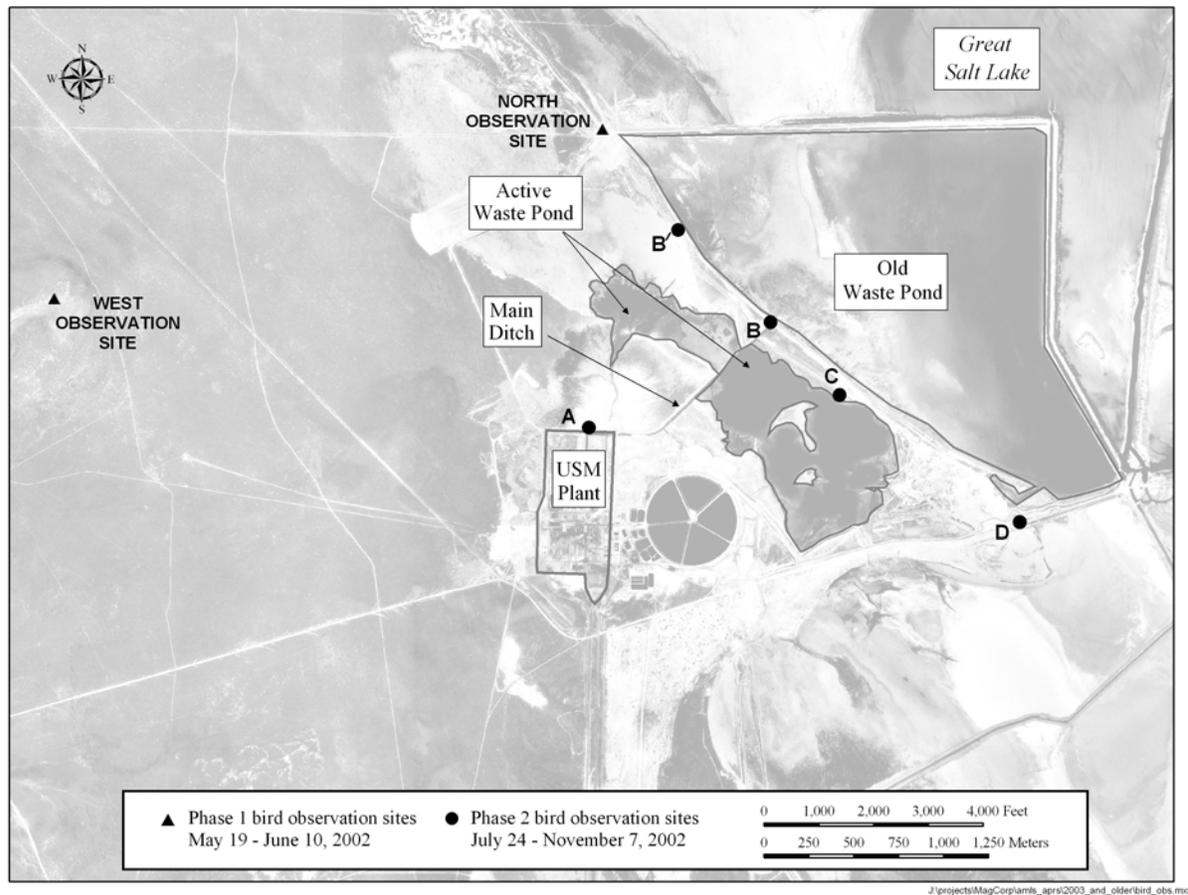


Figure 2.2. Observation locations in the 2002 bird survey.

The 24 days on which we made observations represent only a fraction of the total number of days during the entire study period of mid-May through early November (approximately 175 days). Furthermore, our observation periods on most of the 24 days were for only a portion of the day. Therefore, the results of this bird observation study represent only a small fraction of the total bird activity expected at the USM facility ponds during this period.

Table 2.2 lists the species and their approximate numbers that we observed in the general vicinity of the USM facility vicinity during the 2002 bird survey. The list in the table demonstrates that many birds are commonly in the general area of the USM facility. We observed approximately 7,000 individual birds of over 60 species at or near the facility during the 2002 bird survey.

Table 2.1. Dates and periods of bird observation during the 2002 survey of bird use at the USM facility

| Phase (see text for description) | Date | Period of observation |
|---|-------------|------------------------------|
| Phase 1 | 5/19/2002 | All day |
| | 5/22/2002 | Late morning through evening |
| | 5/25/2002 | Morning |
| | 6/1/2002 | All day |
| | 6/5/2002 | Morning |
| | 6/6/2002 | Afternoon through evening |
| | 6/8/2002 | Morning |
| | 6/10/2002 | Afternoon through evening |
| Phase 2 | 7/24/2002 | All day |
| | 7/29/2002 | All day |
| | 7/31/2002 | Morning |
| | 8/2/2002 | Afternoon through evening |
| | 8/6/2002 | Afternoon through evening |
| | 8/8/2002 | Morning |
| | 8/13/2002 | Afternoon through evening |
| | 8/15/2002 | Morning |
| | 8/20/2002 | Afternoon through evening |
| | 8/22/2002 | Morning |
| | 8/24/2002 | Afternoon through evening |
| | 8/27/2002 | Afternoon through evening |
| | 8/29/2002 | Morning |
| | 10/22/2002 | Morning |
| 10/25/2002 | Afternoon | |
| 11/7/2002 | Morning | |

Table 2.2. Birds observed in the general vicinity of the USM facility during the 2002 survey

| Bird species (common name) | Bird species (Latin name) | Total observed (double counting controlled)^a |
|--|--------------------------------------|--|
| American avocet ^b | <i>Recurvirostra americana</i> | 45 |
| American kestrel | <i>Falco sparverius</i> | 2 |
| American pipit | <i>Anthus rubescens</i> | 1 |
| American robin | <i>Turdus migratorius</i> | 1 |
| American white pelican, a State of Utah species of special concern (Utah Division of Wildlife Resources, 1998) | <i>Pelecanus erythrorhynchos</i> | 7 |
| Baird's sandpiper | <i>Calidris bairdii</i> | 827 |
| Bank swallow | <i>Riparia riparia</i> | 2 |
| Barn swallow | <i>Hirundo rustica</i> | 9 |
| Black-chinned hummingbird | <i>Archilochus alexandri</i> | 1 |
| Black-throated sparrow | <i>Amphispiza bilineata</i> | 6 |
| Blue-gray gnatcatcher | <i>Polioptila caerulea</i> | 2 |
| Brewer's blackbird | <i>Euphagus cyanocephalus</i> | 1 |
| Brewer's sparrow | <i>Spizella breweri</i> | 17 |
| Broad-tailed hummingbird | <i>Selasphorus platycercus</i> | 2 |
| Brown-headed cowbird | <i>Molothrus ater</i> | 43 |
| California gull ^c | <i>Larus californicus</i> | 5,060 |
| Canada goose | <i>Branta canadensis</i> | 4 |
| Common nighthawk | <i>Chordeiles minor</i> | 25 |
| Common raven ^d | <i>Corvus corax</i> | 177 |
| Curlew | <i>Numenius (spp.)</i> | 2 |
| Ducks/grebes | — | 4 |
| Eastern kingbird | <i>Tyrannus tyrannus</i> | 1 |
| Golden eagle | <i>Aquila chrysaetos</i> | 4 |
| Goldfinches | <i>Carduelis (spp.)</i> | 1 |
| Herring gull | <i>Larus argentatus</i> | 1 |
| Horned lark | <i>Eremophila alpestris</i> | 118 |
| House finch | <i>Carpodacus mexicanus</i> | 3 |
| Killdeer | <i>Charadrius vociferus</i> | 2 |
| Loggerhead shrike | <i>Lanius ludovicianus</i> | 2 |

Table 2.2. Birds observed in the general vicinity of the USM facility during the 2002 survey (cont.)

| Bird species (common name) | Bird species (Latin name) | Total observed (double counting controlled)^a |
|--|--------------------------------------|--|
| Lark sparrow ^e | <i>Chondestes grammacus</i> | 9 |
| Least sandpiper | <i>Calidris minutilla</i> | 27 |
| Lesser yellowlegs | <i>Tringa flavipes</i> | 3 |
| Long-billed curlew, a State of Utah species of special concern (Utah Division of Wildlife Resources, 1998) | <i>Numenius americanus</i> | 9 |
| Long-billed dowitcher | <i>Limnodromus scolopaceus</i> | 6 |
| MacGillivray's warbler | <i>Oporornis tolmiei</i> | 1 |
| Marbled godwit | <i>Limosa fedoa</i> | 3 |
| Mourning dove | <i>Zenaida macroura</i> | 2 |
| Northern harrier ^f | <i>Circus cyaneus</i> | 2 |
| Northern rough-winged swallow | <i>Stelgidopteryx serripennis</i> | 5 |
| Northern shoveler | <i>Anas clypeata</i> | 1 |
| Pelican | <i>Pelecanus</i> (spp.) | 1 |
| Peregrine falcon, a State of Utah endangered species (Utah Division of Wildlife Resources, 1998) | <i>Falco peregrinus</i> | 2 |
| Rock wren | <i>Salpinctes obsoletus</i> | 7 |
| Sage sparrow | <i>Amphispiza belli</i> | 2 |
| Sage thrasher | <i>Oreoscoptes montanus</i> | 5 |
| Sandpipers | — | 412 |
| Savannah sparrow | <i>Passerculus sandwichensis</i> | 2 |
| Semipalmated sandpiper | <i>Calidris pusilla</i> | 3 |
| Shorebirds | — | 3 |
| Short-billed dowitcher | <i>Limnodromus griseus</i> | 1 |
| Snowy plover | <i>Charadrius alexandrinus</i> | 81 |
| Spotted towhee | <i>Pipilo maculatus</i> | 1 |
| Swallows (spp.) | — | 75 |
| Tree swallow | <i>Tachycineta bicolor</i> | 46 |
| Turkey vulture | <i>Cathartes aura</i> | 5 |
| Vesper sparrow | <i>Pooecetes gramineus</i> | 2 |
| Western kingbird | <i>Tyrannus verticalis</i> | 2 |

Table 2.2. Birds observed in the general vicinity of the USM facility during the 2002 survey (cont.)

| Bird species (common name) | Bird species (Latin name) | Total observed (double counting controlled)^a |
|---------------------------------------|--------------------------------------|--|
| Western meadowlark ^g | <i>Sturnella neglecta</i> | 12 |
| Western sandpiper | <i>Calidris mauri</i> | 6 |
| Western scrub-jay | <i>Apelocoma californica</i> | 1 |
| Western wood-pewee | <i>Contopus sordidulus</i> | 3 |
| White-faced ibis | <i>Plegadis chihi</i> | 1 |
| Willet | <i>Catoptrophorus semipalmatus</i> | 15 |
| Wilson's phalarope | <i>Phalaropus tricolor</i> | 3 |
| Yellow warbler | <i>Dendroica petechia</i> | 1 |
| Yellow-headed blackbird | <i>Xanthocephalus xanthocephalus</i> | 1 |
| Yellowlegs | <i>Tringa</i> (spp.) | 1 |
| Yellow-rumped warbler | <i>Dendroica coronata</i> | 1 |
| Total | | 7,133 |

a. Field notes often include counts of birds at a given location at several points during a day. Where the observer suspected that the same birds were being observed at a given location throughout the day, the potentially duplicative counts of birds were not included in this table.

b. Includes birds originally recorded in field notes as avocets.

c. Includes birds originally recorded in field notes as gulls.

d. Includes birds originally recorded in field notes as ravens.

e. Includes birds originally recorded in field notes as larks.

f. Includes a bird originally recorded in field notes as a harrier.

g. Includes birds originally recorded in field notes as meadowlarks.

Table 2.3 lists the birds that we observed coming in contact with the waters of the Main Ditch or the active waste pond during Phase 2 of the 2002 study (16 observation days from July to November).¹ The table also notes which of these birds were observed to dip their bills into the facility's wastewater. As shown in the table, we observed approximately 31 birds of 10 species coming in contact with water in the Main Ditch or the active pond. As described previously, the actual number of birds that came into contact with these waters during the overall study period is much greater than the number that we observed during the study. The adverse effects that I observed in these birds are described in Chapter 5 of this report.

1. Such observations made during Phase 1 are not included in the table since the Phase 1 observations were made from a greater distance than in Phase 2 and may be less reliable.

Table 2.3. Birds observed coming in contact with facility wastewaters in the Main Ditch and active pond during Phase 2 of the 2002 bird survey

| Facility wastewater area | Observation date | Species (common name) | Number observed in contact with water | Observed dipping bill into the water? |
|--------------------------|------------------|------------------------|---------------------------------------|---------------------------------------|
| Main Ditch | 7/24/2002 | Common nighthawk | 1 | Yes |
| | 7/24/2002 | Long-billed dowitcher | 1 | Yes |
| | 7/24/2002 | Yellowlegs | 1 | No |
| | 8/8/2002 | Common nighthawk | 2 | Yes |
| | 8/15/2002 | Western kingbird | 1 | No |
| | 8/29/2002 | Common nighthawk | 1 | Yes |
| Active pond | 7/24/2002 | Baird's sandpiper | 1 | Yes |
| | 7/24/2002 | Tree swallow | 4 | Yes |
| | 7/29/2002 | American avocet | 1 | Yes |
| | 7/29/2002 | California gull | 2 | Yes |
| | 7/29/2002 | Tree swallow | 2 | Yes |
| | 7/31/2002 | American avocet | 1 | Yes |
| | 8/24/2002 | American avocet | 5 | Yes |
| | 8/24/2002 | Bank swallow | 1 | Yes |
| | 8/27/2002 | American white pelican | 1 | No |
| | 8/27/2002 | California gull | 1 | No |
| | 8/27/2002 | Northern shoveler | 1 | Yes |
| | 8/29/2002 | American avocet | 2 | Yes |
| | 10/22/2002 | California gull | 1 | No |

Table 2.4 lists the birds that we observed in the area of the old waste pond during Phase 1 and Phase 2 of the study. Table 2.4 shows that we observed hundreds of birds of many different species at the old waste pond during the 2002 study.

Based on the observations that I made at the facility, I conclude that there are many individuals of many bird species that inhabit and feed in the area of the facility and can be exposed to the contaminants at the facility. I observed many of the birds in and around the waste ponds and ditches at the facility, and I saw some of these birds drinking from the water in the ponds and ditches.

Table 2.4. Observations of bird activity in the old waste pond boundary

| Observation date | Species (common name) | Number observed in contact with water | Observed dipping bill into the water? |
|-------------------------|----------------------------------|--|--|
| 5/19/2002 | California gull | 1 | No |
| 5/19/2002 | Snowy plover | 2 | No |
| 5/22/2002 | California gull | 48 | Yes |
| 5/22/2002 | Ducks or grebes | 4 | No |
| 5/22/2002 | Snowy plover | 6 | No |
| 5/25/2002 | California gull | 1 | No |
| 5/25/2002 | Snowy plover | 1 | No |
| 6/1/2002 | American avocet | 1 | No |
| 6/1/2002 | Horned lark | 2 | No |
| 6/1/2002 | Snowy plover | 1 | No |
| 6/5/2002 | American avocet | 2 | Yes |
| 6/6/2002 | California gull | 110 | No |
| 6/8/2002 | California gull | 3 | Yes |
| 6/8/2002 | American avocet | 2 | Yes |
| 6/10/2002 | American avocet | 9 | No |
| 6/10/2002 | Common raven | 1 | No |
| 7/24/2002 | Baird's sandpiper | 18 | Yes |
| 7/24/2002 | Sandpipers | 150 | No |
| 7/24/2002 | Snowy plover | 1 | No |
| 7/29/2002 | Baird's sandpiper | 10 | No |
| 7/29/2002 | Least sandpiper | 2 | No |
| 7/29/2002 | Snowy plover | 1 | No |
| 7/31/2002 | Baird's sandpiper | 200 | No |
| 7/31/2002 | Least sandpiper | 6 | No |
| 7/31/2002 | Peregrine falcon | 1 | No |
| 7/31/2002 | Wilson's phalarope | 2 | No |
| 8/2/2002 | Baird's sandpiper | 10 | No |
| 8/2/2002 | Horned lark | 2 | No |
| 8/2/2002 | Semipalmated sandpiper | 2 | No |
| 8/2/2002 | Snowy plover | 7 | No |

Table 2.4. Observations of bird activity in the old waste pond boundary (cont.)

| Observation date | Species (common name) | Number observed in contact with water | Observed dipping bill into the water? |
|-------------------------|----------------------------------|--|--|
| 8/6/2002 | Horned lark | 8 | No |
| 8/6/2002 | Least sandpiper | 1 | No |
| 8/6/2002 | Snowy plover | 9 | No |
| 8/6/2002 | Western sandpiper | 4 | Yes |
| 8/8/2002 | California gull | 1 | No |
| 8/8/2002 | Horned lark | 1 | No |
| 8/8/2002 | Snowy plover | 7 | Yes |
| 8/13/2002 | Baird's sandpiper | 4 | Yes |
| 8/13/2002 | Least sandpiper | 3 | Yes |
| 8/13/2002 | Snowy plover | 2 | No |
| 8/13/2002 | Western sandpiper | 1 | Yes |
| 8/15/2002 | Horned lark | 1 | No |
| 8/15/2002 | Snowy plover | 3 | Yes |
| 8/20/2002 | Snowy plover | 3 | Yes |
| 8/24/2002 | Long-billed curlew | 3 | No |
| 8/24/2002 | Marbled godwit | 3 | No |
| 8/24/2002 | Snowy plover | 2 | Yes |
| 8/27/2002 | Snowy plover | 3 | Yes |
| 10/22/2002 | California gull | 1 | No |
| 10/25/2002 | Horned lark | 5 | No |

2.3.2 Other observations of wildlife at the facility

Other observers have also noted wildlife at the USM facility. Most of these observations were reported by federal or state agency officials during facility inspections or by federal contractors hired to conduct an ecological survey at the facility.

An animal reconnaissance survey was conducted in 1983 at the facility (Glover, 1983). The survey concluded that the black-tailed jackrabbit (*Lepus californicus*) was abundant in the area, and the desert cottontail (*Sylvilagus audubonii*) and coyote (*Canis latrans*) were common. Small mammals were present but scarce, including the pocket mouse (*Perognathus* spp.), kangaroo rat (*Dipodomys* spp.), white-footed mouse (*Peromyscus leucopus*), woodrat (*Neotoma* spp.), and

pocket gopher (*Thomomys* spp.). The survey report also stated that other mammals were present in the area, including mule deer (*Odocoileus hemionus hemionus*), pronghorn antelope (*Antilocapra americana americana*), badger (*Taxidea taxus*), and weasel (*Mustela* spp.). Several bird species were also observed in the area, including golden eagle (*Aquila chrysaetos*), magpie (*Pica* spp.), sage sparrow (*Amphispiza belli*), meadowlark (*Sturnella neglecta*), and raven (*Corvus corax*) (Glover, 1983).

Another wildlife survey near the USM facility was conducted in 1999 by the U.S. EPA (Halford et al., 1999). This survey included observations of animals or animal signs and the trapping of small mammals. Mammals (or their signs) observed at the facility were cottontail rabbit (*Sylvilagus auduboni* and/or *nuttalli*), coyote, badger, pygmy rabbit, black-tailed jackrabbit, deer mouse, and harvest mouse (*Reithrodontomys maniculatus*). Birds observed at the facility included barn swallow (*Hirundo rustica*), bank swallow (*Riparia riparia*), California gull (*Larus californicus*), horned lark (*Eremophila alpestris*), killdeer (*Charadrius vociferous*), raven, western meadowlark, loggerhead shrike (*Lanius ludovicianus*), starling (*Sturnus vulgaris*), and hummingbirds (*Selasphorus* spp.). One bull snake (*Pituophis melanoleucus*) was also observed. However, the reconnaissance survey did not target reptiles, and the report concluded that it is likely that other reptiles reside at the facility (Halford et al., 1999).

In addition, other observers have noted various species of birds such as avocets, gulls, pelicans, grebes, killdeer, kingfishers, and goldeneyes in or near the facility's ditches and ponds (Glover, 1983; Magnesium Corporation of America, 1992, 1993, 1994, 1995; U.S. Fish & Wildlife Service, 1998a, 1998b, 1998c; Halford et al., 1999; Kercher, 1999; Paul and Manning, 2001). Other observers have also observed many birds in the general area of the USM facility, including golden eagles, shrikes, swallows, larks, sparrows, nighthawks, goldfinches, starlings, flycatchers, warblers, magpies, ravens, and hummingbirds (Glover, 1983; U.S. Fish & Wildlife Service, 1998c; Halford et al., 1999; Kercher, 1999). In one incident, a nighthawk was unable to fly after flying through the facility's smokestack plume (U.S. Fish & Wildlife Service, 1998c). A barn owl was observed in the sanitary lagoon area during an August 2006 visit by one of the authors of this report (Douglas Beltman).

Direct and indirect observations of mammals and reptiles at the facility have also been made on many occasions. A variety of small mammals (mice, rats, rabbits, bats, and gophers) have been observed using habitat at the facility, including the areas surrounding the wastewater ponds (Glover, 1983; U.S. Fish & Wildlife Service, 1998b; Halford et al., 1999; Kercher, 1999; Stackhouse, 2002; Parametrix, 2004). USM consultants observed numerous small mammal burrows, coyote scat, and a large amount of rabbit scat in habitat areas between facility waste piles during reconnaissance surveys or sample collection efforts conducted in 2002 through 2004 (Parametrix, 2004). Larger mammals such as pronghorn, mule deer, and coyote and their sign (tracks or scat) have been observed at or near the facility (Glover, 1983; U.S. Fish & Wildlife Service, 1998a, 1998c; Halford et al., 1999; Stackhouse, 2002). A possible badger burrow was

found near the west edge of the smut piles (Halford et al., 1999). Additionally, one dead bull snake was found on a road near the smut piles (Halford et al., 1999).

2.4 Conclusions

The USM facility is located in an undisturbed natural setting where many individuals of many species of wildlife live, feed, and drink. It is adjacent to the Great Salt Lake, which is one of the most important bird habitats in the western United States and attracts millions of birds each year. It is also located in a relatively undisturbed ecosystem that supports many kinds of plants and animals, and many species of birds, mammals, and reptiles have been reported at and near the facility.

I (Mark Stackhouse) conducted a survey of bird activity at the USM facility in 2002. Based on the survey, I conclude that many birds of many different species inhabit the area of the facility. I observed some of these birds in or near the waste ponds and ditches at the facility, confirming that birds do use the waste disposal areas at the facility. Therefore, the abundant wildlife in the area of the facility comes in contact with the contaminants at the facility.

3. Environmental Contamination Caused by the USM Facility

This chapter describes the environmental contamination caused by chlorinated hydrocarbons and highly acidic water at the facility. The primary waste disposal areas at the facility that are referred to in this chapter are shown in Figure 3.1.

3.1 Chlorinated Hydrocarbon Chemicals at the Facility

3.1.1 Background on chlorinated hydrocarbons

The USM facility produces, disposes, and releases into the environment many different chlorinated chemicals (SAIC, 1999a; URS Operating Services, 2002a, 2003). The focus of data collection activities at the USM facility has been on dioxins, furans, PCBs, and the chemical hexachlorobenzene. As described in more detail below, these chemicals are environmentally persistent (meaning that they remain in the environment for a long time), bioaccumulate in food chains, and are highly toxic.

Dioxins, furans, and PCBs are classes of chemical compounds that include many similar yet distinct individual compounds, and hexachlorobenzene is a single chemical. These chemicals are all similar in chemical structure (Figure 3.2). The different individual compounds of dioxins, furans, and PCBs differ in the number and position of chlorine atoms that are substituted on the underlying dioxin, furan, or biphenyl carbon structure. The different dioxin, furan, and PCB molecules are called congeners. There are 75 dioxin congeners, 135 furan congeners, and 209 PCB congeners, although typically only some of the congeners are found in the environment at contaminated sites (Carey et al., 1998).

Dioxins, furans, PCBs, and hexachlorobenzene are very persistent in the environment, and can remain without degrading in soil, sediment, or water and continue to contaminate the environment for many decades (Erickson, 1997; Carey et al., 1998). They evaporate from soil or water very slowly. They are highly resistant to chemical reactions with water, oxygen, or other chemicals, and they are resistant to degradation by bacteria or other microbes. These chemicals also tend to bioaccumulate in food chains, and are highly toxic (as described in Chapter 4). Because of their persistence, bioaccumulation, and toxicity, these chemicals have received a great deal of attention as environmental contaminants, are highly regulated, and are produced only as unwanted byproducts (Erickson, 1997; Carey et al., 1998). Furthermore, because most of the data on chlorinated hydrocarbons at the facility are for dioxins, furans, PCBs, and hexachlorobenzene, this report focuses on the environmental effects caused by these chemicals.

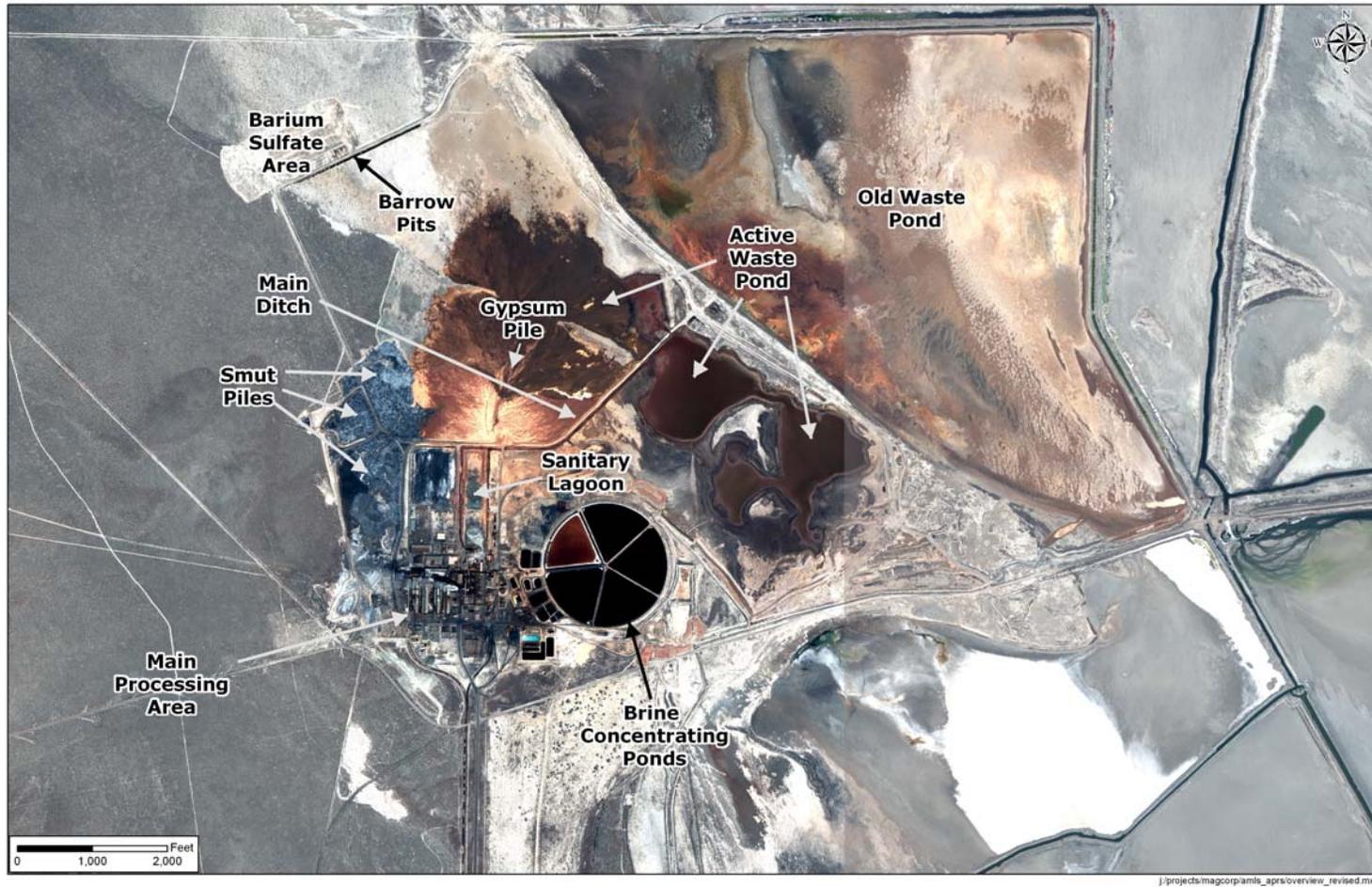


Figure 3.1. Satellite image of the USM facility and primary waste disposal areas.

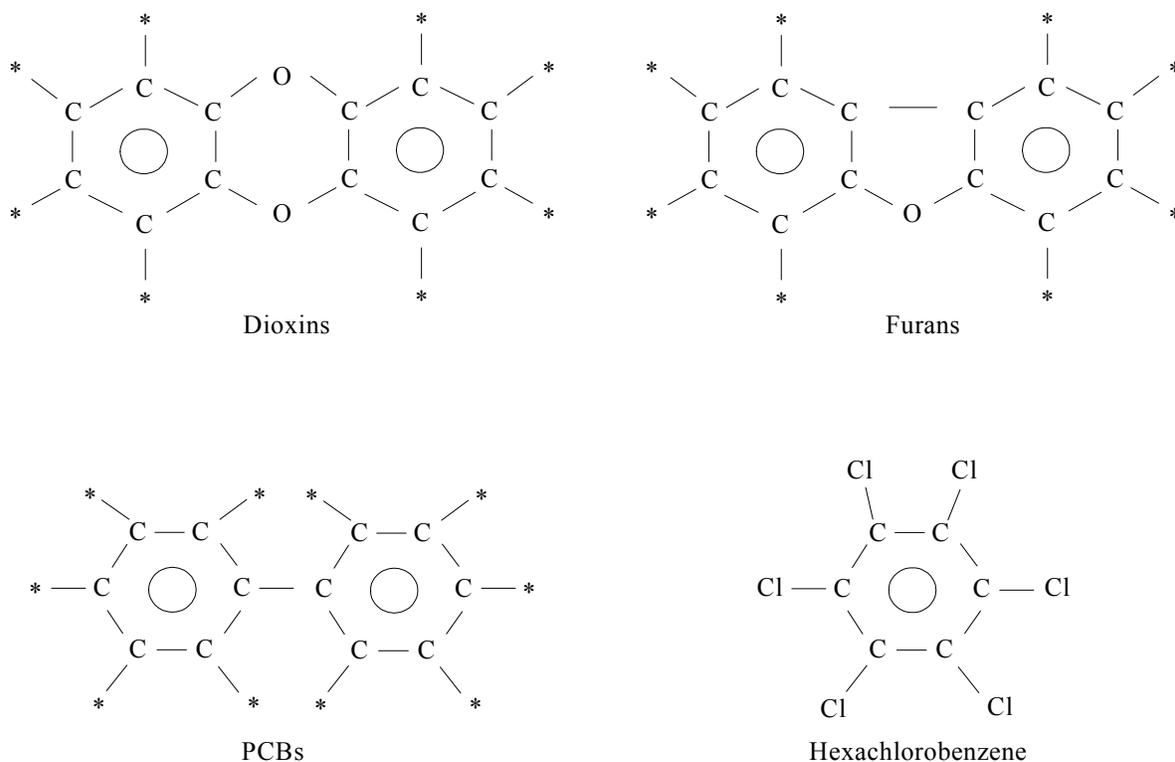


Figure 3.2. Chemical structures of dioxins, furans, PCBs, and hexachlorobenzene.
“C” = carbon atom, “Cl” = chlorine atom, and “*” could be a hydrogen or chlorine atom, depending on the individual molecule, or congener.

3.1.2 Chlorinated hydrocarbon contamination at the USM facility

Samples of soil, sediment, surface water, and biota have been collected from various locations at or near the facility and analyzed for dioxins, furans, PCBs, and hexachlorobenzene. The chemical data used in this report are in the following:

- ▶ Parametrix (2004), which presents the results of studies conducted in 2003 and 2004 by USM as part of an ecological assessment at the facility, and presents summaries of data collected by USM, its predecessor corporation, and federal agencies prior to 2003

- ▶ MWH (2005), which presents the results of a 2004-2005 study on the contamination of the sediments in the active waste pond
- ▶ Analytical chemistry data from the U.S. Fish and Wildlife Service (2007) for bird eggs collected in 2004, 2005, and 2006.

We also used data that are reported in facility study documents prior to 2003 but do not appear to have been included in the Parametrix (2004) report. These data are the results for selected samples reported in the following documents:

- ▶ URS Operating Services, 2002b
- ▶ U.S. EPA Region 7 Laboratory, 1999
- ▶ Sample analytical results reported by an analytical laboratory working for a contractor to the U.S. EPA (case Bates numbers MAG-R8 03242 to MAG-R8 03589 and MAG-R8 03590 to MAG-R8 03914).

The contamination measured at the USM facility is compared to concentrations measured in samples collected from reference areas that are unaffected by chemical releases from the USM facility. Various investigators have collected reference samples from areas that are up to approximately 45 miles away from the USM facility (Figure 3.3), and those data are reported in the data sources listed above.

Soil and sediment contamination

Samples of waste material have been collected from the different waste disposal areas at the facility and analyzed for dioxins, furans, PCBs, and hexachlorobenzene. These waste material samples typically were designated as either soil samples or sediment samples by the investigators who collected the samples. Samples identified by the collectors as soil samples typically were collected from areas with no overlying water, and samples identified as sediment samples were typically collected from areas where there was standing water at the time of sample collection. For example, some samples collected from the old waste pond are designated as soil and some are designated as sediment, depending on whether or not the material was collected from an area with standing water at the time of sample collection. Nevertheless, both the soil and sediment samples were taken from the same waste material. The soil and sediment designations used by the field collectors are retained throughout this report, even though in many cases the samples are actually of waste material that was disposed of by the facility.

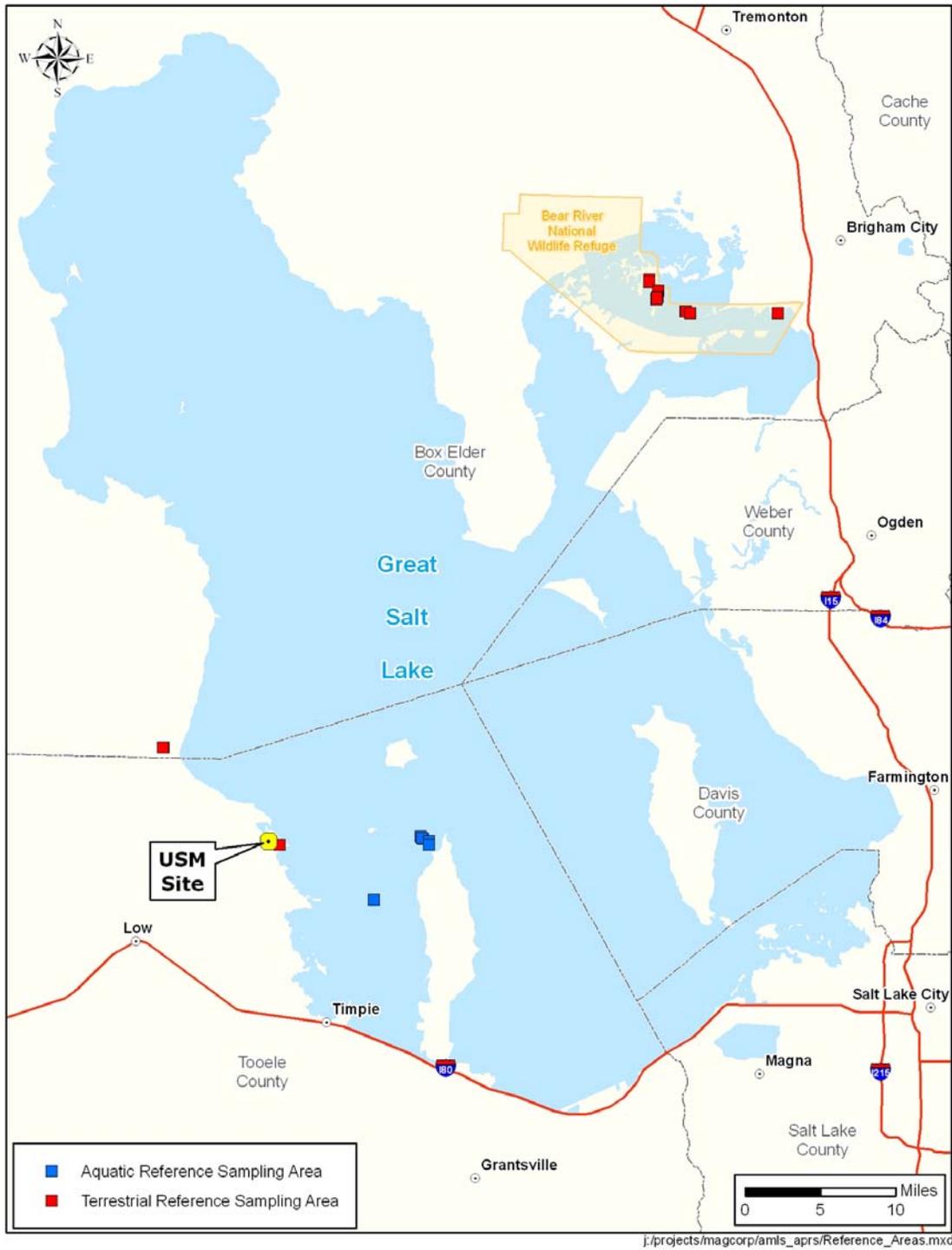


Figure 3.3. Locations of aquatic and terrestrial reference sampling areas.

Figures 3.4 and 3.5 and Table 3.1 present concentrations of total dioxins and furans, total PCBs, and hexachlorobenzene measured in soils at and near the facility and from a reference area.^{1, 2} In Figure 3.4, concentrations are plotted on a logarithmic scale so that the data can be seen. A logarithmic scale means that each bold line on the figure is a factor of 10 higher than the next lowest line. A logarithmic scale is necessary because the differences between the reference areas and facility waste areas are so high, that the reference area data would not be visible on a regular scale plot (e.g., facility concentrations are up to 10,000 times higher than reference concentrations). For comparison, Figure 3.5 plots the same data shown in Figure 3.4 except using a regular scale instead of a logarithmic scale. The rest of the data figures in this report use a logarithmic scale.

I (Douglas Beltman) conclude from the data in the figures and table that soils at the facility are highly contaminated with dioxins, furans, PCBs, and hexachlorobenzene. The old waste pond, gypsum pile, and sanitary lagoon contain the highest concentrations of chlorinated hydrocarbons at the facility. For example, hexachlorobenzene concentrations are up to 134,000 parts per billion (ppb) in old waste pond soils, 98,000 ppb in gypsum pile soils, and 6,000 ppb in sanitary lagoon soils, and were not detected in any of the three reference area soil samples. Soil concentrations at other facility areas are also greater than in reference areas, but these other areas are not as contaminated as the old waste pond, gypsum pile, and sanitary lagoon.

Sediments at the facility are also highly contaminated. Sediment data for total dioxins and furans, total PCBs, and hexachlorobenzene are shown in Figure 3.6 and summarized in Table 3.2. Sediment data for these chemicals have been collected from the active waste pond, the old waste pond, the barrow pits, and from reference areas. There are also PCB data for a small number of sediment samples from the sanitary lagoon.

1. We add the measured concentrations of the individual dioxin and furan congeners together to produce a single concentration of total dioxins and furans in each sample. Dioxins and furans are very similar chemically (see Figure 3.2), and adding them together aids in presenting and describing the contamination at the facility. We do the same with the PCB congeners to produce a single total PCB concentration, and this is a common method of presenting data on dioxins, furans, and PCBs. The individual dioxin, furan, and PCB compounds are treated separately in the evaluation of environmental effects presented in Chapter 4.

2. In the calculation of the total dioxins and furans and total PCBs, a value of zero was used for any individual congener that was not present above the detection limit. Excluding congeners that were not detected will result in an underestimate of the true concentrations, since at least some of the congeners are present but at concentrations less than the detection limit. Including only the detected congeners in the plots ensures that the differences observed between facility and reference areas are real.

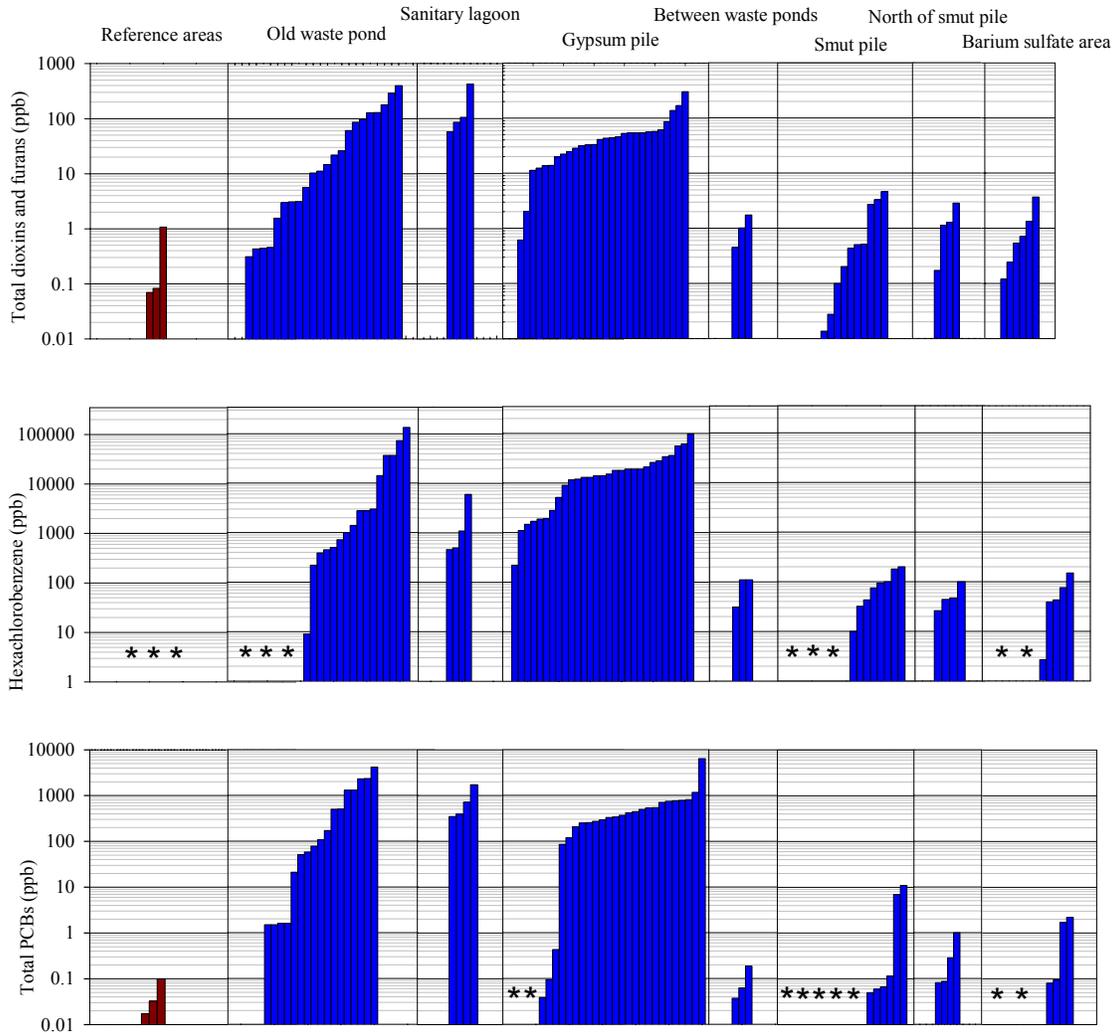


Figure 3.4. Soil concentrations of total dioxins and furans, total PCBs, and hexachlorobenzene. “*” indicates concentration less than the detection limit. The data plotted here are also summarized in Table 3.1. Note that the scale is logarithmic, and that each bold line is 10 times higher than the next lower line. Because the concentration differences are so high, the lower concentrations are not visible on a regular scale plot.

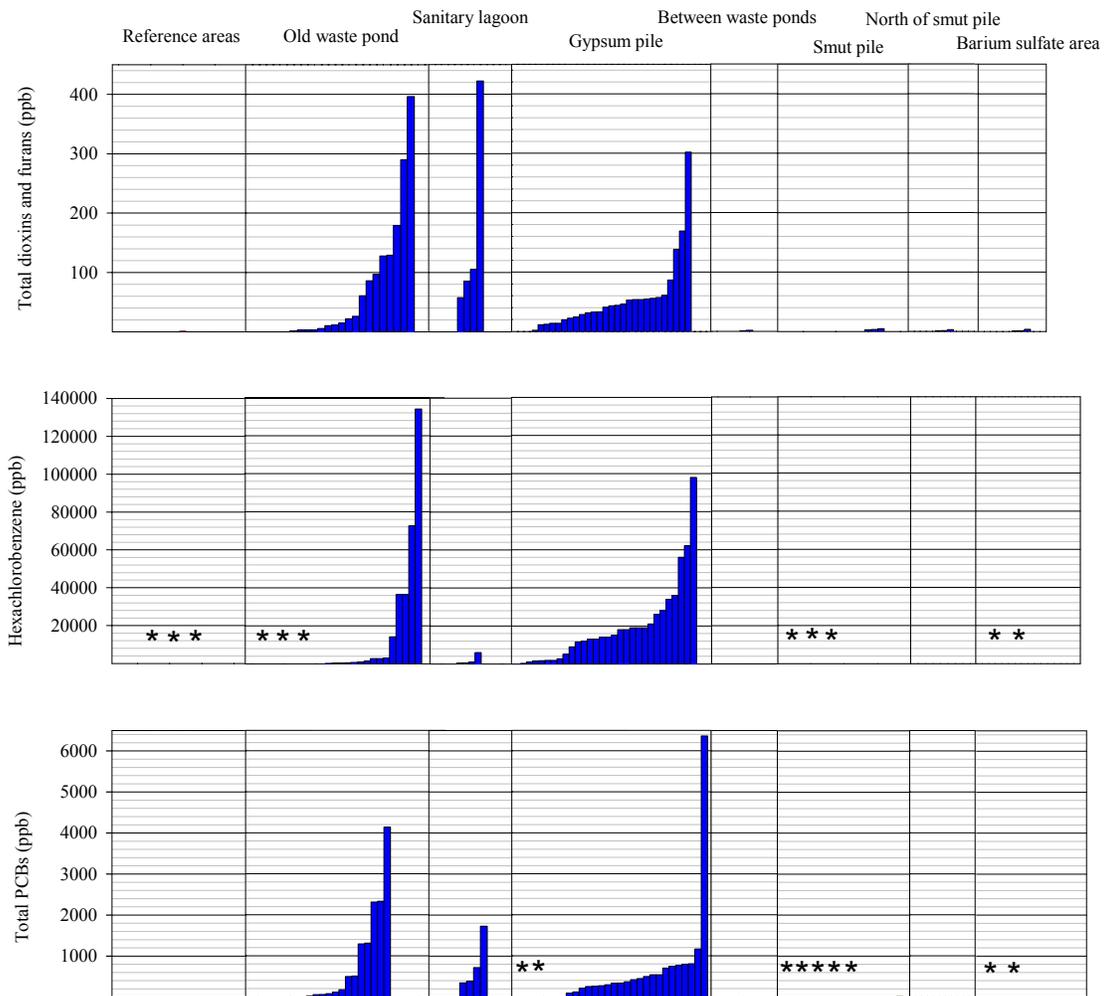


Figure 3.5. Soil concentrations of total dioxins and furans, total PCBs, and hexachlorobenzene (regular scale). “*” indicates concentration less than the detection limit. The data plotted here are the same data that are plotted in Figure 3.4, but this figure uses an arithmetic scale.

Table 3.1. Chemical concentrations in soil at the USM facility and reference areas

| Area ^a | Number of samples | Minimum concentration | Mean concentration | Maximum concentration |
|---------------------------------------|-------------------|-----------------------|--------------------|-----------------------|
| Total dioxins and furans (ppb) | | | | |
| Reference areas | 3 | 0.07 | 0.4 | 1.1 |
| Old waste pond | 22 | 0.31 | 66.7 | 396 |
| Sanitary lagoon | 4 | 57.6 | 168 | 422 |
| Gypsum pile | 28 | 0.6 | 53.7 | 302 |
| Between waste ponds | 3 | 0.4 | 1.1 | 1.7 |
| Smut pile | 10 | 0.01 | 1.2 | 4.6 |
| North of smut pile | 4 | 0.17 | 1.4 | 2.8 |
| Barium sulfate pile | 6 | 0.1 | 1.1 | 3.7 |
| Total PCBs (ppb) | | | | |
| Reference areas | 3 | 0.02 | 0.05 | 0.10 |
| Old waste pond | 17 | 1.5 | 757 | 4,140 |
| Sanitary lagoon | 4 | 347 | 795 | 1,730 |
| Gypsum pile | 27 | nd | 603 | 6,360 |
| Between waste ponds | 3 | 0.04 | 0.01 | 0.19 |
| Smut pile | 11 | nd | 1.67 | 11.0 |
| North of smut pile | 4 | 0.08 | 0.36 | 1.0 |
| Barium sulfate pile | 6 | nd | 0.67 | 2.2 |
| Hexachlorobenzene (ppb) | | | | |
| Reference areas | 3 | nd | nd | nd |
| Old waste pond | 19 | nd | 16,100 | 134,000 |
| Sanitary lagoon | 4 | 460 | 2,015 | 6,000 |
| Gypsum pile | 29 | 220 | 19,700 | 98,000 |
| Between waste ponds | 3 | 31 | 84 | 110 |
| Smut pile | 11 | nd | 67 | 200 |
| North of smut pile | 4 | 26 | 54 | 100 |
| Barium sulfate pile | 7 | nd | 44 | 150 |

a. Sampling areas are shown in Figures 3.1 and 3.3.

nd = not detected. Mean concentrations are calculated using a value of 0 for non-detects.

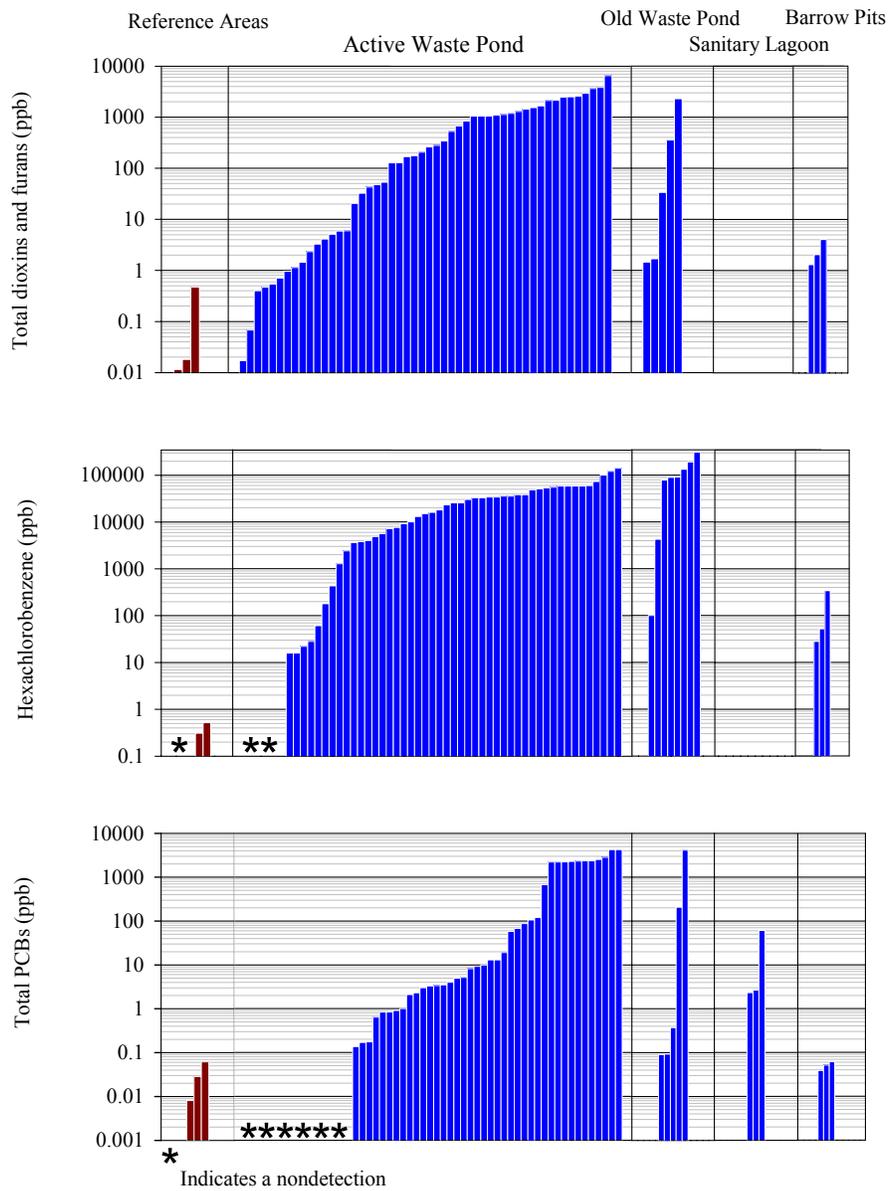


Figure 3.6. Sediment concentrations of total dioxins and furans, total PCBs, and hexachlorobenzene. “*” indicates concentration less than the detection limit. Note that the scale is logarithmic.

Table 3.2. Chemical concentrations in sediment at the USM facility and reference areas

| Area ^a | Number of samples | Minimum concentration | Mean concentration | Maximum concentration |
|---------------------------------------|-------------------|-----------------------|--------------------|-----------------------|
| Total dioxins and furans (ppb) | | | | |
| Reference areas | 3 | 0.01 | 0.17 | 0.47 |
| Active waste pond | 50 | 0.02 | 904 | 6,500 |
| Old waste pond | 5 | 1.4 | 534 | 2,280 |
| Barrow pits | 3 | 1.3 | 2.5 | 4.1 |
| Total PCBs (ppb) | | | | |
| Reference areas | 3 | 0.008 | 0.03 | 0.06 |
| Active waste pond | 46 | nd | 676 | 4,240 |
| Old waste pond | 5 | 0.09 | 869 | 4,140 |
| Sanitary lagoon | 3 | 2.3 | 22 | 61 |
| Barrow pits | 3 | 0.04 | 0.05 | 0.06 |
| Hexachlorobenzene (ppb) | | | | |
| Reference areas | 3 | nd | 0.3 | 0.5 |
| Active waste pond | 49 | nd | 29,400 | 140,000 |
| Old waste pond | 8 | 100 | 113,000 | 310,000 |
| Barrow pits | 3 | 28 | 140 | 340 |

a. Sampling areas are shown in Figures 3.1 and 3.3.

nd = not detected. Mean concentrations are calculated using a value of 0 for non-detects.

Similarly to soils, sediments in the active waste pond and old waste pond contain the highest concentrations of chlorinated hydrocarbon chemicals at the facility. Concentrations in these areas are many thousands of times greater than concentrations at reference areas. For example, total dioxin and furan concentrations in sediment are up to 2,280 ppb in the old waste pond and 6,500 ppb in the active waste pond, compared with a mean of 0.17 ppb in the reference areas. Sediment hexachlorobenzene concentrations are up to 140,000 and 310,000 ppb in the active waste pond and old waste pond, respectively, compared to a mean of 0.3 ppb in the reference areas. The barrow pits are also contaminated, but to a lesser degree than the old and active waste ponds.

The data show that the contamination in the old waste pond is highest near the former inlet area where the wastewater from the USM facility formerly entered the pond (Figure 3.7). Concentrations in the outer portions of the pond are much lower than in the area near the former inlet.

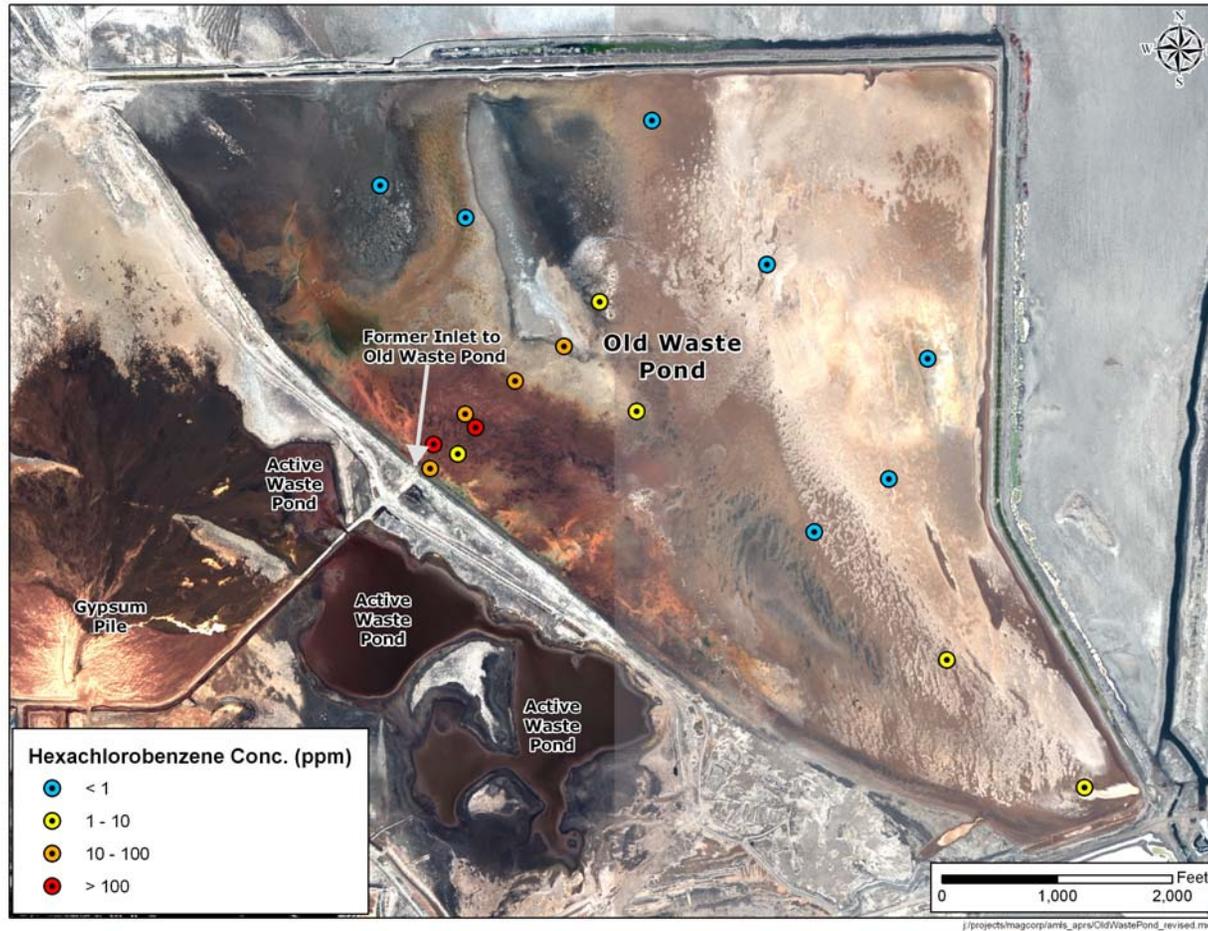


Figure 3.7. Hexachlorobenzene concentrations in soil or sediment of the old waste pond (parts per million, or ppm). Approximate sample locations adopted from Parametrix (2004).

Surface water contamination

Surface water at the USM facility is also contaminated with organochlorine chemicals. Figure 3.8 plots the concentration of total dioxins and furans in water collected from the active waste pond, old waste pond, and from reference areas. Although few samples have been collected, the data clearly show that the concentrations of total dioxins and furans in the water of the active waste pond and old waste pond are hundreds to thousands of times higher than concentrations in water at reference areas.

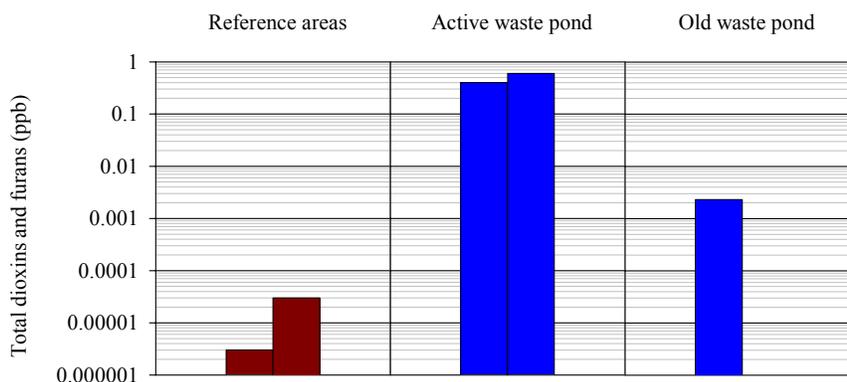


Figure 3.8. Surface water concentrations of total dioxins and furans (ppb). Note that the scale is logarithmic.

Chemical accumulation in biota

The dioxins, furans, PCBs, and hexachlorobenzene at the USM facility can bioaccumulate in the tissues of organisms that are exposed to the chemicals. The chemicals can become incorporated into the food chain from the surrounding environment, and they tend to biomagnify, meaning that tissue concentrations are highest in the highest trophic level organisms (Carey et al., 1998).

Chemical concentrations in plants, invertebrates (e.g., beetles, spiders, brine flies), mice, and bird eggs have been measured at the facility over the last few years. I conclude from the data that biota at the facility are contaminated with the organochlorine chemicals that the facility produces. Mice collected from all three areas sampled at the facility (the sanitary lagoon, the area between the old and active waste ponds, and the area north of the smut pile) are contaminated (Figure 3.9), and mice from the sanitary lagoon are the most contaminated. Mice from the reference area contained hexachlorobenzene at 1.6 ppb and < 0.34 ppb, whereas the maximum concentrations in mice from the facility were 2,400 ppb from the sanitary lagoon, 240 ppb from between the waste ponds, and 18 ppb from north of the smut pile. Concentrations of total dioxins and furans and total PCBs are similarly elevated in mice at the facility.

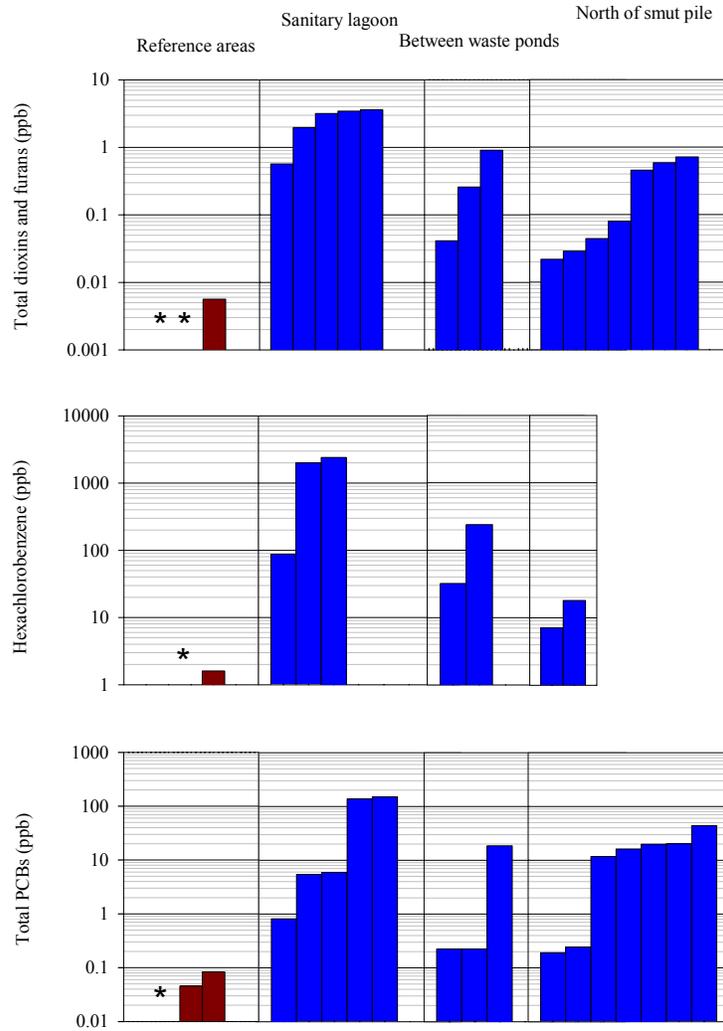


Figure 3.9. Concentrations of total dioxins and furans, total PCBs, and hexachlorobenzene in mice (whole bodies). “*” indicates concentration less than the detection limit. Note that the scale is logarithmic.

Plants and invertebrates from the sanitary lagoon are also the most highly contaminated of any collected at the facility (Figures 3.10 and 3.11, respectively). Concentrations of total dioxins and furans, total PCBs, and hexachlorobenzene are thousands of times higher in plants and invertebrates collected from the sanitary lagoon than from reference areas, and hundreds of times higher in samples collected from other areas at the facility.

Bird eggs have also been collected from nests at or near the facility and analyzed for contaminants. Eggs were collected in 2004, 2005, and 2006 from nests of American avocets, snowy plovers, and horned larks at or near the facility. Nest locations included the bed of the old waste pond, vegetated areas between the old and active waste ponds, and the beds of solar evaporation ponds immediately south of the USM facility. Eggs were also collected from reference areas for comparison. The bird eggs collected from and near the facility have much higher concentrations of dioxins, furans, PCBs, and hexachlorobenzene than eggs from reference areas, as shown in Figure 3.12. Therefore, I conclude that the chemicals produced and disposed of by the USM facility have entered the food web around the facility, are accumulated by birds that feed in the area, and are deposited into the eggs of those birds.

Summary

I conclude from the data that the USM facility has contaminated the environment at and near the facility with high concentrations of chlorinated chemicals, and that the contaminants are consumed by wildlife. Every component of the environment that has been sampled is highly contaminated with dioxins, furans, PCBs, and hexachlorobenzene. Soils, sediment, surface water, mice, plants, invertebrates, and bird eggs collected at or near the USM facility all contain concentrations of these chemicals that are hundreds to thousands of times higher than concentrations in reference areas. The contamination of the bird eggs demonstrates that the chemicals produced and disposed of by the facility have entered the food chain, and are being accumulated by birds that feed in the area. I evaluate the toxicological significance of this environmental contamination in the next chapter.

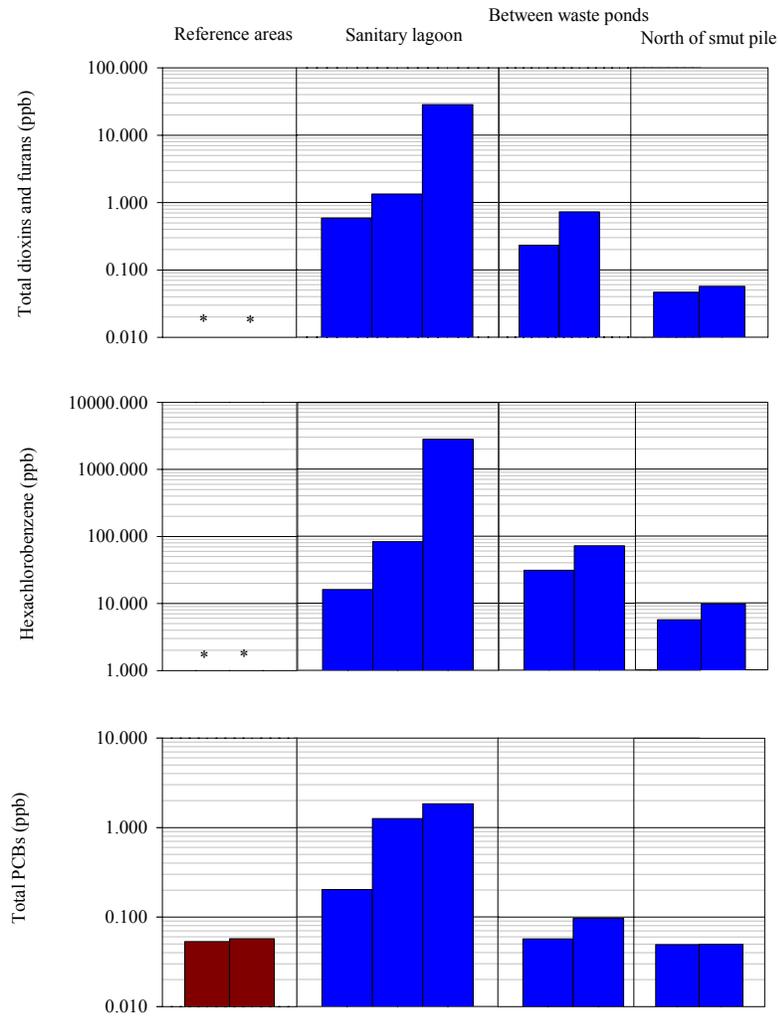


Figure 3.10. Concentrations of total dioxins and furans, total PCBs, and hexachlorobenzene in plants. “*” indicates concentration less than the detection limit. Note that the scale is logarithmic.

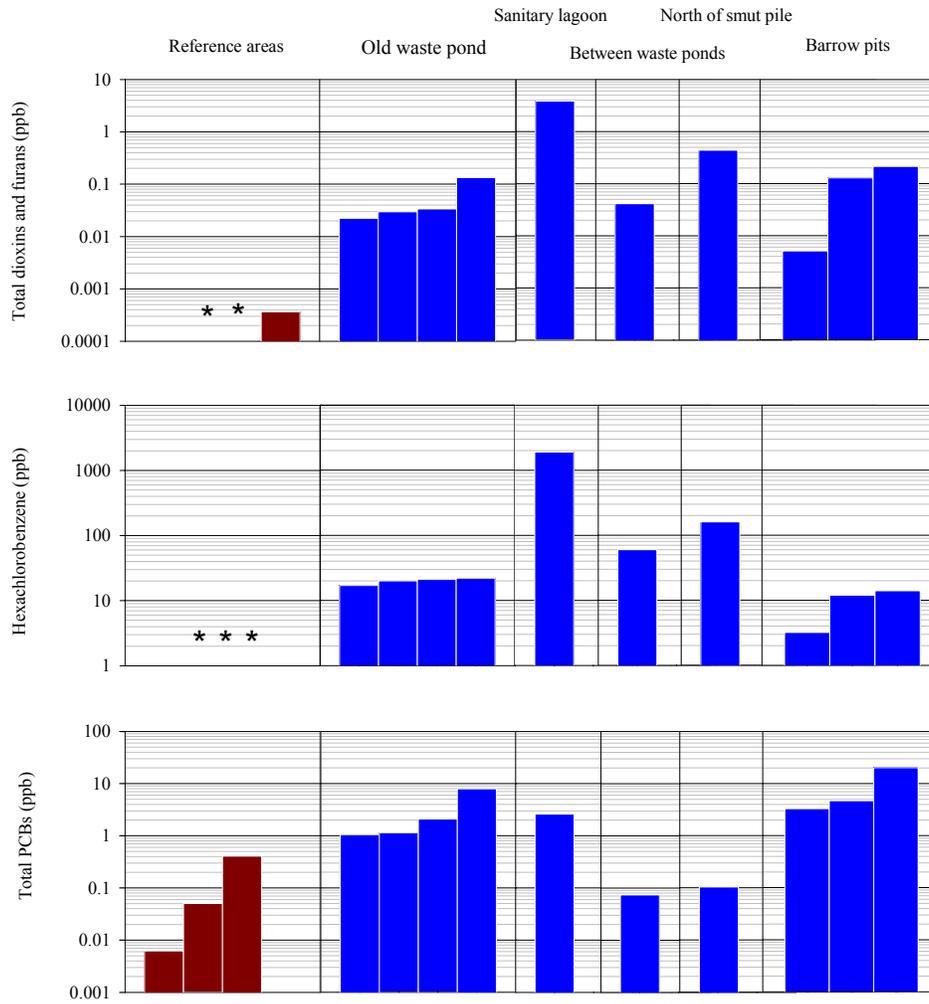


Figure 3.11. Concentrations of total dioxins and furans, total PCBs, and hexachlorobenzene in terrestrial or aquatic invertebrates. “*” indicates concentration less than the detection limit. Note that the scale is logarithmic.

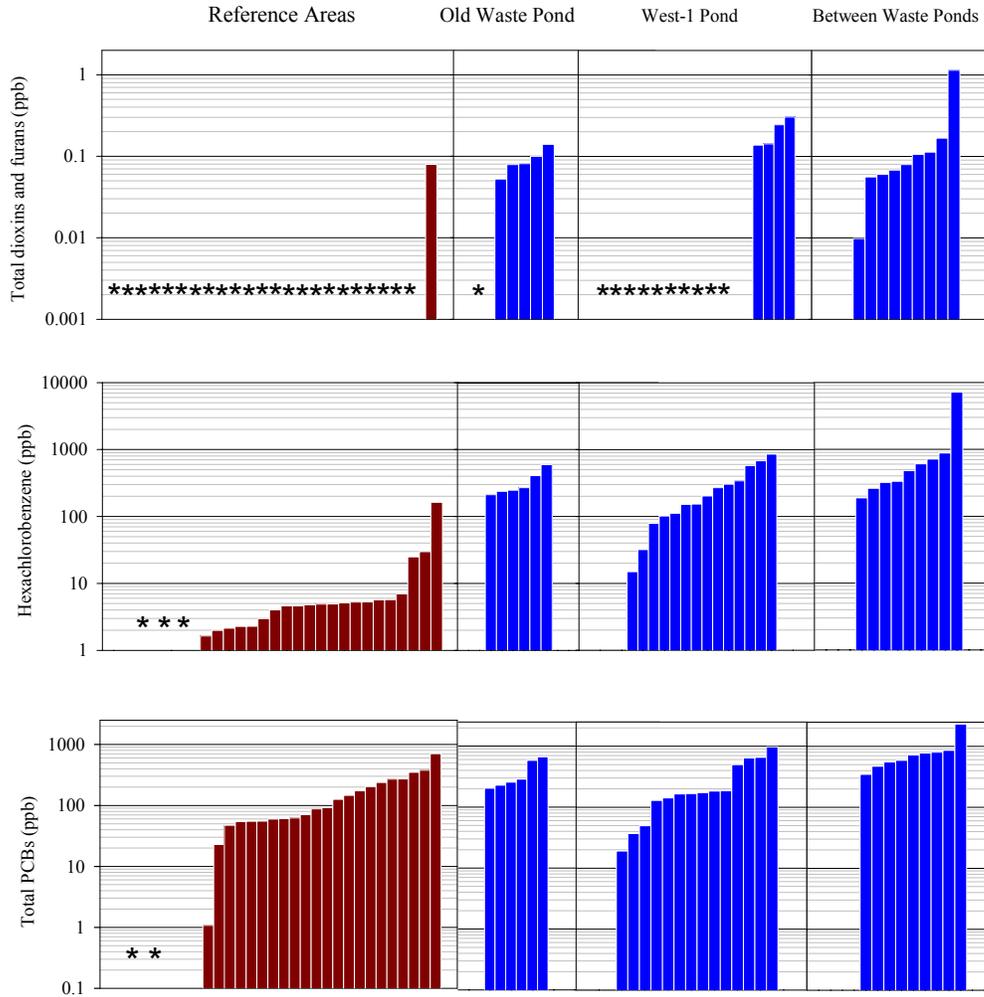


Figure 3.12. Concentrations of total dioxins and furans, total PCBs, and hexachlorobenzene in bird eggs. “*” indicates concentration less than the detection limit. Note that the scale is logarithmic. West-1 Pond is adjacent to the USM facility.

3.2 Highly Acidic Wastewater at the Facility

The USM facility also produces hydrochloric acid that is discharged as part of the wastewater stream into several ditches that lead away from the facility. The ditches flow together to form the Main Ditch, which flows into the active waste pond. The wastewater in the active waste pond is allowed to evaporate and percolate into the soil (URS Operating Services, 2002b). Because of the highly acidic solution discharged into the ditch system and active wastewater pond, the water in the ditches and pond is highly acidic. Acidity is typically measured and expressed as pH on a scale of 0 to 14: a pH of 7.0 is neutral, lower values are more acidic, and higher values are more basic. Figure 3.13 shows the pH values for common foods or solutions. An important consideration in evaluating pH values is that each unit change in pH is a tenfold change in acid strength.³ For example, in Figure 3.13, battery acid at a pH of 1.0 is approximately 20 times more acidic than lemons at a pH of 2.3 and 1,600 times more acidic than tomatoes at a pH of 4.2.

Until recently, the USM facility regularly measured pH in the Main Ditch and the active waste pond (Thomas G. Tripp deposition, January 6, 2003). Table 3.3 lists the measurements since 1986, when the active pond was created, through 1999.⁴ The table lists the sampling location name as it is reported in the USM documents, and the presumed location based on the deposition testimony of Mr. Thomas Tripp of USM (Thomas G. Tripp deposition, January 6, 2003).

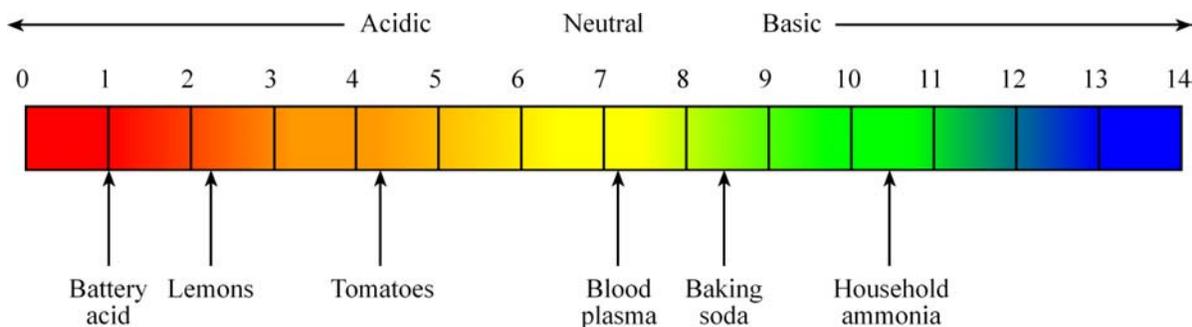


Figure 3.13. The pH scale and some example pH values (data from Weast and Astle, 1980; and Kotz and Purcell, 1991).

3. pH is calculated as the negative of the log of H^+ ion concentration (the active component of acid) in solution.

4. The outer dike of the old waste pond failed in 1984. From 1984 to 1986, the facility discharged wastewater into the "01 solar pond" (Olafson, 1988).

Table 3.3. pH measurements of the Main Ditch and active waste pond made by USM, 1986-1999

| Presumed location | Location name (as reported) | pH | Month | Year | Document Bates number |
|--------------------------|------------------------------------|-----------|-------------------|-------------------|------------------------------|
| Main Ditch | Waste Water Stream | 1.5 | June ^a | 1987 | MAG-R8 30053 |
| Main Ditch | Waste Water Canal | 1.2 | June | 1989 | DMA-0300590 |
| Main Ditch | Red River | 1.1 | June | 1992 | DMA-0144705 |
| Main Ditch | Red River East | 1.1 | June | 1992 | DMA-0144705 |
| Main Ditch | Red River | 0.78 | October | 1992 | DMA-0144707 |
| Main Ditch | RR | 0.85 | December | 1992 | DMA-0144708 |
| Main Ditch | Red River | < 1 | March | 1993 | DMA-0144709 |
| Main Ditch | R. River | 0.85 | June | 1993 | DMA-0144710 |
| Main Ditch | Red River | 1.13 | November | 1993 | DMA-0144711 |
| Main Ditch | Red River | 1.01 | January | 1994 | DMA-0144713 |
| Main Ditch | Red River | 1.21 | March | 1994 | DMA-0144719 |
| Main Ditch | Red River | 1.15 | April | 1994 | DMA-0144718; DMA-0144720 |
| Main Ditch | Red River | 1.0 | May | 1994 | DMA-0273959 |
| Main Ditch | Red River | 0.88 | July | 1994 | DMA-0273954 |
| Main Ditch | Red River | 0.88 | August | 1994 | DMA-0273952 |
| Main Ditch | Red River | 0.98 | December | 1994 | DMA-0273934 |
| Main Ditch | Red River | 1.20 | July | 1995 | DMA-0144723 |
| Main Ditch | Red River | 0.9 | September | 1995 | DMA-0144724; DMA-0144724 |
| Main Ditch | Red River | 0.98 | September | 1996 | DMA-0052588 |
| Main Ditch | Red River | 0.9 | February | 1997 | MAG-R8 28119 |
| Main Ditch | Red River | 1.11 | January | 1998 | MAG-R8 26820 |
| Main Ditch | Red River | 1.25 | January | 1998 | DMA-0270379 |
| Main Ditch | Red River | 0.86 | March | 1998 | MAG-R8 26819 |
| Main Ditch | Red River | 0.84 | February | 1999 | DMA-0286494 |
| Active pond | New Plant Waste Pond | 2.3 | September | 1986 ^b | DMA-0289924 |
| Active pond | New Plant Waste Pond | 1.8 | October | 1986 ^b | DMA-0289924 |
| Active pond | New Plant Waste Pond | 2.3 | October | 1986 ^b | DMA-0289924 |
| Active pond | New Plant Waste Pond | 2.2 | November | 1986 ^b | DMA-0289924 |

Table 3.3. pH measurements of the Main Ditch and active waste pond made by USM, 1986-1999 (cont.)

| Presumed location | Location name (as reported) | pH | Month | Year | Document Bates number |
|-------------------|-----------------------------|------|-------------------|-------------------|--------------------------|
| Active pond | New Plant Waste Pond | 2.3 | November | 1986 ^b | DMA-0289924 |
| Active pond | New Plant Waste Pond | 1.9 | December | 1986 ^b | DMA-0289924 |
| Active pond | New Plant Waste Pond | 2.1 | December | 1986 ^b | DMA-0289924 |
| Active pond | New Plant Waste Pond | 1.7 | January | 1987 ^b | DMA-0289924 |
| Active pond | New Plant Waste Pond | 1.9 | February | 1987 ^b | DMA-0289924 |
| Active pond | New Plant Waste Pond | 1.8 | February | 1987 ^b | DMA-0289924 |
| Active pond | Evaporation Pond | 2.1 | June ^a | 1987 | MAG-R8 30053 |
| Active pond | Waste Pond | 1.6 | June | 1989 | DMA-0300590 |
| Active pond | Waste Pond | 1.0 | June | 1989 | MAG-R8 31397 |
| Active pond | Waste Pond | 1.0 | June | 1992 | DMA-0144705 |
| Active pond | Waste Pond | 0.72 | October | 1992 | DMA-0144707 |
| Active pond | WP | 0.85 | December | 1992 | DMA-0144708 |
| Active pond | Waste Pond | < 1 | March | 1993 | DMA-0144709 |
| Active pond | Pond | 0.50 | June | 1993 | DMA-0144710 |
| Active pond | Pond | 1.21 | November | 1993 | DMA-0144711 |
| Active pond | East Pond | 6.49 | November | 1993 | DMA-0144711 |
| Active pond | West Waste Pond | 0.92 | January | 1994 | DMA-0144713 |
| Active pond | East Waste Pond | 3.27 | January | 1994 | DMA-0144713 |
| Active pond | East Waste Pond | 3.1 | February | 1994 | DMA-0144717 |
| Active pond | East Waste Pond | 6.00 | March | 1994 | DMA-0144719 |
| Active pond | West Waste Pond | 0.96 | March | 1994 | DMA-0144719 |
| Active pond | W. Pond | 1.00 | April | 1994 | DMA-0144718; DMA-0144720 |
| Active pond | E. Pond | 6.36 | April | 1994 | DMA-0144718; DMA-0144720 |
| Active pond | West Waste Pond | 1.2 | May | 1994 | DMA-0273959 |
| Active pond | East Pond | 7.0 | May | 1994 | DMA-0273959 |
| Active pond | West Waste Pond | 0.74 | July | 1994 | DMA-0273954 |
| Active pond | East Waste Pond | 5.8 | July | 1994 | DMA-0273954 |
| Active pond | West Waste Pond | 0.95 | August | 1994 | DMA-0273952 |
| Active pond | West Waste Pond | 0.97 | December | 1994 | DMA-0273934 |
| Active pond | East Waste Pond | 2.38 | December | 1994 | DMA-0273934 |

Table 3.3. pH measurements of the Main Ditch and active waste pond made by USM, 1986-1999 (cont.)

| Presumed location | Location name (as reported) | pH | Month | Year | Document Bates number |
|-------------------|-----------------------------|------|-----------|------|--------------------------|
| Active pond | West Pond | 0.8 | September | 1995 | DMA-0144724 |
| Active pond | West Pond | 1.20 | July | 1995 | DMA-0144723 |
| Active pond | West Waste Pond | 0.8 | September | 1996 | DMA-0052588; DMA-0144724 |
| Active pond | West Pond | 1.0 | February | 1997 | MAG-R8 28119 |
| Active pond | East Pond | 1.3 | February | 1997 | MAG-R8 28119 |
| Active pond | East Waste Pond | 0.98 | January | 1998 | MAG-R8 26820 |
| Active pond | East Pond | 1.05 | January | 1998 | DMA-0270379 |
| Active pond | East Pond | 0.83 | March | 1998 | MAG-R8 26819 |
| Active pond | East Pond | 0.8 | February | 1999 | DMA-0286494 |

a. Sampling month not stated, but presumed based on text in source document.

b. Year not stated but presumed based on text in source document.

The pH in the Main Ditch recorded in USM documents since 1986 ranges from 0.78 to 1.5. Most of the values are less than 1.0, which is approximately 1 million to 10 million times more acidic than the adjacent Great Salt Lake (USGS, 2003). These data demonstrate that the facility discharges highly acidic water into the active waste pond.

The pH values for the active pond listed in Table 3.3 range from 0.5, measured in June 1993, to 7.0, measured in May 1994. Most of the pH values are less than 2.0, and many (approximately one-quarter) are less than 1.0. The data do not indicate a strong trend in pH values over time. These data demonstrate that the water of the active pond is highly acidic, with pH often less than 1.0, which is more acidic than battery acid. Ponds with such high acidity do not occur naturally in the environment.

Other investigators have also measured the pH of the active pond (Table 3.4). These data are generally consistent with those collected by the facility in that they demonstrate that the active pond water is highly acidic. These measurements, taken in 1999 and 2001, range from 1.04 to 1.3 for the pH in the active pond (Table 3.4; Columbia Analytical Services, 1999; SAIC, 1999b). SAIC (1999b) also measured the pH in ponded water in the old waste pond near the northeast side of the pond (which is the side away from the facility) at 2.79. In comparison, the pH of rainwater averaged 6.2 in northern Utah in 2001 (NADP, 2001), and pH at five stations in the south portion of the Great Salt Lake in 2001 ranged from 6.5 to 8.4 (USGS, 2003). Thus the water in the old waste pond is also acidic, many years after direct discharges of acidic water to the pond stopped.

Table 3.4. pH measurements in the Main Ditch, active pond, and old waste pond made by investigators other than USM, 1999-2001

| Location | pH | Month | Year | Reference |
|------------------------------------|------|-----------|------|---|
| Main Ditch | 1.55 | September | 1999 | Columbia Analytical Services, 1999; SAIC, 1999b |
| | 1.58 | September | 1999 | Columbia Analytical Services, 1999; SAIC, 1999b |
| Active pond | 1.04 | September | 1999 | Columbia Analytical Services, 1999; SAIC, 1999b |
| | 1.11 | September | 1999 | Columbia Analytical Services, 1999; SAIC, 1999b |
| | 1.3 | September | 2001 | URS Operating Services, 2002b |
| Old waste pond (northeast side) | 2.79 | September | 1999 | Columbia Analytical Services, 1999; SAIC, 1999b |

3.3 Conclusions

I conclude from the chemical data collected at the USM facility that the facility has contaminated the environment at and near the facility with high concentrations of organochlorine contaminants. Soils, sediment, and surface water at the facility contain concentrations of chlorinated dioxins, furans, PCBs, and hexachlorobenzene that are many thousands of times higher than at reference areas. The contamination has also entered the food web, and plants, invertebrates, mice, and bird eggs at the facility contain the chemicals released from the facility at concentrations that are thousands of times higher than at reference areas.

The USM facility also discharges highly acidic water into the active wastewater pond. Many measurements of pH in the active pond over many years confirm that the pond contains very acidic water, often with a pH of less than 1.0, which is more acidic than battery acid. Such ponds of highly acidic water do not occur naturally in the environment.

4. Threats to the Environment From the Chlorinated Hydrocarbon Contamination at the Facility

The information presented in the previous chapter demonstrates that the USM facility has contaminated the environment at and near the facility with chlorinated hydrocarbon chemicals. Concentrations of these chemicals are hundreds to thousands of times higher at and near the facility than in nearby reference areas. In this chapter, I (Douglas Beltman) evaluate the threats to the environment posed by USM's contamination of the environment with dioxins, furans, PCBs, and hexachlorobenzene.

This chapter begins with a description of the approach that I used to assess the environmental threats caused by the chemicals at the USM facility. Section 4.2 then presents a brief summary of the toxicity of dioxins, furans, PCBs, and hexachlorobenzene to ecological resources. The sections that follow then present an analysis of the threats to wildlife posed by these chemicals, given the chemical concentrations measured in the environment at and near the facility.

4.1 Approach for Assessing Environmental Threats

I evaluated the environmental threats caused by the USM facility's contamination of the environment with dioxins, furans, PCBs, and hexachlorobenzene by considering the potential for the chemicals in soil, sediment, surface water, and biota at and near the facility to cause toxicity to ecological resources.

The available data for the facility include concentrations of dioxins, furans, PCBs, and hexachlorobenzene in soil, sediment, and surface water, in the tissues of plants, invertebrates, and small mammals that are consumed by wildlife, and in bird eggs. To assess the potential for the measured concentrations of these chemicals to cause toxicity, I first compiled and reviewed available literature on the uptake and toxicity of these particular chemicals to wildlife. I reviewed two types of documents: (1) original studies published in the scientific literature, including field studies, laboratory studies, and studies that combine both field and laboratory elements; and (2) review articles or documents that synthesize the available information from original studies. Included in this second type of documents are reports authored by state, provincial, federal, or international agencies that rely on a broad array of toxicological studies to derive chemical threshold or benchmark concentrations that are used to assess the potential for environmental contamination to cause harm.

Based on my review of the literature, I identified relevant literature that provides toxicological information to which the chemical concentrations measured at the USM facility should be compared. I identified studies or documents that provide the following types of information or data on dioxins, furans, PCBs, and hexachlorobenzene:

- ▶ Concentrations in soil, sediment, and surface water at or above which toxicity to biota occurs, primarily through the chemicals entering the food chain and causing toxicity to upper trophic level organisms
- ▶ Concentrations in dietary items, such as small mammals, plants, and invertebrates, at or above which toxicity occurs in wildlife that consume these items in their diet
- ▶ Concentrations in bird eggs that cause toxicity to the developing embryo or hatched chick.

The specific studies, documents, and concentrations I used to compare with the data for the USM facility are described in detail in the following sections.

In comparing chemical concentrations at the facility with toxicological information from the literature, I considered the fact that actual chemical exposure and toxicity in the wild is dependent on many factors, including:

- ▶ *Variability in organism exposure to chemicals in the environment.* Organisms can differ in their actual exposure to chemicals depending on their feeding habits and life history. Exposure can vary from season to season or year to year, depending on environmental conditions. As a result, organisms of the same species living in similar areas can have different exposure to chemicals in the environment.
- ▶ *The inherent biochemical sensitivity of the exposed organisms to the chemical.* Chemical sensitivity often varies considerably between species, as well as between individuals of the same species.
- ▶ *The life stage of the exposed organism.* Dioxins, furans, PCBs, and hexachlorobenzene tend to be most toxic to developing embryos and young, but other life stages are affected as well.
- ▶ *The susceptibility of the exposed organism to chemical toxicity.* Organisms that are under stress from hunger, thirst, nutritional deficiencies, exhaustion, disease, cold, or heat can be more susceptible to chemical toxicity. For example, organisms in the desert may be more susceptible to the adverse effects of pollutants because they live in a highly demanding environment with its own inherent stresses (Everts, 1997).

- ▶ *Physical and geochemical properties of the soil, sediment, or surface water that can affect the bioavailability of the chemicals.* For example, chlorinated hydrocarbons tend to be more bioavailable from soil or sediment with low organic carbon content than from soil or sediment with high organic carbon content.

Another potential source of variability is the application of laboratory toxicity data to field conditions. Most of our knowledge about the toxicity of chemicals comes from laboratory toxicity studies on relatively few bird and mammal species. These studies use animals that are healthy, well-fed, and under benign laboratory conditions, and that typically monitor only a handful of toxicological endpoints at a time. Therefore, the uncertainty in translating the results from laboratory toxicity studies to field conditions also makes it difficult to rely on single concentrations as toxic thresholds.

Because of these uncertainties, I considered the available data on chemical exposure at the USM facility and the available toxicological data as a whole, rather than attempting to identify a single chemical contamination level at the facility that marks a hypothetical line at which harm occurs. It is a common practice when assessing environmental harm from chemicals to consider a broad array of toxicological studies and data and evaluate the data as a whole.

Using the results from many studies and publications (described in detail below), I drew overall conclusions regarding the likelihood that the concentrations at the facility are sufficient to harm wildlife. There are several exceptions, as explained in detail in the following sections, where I had to use the results of only a single study or a handful of studies to compare to concentration data for the facility because they were the only relevant studies available for a particular chemical.

Assessing whether environmental contamination at a particular site is sufficient to harm the environment is relatively straightforward for sites that are clean relative to the body of toxicological information, and for sites that are highly contaminated relative to the body of toxicological information. It becomes more difficult for sites that fall somewhere in between. Based on the analysis I present in the following sections, the contamination at the USM facility is so high that there is a high probability that the contamination is causing adverse effects to wildlife, and therefore it is relatively straightforward to reach the conclusion that contamination at the facility poses a threat to the environment. Because of this threat, actions must be taken at the facility to stop plants and animals from being exposed to the chemicals in soil, sediment, and surface water.

4.2 The Environmental Toxicity of Dioxins, Furans, PCBs, and Hexachlorobenzene

4.2.1 Background

Dioxins, furans, PCBs, and hexachlorobenzene in the environment accumulate in the tissues of organisms, including plants, invertebrates, fish, amphibians, reptiles, birds, and mammals (Carey et al., 1998). These chemicals also degrade slowly, and ecosystem contamination can persist for many decades (Carey et al., 1998). Most of the exposure of ecological resources to these chemicals occurs when they eat contaminated food. These chemicals can biomagnify up food chains, meaning that upper trophic level organisms, such as predatory birds and mammals, are often the organisms that are the most highly exposed (Carey et al., 1998). The embryos or young of these contaminated organisms become exposed to the chemicals through maternal transfer of contaminants to eggs (for birds and fish) or transfer across the placenta or from milk (for mammals; Carey et al., 1998).

Dioxins, furans, PCBs, and hexachlorobenzene are very toxic to birds and mammals. Embryos and young are particularly sensitive to their toxic effects. At sufficient concentrations these chemicals cause acute mortality, meaning the organisms die quickly after exposure. Acute mortality to embryos and young from exposure to these chemicals has been documented in the environment (Eisler, 1986; Kubiak et al., 1989; Custer et al., 2005). In addition to acute mortality, these chemicals also cause other kinds of adverse effects which can lead indirectly to death, such as cancer, endocrine system disruption, behavioral effects, deformities, porphyria (which is a disruption in the synthesis of heme, a key component of hemoglobin and other enzymes), altered biochemical functioning, weight loss, or reduced immune system competence (Carey et al., 1998).

Animal reproduction is especially sensitive to the toxic effects of dioxins, furans, PCBs, and hexachlorobenzene. Developing embryos or young typically can die from exposure concentrations much less than those that cause death in adult organisms (Peterson et al., 1993; Eisler and Belisle, 1996; Carey et al., 1998). These chemicals also can cause deformities in developing embryos, such as cleft palate, skull and facial deformities, heart deformities, and deformities of the kidney (Peterson et al., 1993). In addition, these chemicals can affect the biochemical system of the embryos or young so that their growth rates are reduced (Carey et al., 1998). Other effects on embryos or young include altered enzyme induction and decreased ability to resist diseases or pathogens (Carey et al., 1998). These types of adverse effects (reduced growth, decreased disease or pathogen resistance) can lead indirectly to death of the organism by reducing the ability of the organism to survive in the wild.

In addition to direct toxicity to embryos or young, these chemicals can also disrupt animal reproduction by altering the hormonal systems or behavior in adults, thereby reducing the ability of the adults to breed and raise young successfully (Peterson et al., 1993; Carey et al., 1998). For

example, exposure to PCBs alters pre-mating behavior in birds so that the mating and egg production cycle is altered or delayed. It can also cause decreases in parental nest attentiveness, with corresponding decreases in success in raising young (Kubiak et al., 1989; Fisher et al., 2006). Some of these effects have been shown to recur for several generations of birds after an initial dosing with PCBs, despite the fact that the subsequent generations are not themselves exposed to PCBs (Fernie et al., 2001, 2003).

4.2.2 The TCDD-eq approach to evaluating mixture toxicity

Some of the individual dioxin, furan, and PCB congeners, as well as hexachlorobenzene, can all cause toxicity through a specific biochemical mechanism that first involves the binding of the chemical to a specific complex within cells called the aryl hydrocarbon receptor (Ah receptor) (Peterson et al., 1993; van Birgelen, 1998). After binding with the Ah receptor, the chemical:Ah receptor complex induces a cascade of biochemical reactions that can result in toxicity at very low exposure concentrations. The model or primary example chemical for Ah receptor binding and subsequent toxicity is one of the chemical forms, or congeners, of dioxin, 2,3,7,8-tetrachlorinated dibenzo-p-dioxin (2,3,7,8-TCDD). This particular chemical has been extensively studied in laboratory and field studies, and it is very toxic to birds and mammals (Carey et al., 1998). Some other congeners of dioxin, as well as some of the furan and PCB congeners and hexachlorobenzene, also cause toxicity through the same mechanism of binding to the Ah receptor (Peterson et al., 1993; Appendix B). A list of the individual congeners that are known to cause toxicity through binding to the Ah receptor is included in Table 4.1.

Table 4.1. TCDD TEFs for dioxin, furan, and PCB congeners and hexachlorobenzene

| Chemical ^a | TEF for toxicity to mammals ^b | TEF for toxicity to birds ^c | TEF for toxicity to fish ^c |
|------------------------|--|--|---------------------------------------|
| 2,3,7,8-TCDD | 1 | 1 | 1 |
| 1,2,3,7,8-pentaCDD | 1 | 1 | 1 |
| 1,2,3,4,7,8-hexaCDD | 0.1 | 0.05 | 0.5 |
| 1,2,3,6,7,8-hexaCDD | 0.1 | 0.01 | 0.01 |
| 1,2,3,7,8,9-hexaCDD | 0.1 | 0.1 | 0.01 |
| 1,2,3,4,6,7,8-heptaCDD | 0.01 | < 0.001 | 0.001 |
| OctaCDD | 0.0003 | 0.0001 | < 0.0001 |
| 2,3,7,8-TCDF | 0.1 | 1 | 0.05 |
| 1,2,3,7,8-pentaCDF | 0.03 | 0.1 | 0.05 |
| 2,3,4,7,8-pentaCDF | 0.3 | 1 | 0.5 |
| 1,2,3,4,7,8-hexaCDF | 0.1 | 0.1 | 0.1 |

Table 4.1. TCDD TEFs for dioxin, furan, and PCB congeners and hexachlorobenzene (cont.)

| Chemical^a | TEF for toxicity to mammals^b | TEF for toxicity to birds^c | TEF for toxicity to fish^c |
|-----------------------------------|--|--|---|
| 1,2,3,6,7,8-hexaCDF | 0.1 | 0.1 | 0.1 |
| 1,2,3,7,8,9-hexaCDF | 0.1 | 0.1 | 0.1 |
| 2,3,4,6,7,8-hexaCDF | 0.1 | 0.1 | 0.1 |
| 1,2,3,4,6,7,8-heptaCDF | 0.01 | 0.01 | 0.01 |
| 1,2,3,4,7,8,9-heptaCDF | 0.01 | 0.01 | 0.01 |
| OctaCDF | 0.0003 | 0.0001 | < 0.0001 |
| 3,3',4,4'-tetraCB (PCB77) | 0.0001 | 0.05 | 0.0001 |
| 3,4,4',5-tetraCB (PCB81) | 0.0003 | 0.1 | 0.0005 |
| 3,3',4,4',5-pentaCB (PCB126) | 0.1 | 0.1 | 0.005 |
| 3,3',4,4',5,5'-hexaCB (PCB169) | 0.03 | 0.001 | 0.00005 |
| 2,3,3',4,4'-pentaCB (PCB105) | 0.00003 | 0.0001 | < 0.000005 |
| 2,3,4,4',5-pentaCB (PCB114) | 0.00003 | 0.0001 | < 0.000005 |
| 2,3',4,4',5-pentaCB (PCB118) | 0.00003 | 0.00001 | < 0.000005 |
| 2',3,4,4',5-pentaCB (PCB123) | 0.00003 | 0.00001 | < 0.000005 |
| 2,3,3',4,4',5-hexaCB (PCB156) | 0.00003 | 0.0001 | < 0.000005 |
| 2,3,3',4,4',5'-hexaCB (PCB157) | 0.00003 | 0.0001 | < 0.000005 |
| 2,3',4,4',5,5'-hexaCB (PCB167) | 0.00003 | 0.00001 | < 0.000005 |
| 2,3,3',4,4',5,5'-heptaCB (PCB189) | 0.00003 | 0.00001 | < 0.000005 |
| Hexachlorobenzene | 0.0001 ^d | 0.0001 ^d | 0.0001 ^d |

TEF: Toxic Equivalency Factor (see text for explanation).

a. Dioxin, furan, or PCB congeners that are not listed in the table are assumed to have a TEF of zero, meaning they do not cause toxicity through the Ah receptor (see text for details).

b. From Van den Berg et al., 2006, except where noted.

c. From Van den Berg et al., 1998, except where noted.

d. From Appendix B.

Because individual dioxin, furan, and PCB congeners and hexachlorobenzene all act through the same toxicity mechanism, they often are treated as a single class when assessing the toxicity of a mixture of the chemicals. However, the individual congeners within the class are not all equally potent at binding to the Ah receptor and causing toxicity. Therefore, the relative toxic potency of each congener must be considered. To do this, the toxic potency of individual congeners is compared to the potency of 2,3,7,8-TCDD to translate the measured concentrations of individual chemicals into a toxicologically equivalent concentration of 2,3,7,8-TCDD. Then, the 2,3,7,8-TCDD equivalent concentrations of all of the congeners (including 2,3,7,8-TCDD) are added to produce a cumulative concentration of 2,3,7,8-TCDD that would have a toxic potency similar to the mixture. The sum of these 2,3,7,8-TCDD equivalent concentrations represents the concentration of only the congener 2,3,7,8-TCDD that would have the same toxic potency as the mixture of congeners that is present. This TCDD-eq concentration can then be compared to the extensive toxicological literature on the toxicity of 2,3,7,8-TCDD to organisms. This approach to evaluating the toxicity of environmental mixtures of dioxins, furans, and PCBs by converting the mixture concentration to an equivalent 2,3,7,8-TCDD concentration is termed the TCDD-eq approach. This approach has been widely used, has undergone extensive peer review, and has been shown to be effective at evaluating the toxicity of complex congener mixtures in the environment (U.S. EPA, 2003).

There are four criteria for including a chemical in the TCDD-eq approach (U.S. EPA, 2003): (1) the chemical must be structurally similar to 2,3,7,8-TCDD; (2) it must bind to the Ah receptor; (3) it must cause toxic effects similar to those caused by 2,3,7,8-TCDD; and (4) it must bioaccumulate. For a chemical to be included in the TCDD-eq approach, its toxicity relative to the toxicity of 2,3,7,8-TCDD must also be known.

The potency of individual dioxin, furan, and PCB congeners compared to 2,3,7,8-TCDD has been determined by an international group of experts. They considered the toxicological literature and developed consensus potency factors for individual congeners that are called TEFs. TEFs have been developed for dioxin, furan, and PCB congeners for mammals, birds, and fish (Table 4.1). The TEFs developed by the international group of experts have been widely used in toxicological evaluations and ecological risk assessments (U.S. EPA, 2003). Although the international group of experts did not develop a TEF for hexachlorobenzene, it also meets the criteria for inclusion in the TCDD-eq approach, and its TEF is included in Table 4.1 (from Appendix B).

The TCDD-eq approach is useful because it provides a method to assess the toxicity of mixtures of dioxins, furans, PCBs, and hexachlorobenzene. However, the approach considers only the toxicity of these chemicals that is caused through binding with the Ah receptor, and other types of toxicity are not considered in the TCDD-eq approach (U.S. EPA, 2003). Therefore, in addition to the TCDD-eq approach, I also assessed the toxicity of these chemicals by comparing measured concentrations directly to toxicity information for individual chemicals, where available.

4.3 Comparison of Facility Contaminant Concentrations to Soil, Sediment, and Surface Water Benchmarks of Environmental Contamination

4.3.1 Benchmarks of environmental contamination

I evaluated the chemical concentrations measured in facility soil, sediment, and surface water at and near the facility by comparing them to available benchmarks that have been established by various state, federal, and international agencies for evaluating environmental contamination. For 2,3,7,8-TCDD, TCDD-eq, PCBs, and hexachlorobenzene, sources of benchmarks of environmental contamination include:

- ▶ A compilation of available sediment benchmarks prepared in 2000 for Environment Canada (MacDonald et al., 2000). This compilation includes sediment contamination benchmarks from many different sources, including some of the sources specifically mentioned below.
- ▶ Ambient water quality criteria established by the U.S. EPA (for PCBs only; U.S. EPA, 2006b).
- ▶ Guidelines for the protection of wildlife developed by the Canadian Council of Ministers of the Environment (2003).
- ▶ Environmentally protective values developed by agencies of the government of the Netherlands (Stortelder et al., 1989; Liem et al., 1993; Verbruggen et al., 2001).
- ▶ Values developed by the U.S. EPA and NOAA as part of program-wide or regional ecological assessments of contamination (U.S. EPA, 1993a, 1995, 1999; MacDonald Environmental Sciences, 1999).
- ▶ Environmental quality guidelines developed by state or provincial governments (e.g., Persaud et al., 1993; NYSDEC, 1998).

The different benchmarks were developed using different underlying data and assumptions, but they all are designed as a means of evaluating actual or potential ecological harm caused by contaminants in soil, sediment, and surface water. Some of the soil and sediment benchmarks consider only direct toxicity to organisms, and some consider bioaccumulation up the food chain and subsequent toxicity to higher level predators. Moreover, the benchmarks were developed with different levels of protection in mind. The intended levels of protection can be grouped into the following categories:

- ▶ “Safe” levels of contamination, which are concentrations at and below which no adverse environmental effects are expected
- ▶ “Low” levels of contamination, which are concentrations at which adverse environmental effects are expected, but either the probability or the severity of the effects is relatively low
- ▶ “Severe” levels of contamination, which are concentrations at and above which severe environmental effects are expected, such as death or substantially reduced reproduction in many or most of the exposed organisms.

I relied on these benchmarks for several reasons. First, the benchmarks incorporate substantial effort in identifying, compiling, reviewing, and synthesizing the underlying original literature. In relying on original literature, many of the benchmarks also explicitly incorporate and reflect the variability that is inherent in environmental toxicity data. Second, the benchmarks were designed to be compared to environmental concentration data to identify sites or areas that are contaminated enough to pose threats to ecological receptors, which is the same objective that I have in this chapter. Third, the benchmarks have been widely used as effective tools for evaluating site contamination.

Soil

Table 4.2 lists contamination benchmark concentrations for TCDD-eq, hexachlorobenzene, and PCBs in soil. Only a few toxicity benchmarks are available for these chemicals in soil:

- ▶ For TCDD-eq, there is only a single value available, 3.0 parts per trillion (ppt) developed by an agency in the Netherlands that represents a safe level.
- ▶ For PCBs, only a single benchmark value of 1,300 ppb is available. This benchmark is the soil quality guideline developed by the Canadian Council of Ministers of the Environment for the protection of ecological resources, and it is also intended to identify a safe level of contamination.
- ▶ For hexachlorobenzene, the Netherlands has established a value of 24 ppb that represents a safe level of contamination, and the Canadian government has established a safe level of 50 ppb hexachlorobenzene. The Netherlands has also set a value of 2,000 ppb that represents a severe level of environmental contamination (termed “serious risk” in the supporting documents). Severe environmental contamination is defined by the Netherlands as the concentration at which toxicity to 50% of the species present is expected (Verbruggen et al., 2001).

Table 4.2. Benchmarks for assessing soil contamination of TCDD-eq, PCBs, and hexachlorobenzene based on ecological effects

| Contaminant | Value ^a | Benchmark type | Basis | Issuing agency | Citation |
|-------------------|-----------------------|---------------------|---------------------------------------|---|--|
| TCDD-eq | 3.0 pptr ^b | Safe level | Food chain bioaccumulation | Netherlands National Institute of Health and Environmental Protection | Liem et al., 1993 |
| PCBs (total) | 1,300 ppb | Safe level | Food chain bioaccumulation | Canadian Council of Ministers of the Environment | Canadian Council of Ministers of the Environment, 2003 |
| Hexachlorobenzene | 24 ppb | Safe level | Direct toxicity to soil invertebrates | Netherlands National Institute of Public Health and the Environment | Verbruggen et al., 2001 |
| | 50 ppb | Safe level | Not specified | Canadian Council of Ministers of the Environment | Canadian Council of Ministers of the Environment, 2003 |
| | 2,000 ppb | Severe effect level | Direct toxicity to soil invertebrates | Netherlands National Institute of Public Health and the Environment | Verbruggen et al., 2001 |

a. All concentrations are expressed on a dry weight soil basis.

b. Calculated using mammal TEFs.

Sediment

There are dozens of benchmarks available for TCDD-eq, PCBs, and hexachlorobenzene in sediment. Table 4.3 presents sediment benchmarks for these chemicals that have been issued by state, provincial, or federal agencies. The range in the values reflects different intended levels of protectiveness (e.g., safe, low effect, or severe effect levels), protection endpoints (e.g., direct toxicity to aquatic invertebrates or food chain bioaccumulation), different underlying toxicological databases, and different assumptions about ecological receptor exposure.

There is a single safe level benchmark available for TCDD-eq in sediment of 0.85 pptr, and two low effect levels of 15 and 21.5 pptr. The benchmarks for total PCBs in sediment range from 10 ppb to 150 ppb for safe levels and 70 ppb to 500 ppb for low effect levels, and there is a single value of 5,300 ppb for the severe effect level. MacDonald Environmental Sciences (1999) conducted a detailed evaluation of the available sediment benchmarks for PCBs in an attempt to develop “consensus” benchmarks from the wide range of available values. They concluded that consensus benchmarks for PCBs in sediment are approximately 40 ppb as a safe level, 400 ppb as a low effect level, and 1,700 ppb as a severe effect level (which they term an “extreme” toxicity level).

Table 4.3. Guidelines or criteria for sediment contamination

| Chemical | Value^a | Benchmark type | Freshwater (FW) or saltwater (SW) | Issuing agency | Citation |
|----------------------|--------------------------|---|--|--|--|
| TCDD-eq ^b | 0.85 pptr | Safe level | FW/SW | Canadian Council of Ministers of the Environment | Canadian Council of Ministers of the Environment, 2003 |
| TCDD-eq ^c | 15 pptr | Safe level | FW | Netherlands | Liem et al., 1993 |
| TCDD-eq ^b | 21.5 pptr | Low effect level | FW/SW | Canadian Council of Ministers of the Environment | Canadian Council of Ministers of the Environment, 2003 |
| PCBs – total | 10 ppb | Safe level | FW | Ontario | Persaud et al., 1993 |
| | 14 ppb ^d | Safe level | FW | New York State | NYSDEC, 1998 |
| | 20 ppb | Safe level | FW | Netherlands | As cited in MacDonald et al., 2000 |
| | 20 ppb ^d | Safe level | FW/SW | Environment Canada | As cited in MacDonald et al., 2000 |
| | 34.1 ppb ^d | Safe level | FW | Canadian Council of Ministers of the Environment | Canadian Council of Ministers of the Environment, 2003 |
| | 50 ppb | Safe level (for disposal of dredged material) | FW | Wisconsin | As cited in MacDonald et al., 2000 |
| | 50 ppb | Safe level (for disposal of dredged material) | FW | Ontario | As cited in MacDonald et al., 2000 |
| | 70 ppb | Low effect level | FW | Ontario | Persaud et al., 1993 |
| | 100 ppb ^d | Low effect level | FW/SW | Environment Canada | As cited in MacDonald et al., 2000 |
| | 150 ppb | Safe level | FW | Netherlands | As cited in MacDonald et al., 2000 |
| 200 ppb ^d | Low effect level | FW/SW | Environment Canada | As cited in MacDonald et al., 2000 | |

Table 4.3. Guidelines or criteria for sediment contamination (cont.)

| Chemical | Value^a | Benchmark type | Freshwater (FW) or saltwater (SW) | Issuing agency | Citation |
|-------------------------|--------------------------|-----------------------|--|------------------------|------------------------------------|
| PCBs – total (cont.) | 272 ppb | Low effect level | FW | British Columbia | As cited in MacDonald et al., 2000 |
| | 277 ppb | Low effect level | FW | Canada | As cited in MacDonald et al., 2000 |
| | 400 ppb | Not specified | FW | Netherlands | As cited in MacDonald et al., 2000 |
| | 500 ppb | Low effect level | FW | Oregon | As cited in MacDonald et al., 2000 |
| | 5,300 ppb | Severe effect level | FW | Ontario | Persaud et al., 1993 |
| | 40,000 ppb | Not specified | FW | Canada | As cited in MacDonald et al., 2000 |
| Hexachloro- benzene | 1.0 ppb | Safe level | FW/SW | Environment Canada | As cited in MacDonald et al., 2000 |
| | 1.4 ppb | Safe level | FW/SW | Netherlands | Verbruggen et al., 2001 |
| | 3.8 ppb | Safe level | SW | British Columbia | As cited in MacDonald et al., 2000 |
| | 3.8 ppb | Safe level | SW | State of Washington | As cited in MacDonald et al., 2000 |
| | 10 ppb | Safe level | FW | Ontario | Persaud et al., 1993 |
| | 10 ppb | Safe level | FW | British Columbia | As cited in MacDonald et al., 2000 |
| | 20 ppb | Low effect level | FW | Ontario | Persaud et al., 1993 |

Table 4.3. Guidelines or criteria for sediment contamination (cont.)

| Chemical | Value^a | Benchmark type | Freshwater (FW) or saltwater (SW) | Issuing agency | Citation |
|-------------------------------|--------------------------|---|--|-----------------------|------------------------------------|
| Hexachloro-benzene (cont.) | 20 ppb | Low effect level | FW | British Columbia | As cited in MacDonald et al., 2000 |
| | 20 ppb | Safe level | FW | Canada | As cited in MacDonald et al., 2000 |
| | 23 ppb | Low effect level | SW | British Columbia | As cited in MacDonald et al., 2000 |
| | 23 ppb ^d | Safe level | SW | State of Washington | As cited in MacDonald et al., 2000 |
| | 30 ppb | Low effect level | FW/SW | Environment Canada | As cited in MacDonald et al., 2000 |
| | 100 ppb ^d | Safe level | FW/SW | Environment Canada | As cited in MacDonald et al., 2000 |
| | 120 ppb ^d | Safe level | FW/SW | New York State | NYSDEC, 1998 |
| | 230 ppb | Safe level (for disposal of dredged material) | SW | British Columbia | As cited in MacDonald et al., 2000 |
| | 240 ppb ^d | Severe effect level | FW | Ontario | Persaud et al., 1993 |
| | 240 ppb | Severe effect level | FW | British Columbia | As cited in MacDonald et al., 2000 |
| | 2,000 ppb | Severe effect level | FW/SW | Netherlands | Verbruggen et al., 2001 |

a. Concentrations are expressed on a dry weight basis.

b. Calculated using TEFs for fish.

c. Calculated using TEFs for mammals.

d. Assumes 1% organic carbon content in sediment.

Safe level sediment benchmarks for hexachlorobenzene range from 1.0 ppb to 120 ppb (although most of the values are less than 20 ppb), whereas low effect level benchmarks range from 20 to 30 ppb. The overlap between the ranges of the safe and low effect levels reflects the variability inherent in the benchmarks from study to study, and also may result from the fact that there are far fewer low effect level benchmarks than safe level benchmarks available, and thus the low effect level benchmarks incorporate less variability. For the severe effect level, benchmark concentrations range from 240 ppb to 2,000 ppb hexachlorobenzene.

Surface water

For surface water, there are only a few criteria or standards available, all of which represent safe levels of chemicals in water (Table 4.4):

- ▶ For TCDD-eq, the Netherlands National Institute of Public Health and Environmental Protection established a criterion of 0.05 ppb (dissolved)
- ▶ For PCBs, the U.S. EPA has promulgated an ambient water quality criterion value of 0.014 ppb (total) (U.S. EPA, 2006b), and that value has been incorporated by many states (including Utah) as promulgated water quality standards
- ▶ For hexachlorobenzene, the Netherlands has proposed a water quality criterion of 0.00035 ppb (total) for the protection of wildlife (Stortelder et al., 1989).

Although there are only a few benchmarks available for these contaminants in surface water, the surface water data available for the USM facility is also sparse. These data do not provide much additional insight into environmental threat at the facility's ditches and ponds beyond that provided by the sediment data for these areas.

4.3.2 Facility concentration data compared to environmental benchmarks

I compared the range of concentrations at the facility to the range of benchmarks. Given that the range of benchmarks represent a range of underlying assumptions and methods, the more benchmarks that concentrations at the facility exceed, and the larger the exceedences, then the greater the probability that concentrations at the facility are high enough to harm environmental resources.

Table 4.4. Guidelines or criteria for surface water contamination

| Chemical | Value | Benchmark type | Freshwater (FW) or saltwater (SW) | Issuing agency | Citation |
|----------------------|-----------------------|----------------|-----------------------------------|---|--------------------------|
| TCDD-eq ^a | 0.05 pptr (dissolved) | Safe level | FW/SW | Netherlands National Institute of Public Health and Environmental Protection | Liem et al., 1993 |
| PCBs-total | 0.014 ppb (total) | Safe level | FW/SW | U.S. EPA | U.S. EPA, 2006b |
| Hexachloro-benzene | 0.00035 ppb (total) | Safe level | FW | Netherlands Ministries of Housing, Physical Planning & Environment and Transport and Public Works | Stortdelder et al., 1989 |

a. TCDD-eq calculated using mammal TEFs.

Soil contamination

Figure 4.1 plots concentrations of TCDD-eq (using mammals TEFs), PCBs, and hexachlorobenzene in surface soil at the facility against the benchmarks listed in Table 4.2. The plots are on a logarithmic scale so that the concentrations and benchmarks can all be seen. The differences between benchmark concentrations and concentrations at the facility are so great that the benchmarks cannot be seen on the plot using a regular scale.

The TCDD-eq safe soil benchmark (3.0 pptr) is exceeded in at least one sample from each of the waste areas at the facility, as well as in one of the samples from the reference area. Concentrations in samples from the sanitary lagoon, gypsum pile, and selected areas of the old waste pond (particularly in the area of the former inlet to the pond, as described in Chapter 3) are hundreds to thousands of times higher than the benchmark. TCDD-eq soil concentrations in other areas at the facility also exceed the benchmark, but by a lesser amount. Hexachlorobenzene concentrations compared to benchmarks are similar: soil concentrations in the sanitary lagoon, gypsum pile, and selected areas of the old waste pond exceed the safe soil benchmarks by many hundreds to thousands of times, and they are many times greater than the severe effect level benchmark (2,000 ppb). Some hexachlorobenzene soil concentrations in other facility areas also exceed the safe benchmarks. In contrast to TCDD-eq and hexachlorobenzene, only a few of the samples from the sanitary lagoon, gypsum pile, and old waste pond exceed the safe benchmark for PCBs of 1,300 ppb.

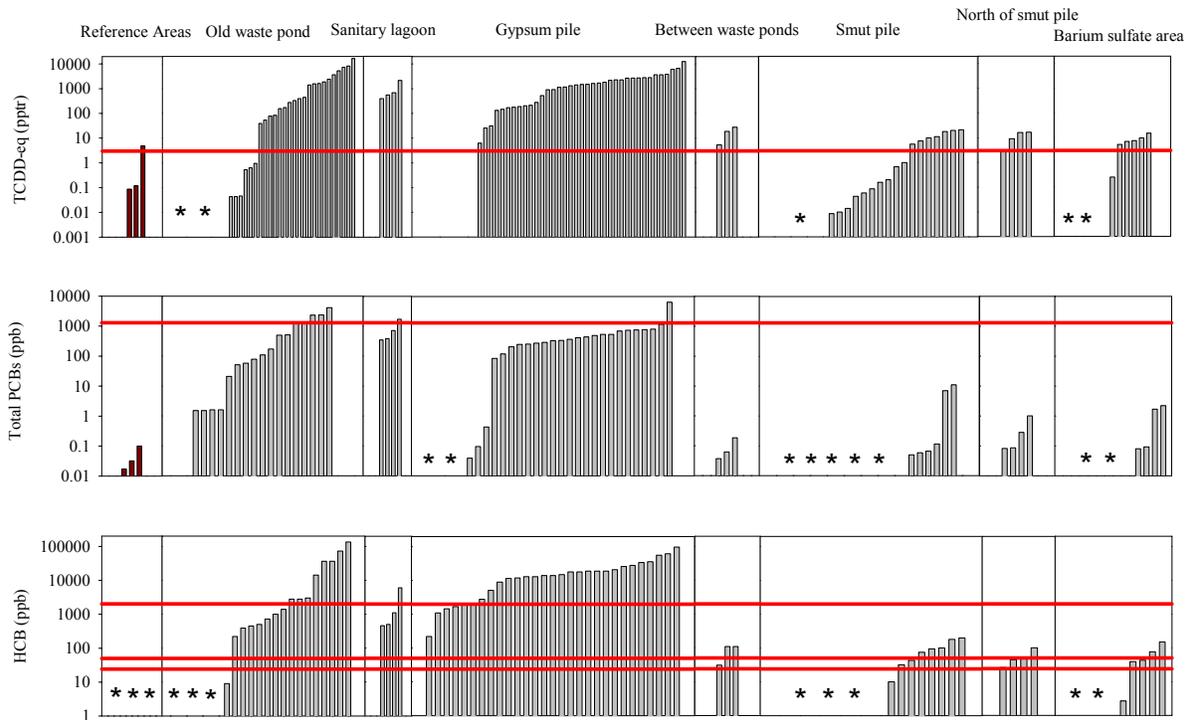


Figure 4.1. Surface soil concentrations at the site compared to toxicity benchmarks. “*” means that the concentrations are less than the detection limit. Note that the scale is logarithmic.

Sediment contamination

Surface sediment contamination data are available for the active waste pond, old waste pond, barrow pits, and sanitary lagoon. Figure 4.2 plots facility concentrations against the benchmarks listed in Table 4.3.

TCDD-eq concentrations in sediments of the active waste pond exceed the safe and low effect level benchmarks by many thousands of times (no severe effect level benchmark is available). Some samples from the area of the old waste pond near the former inlet also exceed the safe and low effect level benchmarks by thousands of times, whereas samples from other areas of the old waste pond exceed none of the benchmarks or only the lowest safe benchmark. All samples from the sanitary lagoon and barrow pits also exceed the lowest safe level benchmark, and some of the samples exceed all of the benchmarks.

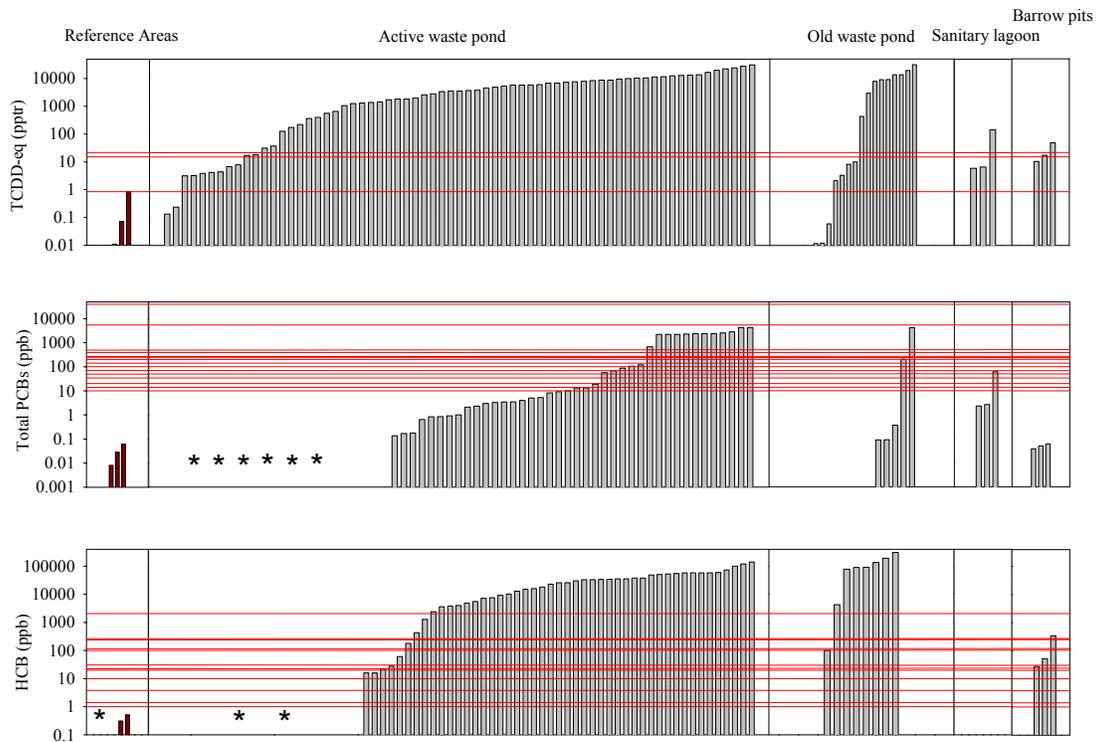


Figure 4.2. Surface sediment concentrations at the site compared to toxicity benchmarks. “*” means that the concentrations are less than the detection limit. Note that the scale is logarithmic.

For PCBs, most samples from the active waste pond and two samples from the old waste pond exceed most of the benchmarks, including the consensus severe effect level benchmark from MacDonald Environmental Sciences (1999) of 1,700 ppb. The remaining samples from the old waste pond, as well as the samples from the barrow pits, do not exceed any of the benchmarks.

Hexachlorobenzene concentrations in sediments of the active waste pond and the old waste pond exceed all of the benchmarks, including the benchmarks for severe effects. Concentrations are hundreds to thousands of times higher than the safe level and low effect level benchmarks, and up to hundreds of times higher than the severe effect level benchmarks. In the barrow pits, sediment hexachlorobenzene concentrations are higher than two of the three severe effect level benchmarks or fall between the low effect level and severe effect level benchmarks.

Surface water contamination

There are no facility data on dissolved concentrations of TCDD-eq in surface water, so no comparison to the benchmark can be made.

There is a single surface water sample from the active waste pond that has been analyzed for PCBs, and the sample had a concentration of 0.65 ppb, which is many times greater than the safe level of 0.014 ppb. Similarly, hexachlorobenzene concentrations of 9.4, 14, and 25.8 ppb measured in the three surface water samples from the active pond are many thousands of times greater than the safe level benchmark of 0.00035 ppb.

4.3.3 Summary

Based on a comparison of organochlorine chemical concentrations at the facility with safe, low effect, and severe effect level benchmarks, I conclude that the contamination in the soils, sediments, and surface water at the facility is a threat to ecological resources in the area.

The concentrations of TCDD-eq and hexachlorobenzene in the soils and sediments at the USM facility are hundreds to thousands of times greater than safe levels, and many times greater than severe effect levels. These areas are the sanitary lagoon, gypsum pile, active waste pond, and the area of the old waste pond near the former inlet. The severe effect levels generally represent concentrations at and above which serious effect to the environment are expected. For example, benchmarks developed by the Netherlands define severe effect as mortality to 50% of the species that are exposed to the chemical. The exceedences of severe effect level benchmarks in soils and sediments at the facility is consistent with the observations of the sediments of the old waste pond, in which brine fly larvae were “virtually absent” during surveys performed by consultants to USM in 2004 (Parametrix, 2004).

The concentrations of TCDD-eq and hexachlorobenzene in other contaminated areas at the facility also exceed safe level benchmarks. These areas include the smut pile, barrow pits, areas of the old waste pond other than the area near the former inlet, and areas north of the smut pile and between the two waste ponds. Although these areas cannot be considered safe for ecological resources, the degree of contamination in these areas appears to be much less than in other areas at the facility where severe effect level benchmarks are exceeded by many times.

4.4 Dietary Exposure of Birds and Mammals to Chlorinated Hydrocarbons at the Facility

Chapter 2 lists bird and mammal species that have been observed or are expected to be found at or near the facility. Exposure of predatory wildlife to the dioxins, furans, PCBs, and hexachlorobenzene at the USM facility is of particular concern, since these contaminants biomagnify up food chains and reach their highest concentrations in the diets of top-level predators. Examples of predatory wildlife that have been documented at or near the USM facility include coyote, badger, weasel, barn owl, golden eagle, loggerhead shrike, and raven. Wildlife that consume invertebrates, such as many species of shorebirds, swallows, California gull, western meadowlark, horned lark, killdeer, magpie, and wildlife that consume plants, such as mice, rabbits, mule deer, and antelope, have also been documented at or near the USM facility and are exposed to contaminants in their diets.

From the evaluation of soil, sediment, and surface water contamination at the facility, I concluded that the contamination at the facility is a threat to the environment. To verify that conclusion and to obtain more specific information on the harm to the environment, I compare concentrations in plants, invertebrates, and mice (which are all consumed by birds and mammals) at the facility with benchmarks for contamination in wildlife diet. This evaluation also provides more specific information on the nature of the threats to wildlife at the facility.

4.4.1 TCDD-eq

I evaluated the combined dietary toxicity of dioxins, furans, PCBs, and hexachlorobenzene that occurs through the Ah receptor using the TCDD-eq approach. I calculated TCDD-eq concentrations from data on chemical concentrations in wildlife dietary items, and compared the TCDD-eq concentrations to toxicological literature on the toxicity of 2,3,7,8-TCDD to wildlife through dietary exposure.

Dietary concentrations causing toxicity to wildlife

Using data from controlled laboratory studies on the dietary toxicity of 2,3,7,8-TCDD or 2,3,7,8-TCDD-like chemicals to birds and mammals, federal and state agencies have developed dietary threshold or guideline concentrations for the protection of wildlife (Table 4.5). These values integrate the fairly extensive toxicological literature on the dietary toxicity of 2,3,7,8-TCDD to birds and mammals. The benchmarks shown in Table 4.5 use standard assumptions regarding food consumption rates and sensitivity to 2,3,7,8-TCDD toxicity, and develop values or ranges that are protective of wildlife that consume food that is contaminated with 2,3,7,8-TCDD or similar compounds. The types of adverse effects taken into consideration include reduced ability to reproduce and death. It should be noted that none of the dietary thresholds shown in Table 4.5 are

Table 4.5. Wildlife protection benchmarks for TCDD-eq in diet

| Wildlife type | Safe benchmark for TCDD-eq in diet ^a | Issuing agency | Citation |
|-------------------|---|---|--|
| Birds and mammals | 10-12 pptr | U.S. Fish and Wildlife Service | Eisler, 1986 |
| Birds | 3-14 pptr | U.S. EPA | U.S. EPA, 1993a |
| Birds | 4.75 pptr | Canadian Council of Ministers of the Environment | Canadian Council of Ministers of the Environment, 2003 |
| Mammals | 2.3 pptr | New York State Department of Environmental Conservation | Newell et al., 1987 |
| Mammals | 0.5-1.0 pptr | U.S. EPA | U.S. EPA, 1993a |
| Mammals | 0.7 pptr | Canadian Council of Ministers of the Environment | Canadian Council of Ministers of the Environment, 2003 |

a. TCDD-eq concentrations are calculated using either bird or mammal TEFs depending on which type of organism the threshold is for. Concentrations are based on wet weight of diet consumed.

based on studies using chickens, which appear to be much more sensitive to 2,3,7,8-TCDD toxicity than any of the wild bird species tested to date.

Therefore, the concentrations shown in Table 4.5 represent safe levels of TCDD-eq in wildlife diet at and below which there are little or no effects on wildlife. As shown in the table, safe level benchmarks for TCDD-eq in diet are fairly consistent across agencies. The benchmarks also tend to be lower for mammals than for birds, indicating that mammals tend to be more sensitive to 2,3,7,8-TCDD toxicity than birds. At dietary concentrations higher than those listed in the table, wildlife are at risk from toxicological effects that include death and reduced ability to reproduce.

Comparison of facility data to wildlife dietary benchmarks for TCDD-eq

Figure 4.3 plots TCDD-eq concentrations in mice, invertebrates, and plants collected from the USM facility and compares the concentrations to the benchmarks listed in Table 4.5 for dietary toxicity to birds. As shown in the figure, samples of mice, invertebrates, and plants collected from the sanitary lagoon contain TCDD-eq concentrations that are hundreds of times higher than safe levels. Mice from all other areas across the facility also exceed the safe levels, by factors of up to 10. Some samples of invertebrates and plants from areas other than the sanitary lagoon also exceed some of the safe level benchmarks.

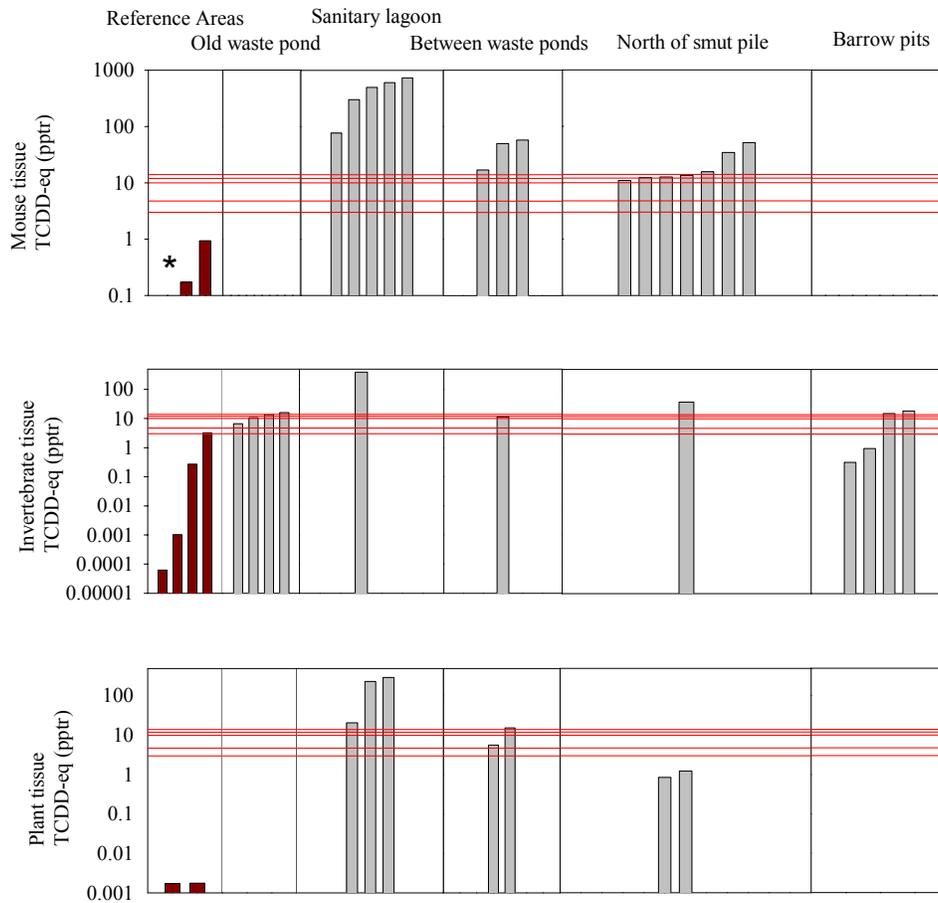


Figure 4.3. TCDD-eq concentrations in mice, invertebrates, and plants compared to dietary toxicity benchmarks for birds. “*” means that all compounds that are included in the TCDD-eq calculation were below detection limits. Note that the scale is logarithmic.

Figure 4.4 plots TCDD-eq concentrations in mice, invertebrates, and plants and compares the concentrations to the dietary toxicity benchmarks for mammals listed in Table 4.5. The results are similar to those for birds, except that the concentrations exceed the safe levels by a greater amount since the safe levels for mammals are lower than for birds. Food items from the sanitary lagoon are the most contaminated, and concentrations of TCDD-eq in mice, invertebrates, and plants from this area are many hundreds of times higher than safe dietary levels for mammals. Mice from other areas at the facility also have concentrations that exceed the safe dietary levels, by 10 times or more. Invertebrate and plant samples from areas other than the sanitary lagoon also exceed some of the safe dietary levels.

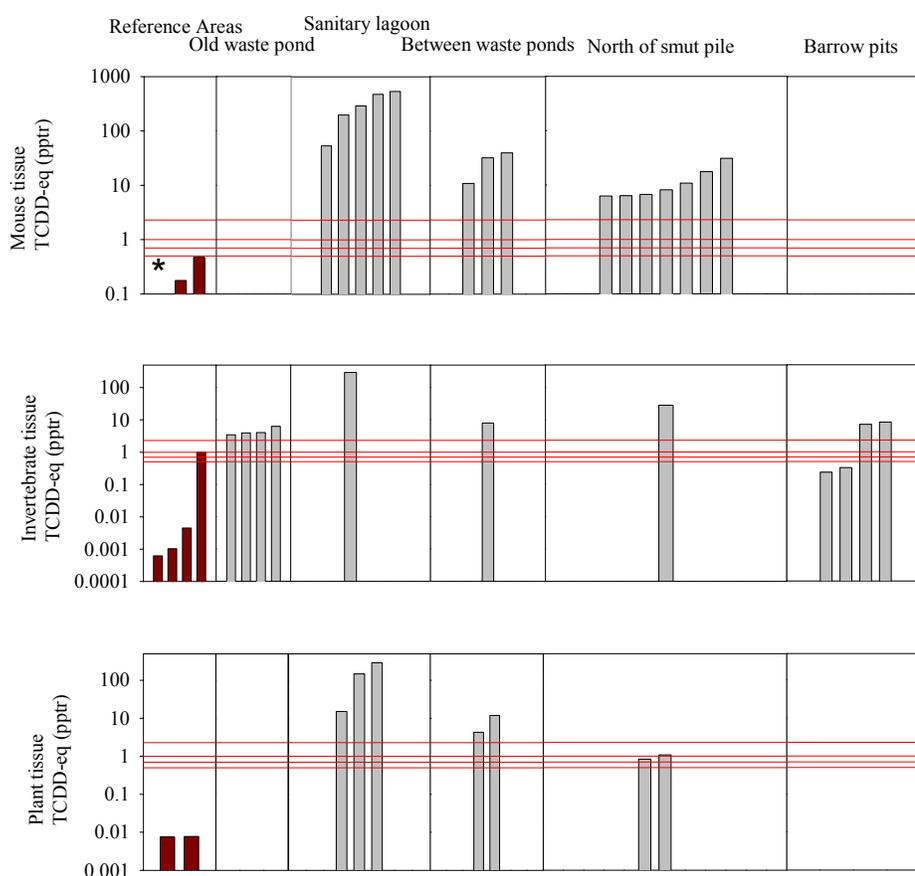


Figure 4.4. TCDD-eq concentrations in mice, invertebrates, and plants compared to dietary toxicity benchmarks for mammals. “*” means that all compounds that are included in the TCDD-eq calculation were below detection limits. Note that the scale is logarithmic.

I conclude from this comparison that birds and mammals that feed at or near the facility are exposed to concentrations of chemicals in their diet that greatly exceed safe levels, and therefore that the contamination is a threat to wildlife that feed there.

4.4.2 Hexachlorobenzene

Hexachlorobenzene is included in the calculations of TCDD-eq presented above. The TCDD-eq method considers only the toxicity of hexachlorobenzene that is caused through the Ah receptor mechanism, similar to 2,3,7,8-TCDD. However, hexachlorobenzene is relatively weak in causing toxicity through the Ah receptor mechanism, and it causes toxicity to wildlife through mechanisms other than the Ah receptor (Hahn et al., 1989). In addition, there are data available from laboratory toxicity studies in which birds or mammals are exposed through the diet to this chemical alone. Therefore, in addition to considering hexachlorobenzene toxicity with the TCDD-eq approach described above, I also assessed the potential for hexachlorobenzene alone to harm wildlife at the facility through dietary consumption.

Dietary concentrations causing toxicity to wildlife

The dietary toxicity of hexachlorobenzene to mammals has been well studied. The International Programme on Chemical Safety (1997) provides a literature review on the toxicity of hexachlorobenzene to mammals. Most of the studies have been conducted on rodents, such as mice and rats, but some other species, such as mink, ferret, cat, dog, monkey, and pig, have also been studied. Hexachlorobenzene tends to be most toxic when fed to females before, during, or after pregnancy, with animal reproduction being particularly susceptible to the chemical. For example, maternal doses from 1,400 to 4,000 ppb in the diet of rats and cats cause reduced litter sizes, reduced offspring survival, reduced offspring growth, and liver toxicity (International Programme on Chemical Safety, 1997).

Badgers have been observed at and near the USM facility, and as predators they can be highly exposed to hexachlorobenzene in their diet. There is no hexachlorobenzene toxicity data available specifically for badgers, but studies have been conducted on mink, which are in the same family as badgers (mustelidae). In one study, mink fed diets with 1,000 ppb hexachlorobenzene had increased infant mortality (Rush et al., 1983), and in another study the same dose caused reduced infant birth weights (Bleavins et al., 1984). In both of these studies, 1,000 ppb was the lowest dose tested (besides the control dose of 0 ppb), so a safe level cannot be determined.

There are fewer studies available on the dietary toxicity of hexachlorobenzene to birds. Table 4.6 lists the lowest effect concentrations observed in studies where hexachlorobenzene was fed to birds. The effects observed at the concentrations listed in the table include liver damage, decreases in egg production or chick survival, or porphyria, which is a disruption in the synthesis of heme, a key component of hemoglobin and other enzymes. For most of the studies, more severe effects, including mortality, were observed at higher concentrations, but only the lowest dose that caused toxicity is shown. The lowest effect concentration listed in Table 4.6 is 5,000 ppb in food given to Japanese quail for 90 days, with porphyria and enlargement of the liver observed at this dose (Vos et al., 1971). No effects were observed in the study at the next lowest dose of 1,000 ppb in diet, so the safe level in the study is somewhere between 1,000 and 5,000 ppb in diet.

Table 4.6. Lowest effect concentrations in laboratory studies on the dietary toxicity of hexachlorobenzene to birds

| Organism | Duration | Effect concentration (in diet) | Effect | Citation |
|-----------------|-----------------|---|--|----------------------|
| Japanese quail | 90 days | 5,000 ppb | Liver damage; enlarged liver; porphyria | Vos et al., 1971 |
| Japanese quail | 90 days | 20,000 ppb (fed to egg-laying females) | Decreased survival of chicks | Schwetz et al., 1974 |
| Japanese quail | Not reported | 20,000 ppb | Signs of porphyria; decreased reproduction | Vos et al., 1969 |
| Japanese quail | 14 days | 80,000 ppb | Signs of porphyria | Fletcher, 1972 |
| Chicken | 7 days | 100,000 ppb | Delay in egg production | Hansen et al., 1978 |

Comparison of facility data to dietary hexachlorobenzene concentrations causing toxicity to wildlife

Hexachlorobenzene concentrations in samples of mice, invertebrates, and plants from the sanitary lagoon are all greater than 1,000 ppb, a concentration that causes toxicity to mink. Concentrations in two of three mice samples, the single invertebrate sample, and one of three plant samples from the sanitary lagoon area are between 1,900 and 2,800 ppb. Hexachlorobenzene concentrations in mice, invertebrates, and plants from all other facility areas are less than 1,000 ppb, although the safe level for hexachlorobenzene in mink diet is not known. Hexachlorobenzene concentrations from all of the facility areas are less than the 5,000 ppb shown to cause toxicity to birds.

4.4.3 Incidental ingestion of contaminated soil and sediment

Most wildlife incidentally ingest soil or sediment while they are feeding and/or grooming (U.S. EPA, 1993b). For example, semipalmated sandpipers, which feed by sticking their bills into the mud to find invertebrates, take in approximately 1 part mud for every 2 parts of food (U.S. EPA, 1993a, 1993b). Many other bird and mammal species consume approximately 2% to 20% of their diet as soil or sediment (U.S. EPA, 1993a, 1993b). Moreover, some wildlife species intentionally ingest soil or sediment to obtain nutrients (U.S. EPA, 1993a, 1993b). Some birds gather mud for nest building, and many birds ingest sand or grit to aid in food digestion (Terres, 1980). Therefore, wildlife that feed at the USM facility are exposed not only to organochlorine chemicals in the plants and animals they consume, but also in the soil and sediment that they incidentally ingest while feeding.

The evaluation of TCDD-eq and hexachlorobenzene contamination in wildlife dietary items presented above does not take into account the additional dose of contaminants that wildlife feeding at the facility receive from incidental ingestion of soil or sediment. Soil and sediment at the facility are highly contaminated with organochlorine chemicals, and as wildlife feed there they will receive an additional dose of these chemicals from the contaminated soil and sediment. However, this additional dose from soil or sediment is difficult to quantify, and there are uncertainties as to the bioavailability of contaminants in soil or sediment compared to their bioavailability when accumulated in prey tissue.

Many soil and sediment samples from the facility contain concentrations in excess of 1,000 ppt TCDD-eq. If a bird or mammal consumes 2% of its diet as soil or sediment from these areas, it would consume in excess of 20 ppt TCDD-eq through soil or sediment ingestion alone, which exceeds all of the safe levels for wildlife diet. Therefore, the incidental ingestion of contaminated soil or sediment at the facility alone can exceed safe dietary levels. When combined with the analysis presented above for chemicals in wildlife prey items (plants, invertebrates, and mice), it strengthens the conclusions that the dietary intake of chemicals by wildlife at the facility greatly exceeds safe levels.

4.4.4 Summary of wildlife dietary exposure

Concentrations of organochlorine chemicals have been measured at the facility in mice, aquatic and terrestrial invertebrates, and plants, all of which are consumed by birds and mammals. Based on a comparison of the concentrations in these wildlife food items with benchmarks, I conclude that the contamination at the facility poses a threat to wildlife that feed at and near the facility. This conclusion is consistent with and confirms the evaluation of soil, sediment, and surface water contamination.

Concentrations of TCDD-eq in mice, invertebrates, and plants from the sanitary lagoon at the USM facility are many times greater (most are many hundreds of times greater) than safe levels for birds and mammals. Mice from other areas at the facility are also contaminated at levels that are up to 10 times greater than safe levels. Some invertebrate and plant samples also contain TCDD-eq concentrations that are greater than the safe levels.

Hexachlorobenzene concentrations in mice, invertebrates, and plants at the facility are only slightly less than concentrations that have been shown to cause toxicity to mink (which is in the same family as the badger, which live near the facility).

When incidental ingestion of soil or sediment is also considered, the dietary intake of chemicals by wildlife at the facility is higher than that measured in prey items alone. Birds and mammals consume soil or sediment incidentally while feeding, and this incidental ingestion will add to the chemical doses received by wildlife in their food. When this additional dose is considered, it strengthens my conclusion that wildlife at the facility consume chemicals above safe levels.

4.5 Chlorinated Hydrocarbons in Bird Eggs Near the Facility

In 2004, 2005, and 2006, the U.S. EPA collected snowy plover, American avocet, and horned lark eggs from nests at and near the USM facility and analyzed them for contaminants. The nests were located on the bed of the old waste pond, on the bed of solar evaporation ponds adjacent to the facility, in areas between the active and old waste ponds, or along the shore of the Great Salt Lake near the facility (Figure 4.5 and Figure 4.6). Eggs were also collected from several areas along the Great Salt Lake as reference samples. This section compares the concentrations of TCDD-eq and hexachlorobenzene in the eggs to concentrations that are known to cause toxicity to bird eggs.

The bird egg contaminant data provide another means by which threats to wildlife from contamination at and from the facility should be assessed. Because of its location, many birds of many species frequent the area at and near the facility, and many birds nest in the area. The bird egg data provide a way to directly assess a specific type of toxicity that may be occurring at the facility because of the contamination, toxicity to developing bird eggs.

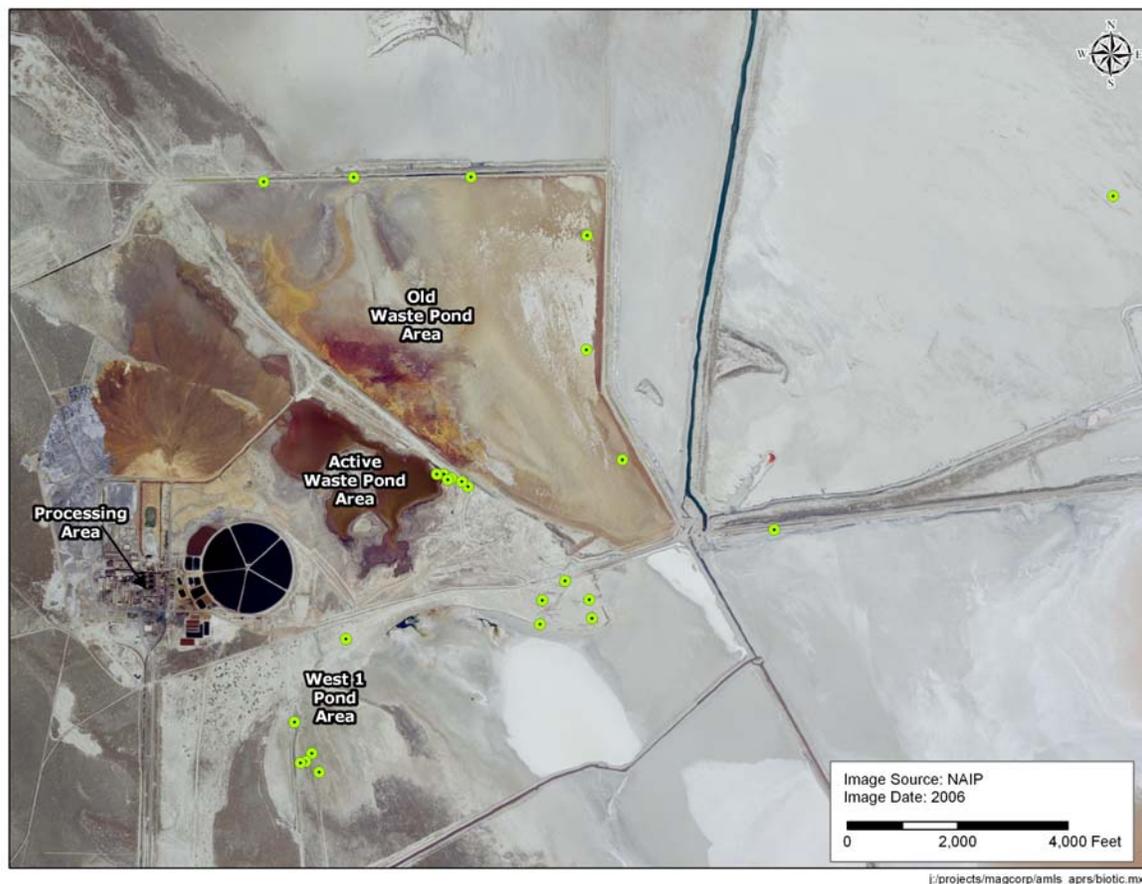


Figure 4.5. Bird egg collection locations at and near the facility.

4.5.1 TCDD and TCDD-like chemicals

Background on toxicity to bird eggs

2,3,7,8-TCDD and similar chemicals are incorporated into bird eggs as the eggs form within the mother bird's body. Maternal birds that are exposed to the chemicals in their diets deposit the chemicals into eggs as the eggs are formed within their oviducts. The toxic effects of these chemicals on bird eggs have been studied extensively in laboratory studies in which the chemicals are injected into clean eggs. At high enough concentrations, 2,3,7,8-TCDD and similar chemicals in bird eggs can kill the developing embryo. At lower concentrations, these chemicals cause skeletal deformities, heart deformities, reduced chick size, and altered biochemistry.



Figure 4.6. Snowy plover standing at a nest on the old waste pond bed.

Different bird species have different sensitivities to the toxicity of 2,3,7,8-TCDD and similar chemicals. Of the approximately 20 bird species that have been tested, the chicken is the most sensitive to 2,3,7,8-TCDD and similar chemicals in eggs (Barron et al., 1995). Concentrations of approximately 100 to 200 pg/g TCDD-eq in chicken eggs cause high rates of egg mortality (Brunstrom, 1989; Powell et al., 1996; Henshel et al., 1997). Concentrations that cause mortality in the eggs of other bird species are typically 10 or more times higher than these concentrations (Brunstrom, 1988; Nosek et al., 1993; Hoffman et al., 1995, 1996, 1998; Powell et al., 1997, 1998; Custer et al., 2005). The sensitivities to 2,3,7,8-TCDD toxicity of snowy plovers, American avocets, and horned larks, the three species whose eggs were collected from the USM facility and nearby areas and analyzed for contaminants, have not been studied.

Sublethal effects of 2,3,7,8-TCDD and similar chemicals to bird eggs have been studied less often than egg mortality. Nevertheless, studies have shown that these chemicals cause toxic effects at egg concentrations less than those that cause direct death to the eggs. Sublethal effects that have been observed in developing embryos or hatched chicks include (Peterson et al., 1993; Carey et al., 1998; Hoffman et al., 1998):

- ▶ Various kinds of deformities in the developing embryo, including skeletal deformities, heart deformities, and edema, which is an accumulation of excessive fluid in tissues that causes swelling
- ▶ Reduced growth
- ▶ Alterations in biochemistry, particularly of the liver.

The results of the Hoffman et al. (1998) study on American kestrel eggs are used here to assess the contamination in bird eggs at the USM facility for the following reasons:

1. The study focuses on sublethal toxicity rather than just egg mortality in a wild species. There no other studies on wild bird species that investigated sublethal endpoints as fully as the Hoffman et al. (1998) study.
2. From the available toxicological data, the American kestrel falls somewhere in the middle of the range of sensitivities to 2,3,7,8-TCDD toxicity of the bird species that have been tested so far, and therefore results for this species may be more generally applicable to snowy plovers, American avocets, and horned larks than results from other test species. However, it should be pointed out that the sensitivity of American avocet, snowy plover, and horned lark to 2,3,7,8-TCDD toxicity is not known, and they may be more or less sensitive than the American kestrel.
3. The study was conducted using a robust experiment design, produced statistically significant results, and was published in a peer-reviewed journal.

Therefore, the Hoffman et al. (1998) study is the best and most appropriate study to use in evaluating the concentrations measured in the bird eggs collected at and near the USM facility.

Hoffman et al. (1998) injected American kestrel eggs with the PCB congener PCB126, which acts similarly to 2,3,7,8-TCDD and has an avian TEF of 0.1, meaning that it is approximately 10 times less potent than 2,3,7,8-TCDD in causing toxicity to birds. For example, a PCB126 concentration of 1,000 pptr in an egg is equivalent to a concentration of 2,3,7,8-TCDD of 100 pptr. In the Hoffman et al. (1998) study, a concentration of approximately 65,000 pptr of PCB126 (or 6,500 pptr TCDD-eq) caused mortality to approximately 50% of the eggs that were injected. However, sublethal effects occurred at much lower concentrations. At 230 pptr of PCB126

injected into eggs (or 23 pptr TCDD-eq), which was the lowest dose tested, total weight (not including the yolk sac), liver weight, and femur length in embryos at hatching were all significantly reduced compared to control kestrels. At the next highest dose of 2,300 pptr of PCB126 (230 pptr TCDD-eq), embryo liver weights were decreased relative to controls, and a higher incidence of malformations or edema (which is an abnormal swelling of tissue) was observed in dosed birds (42%) versus control birds (12%). At 23,000 pptr of PCB126 injected into eggs (2,300 pptr TCDD-eq), reductions in total weight and liver weight were also observed, and the frequencies of malformations and edema were higher than at the lower doses. These effects are all consistent with the effects caused by 2,3,7,8-TCDD and related compounds (Hoffman et al., 1998).

Therefore, 23 pptr is a low effect toxicity level for TCDD-eq in bird eggs, and at 230 pptr the effects are more severe.

Concentrations measured in eggs collected near the facility

In 2004, 2005, and 2006, the U.S. EPA collected and analyzed the eggs of three different bird species from nests at or near the facility: snowy plover, American avocet, and horned lark. Snowy plover and American avocet are both shorebird species, meaning that they feed and nest along the shores of lakes and ponds, and they consume primarily insects and other invertebrates that they find along shorelines. The horned lark is a small land bird that nests on the ground and eats primarily invertebrates such as insects, spiders, and snails. Snowy plover and American avocet eggs were also collected from reference areas on the shore of the Great Salt Lake well away from the facility.

Figure 4.7 compares TCDD-eq in the eggs of snowy plovers, American avocets, and horned larks against the results of the Hoffman et al. (1998) study. The highest TCDD-eq concentration is in a horned lark egg collected from between the old and active waste ponds, at 788 pptr, which is more than three times higher than the 230 pptr concentration that caused more severe toxic effects to eggs in the Hoffman et al. (1988) study. All of the other eggs collected from this area, which were snowy plover eggs, had TCDD-eq concentrations above the 23 pptr level, ranging up to 216 pptr. Similarly, all of the eggs collected from the old waste pond, which were snowy plover eggs, exceed 23 pptr TCDD-eq. Most of the eggs from the old waste pond have concentrations that are at least two times greater than 23 pptr, and several are four or more times greater. At and near the West-1 pond adjacent to the USM facility, two snowy plover eggs had concentrations of 262 pptr and 331 pptr, which are more than 10 times greater than the 23 pptr level and greater than the 230 pptr level. In addition, concentrations in two American avocet eggs and three horned lark eggs from the West-1 Pond area exceed 23 pptr.

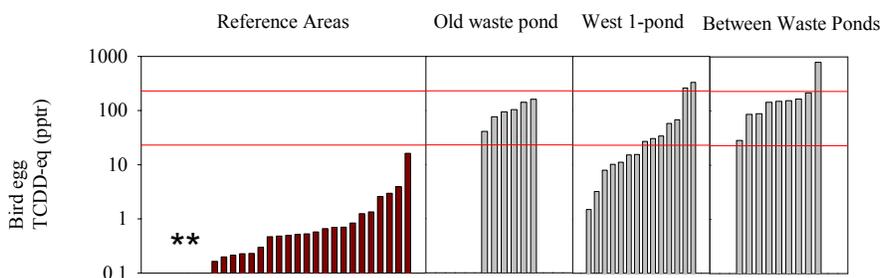


Figure 4.7. TCDD-eq concentrations in bird eggs from at and near the facility and from reference areas. “**” means that all compounds that are included in the TCDD-eq calculation were below detection limits. Note that the scale is logarithmic.

I conclude therefore that the concentrations of TCDD-eq in bird eggs from and near the facility are greater than concentrations that are toxic to bird eggs. If TCDD-eq is as about or more toxic to American avocets, snowy plovers, or horned larks than to the comparison species of American kestrel, then the chicks that hatch from nests at and near the facility suffer from significantly decreased weights and various deformities. These effects can decrease the ability of the hatched chicks to survive in the wild.

4.5.2 Hexachlorobenzene

Background on toxicity to bird eggs

The toxicity of hexachlorobenzene in eggs to developing bird embryos has been studied in both laboratory and field settings, although only a handful of species have been tested. The papers I reviewed are Avrahami and Steele (1972); Schwetz et al. (1974); Boersma et al. (1986); Jarman et al. (1996); and de Roode et al. (2002).

Of these studies, the Boersma et al. (1986) study provides the most relevant and useful data for comparison to hexachlorobenzene concentrations in bird eggs collected from and near the USM facility. The Boersma et al. (1986) study, which was conducted on herring gulls, uses a robust study design, provides a comprehensive statistical analysis of the test data, and includes the widest array of toxicity endpoints. At 1,500 ppb hexachlorobenzene in eggs, the lowest dose tested, embryo weight was reduced, and at 5,000 ppb, most of the eggs died. A dose of 4,300 ppb was calculated to cause death to approximately 50% of the eggs.

Concentrations measured in eggs collected near the facility

A horned lark egg collected from between the old and active waste ponds contained a concentration of 7,190 ppb hexachlorobenzene, which is well above the 5,000 ppb concentration that killed most of the bird eggs in the Boersma et al. (1986) study.

The other egg hexachlorobenzene concentrations are all less than 1,500 ppb, which is the concentration at which reduced embryo size was observed in the Boersma et al. (1986) study. Snowy plover eggs from nests on the beds of the old waste pond and West-1 Pond have concentrations in the range of 500 ppb to 900 ppb. Although these concentrations are less than the 1,500 ppb value, they still may be sufficient to cause toxicity to the eggs. First, in the Boersma et al. (1986) study, 1,500 ppb was the lowest dose tested, so effects may occur at lower concentrations as well. Second, if snowy plovers are only slightly more sensitive to hexachlorobenzene toxicity than herring gulls, then the concentrations measured in the plover eggs at and near the facility are sufficient to cause harm.

Therefore, I conclude that hexachlorobenzene concentrations in some eggs at and near the facility are sufficient on their own to cause severe toxicity to eggs. Concentrations in many of the eggs are in the range of possible toxicity.

4.6 Conclusions

I conducted three independent analyses to assess the potential for organochlorine chemicals at and from the facility to harm environmental resources: (1) a comparison of chemical concentrations measured in soil, sediment, and surface water to multiple environmental benchmarks, including safe, low effect, and severe effect level benchmarks; (2) a comparison of chemical concentrations measured in wildlife dietary items to safe level benchmarks or observed effect levels for wildlife diet; and (3) a comparison of chemical concentrations measured in bird eggs with observed effect levels. The three comparisons are independent in that they rely on separate environmental data from the facility and distinct benchmark or effect level concentrations from different studies and sources. The results of the three types of comparison are summarized in Table 4.7.

The results of the three analyses are consistent. Concentrations of organochlorine chemicals at the facility exceed environmentally safe levels by many thousands of times, and they exceed low and severe effect levels by up to hundreds to thousands of times. Therefore, organochlorine chemicals at the facility are a threat to environmental resources. The consistency of the results across the three independent analyses is meaningful, and it adds weight to the conclusion that the organochlorine chemicals at the facility are a threat to the environment. The threat is highest at several areas at the facility where organochlorine concentrations are much higher than in other areas: the sanitary lagoon, gypsum pile, active waste pond, and the former inlet area of the old waste pond.

Table 4.7. Summary of the three evaluations conducted on the potential for organochlorine chemicals at the facility to harm wildlife

| Evaluation | Summary of conclusions |
|---|---|
| Comparison of contaminant concentrations in soil, sediment, and surface water with environmental benchmarks. | TCDD-eq and hexachlorobenzene concentrations exceed safe, low effect, and severe effect levels by up to hundreds to thousands of times in the sanitary lagoon, active waste pond, gypsum pile, and inlet area of the old waste pond. Concentrations in other areas at the facility also exceed safe levels as well as some low effect and severe effect levels. |
| Comparison of contaminant concentrations in mice, invertebrates, and plants with wildlife diet benchmarks or effect levels. | TCDD-eq concentrations in mice, invertebrates, and plants from the sanitary lagoon are many times greater (in most cases, hundreds of times greater) than safe levels for wildlife diet. TCDD-eq concentrations in mice, invertebrates, and plants from other areas at the facility are also greater than safe levels. Hexachlorobenzene concentrations in some dietary items exceed levels that are toxic to wildlife. Incidental soil and sediment ingestion by wildlife during feeding at the facility increases the doses of chemicals that wildlife receive. |
| Comparison of contaminant concentrations in bird eggs with effect levels. | TCDD-eq concentrations in eggs of all birds species (snowy plover, American avocet, and horned lark) collected at and near the facility exceed concentrations shown to cause adverse effects to bird embryos. Hexachlorobenzene in the eggs can also cause toxicity on its own. |

From the evaluation of organochlorine chemical concentrations in soil and sediment, the effects that are expected to occur at the facility include death to at least 50% of the organisms exposed to the contaminated soil or sediment and reduced reproduction. Based on the evaluation of organochlorine chemicals in wildlife diet, the expected adverse effects are reduced ability to reproduce and reduced survival. From the evaluation of bird eggs, the expected effects include egg mortality and reduced growth and deformities in bird chicks (which can reduce the chicks' ability to survive in the wild). When considered together, the expected environmental effects include reduced survival and ability to survive, and reduced reproduction.

The organochlorine chemicals at and from the facility are environmentally persistent and can remain in the environment for decades. For example, the bed of the old waste pond is still highly contaminated with dioxins, furans, PCBs, and hexachlorobenzene even though the facility stopped discharging wastewater to the pond in 1984. Furthermore, the contamination at the facility can spread to surrounding areas (including the Great Salt Lake), either through windblown dust or through breaches in the waste pond dikes, such as the breach of the old waste pond outer dike that occurred in 1984. Therefore, unless the high concentrations of organochlorine chemicals at the facility are remediated, they will continue to pose a threat to the environment for many decades.

5. Environmental Threats from Highly Acidic Pond Water

As described in Chapter 3, the ditches and active wastewater pond at the USM facility contain highly acidic water with very low pH (the water pH is often approximately 1.0 or less). The acidity of the water is caused by high concentrations of hydrochloric acid in the water. This chapter presents an evaluation of the possible harm to wildlife from exposure to the highly acidic water of the facility's ditches and active wastewater pond.

5.1 Hydrochloric Acid

Strong hydrochloric acid is very corrosive to biological tissue (Wexler, 1998). Ingestion can cause corrosion of the mucous membranes, esophagus, and stomach tissue, leading to perforation or hemorrhaging of the gastric lining (Wexler, 1998). Over a longer timeframe, ingestion can also cause circulatory collapse, which is often the ultimate cause of death from ingestion (Wexler, 1998). Contact with skin or eyes can cause severe acid burns (Wexler, 1998).

The severity and timeframe of the toxic effects of hydrochloric acid are in part related to the strength of the acid. Most of the available literature on the toxicity of hydrochloric acid is for a solution of pure hydrochloric acid (pH of approximately 0.1), which causes severe tissue damage immediately on contact. In addition, the available safety and regulatory information on hydrochloric acid solutions of strength similar to that of the USM ponds provide some indication of the toxicity of pond solutions. The European Community Commission has classified hydrochloric acid of a strength from 1% to 5% (approximately pH 1.6 to pH 0.86, which corresponds with most pH measurements from the active pond) as being corrosive and causing severe burns (European Commission, 1996). At a strength of 0.5% to 1% (approximately pH 1.9 to 1.6), hydrochloric acid has been classified by the European Commission as being corrosive and causing burns (European Commission, 1996). The Material Safety Data Sheet has the following description of the potential health effects of ingesting a hydrochloric acid solution of approximately pH 1.1 (Fisher Scientific, 2000):

May cause circulatory system failure. Causes severe digestive tract burns with abdominal pain, vomiting, and possible death. May cause corrosion and permanent tissue destruction of the esophagus and digestive tract.

Several studies provide more specific information on the adverse effects of ingesting hydrochloric acid solutions. Hall et al. (1980) found no mortality when mice drank hydrochloric acid solutions of pH 2.0 or 2.5 (approximately 20 to 50 times less acidic than the minimum pH of 0.74 measured in the USM active pond) for six weeks. However, mice that drank this water gained less weight than control mice that received water of pH approximately 6.3 (Hall et al., 1980). Similarly, rats exposed to 0.3% hydrochloric acid in drinking water, which corresponds to a pH of approximately 2.1, developed peptic acid-like lesions over 16 days (Matzner and Windwer, 1937; as cited in International Programme on Chemical Safety, 1967). Therefore, hydrochloric acid solutions that are many times less acidic than the USM ponds can cause gastrointestinal effects in mammals that can result in decreased weight gain.

Foster (1999) contains data on the toxicity of hydrochloric acid solutions to birds. Foster conducted a feeding and drinking water study of the effects of acid on mallard ducklings. The ducklings were given drinking water of pH 3.0, and their survival was monitored over four days. Six of the nine ducklings that drank this water died within four days, when the study was terminated. For comparison, none of the nine ducklings exposed to drinking water of pH 4.7 died. Thus drinking water of pH 3.0, which is 100 times less acidic than USM pond water at pH 1.0, caused mortality to birds in the study.

A study by Hooper et al. (2006) on water collected from the active waste pond at the facility confirms that the acidic water is corrosive to bird tissue, and that mallards and finches drink very little of the pond water when it is offered to them in a laboratory setting for 24 hours.

5.2 Distress in Birds that Came in Contact with Pond Water at the Facility

This section presents observations of birds that came in contact with USM's wastewaters in ditches or ponds. Section 5.2.1 describes bird deaths associated with exposure to this water, and Section 5.2.2 describes behavior that we observed in our 2002 survey in birds that came in contact with the water in the Main Ditch or active waste pond.

5.2.1 Behavioral observations made during the 2002 bird survey at the facility

During Phase 2 of the 2002 observational study of bird use at the USM facility, I (Mark Stackhouse) made detailed observations of bird behavior and signs of distress in birds that came in contact with wastewater in the ditches or ponds at the facility. I am qualified to provide expert opinions regarding behavioral symptoms of birds in distress based on my extensive experience in both observing healthy birds in natural settings and rehabilitating sick and injured birds, as described in Appendix A. Birds often attempt to mask outward signs of distress to avoid

providing cues to predators. Therefore, visible signs of distress seen in birds in the field are typically indicative of serious health problems.

The signs of distress that I observed in birds that came in contact with wastewaters at the facility can be grouped into three basic categories, which suggest different types of problems. The most common symptom of distress observed was vigorous head shaking or gagging, which is often seen in birds experiencing severe irritation in the upper gastrointestinal tract, especially the throat and mouth. In all cases, this head shaking or gagging occurred immediately after the bird dipped its bill into the highly acidic wastewater at the facility. Second, some birds showed signs of irritation or injury to their legs and feet during and immediately after contact with the acidic ponds, as described below. Finally, some birds exhibited general malaise and lethargy after coming into contact with the acidic water, a condition that often indicates more fundamental internal problems such as multiple system stress or circulatory system shock. Many birds showed more than one of these types of symptoms. For example, American avocets, the birds I observed most frequently at the active waste pond and which generally spent the most time in the water, usually showed all three types of symptoms.

Irritation of the mouth or upper gastrointestinal tract

Nearly all of the birds that I observed during the study coming in contact with the acidic waters of the active pond touched their bills to the water at least once (12 of 13 occurrences in July and August 2002, for example). The bill touches ranged from a brief dip, in which the bird may or may not have taken water into its mouth, to the example of the northern shoveler observed on the active pond on August 27, 2002, which completely submerged its head into the pond water and made swallowing motions.

I observed American avocets on the active waste pond for extended periods of time (several hours or more) on July 29 (one bird), July 31 (one bird), August 24 (five birds), and August 29 (two birds). I observed all of these birds dipping their bills into the water and apparently drinking or attempting to feed. Immediately after submerging their bills in the pond water, each bird showed signs of irritation in the throat or mouth. Specifically, the birds shook their heads rapidly from side to side, sometimes with their mouths held open, and on two occasions, made gagging motions. These actions often continued for extended periods of time, suggesting that they were suffering from a continuing irritation. Although such head shaking or gagging behavior can be observed in healthy birds, it is relatively uncommon, is of brief duration, and is usually associated with attempting to eject some foreign substance from the mouth or upper throat area immediately after feeding. For example, I observed flocks of approximately 4,000-5,000 American avocets for several hours along the south shore of the Great Salt Lake on the morning of August 2, 2002, and during that time did not observe any of the birds performing the head shaking or gagging behavior seen at the active waste pond.

During a study observation period on the afternoon of August 27, 2002, a northern shoveler landed on the active wastewater pond. After swimming around for approximately one minute, the bird apparently attempted to feed or drink by plunging its bill, head, and neck into the water. Each time the bird raised its head or bill out of the water, it engaged in increasingly more vigorous bill shaking and gagging to the point where it lifted its bill up to vertical as it shook its head and gagged. Approximately seven minutes after landing on the pond, the bird flew to the south and landed out of sight near the facility's storage ponds.

Irritation of feet and legs

Among the birds I observed making contact with the water of the active pond during the 2002 study, the American avocets spent the most time standing in the water, often staying in the water for hours at a time. Most of the avocets observed at the pond showed behaviors that suggested some type of problem or irritation with their feet or legs. These behaviors included limping, hopping on one foot, and in one case, apparent difficulty in moving without flapping its wings. At least one avocet (on July 31) was seen with its legs dangling in an unnatural position as it flew away from the pond – often a sign of a serious leg injury. Other signs of irritation to the feet and legs included excessive or continual picking at the feet with the bill, shaking the feet out of the water, and an apparent reluctance to lower one leg or the other into the water. I observed these behaviors in nearly all of the avocets that stood in the water of the active pond.

Lethargy and other general signs of distress

Most of the birds I observed on the pond for more than a few minutes exhibited unusual lethargy or abnormally reduced activity and a general lack of alertness. For example, the American avocets that I saw coming in contact with the active pond water showed much lower levels of activity at the pond than would be normal for that species. These behaviors, which were unusual in their frequency of occurrence in birds at the pond, are typically associated with a general lack of good health due to systemic problems or circulatory system stress.

Another example of observations I made during the 2002 bird survey of birds exhibiting general physical distress after coming in contact with the active pond involved a tree swallow. On July 24, a group of swallows was traversing the pond from north to south. At least four of the swallows dipped to the water surface and drank from the pond. After dipping to the pond surface a second time, one of these four birds appeared to have difficulty flying and maintaining altitude. Its flight became erratic, and it eventually disappeared from sight past the opposite shore of the pond. None of the other swallows in the group exhibited this behavior.

5.2.2 Bird deaths associated with exposure to USM facility wastewaters

Several bird carcasses have been found in or near wastewater ponds at the facility. During the 2002 bird study, an American white pelican was observed near the active wastewater pond and later found dead near the pond. On August 27, at the start of that day's observation period at 2:55 p.m., the bird was already present in the active wastewater pond, standing in approximately 3 inches of water. Approximately 1.5 hours later, the bird walked onto the shore of the pond and sat, where it remained mostly motionless for the rest of the day. The bird was observed to slowly slump to its side with its head drooping during this period. The next morning the bird was dead.

The pelican carcass was sent to the USGS National Wildlife Health Center in Madison, Wisconsin, for evaluation. The cause of death could not be determined, but the bird was diagnosed with small stomach ulcers and mild kidney damage (USGS, 2002; National Wildlife Health Center, 2003; C. Meteyer, USGS National Wildlife Health Center, personal communication, January 27, 2003). The bird also appeared to be dehydrated (National Wildlife Health Center, 2003).

During an August 24, 1998, site inspection conducted by the U.S. Fish and Wildlife Service, U.S. EPA, and Utah Department of Environmental Quality, a dead gull was observed in the Main Ditch (U.S. Fish & Wildlife Service, 1998b). The carcass could not be recovered because of the hazardous conditions, and it was reported by an employee of the USM facility that the carcass "was gone" on August 27, 1998, possibly because of heavy rain the night before (U.S. Fish & Wildlife Service, 1998b).

In addition, 15 dead California gulls and one dead Sabine's gull were collected on July 31 and August 3, 1992, from a temporary pond on the USM property that was reported to be cooling water from the facility's manufacturing process that overflowed onto the ground (U.S. Fish & Wildlife Service, 1998b). Two of the gulls found dead in the temporary pond were submitted to the U.S. Fish & Wildlife Service National Wildlife Health Research Center for diagnostic testing (U.S. Fish & Wildlife Service, 1998b). These two gulls had been observed on the ponded water for several days before their deaths (U.S. Fish & Wildlife Service, 1998b). The cause of death for the two birds that were examined could not be determined.

5.3 Conclusions

USM's active wastewater pond contains highly acidic water that typically has a pH value of 1 or less, making it stronger than battery acid. Hydrochloric acid of this strength is highly corrosive to biological tissue and is toxic when ingested. Therefore, the water in the ditches and active wastewater pond at the USM facility poses a threat to any wildlife that come in contact with the water.

Birds that come in contact with the highly acidic water are harmed. Birds in the active waste pond show signs of distress including head shaking or gagging, irritation of the feet or legs, and lethargy.

Therefore, the highly acidic water in the active waste pond is a threat to wildlife, and particularly birds, at the facility. Birds that come in contact with the water suffer from the corrosive effects of the acid.

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A. Expert Qualifications and Prior Testimony

A.1 Qualifications

Douglas Beltman

Mr. Beltman is an environmental scientist who specializes in evaluating the effects of environmental contaminants on ecological receptors. He has conducted detailed assessments of the ecological impacts of environmental contaminants at numerous sites across the country, including sites contaminated by metals, acid mine drainage, oil spills, PCBs and other chlorinated compounds, organic solvents, and pesticides. His experience includes designing and conducting detailed field, laboratory, and literature-based assessments of the ecological impacts of hazardous waste sites on birds, mammals, fish, benthic invertebrates, and plants. He has directed, conducted, or otherwise been involved in over 60 Superfund site ecological risk assessments, approximately 25 natural resource injury assessments as part of natural resource damage assessments, and other ecological harm investigations for court actions.

Mr. Beltman has specific expertise related to assessing environmental harm to wildlife. Many of the environmental assessments at hazardous waste sites that he has conducted have specifically focused on impacts to wildlife. For example, he was the lead technical advisor to the United States and state governments on the assessment of injuries to birds resulting from PCB releases into the Hudson River. He served in a similar capacity for the assessment of injuries to birds from PCB releases into the Fox River/Green Bay (Wisconsin/Michigan) and birds and other wildlife from PCB releases into the Kalamazoo River (Michigan). He was the lead author of the government's bird injury reports for both of those cases. Other sites where he has also directed or conducted the assessments of adverse effects on wildlife from hazardous substance exposure include the Joliet Army Ammunition Plant (Illinois), LCP Chemicals (Georgia), Indian Refinery (Illinois), Guadalupe oil field (California), Houston Ship Channel (Texas), and numerous western mining sites. His experience includes constructing species-specific food chain bioaccumulation models, developing and applying toxicity reference values, evaluating confounding effects of multiple contaminants, assessing population-level impacts, and designing and conducting field studies.

Before joining Stratus Consulting, Mr. Beltman was an ecologist in the U.S. EPA Region 5 Superfund program, where he was the co-chair of the Biological Technical Assistance Group, a group of government scientists that was regularly convened to address ecological harm issues at hazardous waste sites. Mr. Beltman authored regional U.S. EPA guidance on conducting

ecological risk assessments and participated in workgroups that developed national agency guidance on conducting ecological risk assessments.

Mr. Beltman's work has been published in journals such as *Environmental Toxicology and Chemistry*, *TheScientificWorld*, *Environmental Management*, *Comparative Biochemistry and Physiology*, and *EOS*, and has been presented in over 20 presentations at the annual meetings of the Society of Environmental Toxicology and Chemistry.

Mr. Beltman holds an MS in land resources from the University of Wisconsin-Madison, and his master's thesis was on the impacts of forestry management practices to avian populations. He also holds a BS (summa cum laude) in chemistry from the University of Rochester, and he is a member of the Society of Environmental Toxicology and Chemistry.

Mr. Beltman's expert opinions are presented in Chapters 1, 3, and 4 of this report.

Mark Stackhouse

Mr. Stackhouse is a professional ornithologist with over 25 years of experience in conducting field ornithological research; he has spent over 180 days a year in the field conducting bird study or observation work in Utah for the past 18 years. For the past eight years, he has been a full-time professional guide to bird watchers, and is a frequent lecturer to clubs, societies and professional organizations about birds.

In addition to having extensive field experience, Mr. Stackhouse has extensive experience rehabilitating sick and injured wild birds. For six years at the Dayton (Ohio) Museum of Natural History, and for 12 years at Tracy Aviary in Salt Lake City, Mr. Stackhouse rehabilitated and closely observed thousands of birds suffering from a wide variety of injuries and sicknesses. He was in charge of the Tracy Aviary (Salt Lake City) bird rehabilitation center, which received approximately 600 birds per year for rehabilitation that represented over 200 species of birds native to Utah and many other species native to North America. With this experience, Mr. Stackhouse was able to observe closely and learn about the behavior of birds suffering from many different kinds of illnesses and injuries.

Mr. Stackhouse also has 15 years of experience teaching college-level field ornithology courses at a variety of institutions, including the Dayton Museum of Natural History (Dayton, Ohio), Tracy Aviary (Salt Lake City, Utah), and Westminster College (Salt Lake City, Utah). He is a contributor to the *National Geographic Society Field Guide to the Birds of North America* and a member of the Utah Ornithological Society Bird Records Committee. He is the compiler of the Salt Lake City Christmas Bird Count for the National Audubon Society, and conducts numerous Breeding Bird Surveys for the U.S. Geological Survey each year.

Mr. Stackhouse has a BS in biology from Earlham College in Richmond, Indiana, and a BS in range science/land rehabilitation from Utah State University. He has also conducted graduate study in ecology at Utah State University.

Mr. Stackhouse's expert opinions are presented in Chapters 1, 2, and 5 of this report.

A.2 Case in Which Testimony Has Been Provided

Neither Mr. Beltman nor Mr. Stackhouse have provided testimony in deposition or trial in the last four years.

B. Hexachlorobenzene in the TCDD-eq Approach

Chapter 4 of the accompanying report describes the TCDD-eq approach to evaluating the toxicity of 2,3,7,8 TCDD and similar compounds. There are four criteria for including a specific compound in the TCDD-eq approach: (1) the compound must be structurally similar to 2,3,7,8-TCDD; (2) it must bind to the Ah receptor; (3) it must cause toxic effects similar to those caused by 2,3,7,8-TCDD; and (4) it must bioaccumulate (U.S. EPA, 2003).

Hexachlorobenzene is a chlorinated hydrocarbon that meets the four criteria for inclusion in the TCDD-eq approach. First, hexachlorobenzene is a chlorine-substituted planar aromatic compound and is structurally similar to 2,3,7,8-TCDD (see Figure 3.2 in the accompanying report). Although hexachlorobenzene contains only a single aromatic ring whereas 2,3,7,8-TCDD contains two, there still is an overall structural similarity between hexachlorobenzene and 2,3,7,8-TCDD.

Second, the study by Hahn et al. (1989) demonstrates that hexachlorobenzene binds to the Ah receptor in mice and rats. The results of the Hahn et al. (1989) study show that hexachlorobenzene binds to the Ah receptor and can compete with 2,3,7,8-TCDD for Ah receptor binding sites. Furthermore, the study demonstrates that once bound to the Ah receptor, the hexachlorobenzene:Ah complex is taken up into the nucleus, as occurs for 2,3,7,8-TCDD bound to Ah receptor. The affinity of hexachlorobenzene for Ah receptor binding is much less than that of 2,3,7,8-TCDD, however, and Hahn classifies hexachlorobenzene as a “weak” Ah agonist.

Third, the toxic effects of hexachlorobenzene include effects that are also caused by 2,3,7,8-TCDD, including induction of specific hepatic enzyme systems, such as cytochrome P450 enzymes that are known to be regulated by the Ah receptor (Rush et al., 1983; Carpenter et al., 1985a, 1985b, 1985c; Hahn et al., 1989; Machala et al., 1996; Sinclair et al., 1997), hepatic porphyrin accumulation and excretion (Goldstein et al., 1978; Carpenter et al., 1985c; Sinclair et al., 1997), alterations in thyroid hormone levels and activity (Loaiza-Perez et al., 1999), liver damage (Vos et al., 1971; Schwetz et al., 1974), tumor promotion (van Birgelen, 1998), adverse effects on the immune system (de Roode et al., 2002), wasting syndrome (Courtney, 1979), terata (Courtney, 1979), and reproductive effects (Vos et al., 1971; Schwetz et al., 1974; Hansen et al., 1978; Bleavins et al., 1984). Finally, the bioaccumulation of hexachlorobenzene has been demonstrated in numerous studies of fish, wildlife (birds and mammals), and humans (International Programme on Chemical Safety, 1997; Agency for Toxic Substances and Disease Registry, 2005).

Based on an evaluation of the four criteria, van Birgelen (1998) concluded that hexachlorobenzene should be included in the TCDD-eq method when assessing the toxicity of all TCDD-like compounds in environmental samples. Pohl et al. (2001) came to the same conclusion. However, the international group of experts that developed TEFs for dioxin, furan, and PCB congeners did not develop a TEF for hexachlorobenzene.¹ Therefore, to include hexachlorobenzene in the TCDD-eq approach, a TEF must be developed from the available literature.

Table B.1 lists studies which examined the toxicity of hexachlorobenzene and 2,3,7,8-TCDD in side-by-side experiments, and thus can be used to determine the potency of hexachlorobenzene relative to 2,3,7,8-TCDD. As shown in the table, the number of studies available to evaluate the toxic potency of hexachlorobenzene relative to 2,3,7,8-TCDD is limited. The available studies include those using mice, rat cells, and chicken cells. On a mass basis, the potency of hexachlorobenzene ranges from 0.00006 to 0.0005 relative to 2,3,7,8-TCDD, with a mean value of 0.0002. However, van Birgelen (1998) noted that the endpoint with the highest relative potency, porphyria in mice, may not be appropriate for TEF derivation since hexachlorobenzene (unlike 2,3,7,8-TCDD) can cause porphyria through multiple biochemical pathways rather than just the Ah receptor mediated pathway. If the potency factor of 0.0005 is removed, the mean value for the studies listed in Table B.1 is 0.0001.

Using the same studies as those shown in Table B.1, van Birgelen (1998) derived a TEF for hexachlorobenzene of 0.0001. Pohl et al. (2001) used this TEF in a comparison of public health guidance values for hexachlorobenzene and 2,3,7,8-TCDD and concluded that the TEF-adjusted values for hexachlorobenzene are well correlated with those for 2,3,7,8-TCDD, providing further evidence that the TEF of 0.0001 is appropriate for hexachlorobenzene. Therefore, in this assessment of environmental harm at the USM facility, a TEF of 0.0001 for hexachlorobenzene is used in the TCDD-eq approach.

1. In a 2006 update to the TEFs for mammals, an international panel observed that some of the older laboratory toxicity studies conducted with hexachlorobenzene may have used hexachlorobenzene that was contaminated with trace levels of dioxins and furans, and therefore the presence of the dioxins and furans could have confounded the results. However, Goldstein et al. (1978) demonstrated that dioxins and furans present in impure formulations of hexachlorobenzene are not responsible for the observed toxicity. Furthermore, a careful review of laboratory toxicity study methods shows that most studies use purified or analytical-grade hexachlorobenzene rather than commercial hexachlorobenzene and thus contain no detectable amounts of dioxins or furans (e.g., Hahn et al., 1989).

Table B.1. Studies used to estimate a TEF for the potency of hexachlorobenzene relative to 2,3,7,8-TCDD

| Study endpoint | 2,3,7,8-TCDD concentration causing the effect | Hexachlorobenzene concentration causing the effect | Hexachlorobenzene potency relative to 2,3,7,8-TCDD | Source |
|--|--|---|---|-----------------------|
| Ah receptor binding affinity in rat cells | NA | NA | 0.00009 (molar basis) 0.00008 (mass basis) | Hahn et al., 1989 |
| Porphyria in mice | 50 ppb | 100,000 ppb | 0.0005 (mass basis) | Hahn et al., 1989 |
| Uroporphyrin accumulation in chicken cells | 0.002-0.004 nM | 25-35 nM | 0.00006-0.0002 (molar basis) 0.00005-0.0002 (mass basis) | Sinclair et al., 1997 |
| EROD induction in chicken cells | 0.014-0.020 nM | 130-150 nM | 0.00009-0.00015 (molar basis) 0.00008-0.00013 (mass basis) | Sinclair et al., 1997 |
| Mean (range) | | | 0.0002 0.00006-0.0005 | |

Potencies on a molar basis are converted to potencies on a mass basis by multiplying by 0.89, which is the ratio of molecular weights of hexachlorobenzene (285) and 2,3,7,8-TCDD (322).